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

# Geomorphology Study
# Study Plan Section 6.5

# Initial Study Report
# Part A: Sections 1-6, 8-10

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

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

Prepared by

Tetra Tech

Watershed GeoDynamics

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# LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

| Abbreviation | Definition |
|---|---|
| AEA | Alaska Energy Authority |
| AOI | Area Of Interest |
| AOW | Additional Open Water |
| APSRS | Aerial Photography Summary Record System |
| ASPRS | American Society for Photogrammetry and Remote Sensing |
| BAB | Bar/Attached Bar |
| BIC | Bar Island Complex |
| CC | Chute Channel |
| cfs | Cubic feet per second |
| dbh | diameter breast height |
| DEM | Digital elevation model |
| EDAC | Earth Data Analysis Center |
| EFDC | Environmental Fluid Dynamics Code |
| EROS | Earth Resources Observation and Science |
| EXP | Exposed Substrate |
| FA | Focus Area |
| FERC | Federal Energy Regulatory Commission |
| FFY | Federal Fiscal Year |
| FGM | Fluvial Geomorphology Modeling below Watana Dam Study |
| GAA | Geomorphic Assessment Area |
| GB | gravel bar |
| GEO | Geomorphology Study |
| GIS | Geographic Information System |
| HEC-SSP | Hydraulic Engineering Center Statistical Software Package |
| IFS | Instream Flow Study |
| ISR | Initial Study Report |
| LiDAR | Light Detection and Ranging |

| Abbreviation | Definition |
|---|---|
| LP III | Log-Pearson Type III |
| LR | Lower River |
| LWD | large woody debris |
| Mat-Su | Matanuska-Susitna |
| MBI | Modified Braiding Index |
| MC | main channel |
| MFP | mature floodplain |
| mg/L | milligrams per liter |
| MR | Middle River |
| MSL | mean sea level |
| MVUE | Minimum Variance Unbiased Estimator |
| NWIS | National Water Information System |
| OCH | Overbank Channel |
| OFP | old floodplain |
| OS | Operating Scenario |
| PAD | Pre-Application Document |
| PC | paleo channel |
| pcf | pounds per cubic foot |
| PM&E | protection, mitigation and enhancement |
| RIFS | Riparian Instream Flow Study |
| RSP | Revised Study Plan |
| SC | side channel |
| SCC | side channel complex |
| SPD | Study Plan Determination |
| sq. ft/mi | square feet per mile |
| SS | side slough |
| TD | tributary delta |
| TR | tributary |

| Abbreviation | Definition |
|---|---|
| UR | Upper River |
| US | upland slough |
| USAF | United States Air Force |
| USGS | U.S. Department of the Interior, Geological Survey |
| USR | Updated Study Report |
| VB | vegetated bar |
| VI | Vegetated Island |
| WY | Water Year |
| YFP | young floodplain |

# 1. INTRODUCTION

On December 14, 2012, Alaska Energy Authority (AEA) filed its Revised Study Plan (RSP) with the Federal Energy Regulatory Commission (FERC or Commission) for the Susitna-Watana Hydroelectric Project (FERC Project No. 14241), which included 58 individual study plans (AEA 2012). Included within the RSP was the Geomorphology Study, Section 6.5. RSP Section 6.5 focuses on characterizing the geomorphology of the Susitna River and evaluating the effects of the Project on the geomorphology and dynamics of the river.

On February 1, 2013, FERC staff issued its study determination (February 1 SPD) for 44 of the 58 studies, approving 31 studies as filed and 13 with modifications. On April 1, 2013 FERC issued its study determination (April 1 SPD) for the remaining 14 studies; approving one study as filed and 13 with modifications. RSP Section 6.5 was the one study approved with no modifications in FERC's April 1 SPD**.**

In Quarter 1 and 2 of 2013, the Geomorphology Study developed 7 technical memorandums based on 2012 studies and one field report based on 2013 winter studies (Note: The Fluvial Geomorphology Modeling Approach TM was developed by the Fluvial Geomorphology Modeling below Watana Dam Study [Study 6.6]):

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

In addition, Field Assessment of Underwater Camera Pilot Test for Sediment Grain Size Distribution (Tetra Tech 2013i) is included as Attachment A to this ISR.

A large part of the effort associated with the Geomorphology Study is documented in the above reports which are frequently referenced in this report. These early efforts were performed to help guide the development of other studies. As examples, the geomorphic reach delineation (Tetra Tech 2013b) was developed in 2012 in order to provide a standard stratification of the Susitna River system to be used by other studies. The assessment of potential channel change in the Lower Susitna River (Tetra Tech 2013c) was developed to help inform the decisions on the downstream limit for the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6) as well as several other studies.

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

# 2. STUDY 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 and riparian habitats. The results of this study, along with results of the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6), 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 below Watana Dam Study (Study 6.6), determine the likely changes to existing habitats through time and space.

In order to achieve the study goals, there are 11 study objectives:

1. 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 of channel and floodplain geomorphology.

- Identify and describe the primary geomorphic processes that create, influence, and maintain mapped geomorphic features.

2. Collect sediment transport data to supplement historical data to support the characterization of Susitna River sediment supply and transport.
3. Determine sediment supply and transport in Middle and Lower Susitna River Segments.
4. Assess geomorphic stability/change in the Middle and Lower Susitna River Segments.
5. 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.
6. 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.
7. 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 at selected sites.
   - Estimate potential change in macrohabitat areas based on initial estimates of change in stage from Project operations.
   - Optional – If Focus Areas are extended into the Lower Susitna River Segment, perform analysis of macrohabitat wetted area versus flow relationships for additional sites and flows.
8. Characterize the proposed Watana Reservoir geomorphology and changes resulting from conversion of the channel/valley to a reservoir.
9. Assess large woody debris transport and recruitment, their influence on geomorphic forms and, in conjunction with the Fluvial Geomorphology Modeling below Watana Dam Study, effects related to the Project.
10. Characterize geomorphic conditions at stream crossings along access road/transmission line alignments.
11. Integration with the Fluvial Geomorphology Modeling below Watana Dam 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.

# 3. STUDY AREA

The study area for the Geomorphology Study is the Susitna River from its confluence with the Maclaren River (PRM 261.3[RM 260]) downstream to the mouth at Cook Inlet (PRM 3.3[RM 0]). The study area has been divided into three large-scale river segments:

- Upper Susitna River Segment: Maclaren River confluence (PRM 261.3[RM 260]) downstream to the proposed Watana Dam site (PRM 187.1 [RM 184]).
- Middle Susitna River Segment: Proposed Watana Dam site (PRM 187.1 [RM 184]) downstream to the Three Rivers Confluence (PRM 102.4 [RM 98]).
- Lower Susitna River Segment: Three Rivers Confluence (PRM 102.4 [RM 98]) downstream to Cook Inlet (PRM 3.3 [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 3-1. 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.

# 4. METHODS AND VARIANCES IN 2013

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

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

The study area is the length of the Susitna River from its mouth at Cook Inlet (PRM 3.3 [RM 0]), upstream to the proposed Watana Dam site (PRM 187.1 [RM 184]) (Lower River and Middle River), and upstream of the proposed Watana Dam site, including the reservoir inundation zone and on upstream to the Maclaren River confluence (PRM 261.3 [RM 260]) (Upper River). 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.

The goal of this study component is to geomorphically characterize the Project-affected river channels including determination of geomorphically similar reaches that then form the basis for both selecting areas for detailed analysis (Focus Areas) of existing conditions and extrapolating the results to similar reaches. Portions of this effort were performed in 2012 including development of the geomorphic classification system (Section 4.1.2.1) and initial delineation of geomorphic reaches (4.1.2.2). The Upper River (UR) was divided into 6 reaches (UR-1 throughUR-6), the Middle River (MR) was divided into 8 reaches (MR-1 through MR-8) and the Lower River (LR) was divided into 6 reaches (LR-1 through LR-6). Field data collection and analysis of photogrammetric and topographic data were conducted in 2013 in the Middle River and Lower River. These studies resulted in the material presented in the characterization of the Susitna River (4.1.2.3). Field data collection included geomorphic mapping of the Focus Areas which resulted in identification of a conceptual model of geomorphic succession in the Middle River, measurement of the heights of geomorphic surfaces for preliminary determination of inundation frequencies and durations, sampling to characterize the bed and bank materials and development of a model of channel evolution within the Middle River. Comparison of time-sequential aerial photography provided an approximately 60 year (1950-2012) view of geomorphic and vegetation changes in the Middle and Lower River segments in two similar time intervals, 1950-1982 and 1982-2012.

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 in-channel (primarily fish) and channel margin (riparian) habitats, is changes in the volume of sediment in storage within discrete types of storage units, that can generally be separated into mid-channel (bars and islands) and bank-attached (floodplain and terrace) 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 and the rate of turnover of the valley bottom (Harvey et al. 2003; Harvey and Trabant 2006; Everitt 1968; Merigliano et al. 2013; Gurnell et al. 2001). 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 and the suite of accompanying channel types were assessed by GIS-based comparisons of time-sequential aerial photography. Suitable aerial photography for comparative purposes was available for the 1950s, 1980s, and the present (2012). At varying scales, sediment storage within all the reaches of the Susitna River is affected by geologic (bedrock, glacial, glacio-lacustrine, glacio-estuarine sediments) and geomorphic (terraces, tributary alluvial fans) controls that create constrictions of the valley floor.

On the Susitna River, the end members of a continuum include long-duration sediment storage in terraces, vegetated islands and floodplains that persist for multiple decades to centuries 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 geomorphic classification developed for the Susitna River (Section4.1.2.1). 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.

### 4.1.1. Existing Information and Need for Additional Information

This effort supports the understanding of the conditions in the Susitna River by developing (Section 4.1.2.1) and applying (Section 4.1.2.2) a geomorphic classification system based on form and geomorphic process. The effort supports other studies, including the Fish and Aquatics Instream Flow (Study 8.5), Riparian Instream Flow (Study 8.6), Characterization and Mapping of Aquatic Habitats (Study 9.9), and Ice Processes in the Susitna River (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). In the previous studies the Middle River was described as constrained where the form of the river was significantly affected by non-alluvial factors (Montgomery and Buffington 1993; O'Connor et al. 2003) and the Lower River as less constrained where the form of the river was more likely to be the result of the direct interaction of the flows and the sediment loads (Schumm 2005).

### 4.1.2. Methods

AEA implemented the methods as described in the Study Plan with no variances. 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. In 2012 an initial effort was undertaken to develop the geomorphic classification system and apply it to develop geomorphic reaches. This effort was documented in the technical memorandum, Initial Geomorphic Reach Delineation and Characterization, Middle and Lower Susitna River Segments (Tetra Tech 2013b).

#### *4.1.2.1. Identification and Development of Geomorphic Classification System*

This effort was presented in the technical memorandum (Tetra Tech 2012b). The classification system was developed to utilize the types of information available for the Susitna River at the outset of the Project in order to be able to divide the system into geomorphic reaches that a variety of studies could use in their study planning process. For example, the Fish and Aquatics Instream Flow Study (Study 8.5) used the classification system in the site selection process. The classification system was based on one developed by Schumm (2005) that considered as the main characteristics channel planform, constraints, confinement, gradient, and bed material. The actual classification system is presented in Section 5.1.1.

#### *4.1.2.2. Geomorphic Reach Delineation*

The Lower Susitna River Segment (PRM 3.3 to PRM 102.4 [RM 0 to RM 98]), the Middle Susitna River Segment (PRM 102.4 to PRM 187.1 [RM 98 to RM 184]), and the Upper Susitna River Segment to the Maclaren River confluence (PRM 187.1 to PRM 261.3 [RM 184 to RM 260]) was 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, channel branching index, and hydrology (inflow from major tributaries) for the purpose of stratifying the river into study lengths. Stratification of the river into relatively homogeneous reaches permits extrapolation of the results of sampled data at representative sites within the individual reaches. The geomorphic reaches and their associated characteristics are presented in Section 5.1.2.

#### *4.1.2.3. Geomorphic Characterization of the Susitna River*

Successful identification and characterization of the key geomorphic processes and resulting geomorphic features and surfaces is accomplished by bi-directional integration of field-based observations and measurements (Geomorphology Study) and the outputs from One-Dimensional (1-D) and Two-Dimensional (2-D) Bed Evolution Models and the 2-D Hydraulic Model being developed in the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6). Field-based observations and measurements are used to guide model development and data needs and will be used to provide a reality check on model results. In turn, model outputs will be used to modify, refine, quantify and validate field-based observations and key geomorphic processes. This will be accomplished primarily in the 10 Focus Areas which encompass the range of geomorphic characteristics within the identified Geomorphic Reaches (MR-1 to MR-8) of the Middle River (R2 Resource Consultants, Inc. [R2] 2013a; R2 2013b). After completion of the modeling, and inclusion of the results from other modeling efforts (Ice Processes in the Susitna River [Study 7.6] and Riparian Instream Flow [Study 8.6] Studies), 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 habitats under with-Project scenarios. This information will be provided to the other resource teams for use in their evaluation of potential Project effects.

Based on information collected and developed in support of the reach delineation (RSP 6.5.4.1.2.1; Tetra Tech2013c), mapping of current and historical (1980s and 1950s) fluvial geomorphic features (RSP Section 6.5.4.4) and as part of the field studies conducted in the Fluvial Geomorphology below Modeling Watana Dam Study (RSP Section 6.6.4.1.2.9), the geomorphology of the Middle and Lower Susitna River Segments is being characterized. The characterization is 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 are considered in development of the understanding of the processes that create and influence the geomorphic features of the Susitna River. Of particular importance are 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, 2011 Mat-Su LiDAR in conjunction with 2013 fieldwork (ISR Study 6.6 Section 4.1.2.9 and Section.5.1.2.9 Field Data Collection Methods and Results, respectively) the following have been 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
- Major locations (those discernable from aerial photographs and/or aerial reconnaissance) of recent and historical mass wasting
- Mapping of areas of frequent ice jam events from Ice Processes in the Susitna River Study (Study 7.6) in the Middle River
- Identification of coarse deposits at tributary confluences that may influence the profile of the Susitna River

These products will be updated for any pertinent findings from field work conducted through the next year of study.

#### *4.1.2.3.1. Surficial Geology*

Surficial geologic mapping was conducted to identify and characterize lateral constraints and vertical controls on the Middle and Lower segments of the Susitna River. The geologic map units, lateral constraints, vertical controls and lag deposits were mapped in ArcGIS 10.0 at an approximate scale of 1:10,000 from the 2011 Matanuska-Susitna Borough imagery and LiDAR, in addition to the 2012 color aerial photography. Field verification occurred by boat from July to September 2013 and by helicopter on 9/18/2013 and 9/19/2013.

Geologic map units were mapped as polygons. Alluvial fans were mapped from the fan head to edges of deposition. Alluvial terraces were mapped for surficial alluvium terraces that were more than 15 feet above the water surface in the 2011 Mat-Su LiDAR. Bedrock landslides and non-bedrock landslides were outlined for the extent of the resulting depositional surface. Bedrock grade control and lag deposits which occur in the main channel were outlined within reaches bounded laterally by the water surface in the 2012 aerial photography and by their approximate upstream and downstream extents. Terrace breaklines were added as lines along the tops of slopes captured in the LiDAR to differentiate overlapping alluvial terrace map units. The lateral constraints, vertical controls, and lag deposits were mapped as the following geologic map units:

- Lateral Confinement
  a. Alluvial Fans
  b. Alluvial Terraces
  c. Bedrock Landslides
  d. Landslides - mass wasting
  e. Terraces
- Vertical Constraints
  a. Bedrock Grade Control
- Paleogeology
  a. Lag Deposits

Along the Susitna River, bedrock and lateral constraints were mapped as hashed lines. This was done at the interface between the resistant geologic layer's toe of slope and the adjacent Susitna River main channel. The lines are attributed with the corresponding USGS geologic map units (Wilson et al. 2009) and/or a field verified lithology. The lateral constraints lines were mapped as the following categories:

Qat - Alluvium along major rivers and in terraces (Holocene)
Qbc - Bootlegger Cove Formation
Qes - Estuarine Deposits (Holocene)
Qg - Major moraine and kame deposits (Upper Pleistocene)
Qgc - Glacioalluvium (Upper Pleistocene)
Qge - Glacioestuarine deposits (Upper Pleistocene)
Qgo - Outwash in plains, valley train, and fans (Upper Pleistocene)
Qhg - Young moraine deposits (Holocene)
Qlc - Landslide and colluvial deposits (Holocene and Upper Pleistocene)

Qog - Older Glacial deposits (Middle or Lower Pleistocene)
Qs - Surficial deposits, undivided (Quaternary)
Qsl - Lacustrine, swamp, and fine silt deposits
KJs - Turbiditic sedimentary rocks of the Kahiltnaflysch sequence
Kgd - Granodiorite (Late Cretaceous)
Kivs - Metamophosed intermediate volcanic and sedimentary rocks (Cretaceous)
TKg - Granitic rocks, undivided (Paleocene to Late Cretaceous)
TKgg - Gneiss (Tertiary or Cretaceous metamorphic age)
Tgd - Biotite-hornblende-granodiorite
Tkn - Kenai Group, undivided (Pliocene to Oligocene)
Tmf - Tuffaceous felsic volcanic rocks
Tpgr - Granitic rock of Paleocene age (Paleocene)
Tvu - Tertiary volcanic rocks, undivided (Tertiary)

##### *4.1.2.3.2. Geomorphic Surfaces and Processes*

The geologic mapping efforts supported the concentrated 2013 geomorphic mapping effort within 7 Focus Areas, that lead to the development of (1) two conceptual geomorphic models and (2) a geomorphic surface classification system based on heights of various in channel and out-of-channel features, vegetation succession patterns, observations of ice effects and trends identified by the conceptual geomorphic models. Both products were developed by field observations and measurements including identification of lateral controls, lateral stability (e.g., eroding banks), tree ages and succession, overbank deposition and effects of ice processes. Methods pertaining to the collection of field observations can be found in ISR Study 6.6 Section 4.1.2.9.

The geomorphic surface mapping effort was concentrated within the 7 Focus Areas below Devils Canyon. Because it was necessary to identify governing geologic controls in order to explain the genesis and spatial distribution of geomorphic features within the 7 Focus Areas, the area of study was often expanded either upstream, downstream, or both from the defined Focus Area limits. This expanded area is intended to include all geomorphic surfaces encompassed between upstream and downstream lateral constrictions such as bedrock, moraines, terraces and alluvial fans. These expanded areas of geomorphic study are hereby referred to as Geomorphic Assessment Areas (GAAs) and correspond with each of the 2013 studied Focus Areas (R2 2013a; R2 2013b). Table 4.1-1identifies each GAA and defining PRM boundaries. Names of GAAs correspond to the numerical and common naming convention for Focus Areas.

The geomorphic surface mapping and conceptual geomorphic models are the products of an initial understanding of the geomorphology of the Susitna River. This understanding will be reviewed and updated as various study results are made available. This will include information such as determination of flows required for bed-material mobilization, effective discharge, comparison of 1980s and current cross-section profiles, sediment balance, 1-D Bed Evolution, 2-D Bed Evolution and 2-D Hydraulic 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.

#### 4.1.2.4. Information Required

The following existing information will be used 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 was obtained to conduct this study:

- Current high resolution aerial photography
- Field observations made during 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 Geomorphology Modeling below Watana Dam Study (ISR Study 6.6 Section 4.1.2.9)

### 4.1.3. Variance from Study Plan

There are no variances to the Study Plan for this study component.

## 4.2. Study Component: Bed Load 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 the USGS and was initiated in 2012.

The study covers the Susitna River from Susitna Station (PRM 30 [RM 28]) upstream to the Tsusena Gage (PRM 184 [RM182]) and the Chulitna River, Talkeetna and Yentna rivers near their confluences with the Susitna River. Figure 4.2-1 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 Revised Study Plan except for the 2012 bed-material samples. The data were made available from the USGS in June 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 data on the Talkeetna have been collected by the USGS as part of the USGS National monitoring network since 1966. The Susitna River at Susitna Station and the Yentna River near Susitna Station were added in Q2 2013 after the decision was made to extend the 1-D Bed Evolution Model downstream in the Lower River Segment to Susitna Station (Tetra Tech 2013h).

### 4.2.1. Existing Information and Need for Additional Information

The collection of the data described in this study component supplements sediment transport data collected in the 1980s. The additional data were 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). Sediment Transport relationships reflecting current conditions are important for the sediment transport assessment and sediment balance efforts conducted in study components3 (ISR Study Section 4.1.3, Sediment Supply and Transport Middle and Lower Susitna River Segments) and 6 (ISR Study Section 4.1.6, Reconnaissance-Level Assessment of Project Effects on Lower and Middle Susitna River Segments) of this study and the 1-D and 2-D Bed Evolution modeling being conducted under the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6).

The USGS published a summary report on sediment transport data collected in the 1980s (Knott et al. 1987). The data collected includes suspended-sediment measurements and bed load 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 Yentna River near Susitna Station. The suspended load is divided into a silt/clay component and a sand component. The bed load 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 (WY) 1985 for the various components of the sediment load by applying the rating curves to the mean daily flow record.

Table 4.2-1 presents the sediment loads estimated by the USGS for WY1985 (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).

As part of the analysis for the 2012 Geomorphology Study technical memorandum entitled Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a), the available data for each of the following gages were downloaded from the USGS National Water Information System (NWIS) website (http://waterdata.usgs.gov), and relevant data collected after 1985 were added to the data sets.

- Mainstem Gages

- Middle River Mainstem: Susitna River at Gold Creek Gage (15292000) and Susitna River near Talkeetna Gage (15292100)1
- Lower River mainstem below Three Rivers Confluence: Susitna River at Sunshine Gage (15292780)
- Lower River mainstem below Yentna River: Susitna River at Susitna Station Gage (15294350)

- Primary Tributary Gages
  - Tributary Supply to Three River Confluence (Chulitna River near Talkeetna Gage (15292400) and the Chulitna River below Canyon near Talkeetna gage (15292410)1
  - Talkeetna River near Talkeetna Gage (15292700)
  - Tributary Supply to Lower River: Yentna River near Susitna Station Gage (15294345)

The bulk of these data that were collected through WY1985 were previously analyzed by Knott et al. (1987). The number and types of sediment samples, and the dates of sampling vary among the gages, but generally include both the magnitude and gradation of the suspended sediment and bed load for samples collected between the late-1970s and the late-1980s (Table 4.2-2).

This study component provides information on current transport conditions to support the assessment of Project effects on sediment supply. Sediment data derived from the gages are being used to provide sediment inputs at model boundaries. This information is used by several study components in this study as well as the Fluvial Geomorphology Modeling below Watana Dan Study (Study 6.6).

### 4.2.2. Methods

AEA implemented the methods as described in the Study Plan with the exception of the variances explained below (Section 4.2.3). The following scope of work for performing the collection of the sediment transport data was provided by USGS in 2012 and modified in 2013 to include the bed load measurements for the Talkeetna River near Talkeetna and the complete suite of measurements for the Susitna River at Susitna Station and the Yentna River near Susitna Station:

- Operate and maintain the stream gages near the transport measurement locations.
- Maintain datum at the stream gages.
- Record stage data every 15 minutes at the stream gages.
- Make discharge measurements during visits to maintain the stage-discharge rating curve and to define the winter hydrograph.
- Store the data in USGS databases.

[1] Data from both these gages were combined into a single data set for the USGS (1987) analysis; this approach was adopted for this study as well.

- Collect at least five suspended-sediment samples at Susitna River above Tsusena Creek, Susitna River at Gold Creek, and Susitna River at Sunshine; the Chulitna River near Talkeetna and the Talkeetna River near Talkeetna during the year for concentration and size analysis (collect in 2012, 2013, and 2014).[2] Collect in 2013 and 2014 similar information for the Susitna River at Susitna Station and the Yentna River near Susitna Station.
- Collect, if feasible, at least five bed-material samples during the year at Susitna River above Tsusena Creek, at Gold Creek, at Sunshine and at Susitna Station; the Chulitna River near Talkeetna, the Talkeetna River near Talkeetna and the Yentna River near Susitna Station for bed load transport determination and size analysis (collect in 2012, 2013, and 2014, except Susitna River at Susitna Station, Talkeetna River near Talkeetna, and the Yentna River near Susitna Station, which will be collected in 2013 and 2014 only).
- Collect at least five bed load samples during the year at Susitna River at Gold Creek, Susitna River at Sunshine, Susitna River above Tsusena Creek, Susitna River at Susitna Station, the Chulitna River near Talkeetna, and the Yentna River near Susitna Station for bed load transport determination and size analysis (collect in 2012, 2013, and 2014 except Susitna River at Susitna Station, Talkeetna River near Talkeetna, and the Yentna River near Susitna Station, which will be collected in 2013 and 2014 only, and bed load at Tsusena Creek, which will only be collected in 2012).[3]
- Operate and maintain the stream gage at the Susitna River near Denali (2012, 2013, and 2014).
- Compile suspended and bed load 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, FFY 2015 for the 2014 data. 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.
- 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/).

A summary of the sediment measurements collected (2012 and 2013) and planned for the next year of study is presented in Table 4.2-3.

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[2]These stations were listed in the RSP Section 6.5.4.2.2., but the actual 2012 suspended-sediment measurement locations were Susitna River above Tsusena Creek, Susitna River at Sunshine, Chulitna River below Canyon, Chulitna River near Talkeetna, and Susitna River near Talkeetna.

[3] These stations were listed in the RSP Section 6.5.4.2.2., but the actual 2012 bed load locations were Susitna River above Tsusena Creek, Susitna River at Sunshine, Chulitna River below Canyon, and Susitna River near Talkeetna.

The equipment, techniques, and methods used for sediment sampling by the USGS are referenced in Field Methods for Measurement of Fluvial Sediment (Edwards and Glysson 1998). This methodology was applied to the suspended-sediment, bed load sediment, and bed-material measurements. Site locations were shifted to improve data results. Sites such as the Susitna River at Gold Creek and Chulitna River near Talkeetna had too many boulders to allow for accurate sediment transport measurements and were relocated to the gage sites referred to as Susitna River near Talkeetna and the Chulitna River below Canyon, respectively.

The 2013 bed-material samples were collected by different methods depending on the substrate size. A BM-54 bucket sampler was used at Susitna Station and on the Yentna River where the bed is comprised mostly of sand. A pebble count was conducted at Sunshine. The USGS attempted using a pipe dredge at a few stations, but only had success at Talkeetna River where the material is mostly sand, gravels and small cobbles. The bed material at the remaining stations was sampled using pebble counts due to the coarseness of material. Pebble counts were conducted on exposed portions of the bed during low flows.

The 2012 bed load and suspended-sediment data were combined with existing rating curves to identify the differences and similarities between the historical and current data sets. This information is being 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. The 2013 data will be compared in the next year of study to further evaluate the representativeness of the 1980s data compared with current conditions and if appropriate, the 1980s curves will be adjusted.

### 4.2.3. Variance from Study Plan

The pebble count bed-material samples were not taken in 2012 due to a flood in September 2012 that left the river stage too high to effectively perform pebble counts on exposed bars. This will not affect the ability to meet study objectives as numerous bed-material samples are being collected throughout the Middle and Lower Susitna River Segments as part of the Fluvial Geomorphology Modeling below Watana Dam Study (ISR 6.6 Section 4.1.2.9). The samples include both surface and subsurface bed-material samples. As a result there will be adequate bed-material data to meet study objectives. The bed-material data collection effort includes winter through the ice sampling to obtain bed material in deeper portions of the channel where surface samples cannot be physically collected (dredge samples) and visual samples are not possible during open-water periods due to high turbidity. These data will thoroughly characterize the bed material of the Susitna River throughout the Middle and Lower River segments.

Due to logistical and safety issues, the bed load samples at Tsusena Creek were terminated after 2012, were not collected in 2013, and will not be collected in the future. This will not affect the ability to meet study objectives as alternate means are available to determine the bed load passing the dam site for the without Project condition. For with-Project conditions, the bed load passing the dam site will be zero as all bed load will be trapped in the reservoir. In terms of alternate means of determining he bed load transport at the dam site, there is only a 20 percent difference in the drainage area between the Tsusena Creek and Gold Creek gages, therefore the combination of the considerable bed load data collected at Gold Creek in the 1980s, 2012 and 2013 as well as planned for the next year of study combined with estimates of tributary bed load contributions (See ISR Study 6.6 Section 4.1.2.6) will support estimation of Susitna River bed load at the Watana dam site for existing conditions. The data that has been collected at Tsusena Creek will be used as a check on these calculations.

## 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 (PRM 187.1 [RM 184]) and the Susitna Station gage (PRM 30 [RM 28]). This includes the mainstem Susitna River and its tributaries. The Three Rivers Confluence (PRM 102.4 [RM 98]) separates the Middle Susitna River Segment from the Lower Susitna River segment. Initial estimates of the sediment balance for both the Middle and Lower Susitna River segments were developed in 2012 as part of the Reconnaissance-level Assessment of Project Effects on Lower and Middle Susitna River Segment (ISR Study 6.5 Section 4.6). The effective discharge analysis was completed in 2013, while the refined estimates of the sediment balance and bed mobilization analysis for the Middle Susitna River segment sediment will be completed in the next study year. The future effort will also provide estimates of sediment supply that will be used in the bed evolution modeling efforts described in Section 6.6.

A technical memorandum entitled Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Segments (Tetra Tech 2013a), filed with FERC in March 2013, provides a detailed description of the methods and results. A similar technical memorandum describing the methods and results of the effective discharge analysis is included as Appendix B.

### 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 (PRM 187.1 [RM 184]) and Susitna Station (PRM 30 [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 sediment balance, and the associated changes to geomorphology, in the Middle and Lower Susitna River segments 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 (Study 6.6) through quantification of the sediment supply that will be required as input to the model.

In the 1980s, investigations of the Susitna Project's potential effects on sediment transport were performed. Reservoir and River Sedimentation (Harza-Ebasco 1984) includes a preliminary assessment of potential channel aggradation and degradation in response to the operation of the Susitna Project as formulated in the 1980s. The following summary of the 1980s methods, results, and discussion is extracted from the Harza-Ebasco (1984) report. From the confluence with Portage Creek to the USGS gaging station at Sunshine, the Susitna River was divided into 12 reaches that were delineated, in general, using confluences with major tributaries so that the lengths were short enough that average flow depth, velocity, and slope were representative of the entire reach. Forty-six bed-material samples were collected from the mainstem and side channels of the Susitna River; size distributions of all samples were determined by sieving. Representative gradations for each reach were judiciously selected from all available bed-material data, including additional samples collected by the USGS at gaging stations and grid-by-number characterizations performed by R&M Consultants, Inc. (1982). Calculations of the armoring particle size for the pre- and with-Project dominant discharges were carried out using four methods (1) competent bottom velocity, (2) critical tractive force, (3) the Meyer-Peter and Müller (1948) formula, and (4) the Schoklitsch (1934) formula. The average of the four armoring sizes was taken as the sediment size at incipient motion in each of the 12 reaches. Under pre-Project conditions, the armoring size ranged from 120 mm near the Portage Creek confluence to 30 mm near the Chulitna River confluence, with a general decrease in armoring size in the downstream direction. Under with-Project conditions, the armoring sizes ranged from 40 to 21 mm, again, generally decreasing in the downstream direction. The sediment sizes mobilized under with-Project conditions were calculated to be smaller than the sediment sizes under pre-Project conditions due to the with-Project reduction in the dominant discharge. The armoring size analysis was extended to consider the impacts of with-Project hydrology on sediment delivery from major tributaries. Under pre-Project conditions, the minimum transportable sediment size in the mainstem was considerably larger than the $D_{50}$ of the bed material for the sampled tributaries. This comparison indicated that long-term accumulation at tributary mouths was not likely to occur under pre-Project conditions. Under with-Project hydrologic conditions, the transportable size in the mainstem was either smaller or only slightly larger than the $D_{50}$ of the tributary bed materials, so some sediment may accumulate in the tributary mouths and in the mainstem immediately downstream from the tributary confluences.

Tetra Tech (2013c) performed a preliminary evaluation of critical discharges for incipient motion. The threshold for gravel mobilization was based on a reference condition corresponding to a very low, but measureable, transport rate (Parker et al. 1982; Wilcock 1988) derived from flow and bed load measurements at the USGS gaging stations at Gold Creek and Sunshine. Hydraulic parameters (e.g., top width and hydraulic depth) were not reported for the flow measurements, so these parameters were estimated using hydraulic geometry relationships developed for both gaging locations. The bed slope at each gaging location was based on the local slope of longitudinal profiles developed from 2012 surveyed cross sections at Gold Creek or from 2011 LiDAR mapping at Sunshine. Since bed-surface gradations were not available, the $D_{50}$ was estimated for the combined bed load measurements at each gage so that computed bed load using the Parker (1990) surface-based transport function fit the measured bed load data. Using this procedure, the median ($D_{50}$) size at Gold Creek was estimated to be 67 mm for which the critical discharge for mobilization is approximately 25,000 cfs. At Sunshine, the $D_{50}$ was estimated to be 40 mm, and the estimated critical discharge is approximately 16,000 cfs. Sufficient data were not available at the time Tetra Tech (2013c) was completed to verify the estimated $D_{50}$ values, but the values were deemed reasonable based on qualitative field observations.

### 4.3.2. Methods

AEA implemented the methods as described in the Study Plan with the exception of the variances explained below (Section 4.3.3).The variances consist of work performed that was not scoped in the Study Plan. The methods section is divided into five subsections: (1) Initial Middle Susitna River Segment Sediment Balance, (2) Lower 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 (PRM 102.4 to PRM 32 [RM 98 to 28]) and Middle Susitna River Segment (PRM 187.1 to PRM 102.4 [RM 184 to RM 98]) used a variety of 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 include the mainstem Susitna River, contributing tributaries, and locations of mass wasting. Procedures to estimate sediment supply include the use of regional sediment transport relationships (e.g., regression equations based on watershed area) for ungaged tributaries, and calculation of sediment loads at gaging stations along the mainstem and gaged tributaries. While it is recognized that the gages are spatially separated, comparison of the loads at the gages permits an assessment of whether there is significant storage or loss of sediment between gages. The historical and recent sediment transport measurements collected by USGS were used to develop bed- 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 were available, the data allowed for differentiation of transport by size fraction.

Sediment load versus water discharge rating curves were developed for each portion of the sediment load (i.e., wash load, bed load, total bed-material load) using the available data. In the next year of study, these rating curves will be compared with and possibly supplemented by transport capacity calculations based on hydraulics from the open-water flow routing model and bed-material samples collected as part of the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6) 4, as appropriate. The number and types of sediment samples, and the dates of sampling vary among the gages, but generally include both the magnitude and gradation of the suspended sediment and bed load for samples collected between the late-1970s and the late-1980s. The bulk of the data that were collected through WY1985 were previously analyzed by Knott et al. (1987). As part of this analysis, the available data for each of the gages was downloaded from the USGS National Water Information System (NWIS) website (http://waterdata.usgs.gov), and relevant data collected after 1985 were added to the data sets.

Knott et al. (1987) developed power-function relationships for the data of the form:

$$Q_s = a(Q)^b \qquad (4.2\text{-}1)$$

where:

$Q_s$ = sediment load (tons/day)

$a$ = coefficient
$b$ = exponent
$Q$ = discharge (cubic feet/second)

For consistency with Knott et al. (1987) and standard practice in developing sediment-load rating curves (USGS 1992), similar power function relationships were used for the current study using the updated data sets. These relationships were then compared to the Knott et al. (1987) relationships. Plots of the regression lines for each component of the sediment load and the underlying data were presented in figures in Appendix A of Tetra Tech (2013a).

Where the data could be transformed into an approximately linear relationship, the rating curves were developed using linear, least-squares regression. Where regression did not produce suitable results over the full range of the data, best-fit curves were developed by visually passing a line (or line segments) through the data. Where linear regression was used on transformed data, the Minimum Variance Unbiased Estimator (MVUE) technique (Cohn and Gilroy 1991) was used to remove bias that is introduced into the regression equations by the transformation process. Details of how this was done are provided in Tetra Tech (2013a). The rating curves were then integrated over the relevant hydrographs to estimate the total of each portion of the sediment load. The resulting total sediment loads were then compared to determine if each segment of the reach between the locations represented by the rating curves are net aggradational (i.e., more sediment is delivered to the reach than is carried past the downstream boundary) or net 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 were available for review, the potential for bias in the sediment rating curves was considered and addressed as appropriate using the Minimum Variance Unbiased Estimator (MVUE) bias correction for normally distributed errors.

The Study Plan calls for comparison of the total sediment load for representative average, wet, and dry as well as warm and cool PDO years. Because the full 61-year daily flow record was available for both pre-Project and Maximum Load Following OS-1 conditions, the integration was performed for the full record in lieu of selecting specific years. This more comprehensive approach of using the entire record rather than representative years provides a more thorough assessment of the long-term Project influence on sediment transport. If subsequently needed, the results for representative years can be extracted from the results for the 61 years.

#### *4.3.2.1. Initial Sediment Balance Middle Susitna River Segment (PRM 102.4 to PRM 187.1)*

The initial sediment balance for the Middle River Segment was developed based on the assumption that this reach is in sediment transport equilibrium for the coarse (gravel and cobble) size fractions and is sediment supply limited for the finer (sand and wash load) size fractions. The pre-Project sediment loads at Gold Creek were estimated by integrating the USGS 61-year record of mean daily flows over the applicable rating curve for each sediment-load component at the Susitna River at Gold Creek Gage (1529200) and Susitna River near Talkeetna Gage (15292100)[4]. The loads passing the Watana Dam site were then estimated by prorating this load based on the change in drainage area from Gold Creek to the dam site. The tributary loads were then estimated as the difference between the Gold Creek load and the prorated load at the dam site.

For post-Project conditions, it was assumed that none of the sand and gravel supply and only 10 percent of the wash load will pass through the reservoir, and the supply from the tributaries will be the same as under pre-Project conditions. This assumption is probably sound below-dam for the sand and gravel fraction, but the validity for the wash load fraction is uncertain.

A more detailed sediment balance will be developed in the next year of study for the Middle Susitna River Segment between the proposed Watana Dam site (PRM 187.1) and the Three Rivers Confluence (PRM 102.4) 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 mass wasting locations and bank erosion will also be accounted for in the sediment budget. The volume of sediment from bank erosion will be estimated by comparing the channel location and area developed in the Assess Geomorphic Change Middle and Lower Susitna River Segments study component (ISR Study 6.5 Section 4.4) and comparison of cross-sections surveyed from the 1980s with the 2012 cross sections. Refined estimates of tributary sediment loading will be made as part of the Fluvial Geomorphology Modeling below Watana Dam Study (ISR Study 6.6 Section 4.1.2.6).

Limited USGS sediment data are available for Indian River and Portage Creek (Knott et al. 1986) that could also be used to assist in the estimation of the sediment supply inputs to the Middle River. The data collected by USGS for the Bed Load and Suspended-load Data Collection at Tsusena Creek in the 1980s will be used to refine the estimates of the pre-Project sediment loads in the vicinity of the Watana Dam site.

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[4] Data from both these gages were combined into a single data set for the USGS (1987) analysis; this approach was adopted for this preliminary study, as well.

#### *4.3.2.2. Initial Sediment Balance Lower Susitna River Segment (PRM 32 to PRM 102.4)*

The primary purpose of the Initial Sediment Balance evaluation for the Lower Susitna River Segment was to provide an initial assessment of the potential for the Project to alter sediment transport conditions and channel response in the Lower River. The results of this evaluation provide the basis for assessing the need to perform additional 1-D and 2-D Bed Evolution modeling and other studies related to potential channel change downstream from PRM 79 (RM 75). The sediment balance in the Lower River depends on the transport capacity of the Lower River Segment in relation to the sediment supply from the Middle River Segment, the Chulitna and Talkeetna rivers, and other local tributaries along the reach. The total sediment supply to the Lower River Segment under pre-Project conditions was estimated by integrating the transport capacity rating curves for the relevant gages over the USGS 61-year extended hydrology record. Initial estimates of the total sediment loads under post-Project conditions were made by integrating the curves over the synthetic 61-year Maximum Load Following OS-1 mean daily flow record. The sediment loads passing the Gold Creek gage developed for the Middle River Segment sediment balance were used to represent the upstream supply to the Lower River Segment from the mainstem. Other mainstem and tributary gages used in the analysis include the following:

1. Susitna River at Sunshine (USGS Gage No. 15292780)
2. Susitna River at Susitna Station (USGS Gage No. 15294350)
3. Chulitna River near Talkeetna (USGS Gage No. 15292400) and the Chulitna River below canyon near Talkeetna gage (USGS Gage No. 15292410)[1]
4. Yentna River near Susitna Station (USGS Gage No. 15294345)
5. Talkeetna River near Talkeetna (USGS Gage No. 15292700)

#### *4.3.2.3. Characterization of Bed-material Mobilization*

Bed-material gradations derived from surface and subsurface samples collected in 2013 in the Lower and Middle Susitna River Segments show that the bed surface is substantially coarser than the subsurface (ISR Study 6.6 Section 5.1.9.1). This condition is typical of gravel-bed streams where a coarse surface layer develops to regulate the transport of the full range of particle sizes. During low to moderate flows, the armor layer is not mobilized, shielding the finer subsurface materials and limiting their transport to the upstream supply. The full range of particle sizes in the bed is available for transport only after the coarse surface layer is mobilized. Mobilization of the bed-surface is, therefore, of interest because (1) it governs the bed load transport of gravel and cobbles, which is a key process affecting mainstem and side channel morphology and habitats, and (2) it regulates the supply of sand and fine gravel from the subsurface, which is integral to the process of building depositional features that influence important fish and riparian habitats. The range of flows over which the surface bed material is mobilized (aka incipient motion analysis) can be quantified based on the hydraulic conditions and the bed-material size gradations. Results from the incipient motion analysis can then be used to assess the frequency and duration of bed-material mobilization under the pre- and post-Project condition hydrology. This assessment will be performed on both a monthly and annual basis at the USGS gage locations, the Focus Areas and for reach averaged hydraulic conditions for representative hydrologic conditions (i.e., dry, average, wet).

The concept of incipient motion as advanced by Shields (1936) provides a basis for quantifying mobilization of the bed material. Shields (1936) related the critical shear stress for particle motion ($\tau_c$) to the dimensionless critical shear stress ($\tau^*_c$) and the unit weight of sediment ($\gamma_s$), the unit weight of the water-sediment mixture ($\gamma$), and the median particle size of the bed material ($D_{50}$) (Equation 4.3-1).

$$\tau_c = \tau_c^* \cdot (\gamma_s - \gamma) D_{50} \quad (4.3\text{-}1)$$

One key limitation of this relation is the specification of $\tau^*_c$ (often referred to as the Shields parameter), which can range by a factor of three (Buffington and Montgomery 1997), corresponding to a similar range in the critical shear stress for incipient motion. The large range in published values for $\tau^*_c$ is caused largely by the difficulty in defining and identifying when bed-material motion actually begins (i.e., incipient motion). To work around this limitation, Parker et al. (1982) defined a reference Shields stress ($\tau^*_r$) that corresponds to a dimensionless transport rate $W^* = 0.002$, which represents a very low, but measurable transport rate. For this relationship, $W^*$ is a function of the unit bed load and the total boundary shear stress, both of which are relatively simple parameters to calculate if bed load and discharge measurements are available.

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 because the larger particles project 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 and Müller (1948), and Einstein (1950) recognized this effect in developing their original bed load transport equations, and numerous researchers have continued to evaluate and provide relationships that account for this effect (Egiazaroff 1965; Parker et al. 1982; Andrews 1983; Neill 1968; Proffitt and Sutherland 1983; 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 entrainment 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 this study, the range of discharges associated with bed-surface mobilization will be quantified for most of the geomorphic reaches (Section 5.1.2) included in the 1-D Bed Evolution Model (ISR Study 6.6 Section 5.1.5). Bed-material mobilization will not be characterized in Geomorphic Reach MR-4 (PRM 166.1 to PRM 153.9) because very little, if any, alluvial sediment is stored within this narrow and steep reach (i.e., Devils Canyon). The 1-D Bed Evolution Model will be used to simulate hydraulic conditions under pre- and post-Project hydrology. Bed surface gradations downstream from PRM 146.1 will be based on samples collected in 2013 (ISR Study 6.6 Section 5.1.9.1); gradations upstream of PRM 146.1 will be based on samples collected in the next study year.

At the Gold Creek and Sunshine gaging stations, coupled measurements of flow and bed load will be used with simulated hydraulics and sampled bed surface materials to identify $\tau^*_r$ for $W^*$ = 0.002 following an approach similar to that used by Müller et al. (2005). The resulting values of $\tau^*_r$ will then be compared with reported values from rivers with similarly sized bed material, and either the standard values or an updated set of values will be used to quantify the critical discharge along the project reach. The duration of the critical discharge under pre- and post-Project conditions will then be estimated based on the applicable flow-duration curves.

#### *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 channel planform and geometry. 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.*" 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 transports the most sediment provides useful information to (1) assess the current state of adjustment of the channel, and (2) evaluate the potential effects of post-Project 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).

Estimates of the potential change in effective discharge between historical and post-Project conditions provide a basis for predicting whether the channel capacity will change due to the Project, and if so, the likely trajectory and magnitude of the changes.

Initial estimates of the effective discharge developed in 2013, were computed for the Susitna River at Gold Creek, Sunshine, and Susitna Station gages on the mainstem, and the Chulitna, Talkeetna, and Yentna rivers that are key tributaries in the study reach. The analysis was performed by dividing the full range of flows at each location into equal arithmetic flow classes or bins (Biedenharn et al. 2000). The number of bins used ranged from 25 to 43, with bin sizes of 2,000 cfs for Gold Creek and Chulitna and Talkeetna rivers. A bin size of 4,000 cfs was used for the Sunshine gage on the mainstem and the Yentna River, while a bin size of 8,000 cfs was used for the Susitna Station gage. Data input for this analysis included the daily sediment loads for the 61-year record of mean daily flows for each gage from the above-described sediment balance analysis. Effective discharges were determined for both the pre-Project and Maximum Load Following OS-1 conditions.

### 4.3.3. Variance from Study Plan

The Study Plan calls for comparison of the total sediment load at the Sunshine and Susitna Station gaging stations for an average, wet, and dry year between pre- and post-Project conditions using adjusted post-Project rating curves. Because the 61-year daily flow record was available for both pre-Project and Maximum Load Following OS-1 conditions, the full record was used for this purpose in lieu of selecting specific years for the analysis. Sediment loads were compared on an average annual basis over all years, and the variability assessed by considering the range of annual loads from the 61-year record. This more comprehensive approach to assessing sediment loads provides a better assessment of the long-term Project influence on sediment transport than considering only the three “representative” years. If subsequently needed, the results for representative years can be extracted from the results for the 61 years. The variance provides additional information to support meeting the study objectives.

In addition to Gold Creek, the effective discharge was computed for the mainstem Susitna River at Sunshine and at Susitna Station for both the pre-Project and Maximum Load Following OS-1 conditions. The effective discharge was also computed for the three main tributaries to the Susitna River at the Chulitna, Talkeetna, and Yentna rivers for the same two hydrologic conditions. Because a sufficient period of record was not available, the effective discharge was not calculated at Susitna River below Tsusena Creek. Also, in accordance with the relevant literature, equal arithmetic bins and not logarithmic bins (as incorrectly stated in the RSP) were used in the effective discharge analysis (Biedenharn et al. 2000). The variance provides additional information to support meeting the study objectives.

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

The goal of this study component is to compare current, 1980s and 1950s geomorphic feature data from aerial photography analysis to characterize channel stability and change and the distribution of geomorphic features under unregulated flow conditions. The effort includes use of the best available aerial photographs from the 1950s to provide a longer range assessment of channel change. The 1950s aerial photographs were identified, acquired and processed as part of this study component (Section 4.4.2). The acquisition of the current aerial photography 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 (RSP 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 (RSP Section 6.5.4.7). Digitization of the geomorphic features from the 1980s and 2012 aerials, determination of geomorphic feature areas, and qualitative assessment of channel change were conducted in 2012 for the flows at which the aerials were obtained. Due to a combination of weather and flows conditions, not all aerials originally planned for acquisition in 2012 were obtained at their target flows. A complete set of aerial photographs were flown for the Upper, Middle and Lower Susitna River segments in 2013. The 2013 aerial photographs were also flown in each river segment at a more consistent flow than the 2012 aerial photographs and filled in some small gaps in the coverage in the Upper

River segment. The 2013 aerial photographs are of additional value as they document conditions in the river after the large runoff event in June 2013 as well as the high flows experienced in September 2012. The acquisition of the 2012 and 2013 aerial photography representing the current condition and the 1980s aerial photography is further discussed in Sections 4.5 and 4.7. The study area extends from the mouth of the Susitna River at Cook Inlet to the proposed Watana Dam site (PRM 187.1 [RM 184]).

A technical memorandum entitled Mapping of Geomorphic Features within the Middle and Lower Susitna River Segments from the 1980s and 2012 Aerials (Tetra Tech 2013g) was filed with FERC in March 2013. This effort was conducted as part of the 2012 studies. Additional details on the methods, results and discussion of the analysis of the 1980s and 2012 aerial photography can be found in Tetra Tech (2013g). The acquisition and analysis of the 1950s aerial photographs are efforts that were initiated in 2013 and are not presented in the 2013 technical memorandum.

### 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 streamflows 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). The 1980s 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 were 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 subreaches 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 (Study 8.6) and Ice Processes in the Susitna River (Study 7.6) studies to provide the surface areas of bars likely to become vegetated in the absence of ice-cover formation.

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 provides information useful in identifying LWD recruitment rates (Section 4.9) and characterizing floodplain dynamics important to the Riparian Instream Flow Study (Study 8.6). Therefore, a "turnover" analysis is included as part of this study component.

### 4.4.2. Methods

AEA implemented the methods as describe in the Study Plan with no variances. This study component has been divided into the Middle and Lower Susitna River Segments because the available information differs. The analysis of geomorphic change is being conducted for a single representative discharge. The targeted flow was 12,500 cfs in the Middle River and 36,600 cfs in the Lower River in 2012 and was raised to 40,000 cfs in 2013 based on input from the Fish and Aquatics Instream Flow Study (Study 8.5).

#### *4.4.2.1. Discussion of Aerial Photography Used*

Aerial photographs were acquired for the current condition (2012 and 2013), the1980s and the 1950s.

##### *4.4.2.1.1. 2012 and 2013 Aerial Photography*

In the 2012 Study Technical Memorandum (Tetra Tech 2013g) the mapping of current condition geomorphic features was based on aerial photography acquired in 2012. Table4.4-1 lists the acquired 2012 aerial photography which were used for geomorphic features delineation. A description of processing methodology for the 2012 aerial photography is explained in Tetra Tech (2013f).

A 2013 supplemental aerial photo acquisition effort was 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. Table 4.4-2 lists the aerial photography acquired in 2013 for the Upper, Middle, and Lower River Segments. Aerial photographs near the target flows were acquired in the Lower River Segment from PRM 102.4 to the mouth of the Susitna River at Cook inlet (35,500 cfs at Sunshine) and for the Middle River Segment from PRM 153.6 to PRM 106.8 (11,300 cfs at Gold Creek). Previously, aerial photographs at the target flow were not available for PRM 187.1 to PRM 143.6. Additional 2013 aerial photography was collected in the Middle River Segment from PRM 187.1 to PRM 184.9 (19,200 cfs at Gold Creek), PRM 184.9 to PRM 153.6 (6,200 cfs at Gold Creek) and PRM 106.8 to PRM 102.4 (15,300 cfs at Gold Creek). A description of processing methodology for the 2013 aerial photography is explained in ISR Study 6.5 Section 4.5.2.

##### *4.4.2.1.2. 1980s Aerial Photography*

In Tetra Tech (2013g), the current condition of the Susitna River was compared to a historical condition based on aerial photography acquired in 1980s. A summary of the 1980s aerial data collected is included in Table 4.4-3. The specific aerials that were used to delineate the geomorphic features were identified by date, gage discharge, and PRM. The collection of 1980s aerial photography is explained in Tetra Tech (2013f).

#### *4.4.2.1.3. 1950s Aerial Photography*

In 2013, digital versions of historical 1950s aerial photographs were acquired and orthorectified to provide a longer range assessment of channel change. A summary of the acquired 1950s aerial photograph data is included in Table 4.4-4. The specific aerial photographs that were used to delineate the geomorphic features were identified by date, gage discharge, and PRM. The aerial photographs covering the Lower River are referenced to the Susitna River at Gold Creek and a synthesized discharge from the USGS's extended record for Susitna River at Sunshine (USGS 2012). The synthesized values are not actual measured flows and actual flows may have varied considerably.

##### *4.4.2.1.3.1. Description of 1950s Aerial Photography Acquisition*

To support the study of the geomorphology of the Susitna River an effort was made to identify and acquire archival imagery of the project site for the production of orthophotography. Several sources were contacted to find historical aerial photography for the Susitna River from 1945 through 1960 (referred to herein as the 1950s aerials). The first sources contacted were the Earth Data Analysis Center (EDAC) and Aerometric, Inc. in Anchorage, AK. Aerometric proved not to have 1950s aerials in their archives. EDAC searched the Aerial Photography Summary Record System (APSRS) database, which covers the US Department of Interior and found several US Air Force (USAF) projects, which ranged from 1949 to 1955. The USAF aerial photographs are made available through the USGS Earth Resources Observation and Science (EROS) Center, an archive that can be searched on-line and ordered using the USGS Earth Explorer facility. These aerials were acquired through the USGS.

The area of interest (AOI) polygon was established and finalized in shapefile format on April 23, 2013. To search the USGS Earth Explorer website, a simplified polygon was developed that fully contained the AOI. In Figure 4.4-1, the AOI is shown in magenta and the polygon used to search for archive photography is the surrounding yellow line.

Limiting the search to the years 1946 through 1955, returned a listing of 584 exposures of which approximately 400 exposures were selected for purchase. When choosing the epochs of photography to include in the study, larger sets of exposures flown on single dates was preferred to cover the project area with as few dates of photography as possible. Medium resolution scans of about 350 dpi (75-microns) were available for direct download from the Earth Explorer site, but high-resolution scans needed to be special ordered. An order for 400 custom scans at a resolution of 14 microns was placed on May 1, 2013, and the aerial photographs were received in early September 2013.

The scans were introduced to the aerotriangulation adjustment software on an epoch-by-epoch basis. Preliminary set-up work had been done using the low-resolution scans downloaded from the Earth Explorer website.

Mapping control for the photography was derived from Landsat imagery. The blocks of photography in the study extended well outside of the narrow corridor of the river for which higher resolution orthophotography was available. Therefore, it was necessary that control points for mapping be distributed to the limits of the photo coverage. Landsat imagery offered the broadest and most uniform source for identification of potential control points. Waterbodies and stream courses were the primary features used for control. At the time of photography, there was little infrastructure development in the study area and few identifiable features that might have served as horizontal control could be found. While the 100-foot pixel resolution of the Landsat imagery is rather low precision, the diagnostic statistics of the aerotriangulation adjustments showed sub-pixel residuals for the control points that were chosen. In an effort to improve the Landsat-based adjustment, three of the epochs of photography that cover the Middle River were subjected to a shift after an initial aerotriangulation solution was reached. Holding rigid the relative locations and orientations of the exposures, the preliminary solution was registered to a small collection of points identified in the 2012 orthophotos. In every case, the shifts that resulted from this procedure were smaller in magnitude than the RMSE of the Landsat control. Improvement in the accuracy in some locations was likely balanced by lower accuracy in other locations and the method was not extended to all blocks.

The orthophotos that were generated to cover the AOI came from eight epochs of photography: two dates in 1949, two dates in 1952, two dates in 1953 and single dates in 1951 and 1954 (Table 4.4-4). The orthorectification used the results of the individual solutions reached for each epoch and a DEM derived from IFSAR data. Orthophotos were delivered in the same tiling scheme used for the 2012 and 2013 orthophotos. Tiles were divided into sub-directories named for the date of the source photography for a particular set of orthophotos.

All the photography that was the subject of this work was flown by the USAF. The photography source, other photo block parameters, and control residuals are presented in Table 4.4-5. There were seven aerial cameras used. The documentation from the USGS search provided the camera number and the nominal focal length for six of the cameras used in the study, but no other camera calibration data. The USGS office responsible for camera calibration was contacted and asked for any calibration reports or other records pertaining to any of the seven cameras. They were able to provide standard calibration reports for two of the cameras and lens distortion parameters for two others. Both calibration reports had been issued in 1957 and reflected the analog photogrammetry technology of the time. Instead of coordinate positions for camera fiducial marks, the reports gave separation distances between collimation index markers, a precursor technology to camera fiducials. To support the methods of analytical photogrammetry, it was necessary to use these distances to derive coordinates for the corners of the index markers. It is through the measurement of these registration points in each scan that the geometric centers of the individual exposures are established. The centers of the exposures are critical points because they are the origin for all photo measurements and in the adjustment solution they correspond to the camera position at the time of exposure.

The eight epochs of photography in the study overlap one another where they adjoin. Tying epoch to epoch and performing a single, simultaneous adjustment on all the photography was the preferred approach, but it proved unworkable. The effort was abandoned as it proved to be too difficult to tie across epochs without degrading the quality of the solution for a single epoch. Part of the difficulty was due to the difference in solar illumination and the variation in ground conditions across different epochs of photography, but the poor quality of the imagery certainly contributed. Close examination of the raw imagery provided by the EROS Data Center reveals that at least some of the scans were made from contact prints, not from original negatives. An illustration presented in Figure 4.4-2 reveals that the source material for one particular scan was a torn contact print repaired with transparent tape. While these are the best materials available, the image resolution is limited by the source to such a degree that pattern recognition routines fail to correlate conjugate points reliably. A good deal of manual identification of common features was necessary to knit together even single epochs.

#### *4.4.2.2. Geomorphic Mapping Procedure*

For all three periods and both the Middle River and Lower River segments, similar procedures were used to map the geomorphic features. First the boundary of the area to map the geomorphic features within was defined. This area was generally the active floodplain and the details of its determination are provided in Tetra Tech (2013g). The mapping of the 1980s and 2012 geomorphic features was performed for all areas within the area of geomorphic boundary of the Middle and Lower Susitna River segments. This is in contrast to aquatic macrohabitat mapping, which was performed for 23 selected habitat sites in the Middle River and five habitat sites in the Lower River (see Sections 4.5.2 and 4.7.2 for a description of the macrohabitat mapping).

In 2013, after the decision to model the Three Rivers Confluence with the 1-D Bed Evolution Model was made, the upstream limits of the area of geomorphic delineation were extended upstream 4.4 miles on the Talkeetna River and 9.1 miles on the Chulitna River.

The methodology currently being used to map the 1950s geomorphic features is analogous to that used for the 1980s and 2012 geomorphic features. Geomorphic feature delineations were made using ArcGIS 10.0 at a scale of 1:3,000.Two sets of geomorphic feature classifications were utilized: one for the Lower Susitna River segment and one for the Middle Susitna River segment. While the delineations of geomorphic features reflected the aquatic habitat, they were not always limited to the wetted habitat, but rather encompassed the entire bank to bank extent of the feature. Therefore, the geomorphic features followed defined bank lines and included the wetted habitat, exposed substrate, and other low-lying areas within the banks of the feature.

It should be noted that unlike the delineated geomorphic features, aquatic macro-habitat types have a wetted connection to the Susitna River. The riverine aquatic macrohabitat classifications (main channels, side channels, side sloughs, upland sloughs, and tributaries) apply to the wetted area of the geomorphic feature that has direct or indirect surface-water connection to the main channel. This connection does not have to be direct, but could be through one or more additional geomorphic features. For example, an upland slough could connect to a side slough, which connects to a side channel and ultimately the main channel. If the water body was isolated and there was not a connection to the Susitna River, then the wetted area was mapped as additional open water (AOW). The delineation of aquatic macrohabitat is covered in a separate technical memorandum (Tetra Tech 2013f) and is also described in Sections 4.5.2 and 4.7.2 of this report.

The geomorphic features on the 1950s aerial photographs in both the Middle and Lower River segments are currently being mapped. When this effort is completed, the surface areas of the geomorphic features for the 1950s will be compared to those already developed for the 1980s and 2012. Area measurements (square feet) are calculated in GIS to the sixth decimal point and tabulated to a precision of 1,000 square feet. Each geomorphic feature type within the geomorphic reach and the total area for the reach are summed for comparison. This information has been developed for each of the geomorphic reaches in each segment. In addition, overlays of the 2012 and 1980s feature delineations were provided in Tetra Tech (2013g) to help identify channel change. The identification of geomorphic change from comparison of the 1980s and 2012 aerial photographs and geomorphic feature mapping included:

- Changes in Channel Dimension and Form such as channel widths, lengths, and alignment.
- Identification of Geomorphic Processes such as bank erosion, bar formation, lateral channel migration, meandering, and avulsion.
- Changes in Hydraulic Connections due to the breaching of side sloughs and side channels.
- Identification of Biogeomorphic Process such as beaver dam construction and failure.
- Identification of Vegetation Processes such as encroachment, succession, and removal.

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 for the 1950s as it was for the 1980s, and current conditions. Relatively stable reaches will be identified between the 1950 and 1980s and compared to those that are more dynamic. This has been completed for the 1980s to 2012 period (Tetra Tech 2013g). Specifics of the geomorphic feature mapping for the Middle River and Lower River are presented in the next sections.

#### *4.4.2.3. Middle Susitna River Segment*

Mapping of the geomorphic features required defining several geomorphic feature types in the Middle River. The geomorphic features for the Middle Susitna River segment were based on the same categories as the aquatic habitat types defined in Trihey & Associates (1985). The wetted perimeter of macrohabitat types (main channel, side channel, side sloughs, upland sloughs) along with the exposed substrate and other low-lying areas within the banks defined the extent of a geomorphic feature.

With the inclusion of tributaries, vegetated islands, and additional open water, the Middle River geomorphic features are listed below. Complete definitions for the geomorphic features can be found in Tetra Tech (2013g).

- Main Channels (MC)
- Side Channels (SC)
- Upland Sloughs (US)
- Side Sloughs (SS)
- Tributary (TR)
- Vegetated Island (VI)
- Additional Open Water (AOW)
- Exposed Substrate (EXP)

These geomorphic features were mapped on the 2012 and 1980s aerial photographs previously identified using procedures described above. The same features are currently being mapped on the recently acquired 1950s aerials. The mapping of the current features will be updated based on field observations as well as use of the helicopter video and line mapping performed as part of the Characterization and Mapping of Aquatic Habitats Study (Study 9.9).

#### 4.4.2.4. Lower Susitna River Segment

The extents of the side channels, main channel, anabranches and braid plain in the Lower Susitna River segment, including the Three Rivers Confluence area, were digitized from both the 1980s and 2012 aerials. Planform shifts of the main channel and side channels were identified between the 1983 and current aerial photography. Geomorphic features that are visible on 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 numerous 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.

For the Lower Susitna River segment, geomorphic mapping types were adapted from the habitat types identified in R&M Consultants, Inc. and Trihey & Associates (1985a). These included: vegetated areas, exposed substrate, and aquatic macrohabitat types (main channel, side channels, side sloughs, tributaries, and upland sloughs). Features such as the side channel complex (SCC), bar island complex (BIC), bar/attached bar (BAB), tributary delta, and additional open water were added to the classification. Within this analysis, mainstem was defined as the total of the areas and vegetated islands associated with the main channel, bar island complexes, and side channel complexes. Braid plain is defined as the total of main channel and bar island complexes. The Lower River geomorphic feature classifications are listed below (Tetra Tech, 2013g).

- Main Channel (MC)
- Side Channel (SC)
- Side Channel Complex (SCC)
- Bar Island Complex (BIC)
- Bar / Attached Bar (BAB)
- Side Slough (SS)
- Upland Slough (US)
- Tributary (TR)
- Tributary Delta (TD)
- Vegetated Island (VI)
- Additional Open Water (AOW)

In 2013, orthorectified digital versions of 1950s aerial photographs were acquired and the digitization of geomorphic features will be completed in the next year of study.

The delineations of the 1950s, 1980s and 2012 Lower River geomorphic features will be compared in a "turnover analysis." Similar to what was stated for the Middle River, depending upon the results of the geomorphic analysis in the Lower River, additional historical photographic analysis may be requested as part of future geomorphic studies, but this additional analysis is not included at this time. A decision on whether to acquire additional aerials will be made in the next year of study, with analysis to follow.

#### *4.4.2.5. Turnover Analysis*

The 1950s, 1980s and 2012 geomorphic feature mapping will be used to conduct a quantitative evaluation of channel change or "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 from the 1950s, 1980s and 2012 will be used to determine the rate at which floodplain and islands are converted to channels and conversely the rate at which channels are converted to islands over the period from the 1950s to 1980s and 1980s to 2012. 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 the 1980s, and between the 1980s and 2012. 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 history 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. The turnover analysis data will also be tabulated for each of the Focus Areas in the Middle River segment.

While the long-term changes in river morphology are the result of a range of flows, if significant changes are identified between time-sequential 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 photograph analysis could provide more specific information on the flow magnitude(s) and other conditions (for example, ice formation) that may cause substantial geomorphic adjustments.

#### *4.4.2.6. Information Required*

The following available existing information was used to conduct this study:

- 1980s orthorectified aerial photographs for the Middle and Lower Susitna River Segments.
- 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 photography 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 aerial photography of the Middle River and Lower River to provide coverage at more consistent flow levels than were acquired in 2012 and also to provide post 2012 and 2013 high flow coverage.

### 4.4.3. Variance from Study Plan

No variances occurred in implementing this study component in 2013.

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

The goal of this study component is to delineate current (2012) 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 were 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 (Study 9.9). The classification levels include rivers segment, geomorphic reach, macrohabitats, mesohabitat, and edge habitat. The Geomorphology Study defined the Susitna River segments and geomorphic reaches in Tetra Tech (2013b). The effort in this study component (Section 4.5) mapped approximately 50 percent of the macrohabitat in the Middle River. The results were provided to the habitat characterization study (Study 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 (PRM 102.4 [RM 98]) to the Watana Dam site (PRM 187.1 [RM 184]). Seventeen study sites representing approximately 50 percent of the river studied in the 1980s were studied in the 2012 study (Table 4.5-1). Due to a combination of weather and flow conditions, not all aerial photographs intended to be acquired in 2012 were flown at their target flows. (Table 4.4-1 summarizes the 2012 aerial photo acquisition.) The 2012 effort supplied the information necessary to support the reach stratification and selection of proposed Focus Areas in the Middle River.

A complete set of aerial photographs was flown for the Upper, Middle and Lower Susitna River segments in 2013. The 2013 aerial photographs provide conditions in the river after the large runoff event in June 2013 as well as the high flows experienced in September 2012. The 2013 aerial photographs were also flown in each river segment at a more consistent flow than the 2012 aerial photographs and filled in small gaps in the coverage in the Upper River segment. The remaining portion, approximately 50 percent not mapped for macrohabitat types in the 2012 study, of the Middle Susitna River Segment will be mapped in the next year of study.

A technical memorandum entitled Mapping of Aquatic Macrohabitat Features at Selected Sites in the Middle and Lower Susitna River Segments from the 1980s and 2012 (Tetra Tech 2013f) conducted as part of the 2012 studies, was filed with FERC in March 2013. Additional details on the methods, results and discussion of the analysis of the 1980s and 2012 aerial photographs can be found in the technical memorandum. Sections 4.7, 5.7, and 6.7 present the methods, results, and discussion for mapping of the Lower River aquatic macrohabitats.

### 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 streamflows 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 (PRM 102.4 [RM 98]) and Devils Canyon (PRM 153.9 [RM 150]) ranging from 5,100 to 23,000 cfs (measured at Gold Creek gage [approximately PRM 140.0 [RM 134]]).

Understanding existing geomorphic conditions, how aquatic macrohabitat changes over a range of streamflows, 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 macrohabitat mapping to support the Fish and Aquatics Instream Flow Study (Study 8.5) and will be used in the Ice Processes in the Susitna River Study (Study 7.6) and the Riparian Instream Flow Study (Study 8.6) to provide the surface areas of bars likely to become vegetated in the absence of ice-cover formation.

### 4.5.2. Methods

AEA implemented the methods as described in the Study Plan with the exception of the variances explained below (Section 4.5.3). 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 (aerial photographs for high and medium flows were collected, but no aerial photographs for low flows were collected). A supplemental data collection effort was conducted in 2013 to acquire aerials at 12,500 cfs for the entire Middle Susitna River segment.

The results for the information available in 2012 were analyzed and presented in a March 2013 technical memorandum (Tetra Tech 2013f) as riverine habitat areas for specific flows at three spatial levels for the (1) Middle Susitna River Segment, (2) geomorphic reaches in the Middle Susitna River Segment, and (3) 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 were made for the 17 study sites below Devils Canyon. Comparisons between the remaining 50 percent of the Middle River below

Devils Canyon will be performed in the next year of study. The historical information was only developed for reaches MR-5 through MR-8 (PRM 153.9 to PRM 102.4 [RM 150 to RM 98]) because 1980s aerial photographs from (PRM 187.1 to PRM 153.9 [RM 184 to RM 150]), were not flown at the appropriate discharges.

The methods for this study component have been divided into three tasks: (1) aerial photography, (2) digitize riverine habitat types, and (3) riverine habitat analysis.

#### 4.5.2.1. Aerial Photography

Aerial photographs were acquired for the current condition (2012 and 2013) and the 1980s for use in the aquatic macrohabitat mapping.

##### 4.5.2.1.1. 2012 and 2013 Aerial Photography

Portions of new color aerial photography of the Middle Susitna River Segment (PRM 102.4 to PRM 187.1 [RM 98 to RM 184]) 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 aerial photography coverage collected included PRM 102.4 to PRM 118.9 (RM 98 to RM 122.5) at 22,200 cfs, PRM 102.4 to PRM 143.6 (RM 98 to RM 140) at 12,900 cfs, and PRM 143.6 to PRM 187.1 (RM 140 to RM 184) at 17,000 cfs (see Table 4.4-1).

It was the intent of the study plan to obtain three sets of aerial photography in 2012 at the following approximate discharges: 23,000, 12,500, and 5,100 cfs. (Note: seven sets of aerial photographs were flown and evaluated in the 1985 study at stream flows of 5,100, 7,400, 10,600, 12,500, 16,000, 18,000, and 23,000 cfs.) The combination of weather conditions and river flows only allowed portions of the 23,000 and 12,500 cfs aerial photographs to be collected in 2012. No aerial photographs were obtained for the lowest flow of 5,100 cfs because ice and snow cover formed prior to the Susitna River dropping to this level in 2012. In order to provide a complete set of current aerial imagery, the 17,000-cfs aerial photographs were collected from PRM 143.6 to PRM 242.3.

###### *4.5.2.1.1.1. Description of 2012 Aerial Photography*

In Tetra Tech (2013f), the current condition of the Susitna River was based on aerial photography acquired in 2012 at 17,000 cfs from PRM 187.1 to 143.6 and at 12,500 cfs from PRM 143.6 to 102.4. Table 4.4-1 lists the portions of the acquired 2012 aerial photography that were used to map the geomorphic features. The same aerials were used to map aquatic macrohabitat types. The aerial photography was flown at a scale of 1:12,000 and with a pixel resolution of 1 foot or better. A description of processing methodology for the 2012 aerial photography was provided in Tetra Tech (2013f).

###### *4.5.2.1.1.2. Description of 2013 Aerial Photography*

In 2013 a supplemental aerial photo acquisition effort was performed to obtain aerial photographs at consistent flow rates that were scheduled for collection in 2012, but were not collected due to a combination of weather and flow conditions. Table 4.4-2 lists the aerial photography acquired in 2013. Imagery was collected in five flights, on four different dates.

The flight dates were September 16, 20, 24, and November 6, 2013. A total of 38 flight lines were flown. The 2013 area of interest (AOI) and the image center coordinates for all four flights are shown in Figure 4.5-1.

The 2013 aerial photographs will be used to revise the 2012 current conditions mapping from approximately PRM 184.9 to PRM 143.6. Target flows were acquired in 2013 for the Middle River Segment from PRM 153.6 to PRM 106.8 (11,300 cfs at Gold Creek). Previously, the target flow was not available in the 2012 aerial photographs for PRM 187.1 to PRM 143.6. Additional 2013 aerial photography was collected in the Middle River Segment for PRM 187.1 to PRM 184.9 (19,200 cfs at Gold Creek) and PRM 184.9 to PRM 153.6 (at 6,200 cfs at Gold Creek) and PRM 106.8 to PRM 102.4 (15,300 cfs at Gold Creek).

The aerial photography was processed into orthorectified aerial imagery. Orthoimagery is aerial imagery that has been rectified to a map projection by removing displacement caused by terrain undulation and camera geometry. The orthoimagery has a ground resolution of 1 foot. The datum and projection was Alaska State Plane, Zone 4, North American Datum of 1983. The imagery was supplied as 4 band imagery with the natural color bands red, green, blue, and with near infrared.

To generate the orthoimagery three inputs are required: aerial images, orientation parameters for the imagery and a digital elevation model (DEM). Aerial imagery was collected with a digital aerial camera capable of collecting four spectral bands simultaneously, namely red, green, blue, and near infrared. The orientation describes the position and altitude of the camera at each moment an exposure is taken. For this purpose, kinematic airborne GPS data were collected during the flight. The camera was equipped with an inertial measurement unit. During the flight static GPS data were collected at one or several ground base stations. Data from the airborne GPS unit, the inertial measurement unit and the stationary ground GPS unit were combined in post-processing to derive an initial flight trajectory (i.e. orientations for the imagery). These orientations were then further improved in an aerotriangulation process. In the aerotriangulation the images were tied together by identifying common points in overlapping areas. At the same time, the images were tied to the ground by identifying and measuring surveyed ground-control points in the images. The third input for the orthorectification method is the DEM.

With these three inputs the aerial images were orthorectified to a map projection. The images were then color-balanced. The goal was to improve interpretability of the imagery and to create a seamless mosaic of all images. The radiometrically balanced images were then stitched together along seamlines to create a seamless mosaic across the study area. The mosaic was then clipped to the area of interest. In order to keep the image file size manageable the orthoimage mosaic was saved in individual image tiles.

The processing of the airborne GPS data and the preliminary aerotriangulation was performed by Aero-Metric. The aerotriangulation was performed with the INPHO MATCH-AT, version 5.5.0 software. Tie points were created using autocorrelation routines and manually measuring points. Control points were manually measured. The aerotriangulation for the flights that occurred in September was conducted before the November flights. Therefore, the September project was split into two sub-blocks for processing. Sub-block south contains flights 1 through 23. Sub-block east contains flights 30 through 38. The final run was a simultaneous bundle solution for each sub-block. Surveyed ground-control points were available from Aero-Metrics project number "6110401 Mat Su DMC."

Sub-block south had three horizontal and vertical surveyed points from the Mat Su DMC project. There were also three additional control points used only for vertical control. There were four images that were all water and were not adjusted in the AT. The final adjusted exterior orientation parameter file has the unadjusted GPS/inertial values for those images.

Sub-block east had two surveyed control points used as vertical only control. The photo panels from the Mat Su DMC project had been destroyed.

The check points in the aerotriangulation block were photo-identifiable points, which were measured in a previous project that had the same horizontal and vertical datums. They were relative to the previous project and do not reflect absolute accuracies. The accuracies were summarized in a separate aerotriangulation report (Attachment 1).

The final aerotriangulation, orthorectification, and mosaicking of the imagery will be performed with INPHO OrthoMaster 5.5.0 and INPHO OrthoVista 5.5 software by the Study Team. The following elevation data (DEM) is available for the process: a DEM with 1-meter grid spacing derived from ground classified LiDAR data collected in 2011 and a DEM with 5-meter grid spacing derived from interferometric synthetic aperture radar data collected in 2010. A combination of both DEMs was used as the LiDAR derived DEM does not cover all of the aerial acquisition. Because the LiDAR DEM represents the bare earth and does not include structures such as bridges, it was edited in a few locations to make it usable for orthorectification.

##### *4.5.2.1.2. 1980s Aerial Photography*

In Tetra Tech (2013f), the current condition of the Susitna River was compared to a historical condition based on aerial photography acquired in 1980s. To provide a basis for comparison, digital orthorectified images of the 1980s 12,500-cfs aerial photos were obtained to serve as the base map for overlaying the digitized riverine habitat types from the1980s map book (Trihey and Associates 1985). A summary of the 1980s aerial data used in the comparison is included in Table 4.4-3. The specific aerial photographs that were used to delineate the aquatic macrohabitat types were identified by date, gage discharge, and PRM. The collection of 1980s aerial photography is explained in Tetra Tech (2013f).

### *4.5.2.2. Digitize Riverine Habitat Types*

The digitization of riverine habitat types was conducted as two steps, site selection and the actual delineation of the macrohabitat types.

##### *4.5.2.2.1. Site Selection*

A total of 28 sites on the Susitna River below the Watana Dam site were selected for mapping of 2012 aquatic macrohabitat and comparison with similar mapping in the 1980s. These sites were selected and defined, in terms of their extents, by the Geomorphology Study in coordination with the ongoing Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study

(Study 8.6) and Ice Processes in the Susitna River Study (Study 7.6). Five sites were selected in the Lower Susitna River segment and 23 sites in the Middle Susitna River segment (Table 4.5-1).

In the 1980s, only the portion of the Middle River from PRM 104 to PRM 153 (RM 101 to RM 149) was mapped for habitat (Trihey & Associates1985). Within this 49-mile section of the Middle River, 17 sites were selected to develop comparisons of 2012 aquatic macrohabitat with the aquatic macrohabitat mapped in the 1980s. These sites total 27.2 miles and represent over 50 percent of the 49-mile total length of this portion of the Middle River. The sites were selected to:

- represent a wide range of aquatic macrohabitat types,
- include areas with considerable study information available from the 1980s,
- include sites within all the geomorphic reaches, and
- represent the range of change that has occurred within the Middle River between the 1980s and 2012.

The Middle Susitna River Segment upstream of PRM 153 (RM 150) was not studied in the 1980s; however, the current habitat features are to be delineated for 100 percent of the portion of the segment encompassing Geomorphic Reaches MR-1 and MR-2 (PRM 187.1 to PRM 169.6). Geomorphic Reaches MR-3 and MR-4 (PRM 169.6 to PRM 153.9) were not studied in this effort since field data cannot be collected safely in these reaches due to the extreme gradient and hydraulic conditions in Devils Canyon. Six sites were selected in Geomorphic Reaches MR-1 and MR-2, representing a variety of conditions and totaling 9 miles of the total 17.5 miles of combined Geomorphic Reaches MR-1 and MR-2. Table 4.5.-1 lists the location of all 23 sites in the Middle Susitna River segment selected for mapping of aquatic macrohabitat as part of the 2012 studies (Tetra Tech 2013f).

Though the 2012 effort represents mapping approximately 50 percent of the Middle Susitna, in the next year of study, the remaining portions of the entire Middle River will be mapped for aquatic macrohabitat for current conditions (2012 or 2013). For the 1980s conditions, the remaining areas with available 1980s aerial photographs at the appropriate discharges, PRM 102.4 to PRM 154 (RM 98 to RM 150), will be mapped for aquatic macrohabitat.

##### *4.5.2.2.2. Digitizing Macrohabitat Types*

The macrohabitat assessment comprised both a digitization procedure for the line work and riverine habitat classification.

###### *4.5.2.2.2.1. Digitization Procedure*

Prior to performing the aquatic macrohabitat delineations, boundaries were defined for the selected habitat sites. Within each habitat site, polygons were delineated for exposed substrate, vegetated islands, and wetted habitat types. Wetted areas were mapped as one of the aquatic habitat types only if the area had a connection to the Susitna River. This connection did not have to be direct, but could be through one or more additional wetted habitat types. For example, an upland slough could connect to a side slough, which connects to a side channel and ultimately the main channel. If the water body was isolated and there was not a connection to the Susitna River, then the wetted area was mapped as additional open water (AOW).

Delineations were made using ArcGIS 10.0 at a scale of 1:3000. Habitat delineations from the 2012 aerial photographs were assisted by use of the 2011 Mat Su LiDAR (Matanuska-Susitna Borough 2011) to determine elevation differences to better define the boundary between channel areas and floodplain or island areas. Riverine habitat types from PRM 102.4 to PRM 154 (RM 98 to RM 150) defined in the 1980s were digitized from hard copy maps in the Middle Susitna River Segment Assessment Report (Trihey & Associates 1985). Each habitat type was digitized as a polygon (without slivers). Revisions to the 2012 habitat mapping will be made using the 2013 aerial photographs at a flow of 11,300 cfs from PRM 149 to PRM 143.6. Between PRM 187.1 and PRM 149, the 2013 6,200-cfs flow aerial photographs will be digitized. The 2011 Mat-Su aerial photographs (Matanuska-Susitna Borough 2011) and line mapping videography collected as part of the Characterization and Mapping of Aquatic Habitats Study (Study 9.9) will be used to help classify aquatic macrohabitat types.

The digitization procedures for the 2013 aerial photographs will follow those outlined for the 2012 aerial photographs in the technical memorandum (Tetra Tech 2013f). In general, the area measurements (square feet) were calculated to the sixth decimal point and tabulated to a precision of 1,000 sq. ft. Each habitat type within the habitat sites as well as the total area of the habitat site (control area) was summed for comparison. To verify that all habitat surface areas were accounted for, each habitat type was summed and compared to the control area. Comparisons between summed individual areas and the total control area were considered acceptable if the difference was less than 0.5 percent. The habitat type areas were used in this analysis to compare habitat type surface areas between 1983 and 2012.

###### *4.5.2.2.2.2. Riverine Habitat Classification Definitions*

The aquatic macrohabitat in the Middle Susitna River Segment was classified using categories as defined in Trihey & Associates (1985). The Middle Susitna River Segment macrohabitat types were classified into the following categories: vegetated islands, exposed substrate, and aquatic macrohabitat (main channel, side channel, side sloughs, upland sloughs, and tributary mouths). As previously mentioned, isolated wetted areas were mapped as additional open water and were not considered part of the riverine habitat. The classification definitions for tributaries, exposed substrate, additional open water and the aquatic macrohabitat types were defined in Tetra Tech (2013f).

The riverine aquatic macrohabitat classifications (all channels, sloughs, and tributaries) apply to the wetted area of a feature. The aquatic macrohabitat along with the exposed substrate contained within the banks of perennial vegetation comprise geomorphic features which are bounded at their inlets and outlets. The results of the geomorphic feature mapping are presented in a separate technical memorandum (Tetra Tech 2013g).

#### *4.5.2.3. Riverine Habitat Analysis*

The information developed in the previous task was used to compare 1980s aquatic macrohabitat areas with current conditions. The areas were developed for both 1980s and 2012. The riverine habitat type surface areas for the 1980s and current conditions were compared at both site and reach scales to determine if changes in the habitat areas have occurred. The comparison was only performed for a portion of the reach, since the 1980s study did not cover the Middle Susitna River segment from PRM 154 to PRM 187.1 (RM 150 to RM 184). This effort was completed for the 17,000- and 12,500-cfs aerial photographs collected in 2012.

Because the 2012 aerial photographs were not at the target discharges of 12,500 cfs in the Middle River, a methodology was developed in order to scale the 2012-digitized habitat areas to the comparable 1983 discharge. Scaling factors for the Middle River habitat sites were determined from information developed in the 1980s for four geomorphologically distinct subsegments (Trihey & Associates 1985a). As defined per the 1980s RM system, the extents of these subsegments include RM 101 to RM 113 (PRM 104.9 to PRM 116.5), RM 113 to RM 122 (PRM 116.5 to PRM 125.6), RM 122 to RM 138 (PRM 125.6 to PRM 141.4), and RM 138 to RM 149 (PRM 141.4 to PRM 152.5) (Trihey & Associates 1985a). In the absence of a table of values for the Middle River habitat sites, logarithmic-linear plots displaying total surface area (for each habitat type) versus mainstem discharge at Gold Creek for the four Middle River subsegments were used (Trihey & Associates 1985a) to obtain the areas for given discharges. The total surface area for each habitat type was extracted from the plot at discharges of 12,500, 16,000, and 23,000 cfs.In order to compare the surface area of the digitized 2012 and 1983 habitat types, it was necessary to scale or proportion the 2012 surface areas by their main channel discharges to the 1983 discharge. On the Middle Susitna River segment, the 2012 discharges of 12,900 and 17,000 cfs were scaled to the 1983 target discharge of 12,500 cfs. To perform the scaling, it was assumed that the slope of the logarithmic-linear relationship between wetted area and discharge in the 1980s remained similar for the 2012 condition. The slope of the line is identified by the following equation:

$$\frac{\log(A)\text{-}\log(A_1)}{\log(A_2)\text{-}\log(A_1)} = \frac{Q\text{-}Q_1}{Q_2\text{-}Q_1} \quad (4.5.1)$$

Where:

$Q$ = 2012 Discharge
$Q_1$ = 1983 Discharge, lower bound (less magnitude than Q)
$Q_2$ = 1983 Discharge, upper bound (greater magnitude than Q)
$A$ = 2012 habitat type wetted area
$A_1$ = 1983 habitat type wetted area corresponding to $Q_1$
$A_2$ =1983 habitat type wetted area corresponding to $Q_2$

Solving for $A$ at the desired discharge determines the wetted area per habitat type scaled by the 1983 area-flow relationship.

$$A = 10^{\left[\left(\frac{Q-Q_1}{Q_2-Q_1}\right)\left(log(A_2)-log(A_1)\right)+log(A_1)\right]} \quad (4.52)$$

Dividing $A$ by the area at the 1980s reference area provides a scaling factor to be applied to the areas determined for the 2012 digitized habitat types.

The scaling factors created for each subsegment were used as the scaling factor for each habitat site that fell within the subsegment's boundaries.

### 4.5.3. Variance from Study Plan

It was the intent of the Revised Study Plan Section 6.5.4.5.2.1 to obtain three sets of aerial photography in 2012 at the following approximate discharges: 23,000, 12,500, and 5,100 cfs. Only one set of aerials was actually obtained with the flow for 50 percent of the Middle River at 12,900 cfs and 50 percent of the Middle River at 17,000 cfs. In 2013, it was decided to acquire additional aerial photographs for only the 12,500-cfs target discharge in the Middle River. Aerials were obtained for about 60 percent of the Middle River at 11,300 cfs and 40 percent at 6,200 cfs.

The intent of acquiring three sets of 2012 aerials was to compare the macrohabitat versus flow relationships from current conditions to 1980s information and determine if there is a difference in the habitat areas for current conditions from those mapped in the 1980s at similar flows. With the aerial photography collected for the limited discharges in 2012, AEA concluded that the macrohabitat areas were appreciably different to those mapped in the 1980s (Tetra Tech 2013f). AEA also concluded that aerial photography collected at specified discharges to develop macrohabitat versus flow relationships was not necessary for the 2013 study as the combination of the 2-D hydraulic modeling, bathymetry and topography collected in the Focus Areas can provide direct determination of the area of the various macrohabitat types over the range of flows of interest. Therefore, the macrohabitat area versus flow relationships developed from aerial photographs collected at specified discharges are not needed for the current studies. The objectives of the study will be met without collecting current aerials at three flows as specified in the RSP.

## 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 compare 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 Middle Susitna River segment from PRM 187.1 to PRM 102.4 (RM 184 to RM 98) and the Lower Susitna River segment below PRM 102.4 (RM 98). The initial effort started in 2012 and completed in early 2013 involved the Lower and Middle Rivers. The results of this effort helped determine that additional analysis of Project effects is warranted in the Lower Susitna River segment for the ongoing 2013 studies. As additional information on with-Project hydrology, sediment transport, and geomorphology of the system are developed by the various studies, continued application of the framework to both the Lower and Middle Susitna River segments will provide additional context for identification of Project effects, including interpretation of and integration with the Fluvial Geomorphology Modeling below Watana Dam Study (ISR Study 6.6 Section 4.3) results.

### 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 (PRM 32 [RM 28.5]) and Talkeetna (PRM 102.4 [RM 98]) (measured at Sunshine gage [approximately PRM 88 [RM 84]) ranging from 13,900 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 streamflows 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.

Tetra Tech (2013f) provided the initial basis for assessing the potential for changes to the Middle and Lower Susitna River segment reach morphology due to the Project. The assessments presented in this study component 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 will include a concurrent flow and stage analysis for the Susitna River in the area of the Talkeetna and Chulitna confluences (next year of study). 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.

### 4.6.2. Methods

AEA implemented the methods as described in the Study Plan with the exception of the variances explained below (Section 4.6.3). As part of study implementation, the following three technical memoranda were filed with FERC in early 2013 to detail the streamflow assessment, sediment transport assessment, and the integration of the two into a conceptual framework to identify a possible geomorphic reach response:

- Stream Flow Assessment (Tetra Tech 2013d)
- Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River segments (Tetra Tech 2013a)
- Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River segment (Tetra Tech 2013c)

This section summarizes the methods from these technical memoranda as well as literature review on the downstream effects of the Dam. The literature review was added based on comments received on the PSP and is being performed in conjunction with the Riparian Instream Flow Study (Study 8.6).

#### *4.6.2.1. Streamflow Assessment*

Hydrologic flow data were compiled and analyzed for both the pre- and post-Project conditions in the Susitna River below Watana Dam. The pre-Project condition was based on the 61-year extended flow record developed by the USGS (USGS 2012). The post-Project condition was based on initial runs of the HEC-ResSim Operations Model for a hypothetical operational scenario (OS) referred to as the Maximum Load Following OS-1 scenario. This scenario represents a preliminary operations scenario that was developed by placing the entire variability of the Railbelt electricity load on Susitna-Watana, thus representing a maximum (or worst-case) load following scenario (John Haapala, personal communication, January 24, 2013). The HEC-ResSim model provided Project releases and routed them downstream, thus providing a 61-year simulated flow record at the Gold Creek gaging station (PRM 140) and the Sunshine gaging station (PRM 88). A 61-year simulated flow record for the Susitna Station gaging station (PRM 30) was estimated by adding the difference between the flows at the Sunshine and Susitna Station gaging stations from the USGS (2012) extended record to the simulated flows at the Sunshine gaging station.

This hydrologic analysis was used to compare pre-Project and potential post-Project hydrologic conditions and to subsequently evaluate Project effects on the Susitna River hydrology. This included a comparison of the monthly and annual flow-duration curves (exceedence plots) and plots/tables of flows by month (maximum, average, median, minimum) for the Susitna River at Gold Creek, Susitna River at Sunshine and Susitna River at Susitna Station gaging stations. Similar analyses were conducted for the major tributaries provided in the extended flow record, including the Chulitna, Talkeetna, Skwentna, Willow, Maclaren, and Yentna rivers.

Using the extended flow record prepared by USGS and the results from the Maximum Load Following OS-1 scenario, flood-frequency and flow-duration analyses for pre- and post-Project flows were performed. The flood-frequency analysis was performed using standard hydrologic practices and guidelines as recommended by USGS (1982), using the U.S. Army Corps of Engineers Hydraulic Engineering Center Statistical Software Package (HEC-SSP) that applies standard methods outlined in Bulletin 17B (IACWD 1982). These methods involve fitting a log-Pearson Type III (LP III) frequency distribution to the annual peak flow series. Flow-duration curves, representing the percentage of time each discharge magnitude is equaled or exceeded during the period of analysis, were developed using the mean daily flow data series. Flow-duration curves were developed for each month and on an annual basis for each gage. The details of the methodology are documented in Tetra Tech (2013d).

A concurrent flow and stage analysis will be conducted in the next study year 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 Talkeetna. This effort was intended to inform the decision to potentially extend 1-D Bed Evolution Model up the Chulitna and Talkeetna rivers. However, the decision to extend the 1-D Bed Evolution Model up these tributaries was made in Q1 2013 and presented in the Fluvial Geomorphology Modeling Approach Technical Memorandum (Tetra Tech 2013h). 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. It will also be performed in the next year of study.

#### *4.6.2.2. Sediment Transport Assessment*

The sediment balance was the primary tool used in developing the sediment transport assessment. The sediment balance for both the Middle and Lower Susitna River segments used a variety of 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 include the mainstem Susitna River, contributing tributaries, and locations of bank erosion and mass wasting along the channel margins. Sediment loads calculated at gaging stations along the mainstem and gaged tributaries were the primary source of information for this analysis. The historical and recent sediment transport data collected by USGS (see Section 4.2.2) were used to develop bed load, total bed-material load, and wash-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 were available, the data allowed for differentiation of transport by size fraction. This information was used to perform an overall sediment balance for each component of the sediment load and was developed as part of the Sediment Supply and Transport Middle and Lower Susitna River segment study (Tetra Tech 2013a). This technical memorandum informed the review of the downstream study limit (see Study 6.6 Section 3.2) with an initial assessment to be followed with more detailed work conducted throughout 2013 and into the next year of study to support the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6).

Sediment load versus water discharge rating curves were developed for each portion of the sediment load (i.e., wash load, bed load, total bed-material load). The rating curves were then integrated over the relevant hydrographs to estimate the total of each portion of the sediment load. The resulting total sediment loads were then compared to determine if each segment of the reach between the locations represented by the rating curves are net aggradational (i.e., more sediment is delivered to the reach than is carried past the downstream boundary) or net degradational (i.e., more sediment is carried out of the reach than is delivered from upstream and lateral sources).

#### *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:

$$Q_w.S \sim Q_s.D_{50} \qquad (4.6.1)$$

Where:

$Q_w$ = flow,
$S$ = slope,
$Q_s$ = sediment transport, and
$D_{50}$ = 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:

$$Q_w^-, Q_s^+ \sim b^{\pm}, d^-, \lambda^{\pm}, S^+, P^-, F^+ \qquad (4.6.2)$$

Where:

+ = an increase,
– = a decrease, and
± = 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 paleoflood 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).

Geomorphic response of the Susitna River Middle and Lower segments was predicted using the data developed for the pre- and post-Project flood frequency, flow duration, and sediment load.

The methodology of conceptual framework developed by Grant et al. (2003) was used for this analysis. It relies on the dimensionless variables of the ratio of sediment supply below the dam to that above the dam (S*), and the fractional change in frequency of sediment transporting flows (T*). The dimensionless variables were used to predict the nature and degree of response of the Susitna River below Watana Dam.

The most complete currently available information on flow and sediment transport is at the mainstem (Gold Creek, Sunshine, and Susitna Station) and major tributary (Chulitna, Talkeetna, and Yentna) gages. The tributary flow contributions are unaffected by the dam and sediment contributions are assumed, for this analysis, also to be unaffected. The values of S* and T* were calculated at the mainstem gages. S* was calculated directly from the results of the initial sediment balance (Tetra Tech 2013a) and T* was calculated from the flow-duration curves developed from the streamflow assessment (Tetra Tech 2013d). The T* calculation involves the amount of time the bed is mobilized, so the only additional information that was required was the critical discharge ($Q_{cr}$), which was estimated by applying the Parker (1982) bed load transport equation to flow and sediment transport measurements at the mainstem gages (Tetra Tech 2013c).

Other analytical approaches were also considered to evaluate potential for geomorphic adjustments of the reaches in the river segments due to the Project. These included 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 $D_{50}$ increases and there is a supply of sediment, then MBI increases.
- If the $D_{50}$ 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 will be developed in the next year of study from aerial photography, and the likely changes in these 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.

#### *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) is one such reference, with others including, but not limited to Sabo et al. (2012), Clipperton et al. (2003), Schmidt and Wilcock (2008), Shields et al. (2000), Freidman et al. (1998), Collier et al. (1996), and Williams and Wolman (1984). Efforts have been 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.

#### *4.6.2.5. Information Required*

The following available existing information was used to conduct this study:

- Historical suspended-sediment and bed load data for the Susitna River.
- Flow records for the Susitna River.
- Characterization of bed material from previous studies.
- The following additional information was obtained to conduct this study:
- Suspended and bed load data for the Susitna River at Tsusena Creek, Gold Creek being performed by USGS.
- Extended flow record for the Susitna River and gaged tributaries (Chulitna, Talkeetna and Yentna rivers) within the study area being developed by USGS.
- Channel morphologic data for existing conditions including, width, depth, width/depth ratios, and MBIs.

### 4.6.3. Variances from Study Plan

The literature review on the downstream effects of dams will be completed in 2014 rather than Q4 2013 so it can be coordinated and combined with the Riparian IFS Study. Initial analysis of the modified braiding index (MBI) will be done during the next year of study when information on bed-material gradation and channel aggradation/degradation trends becomes available from the 1-D Bed Evolution Model (ISR Study 6.6 Section 4.1.2.1).

The concurrent flow and stage analysis at Three Rivers Confluence area was not conducted in Q4 2013. One of the purposes of this analysis was to determine the necessity of extending the Mainstem Flow Routing Model up the Talkeetna and Chulitna Rivers to evaluate the potential for Project induced changes in Susitna River flows and stages to alter the flow patterns during peak flows on the Talkeetna and Chulitna rivers. However, one of the recommendations in the Fluvial Geomorphology Modeling Approach (Tetra Tech 2013h) was to include the Chulitna and Talkeetna rivers as modeled river reaches in the 1-D Bed Evolution Model so as to allow direct evaluation of potential Project effects on hydraulic and sediment transport conditions in the lower portions of these two tributaries. The concurrent flow and stage analysis will be conducted in the next year of study; however, the decision to extend the 1-D Bed Evolution Model up the Chulitna and Talkeetna rivers has already been made. The concurrent flow and stage analysis will be useful in understanding modeling results in the Three Rivers Confluence Area and is being performed in the second year of study.

The above variances all involve a delay in completing analyses; however, the delays allow for better integration with other study efforts. None of the delays impact the ability to meet the study objectives.

Hydrologic analysis of alternative scenarios identified in the RSP will not be conducted as part this study (Geomorphology Study) but instead will be conducted as part of Study 8.5 (Fish and Aquatics Instream Flow Study). This variance does not affect the objectives of this study as the technical work is being conducted under a different study.

## 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 to help inform the decision on whether to extend studies into the Lower River below PRM 80. As such, much of the effort was conducted in 2012 and various aspects were reported on in portions of several technical memoranda filed in Q1 2013. These technical memoranda included:

- Stream Flow Assessment (Tetra Tech 2013d): This technical memorandum provided an initial analysis of hydrologic statistics including flow-duration curves (annual and monthly), mean monthly flows, and annual peak flows for pre- and post-Project conditions (maximum load following OS-1); stage exceedence analysis; specific gage analysis; and assessment of discharge effects on ice elevations and cross-sectional flow characteristics. Analyses were conducted for pre-Project conditions and a post-Project scenario referred to as maximum load following OS-1.
- Synthesis of 1980s Aquatic Habitat Information (Tetra Tech 2013e): This technical memorandum used information from the 1980s to help identify whether potential Project effects on aquatic habitat and tributary access in the Lower River warranted additional study and, if necessary, help in planning those studies. The analysis utilized information on aquatic habitat from the 1980s report 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). Information was also summarized from the report Assessment of Access by Spawning Salmon into Tributaries of the Lower Susitna River (R&M Consultants, Inc. and Trihey & Associates 1985b).
- Mapping of Aquatic Macrohabitat Types at Selected Sites in the Middle and Lower Susitna River segments from 1980s and 2012 aerials (Tetra Tech 2013f): For the Lower River segment, this technical memorandum provides results of aquatic macrohabitat type mapping from the 1980s and current aerials at five selected sites along with comparison of results between the two periods.
- Reconnaissance Level Assessment of Potential Channel Change in the Lower River Segment (Tetra Tech 2013c): This document synthesized results from other technical memorandums within an analytical framework (Grant et al. 2003) to develop an initial assessment of potential Project-related changes in channel morphology of the Lower River.

As result of the combination of efforts listed above, the decision was made to extend the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6) to PRM 29.9 (just below the USGS gage at Susitna Station) in the Lower River segment as well as the Fish and Aquatics Instream Flow Study (Study 8.5) and the Riparian Instream Flow Study (Study 8.6) below PRM 80. The decision to extend the studies below PRM 80 in the Lower River Segment is documented in the technical memorandum, Selection of Focus Area and the Study Sites in the Middle and Lower Susitna River for Instream Flow and Joint Resources Studies (R2 2013a). Extension of the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6) to PRM 29.9 is further documented in the technical memorandum, Fluvial Geomorphology Modeling Approach (Tetra Tech 2013h). As part of the extension of the studies into the Lower River, five tributary mouths in the Lower River were included for study of potential Project effects on aquatic habitat and spawning access for adult salmon. The five tributaries are Birch, Trappers, Caswell, Sheep creeks and the Deshka River.

The effort was also performed to determine whether additional development of aquatic habitat versus flow relationships, similar to those developed in the 1980s, be performed in the Lower River segment using aerial photography flown at specified flows if studies are extended into the Lower River. This involved the mapping of current aquatic macrohabitat types at selected sites from 2012 aerials and comparison with mapping performed in the 1980s.

### 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 (PRM 32 [RM 28.5]) and Talkeetna (PRM 102.4 [RM 98]) (measured at Sunshine gage at approximately PRM 88 [RM 84]) ranging from 13,900 to 75,200 cfs. Results of this study provided the initial basis for assessing the potential for changes to the Lower Susitna River segment reach morphology due to the Project. As a result of these and other study efforts, additional studies were planned to further quantify potential Project impacts on aquatic habitat and morphology of the Lower River segment.

### 4.7.2. Methods

AEA implemented the methods as describe in the Study Plan with no variances. This study component is divided into five tasks: (1) change in river stage assessment, (2) synthesis of 1980s habitat information, (3) site selection and stability assessment, (4) aerial photography analysis of riverine habitat study sites, and (5) additional aerial photography analysis of riverine habitat study sites. The fifth task was 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. The determination was made that aquatic habitat studies are to be continued downstream into the Lower River, but these studies will not rely on the aquatic macrohabitat area versus flow relationships similar to those developed in the 1980s. Therefore, the optional task will not be undertaken. It is noted that geomorphic features have been mapped for the entire Lower River from PRM 102.4 to PRM 3.3 for both the 1980s and current conditions and are in the process of being mapped for the 1950s using a set of aerials acquired in Q3 2013.

#### 4.7.2.1. Change in River Stage Assessment

This effort was conducted as part of the 2012 study efforts and is reported on in detail in the technical memorandum, Stream Flow Assessment (Tetra Tech 2013d), filed in Q1 2013.

A tabular and graphical comparison of the change in water-surface elevations associated with the results of the pre-Project and the Maximum Daily Load Following OS-1 streamflow assessment (see Section 4.6.1) 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 (exceedence plots) and plots/tables of stage by month (maximum, average, median, minimum). A graphical plot of a representative cross-section at each gaging station was developed with a summary of the changes in water-surface elevation for the two flow regimes.

A stage exceedence analysis was conducted as a means to evaluate the relative difference in stage between the pre-Project hydrologic conditions and the Maximum Load Following OS-1 hydrologic conditions at two specific locations on the Lower Susitna River corresponding with USGS streamflow gaging sites—Susitna River at Sunshine (USGS Gage No.15292780) and Susitna River and Susitna River at Susitna Station. The results of this analysis provided a preliminary assessment of the change in hydraulic conditions in the Lower Susitna River segment resulting from the Maximum Load Following OS-1 hydrologic conditions.

The primary sources of information used to conduct the stage exceedence analysis at each gage location were (1) the most recent USGS stage-discharge ratings at each site, and (2) the results of the flow-duration analyses for the pre-Project and the Maximum Load Following OS-1 hydrologic conditions as described in Section 4.6.

The mean daily flow record (WY1950 throughWY2010) for each hydrologic condition was first converted to values of stage, in feet, using the most recent USGS stage-discharge ratings. It is noted that the USGS stage-discharge ratings do not account for the effects of ice on river stage. A complete record of stages corresponding to the each value of mean daily flow at each of the two USGS locations for the pre-Project and Maximum Load Following OS-1 conditions was produced (refer to Tetra Tech 2013d).

A stage-duration (exceedence) analysis was then conducted at each gage location, using the complete stage records (WY1950 through WY2010) for the pre-Project and Maximum Load Following OS-1 hydrologic conditions. An annual stage-duration analysis was based on the stage values for the entire period of record, and monthly stage-duration analyses were based on the stage values for each of the 12 months. The stage-exceedence relationships corresponding to the pre-Project hydrologic conditions and the Maximum Load Following OS-1 hydrologic conditions were plotted together to compare the relative changes in stage across the range of exceedence values. A statistical analysis was also conducted to quantify the maximum, minimum, average and median stages by month.

To graphically illustrate how the changes in stage relate to the channel/floodplain morphology at each site, selected stage-exceedence ordinates were converted to water-surface elevations and overlaid on plots of the site cross-section geometry. Representative cross-section geometry was developed at each gaging station location using USGS discharge measurement notes, specifically the incremental flow depths, taken during a recent high-flow measurement. The annual and monthly 10-, 50- and 90-percent exceedence water-surface elevation values were then plotted on the cross-section geometry [refer to Tetra Tech (2013d) for a description of how the incremental flow depths were used to develop the cross-section geometry at each gage location].

Available USGS winter gage data with respect to discharge and ice elevation/thickness was also investigated. Available data from the USGS Susitna River at Sunshine and Susitna River at Susitna Station gages were evaluated to assess potential discharge effects on ice thickness and cross-sectional flow characteristics, namely depth and velocity (Tetra Tech 2013d). Specific ice covered discharge measurement data were reviewed at the two USGS gaging stations. There were 13 discharge measurements taken between 1981 and 1986 at the Sunshine Gage for ice-covered conditions and 23 taken between 1982 and 1993 at the Susitna Station Gage. The data from the handwritten USGS discharge measurement forms were compiled and summarized. Tables were developed that summarized, for each measurement, total measured discharge, ratio of flow depth to ice thickness, total depth, average ice thickness, average flow depth, total ice area, total flow area, and average velocity (see Tetra Tech 2013d). Neither the stage nor the water-surface elevation was surveyed by the USGS during the field discharge measurements. Therefore stage (or water-surface elevation) versus discharge relationships under ice-covered conditions could not be developed and compared against those for open water conditions. Coordination with the Ice Processes in the Susitna River Study (Study 7.6) provided no additional information in regards to ice elevation or thickness at the USGS gages in the Lower River.

#### *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 was provided with the March 2013 technical memorandum Synthesis of 1980s Aquatic Habitat Information (Tetra Tech 2013e). 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 included in the March 2013 technical memorandum. Data were summarized with respect to the anticipated pre- and post-Project flow changes, where applicable.

Acquisition of 2012 aerial photographs at varying discharge conditions and subsequent delineation of wetted habitat area types from those photos provided a measure of change when compared to the 1980s areas (Tetra Tech 2013f). Discharges for some of the aerial photograph acquisition varied from the targeted flows. In order to improve the comparisons between the 1980s and 2012 habitat area types, logarithmic-linear relationships were developed for the Middle River habitat surface area plots of wetted habitat area type versus mainstem discharge presented in the 1980s report (Trihey & Associates 1985a) and then these relationships were applied to the 2012 habitat areas. For the Lower River, a similar method was developed for adjusting 2012 habitat areas, making use of tabulated areas for each site to develop scaling factors relating area and discharge in the 1980s study (R&M Consultants, Inc. and Trihey & Associates 1985a) to apply to the 2012 habitat areas.

#### *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 for study in 2012. These sites were selected in coordination with the Fish and Aquatics Instream Flow Study (Study 8.5) and the Riparian Instream Flow Study (Study 8.6). 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).

#### *4.7.2.4. Aerial Photography Analysis, Riverine Habitat Study Sites (PRM 32 to PRM 102.4 [RM 28 to RM 98])*

Aerial photography analysis of the five selected Lower River sites identified above was performed as part of the 2012 studies and reported on in Q1 2013 in the technical memorandum, Mapping of Aquatic Macrohabitat Types at Selected Sites in the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (Tetra Tech 2013f).

To provide a comparison between the 1980s and current conditions, aerials flown at approximately 36,600 cfs were obtained in 2012 (actual flows ranged from 38,100 to 53,700 cfs). Mapping of aquatic macrohabitat types from the 2012 aerials were made using ArcGIS 10.0 at a scale of 1:3,000. Within each habitat site, polygons were delineated for exposed substrate, vegetated islands, and wetted habitat types. The riverine habitat types were: main channel, primary side channel, secondary side channel, turbid backwater, clearwater/side slough, tributary mouth, and tributary. Detailed descriptions of each habitat type can be found in the habitat analysis technical memorandum (Tetra Tech 2013f).

Wetted areas were mapped as one of the aquatic habitat types only if the area had a connection to the Susitna River. This connection did not have to be direct, but could be through one or more additional wetted habitat types. For example, an upland slough could connect to a side slough, which connects to a side channel and ultimately the main channel. If the water body was isolated and there was not a connection to the Susitna River, then the wetted area was mapped as additional open water (AOW).

Using GIS and the September 6, 1983, aerial photography 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). The current wetted areas of the riverine habitat types, as defined in the 1980s analysis (R&M Consultants, Inc. and Trihey & Associates 1985a), were delineated on the 2012 aerial photographs for the five selected sites.

The aerial photography flown in 2012 was at discharges of 53,700 cfs for Site 1 (SC IV-4), Site 2 (Willow Creek), 46,900 cfs for Site 3 (Goose Creek), 38,100 cfs for Site 4 (Montana Creek), and Site 5 (Sunshine Slough). All of these discharges fell between 36,600 and 59,100 cfs used in the 1983 study. Because the 2012 aerials were not at the target discharge of 36,600 cfs in the Lower River, a methodology was developed in order to scale the 2012 digitized habitat areas to the comparable 1983 discharge. Wetted areas of each habitat type corresponding to several different flows were determined in the 1980s study. These areas were presented as a table of values for each habitat site in the Lower Susitna River Segment (R&M Consultants, Inc. and Trihey & Associates 1985a). These values were then used to determine a relationship between wetted habitat area and discharge. Scaling factors were determined for each habitat type for all of the Lower River segment aquatic macrohabitat sites using the same procedure as detailed for the Lower River in Section 4.5.2.3.

The difference in wetted surface area of the main channel and side channel riverine habitats were compared between the 1983 conditions 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), were compared and contrasted quantitatively, and a qualitative assessment was made of the similarity of the 1980s sites compared to the 2012 sites. The assessment helped determine the applicability of Lower Susitna River segment riverine habitat information developed in the 1980s to possibly supplement information being developed in the current Project studies.

#### *4.7.2.5. Additional Aerial Photography Analysis, Riverine Habitat Study Sites (PRM 32 to PRM 102.4 [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 (Study Section 4.4), a determination of whether to perform a similar effort and comparison for up to two additional discharges (discharges corresponding to the analysis of wetted habitat areas in the Lower Susitna River Segment include 75,200, 59,100, 36,600, 21,100, and 13,900 cfs) was made. The decision was made not to pursue additional analysis of aquatic habitat versus flow relationships using analysis of aerial photography. This decision was made in coordination with the Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Ice Processes in the Susitna River Study (Study 7.6), Characterization and Mapping of Aquatic Habitats Study (Study 9.9), and licensing participants. This task was identified as an optional task in the RSP. It is noted that geomorphic features have been mapped for the entire Lower River Segment for both the 1980s and current conditions and are in the process of being mapped for 1950s using a set of aerial photographs acquired in Q3 2013.

### 4.7.3. Variances from Study Plan

There are no variances to this component of the Study Plan. The effort associated with the task Additional Aerial Photography Analysis, Riverine Habitat Study Sites (PRM 32 to PRM 102.4) will not be performed, but this was identified as an optional task in the RSP.

## 4.8. Study Component: Reservoir Geomorphology

The goal of this study component is to characterize geomorphic changes resulting from conversion of the channel and portions of the river valley to a reservoir. Specific objectives of the Reservoir Geomorphology study component include:

- Estimate reservoir sediment trap efficiency and reservoir longevity.
- Estimate the formation of deltas at reservoir inflows to evaluate 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. Estimate the magnitude of the potential effects of boat-wave erosion if the evaluation indicates the lower portion of the bank is not sufficiently armored and/or boat activity may increase erosion of the upper part of the bank.

For the majority of this study component (Sections 4.8.2.1, 4.8.2.2, and 4.8.2.3), the study area extends from the proposed Watana Dam site (PRM 187.1 [RM 184]) upstream to include the reservoir inundation zone and the portion of the river potentially affected by backwater and delta formation, which is currently assumed to extend approximately 5 miles upstream of the reservoir maximum pool (approximately PRM 232.5 [RM 238]). This portion of the proposed study area is shown in Figure 4.8-1. For the bank and boat-wave erosion downstream of Watana Dam (Section 4.8.2.4) portion of the study component, the study area extends from the proposed Watana Dam (PRM 187.1 [RM 184]) downstream to the Three Rivers Confluence (PRM 102.4 [RM 98]). This study area corresponds to the entire Middle Susitna River Segment (Figure 4.1-2).

### 4.8.1. Existing Information and Need for Additional Information

The Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a) submitted in Q1 2013 provides sediment loadings needed to support the estimates of reservoir longevity and delta formation. The 2012 Upper Susitna River Fish Distribution and Habitat Study (HDR Alaska, Inc. 2013c) submitted in Q1 2013 includes a fish barrier assessment and habitat mapping in tributaries to the Watana Reservoir. This information will support the selection of tributaries where appreciable habitat could potentially become inaccessible should the formation of deltas impact fish passage into the tributaries.

Reservoir and River Sedimentation Final Report, APA Doc. No. 475 (Harza-Ebasco 1984) includes sediment trap efficiencies estimated for the Watana Reservoir using (1) the Brune (1953) curves, and (2) the DEPOSITS numerical model (Peratrovich, Nottingham, & Drage, Inc. 1982). The reservoir capacity at normal maximum pool of 9,470,000 acre-feet at an elevation of 2,185 feet (msl), of which about 5,730,000 acre-feet is the dead storage, was used to estimate reservoir trapping. The trapping efficiency estimated using Brune's median curve is 99 percent; the range in trapping efficiency estimated using Brune's envelope curves is 100 percent (upper envelope curve, coarse sediments) to 96 percent (lower envelope curve, fine-grained sediment).

Conservative estimates of 100-percent trap efficiency produced a cumulative trapped sediment volume of about 410,000 acre-feet over 100 years. This trapping rate, when extrapolated, indicates reservoir longevity of approximately 2,300 years. The trapping efficiency calculated using the DEPOSITS model ranged from 94 to 96 percent for quiescent conditions. Under minimal mixing conditions, the trapping efficiency range decreases to 86 to 93 percent and under maximum mixing conditions the range is 78 to 90 percent.

Reservoir Sedimentation (R&M Consultants, Inc. 1982) contains estimates of trap efficiency for the Watana Reservoir using the Brune (1953) curves. The reservoir storage capacity of 9,650,000 acre-feet was divided by the average annual inflow of 5,880,000 acre-feet to get a capacity-inflow ratio of 1.64. Based on this ratio as input to the Brune curves, a 97-percent median trap efficiency was estimated. A range of 95- to 100-percent trapping was determined using the envelope curves. The conservatively high 100-percent trap efficiency corresponds to a trapped sediment volume of 472,500 acre-feet over 100 years, which indicates reservoir longevity of approximately 2,000 years. Despite the high estimates of trap efficiency from the Brune method, fine glacial sediment was noted as having the potential to pass through the reservoir. Turbidity downstream of the reservoir was expected to decrease sharply during the summer, but possibly increase in winter months. The Susitna Reservoir Sedimentation and Water Clarity Study (Peratrovich, Nottingham, & Drage, Inc. 1982) presents the analysis of turbidity levels in the Watana Reservoir. Based on the results of the DEPOSITS numerical model, maximum turbidity levels at the outlet are on the order of 50 NTUs (200 to 400 mg/L); minimum turbidity levels are on the order of 10 NTUs (30 to 70 mg/L). As noted in the report, in spite of some limitations, the data gathered from outside sources supports the conclusion that Watana Reservoir turbidity levels will be in the range of 10 to 50 NTUs.

R&M Consultants, Inc. (1982) presents unit weights for deposited sediment. Bed load was assumed to have a constant unit weight of 97 pounds per cubic foot. The 50- and 100-year unit weights of finer deposits were estimated using the Lane and Koelzer (1943) method as modified by Miller (1953) at 71.6 and 72.8 pounds per cubic foot, respectively.

Construction and operation of the Project will impound the Watana Reservoir for approximately 45.4 miles upstream from the dam. The reservoir will likely trap essentially all of the coarse sediment load and much of the fine sediment load from the Susitna River (Tetra Tech 2013a). 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 water-surface elevation. Tetra Tech (2013a) includes an estimate of the average annual bed-material load at the Watana Dam under pre-Project conditions that will be coupled with estimates of reservoir trap efficiency and the results of simulated Reservoir Operation Model (ISR Study 8.5 Section 8.5.5.3) to simulate the formation of a delta.

Similar to the mainstem Susitna River delta at the head of the reservoir, deltas of varying size may 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 quantify the magnitude and size distribution of the annual sediment loads from the tributaries that enter the reservoir, which is a data gap. Not all tributaries will deliver substantial sediment loads to the reservoir, and not all tributaries will have extensive accessible fish habitat, so tributaries where deltas have the greatest potential to form and affect upstream fish passage will need to be selected for further study. Accessibility of tributary fish habitat is provided in HDR Alaska, Inc. (2013). Fish usage at the current tributary mouths is included in Study 9.5 Fish Distribution and Abundance Upper River.

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.

### 4.8.2. Methods

AEA implemented the methods as described in the Study Plan with the exception of the schedule related variance explained below (Section 4.8.3). The methods are divided into four areas: (1) reservoir trap efficiency and sediment accumulation rates, (2) delta formation, (3) reservoir erosion, and (4) bank and boat-wave erosion downstream of Watana Dam.

#### *4.8.2.1. Reservoir Trap Efficiency and Sediment Accumulation Rates*

The reservoir trap efficiency influences sediment accumulation rates in the Watana Reservoir. The trap efficiency of a reservoir is defined as the ratio of the quantity of deposited sediment to the total sediment inflow, so it is dependent primarily upon the sediment particle fall velocity and the rate of flow through the reservoir (Strand and Pemberton 1987). The Susitna River will be the primary source of water and sediment inflow to the reservoir; secondary sources include tributaries draining directly into the reservoir, and shoreline/hillslope erosion. The sediment loading by general-size characterization from each of these sources will be evaluated; where determined to be substantial, the average annual sediment loading will be quantified. The combined sediment loading to the reservoir is needed so that the sediment accumulation rates can be calculated as a function of the trap efficiency. The associated sediment accumulation rates will be used to analyze reservoir longevity.

Inflowing sediment loads from the mainstem Susitna River at the Watana Dam were estimated under pre-Project conditions using bed- and suspended-load measurements collected at Gold Creek (Tetra Tech 2013a). These estimates will be refined by integrating the bed- 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 (Cantwell) and the bed-and suspended-load data collected at Gold Creek will be used to further refine sediment--rating curves at Tsusena Creek. The methods described in Section 4.2.2 were used to develop the bed- and suspended-load equations describing the incoming sediment load. Major sediment-producing tributaries draining directly into the reservoir will be characterized as described in Section 4.8.2.2. Similarly, if the sediment loading from the reservoir perimeter is substantial, it will be incorporated as described in Section 4.8.2.3 into the longevity analysis.

Potential additional sediment loading resulting from glacial surge will be investigated in the Glacier and Runoff Changes Study (Study 7.7 Section 7.7.4.3). 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 by the Geomorphology Study. This would include a sediment-loading scenario accounting for glacial surge added to the reservoir trap efficiency and sediment-accumulation analysis in order to estimate the reduction in reservoir life that could result from sediment loading associated with periodic glacial surges.

Due to the large storage capacity of the Watana Reservoir relative to average annual inflow, it is reasonable to assume that all sand and coarser sediment 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 Middle Susitna River Segment. When applied over a long-term horizon (e.g., the 50-year duration of a FERC license), the amount of trapped sediment can be used to evaluate the impacts of sedimentation on reservoir storage capacity. If the evaluation indicates that a substantial amount of fine sediment will deposit in the reservoir, consolidation of the deposits will be considered using the methods such as Lara and Pemberton (1963), Lane and Koelzer (1943), and Miller (1953). (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. The advantage of both Einstein (1965) and Li and Shen (1975) is their incorporation of reservoir-dependent hydraulics along with settling velocities to characterize trapping that can vary in response to reservoir operations and incoming sediment load. A more general estimate of the trap efficiency for the fine sediment will be made using the Brune (1953) method. The Brune method was recommended by Strand and Pemberton (1987) for use in large or normally ponded reservoirs (Morris et al. 2007). It 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. The Brune method relies on the premise that longer detention times (as indicated by dividing the normal reservoir volume by the average annual inflow) increase trapping efficiency. Chen (1975) presents another method that may be considered to check the reasonableness of the trap efficiency determination. The Churchill (1948) method is commonly used to estimate reservoir trap efficiency; however, this method is more applicable for settling basins, small reservoirs, and flood-retarding structures so it will not be used for this study. The proposed methods will provide a basis for estimating the quantity of the various size fractions that both pass through and are trapped in the Watana Reservoir. The reservoir trap efficiency estimates will be used to confirm the appropriateness of the assumption that 100 percent of the bed-material load (sand greater than 0.0625 mm) entering the reservoir is trapped. Additionally, these estimates will provide a check of the results of the numerical modeling simulations of settling, deposition, and re-suspension using the Environmental Fluid Dynamics Code (EFDC) (Hamrick 1992) for the 3-D Reservoir Water Quality Model (ISR Study 5.6 Section 5). The EFDC model results will quantify the amounts and sizes of sediment passing through the Watana Dam outlet works into the Middle Susitna River Segment. The EFDC developed sediment outflow from Watana Dam will be used as upstream boundary condition for the Fluvial Geomorphology Modeling below Watana Dam Study (ISR Study 6.6 Section 4.1.2.9).

#### *4.8.2.2. Delta Formation*

Estimation of the formation of deltas on the mainstem Susitna River and its tributaries as they enter the Watana Reservoir will be based in part on inflowing sediment loads. Because of the potential impacts on fish movement into tributaries that drain directly to the Watana Reservoir, tributaries that require study will be identified in coordination with the Study of Fish Passage Barriers in the Middle and Upper Susitna River and the Susitna Tributaries (Study 9.9). For the identified tributaries, reconnaissance will be performed to characterize the sediment transport regime and identify appropriate methods of calculating yields. In cases where bed-material delivery to the 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. To calculate sediment loads, these sediment rating curves will be integrated over long-term flow hydrographs synthesized for the identified tributaries (ISR Study 8.5 Section 8.5.5.3). 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 will be coupled with the physical constraints imposed by Project operations (i.e., variation in water-surface elevations) on the topset and foreset slopes of the deltas to simulate growth and development of deltas throughout the period of the license (Strand and Pemberton 1987; Morris and Fan 1998). The volume of sediments deposited over periods of interest will be distributed within the topographic constraints of the reservoir fluctuation zone identified for the period when mainstem and tributaries are delivering substantial sediment load. Consideration will be given to which portion of the sediment load would form the delta deposits based on settling characteristics.

#### *4.8.2.3. Reservoir Erosion*

AEA implemented the methods as described in the Study Plan for this study component with the exception of variances explained below (Section 4.8.3).

The reservoir erosion assessment as described in RSP Section 6.5.4.8.2.3 (AEA 2012) will be completed during the next year of study. The work was postponed due to access limitations during the 2013 field season.

#### *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 (5,000 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.

### 4.8.3. Variance from Study Plan

The Study Plan indicated that the assessment of reservoir erosion would take place in 2013. Due to access considerations, the field work and analysis did not take place in 2013, but is planned for the next year of study. There are no other changes to methods described in the Study Plan anticipated, and the study objectives will be met.

## 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 (LWD) in the Susitna River. Specific objectives include:

- Evaluation of LWD recruitment in the Upper, Middle and Lower Susitna River Segments' channels.
- Characterization of the presence, extent, and function of LWD downstream of the Watana Dam site.
- Estimation of the amount of LWD that will be captured in the reservoir and potential downstream effects of Project operation.
- Work in conjunction with the Fluvial Geomorphology Modeling below Watana Dam Study to estimate potential Project effects on LWD 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 Cook Inlet upstream to the confluence with the Maclaren River (PRM 261.3 [RM 260]).

### 4.9.1. Existing Information and Need for Additional Information

The role of LWD 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 islands and bar development, and create and maintain anastomosing channel patterns and side channels (Abbe and Montgomery 1996 and 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 LWD research, little is known of the role of LWD in the morphology and aquatic biology of braided, glacial rivers. LWD may play a role in island formation and stabilization, as well as side-channel and slough avulsion and bank erosion, although the role of LWD 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 LWD 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 LWD in the Susitna River and the role of LWD in channel form and aquatic habitat is needed to evaluate the magnitude of these effects. Construction and operation of the Project will likely alter LWD input and transport downstream of the Watana Dam site. An assessment of the source, transport, and storage of LWD in the Susitna River and the role of LWD 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 LWD management plan and handling of wood that accumulates in the reservoir.

### 4.9.2. Methods

AEA implemented the methods as described in the Study Plan with the exception of variances explained below (Section 4.9.3), which consist of additional work performed beyond that described in the Study Plan.

During 2013, LWD was evaluated using recent and historical aerial photographs and field inventories. A total of 29 proposed LWD sample areas were delineated for more intensive study (Table 4.9-1) and 16 sample areas in the Middle and Lower River Segments were evaluated in 2013. The LWD evaluations will be continued and expanded to the remaining LWD sample areas (assuming areas can be accessed safely) during the next year of study as described in the Study Plan.

#### *4.9.2.1. Aerial Photograph Inventory*

LWD was digitized from the 2012 digital aerial photographs between PRM 75 and PRM 143.6 and within 2013 LWD field assessment areas downstream of PRM 75. Because river flows were higher than the target flows when the 2012 aerials upstream of PRM 143.6 and downstream of

PRM 75 were flown (Table 4.4-1), these areas will be evaluated from either the 2012 or new 2013 aerials after they are acquired. LWD was also digitized from the 1983 aerial photographs within the 2013 Middle River LWD sample areas. LWD was not digitized from the 1983 aerials in the Lower River assessment areas because the bars in the river had changed enough that 1983 conditions were not representative of 2012 geomorphic conditions.

For each set of aerial photographs evaluated, visible pieces of wood over 20 feet long within main channel, side channel, and slough geomorphic features were digitized as a line feature. Each piece was visually assessed to determine (1) if there was a visible root wad, (2) if the wood was part of a log jam, (3) if the wood appeared to be from a local source, and (4) the channel position of the wood (e.g., bank adjacent, apex bar, side of bar, middle of channel, biogeomorphic). Wood length was calculated from the line length. Log jams (defined as three or more touching pieces of wood over 20 feet in length, or beaver dams/lodges) were digitized as polygon features. The channel position was determined, and the area of the polygon was calculated using ArcMap. Details of digitizing methods and coding are provided in Appendix D.1.

#### *4.9.2.2. Field Inventory*

A field inventory of LWD in 16 sample areas took place during July through September 2013 to (1) verify the large wood data collected from the aerial photographs, 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. The 2013 LWD sample areas where field inventories were conducted included the seven Middle River Focus Areas below Portage Creek (Focus Area -104/Whiskers Slough, -113/Oxbow II, -115/ Slough 6A, -128/Slough 8A, -138/Gold Creek, -141/Indian River, and -144/Slough 21), four additional areas in the Middle River (referred to as PRM 109-110, 121-122, 126, and 135-136), and five areas in the Lower River (referred to as PRM 26-28, 40-43, 47-51, 78-82, and 92-93). In the sample areas, each piece of wood over 20 feet in length within the bankfull channel was inventoried using a Trimble GeoExplorer 6000 GeoXH GPS unit loaded with the LWD data dictionary. The following information was collected on each piece of wood (see Appendix D.2 for details):

- GPS location and log orientation (azimuth).
- Wood diameter class and length.
- Root wad attached (Y/N).
- Information on wood freshness (leaves/twig/braches present, bark condition, surface texture).
- Species (balsam poplar, white spruce, paper birch, alder).
- Input mechanism (windthrow, bank erosion, ice processes, biogeomorphic—beaver dams or lodges, etc.).
- Channel position.
- Wetted or bankfull channel.

- Function (scour pool, bar forming, island forming, side channel inlet protection, bank protection, aquatic cover, etc.).
- Stability.

Log jams (defined as three or more touching pieces of wood over 20 feet long) were inventoried separately in each sample area and the following information was collected (see Appendix D.2 for details):

- GPS location.
- Average jam length, width, height.
- Key member length/diameter/root wads.
- Number of other pieces of wood by size class.
- Number of other root wads.
- Channel position.
- Wetted or bankfull channel.
- Stability.
- Function (scour pool, bar forming, island forming, side channel inlet protection, bank protection, aquatic cover, etc.).
- Photograph of each log jam.

All wood field inventory data were downloaded from the GPS unit, post-processed to correct locations, and compiled into a GIS shapefile. Individual log point locations were converted to line features based on length and azimuth data.

On August 22, 2013, a high-flow event occurred with a provisional instantaneous peak of 49,100 cfs at the Gold Creek gage (USGS Gage No. 15292000), which corresponds to an annual recurrence interval between 2- and 5-years. The LWD crew re-visited several previously inventoried LWD sample areas in the Middle River with the Aquatic Substrate mapping crew in September 2013. This provided the opportunity to check if previously inventoried wood had moved at these sample areas.

### 4.9.3. Variance from Study Plan

The August 2013 high-flow event provided the opportunity to assess LWD movement at several sample areas; this was an unanticipated event and was not included in the Study Plan. This will provide additional data on wood movement and helps to meet study objectives including estimates of large woody debris supply and movement during large flow events.

## 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.

#### 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 4.10-1). 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 the next year of study.

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 Alaska, Inc. 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 bed load transport, LWD, 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, Fog, and Cheechako creeks. Smaller streams crossed include tributaries to Prairie 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 up- 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 LWD.

- 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 LWD transport. This analysis will also provide data needed for design of appropriate stream-crossing structures and PM&E measures to minimize effects.

### 4.10.2. Methods

AEA did not implement this component of the Study Plan in 2013. The assessment of the geomorphology of stream crossings along transmission lines and access alignments as described in RSP Section 6.5.4.10 (AEA 2012) will be completed during the next year of study.

### 4.10.3. Variance from Study Plan

The Study Plan indicated that the field assessment of stream crossings would take place in 2013. Due to lack of access to CIRWG lands, the majority of the Gold Creek Corridor and portions of the Chulitna Corridor were not accessible in 2013. This work has been postponed to the next year of study. There are no other changes to methods described in the Study Plan anticipated, and the study objectives will be met as the data can be collected in a single year.

## 4.11. Study Component: Integration of Fluvial Geomorphology Modeling below Watana Dam Study with the Geomorphology Study

The Geomorphology and Fluvial Geomorphology Modeling below Watana Dam (Study 6.6) 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 provide the basic information and context for performing the Fluvial Geomorphology Modeling below Watana Dam Study. During the Fluvial Geomorphology Modeling below Watana Dam 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.

### 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.

### 4.11.2. Methods

AEA implemented the methods as describe in the Study Plan with no variances. Results from the previously described Geomorphology Study components will be compiled and used by the Fluvial Geomorphology Modeling below Watana Dam 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 commonality between the Geomorphology and Fluvial Geomorphology Modeling below Watana Dam study 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 below Watana Dam Study, particularly as they relate to the habitat indicators, include the following:

- The reach delineations under Section 4.1 define and provide descriptions of the geomorphically and ecologically significant macro-scale characteristics of each segment of the study reach. As described in ISR Study 6.6 Section 4.1.2, 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 bed load and suspended-sediment load data that were collected by the USGS under Section 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 4.3) will provide tributary sediment input boundary conditions for both the existing and project conditions bed evolution models. This data will be supplemented with sediment supplies computed as part of the Tributary Delta Modeling (ISR Study 6.6 Section 4.1.2).
- Results from the Assess Geomorphic Change Study Component (Section 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 streamflow analysis under the Reconnaissance-level Assessment of Project Effects study component (Section 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 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 4.8) will provide the upstream sediment input boundary conditions for the Project-conditions bed evolution model. Trap efficiency estimates and the upstream sediment outflow estimates from the Project will be further refined through the reservoir water-quality model (ISR Study 5.6 Section 5).

#### 4.11.3. Variance from Study Plan

There are no variances from the study plan for this study component.

# 5. RESULTS

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

The results for the geomorphic reach classification system (Section 5.1.1) and the geomorphic delineation (Section 5.1.2) were previously presented in a technical memorandum (Tetra Tech 2013b) and are summarized below. The geomorphic characterization (Section 5.3.1) results are presented for the first time below. This characterization is for the Middle River. The characterization of the Lower River along with an update of the Middle River characterization will be performed in the next year of study.

### 5.1.1. Initial Geomorphic Reach Classification System

The first step in the geomorphic reach delineation effort for the Susitna River was the selection of the system to be used to classify and delineate the individual reaches within the three identified segments. Classification of the river segments is required to provide a basis for communication among the various disciplines and to identify relatively homogeneous river reaches 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; Schumm 1968; Kellerhals et al. 1976; Brice 1981; Mosley 1987; Rosgen 1994; Rosgen 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).

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:

- Channel planform (single channel: straight, meandering; multiple channels: braided, anastomosing) – identified from topographic mapping and aerial photography
- Constraints (bedrock, colluvium, moraines, alluvial fans, glacio-lacustrine and glacio-fluvial sediments) – identified from geologic mapping
- 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 and hydraulic modeling
- Gradient – derived from current field survey data and 1980s era data
- Bed materials – derived from current field data collection efforts and 1980s era data.

Based on currently available information, the individual reaches within the three river segments were classified as one of the following categories:

**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 –Wide floodplain with significant sediment storage in unvegetated braid bars

MC2 – Wide floodplain with significant sediment storage in vegetated islands and bars

MC3 – Wide floodplain with vegetated floodplain segments separated by anastomosed channels with downstream base level controls

MC4 – Delta distributary channels

### 5.1.2. Initial Geomorphic Delineation

To perform the geomorphic reach delineation the following geomorphic parameters were developed:

- Gradient
- Sinuosity
- Active channel width
- Valley bottom width
- Entrenchment ratio
- Median bed-material size

- Channel branching index

The procedures to develop these parameters are presented in the technical memorandum (Tetra Tech 2013b).

The resulting parameters and geomorphic reach boundaries are presented in Table 5.1-1. The Upper River (Figure 5.1-1) was divided into six geomorphic reaches, the Middle River (Figure 5.1-2) into eight geomorphic reaches and the Lower River (Figure 5.1-3) into six geomorphic reaches. The longitudinal profile of the Susitna River from Cook Inlet to the headwaters is shown on Figure 5.1-4. The profile tends to reflect the bounding geology along the river (Wilson et al. 2009). Upstream of the Maclaren River confluence the river is bounded by Quaternary-age sediments and the slope is relatively mild (about 6 ft/mile). In the Upper River, between the Maclaren River (PRM 261.3) and the Watana Dam site (PRM 187.1) the slope significantly increases (11-20 ft/mile) and the channel boundary is composed of both Quaternary-age sediments and bedrock (meta-sediments and gneiss). From the Watana Dam site to the head of Devils Canyon (PRM 166.1), the slope is about 11 ft/mile and the channel is bounded by meta-sedimentary and gneissic rocks. The channel slope in Devils Canyon (PRM 166.1 to PRM 153.9) is about 31 ft/mile and the channel is bounded by granitic rocks. Between Devils Canyon and the Three Rivers Confluence (PRM 102.4) the channel slope decreases progressively from about 12 ft /mile to about 7 ft/mile and the reduction in slope is correlated with a reduction in the erosion-resistance of the bounding materials and the transition to an alluvial channel. The upper part of the reach is bounded by primarily meta-sedimentary rocks, the middle by Pleistocene-age glacial deposits and the lower by Pleistocene- and Holocene-age alluvial terraces. Downstream of the Three Rivers Confluence, the bed slope progressively decreases from 6 ft/mile to about 1.5 ft/mile in the lowest reach. The channel is bounded primarily by Pleistocene-age glacial, fluvio-glacial and glacio-lacustrine deposits.

Table 5.1-2 summarizes the geomorphic parameters for each of the reaches. Descriptions of the geomorphic reaches are provided for the Middle and Lower River Segments in the technical memorandum (Tetra Tech 2013b). Descriptions of Geomorphic characteristics for the Upper River Segment will be provided in the next year of study. Information for all three segments will be updated as results from the next year of field data collection effort become available.

### 5.1.3. Geomorphic Characterization of the Susitna River

#### *5.1.3.1. Surficial Geology*

The bedrock and lateral constraint mapping depicts the geologic controls on river form. The mapping is included as Appendix A.1.

#### *5.1.3.2. Geomorphic Surfaces and Processes*

Aerial reconnaissance, review of aerial photography and ground-based observations of the Middle River in general, and the 7 Focus Areas specifically, indicated that there were a number of common geomorphic features and controls within the heavily glaciated (Pleistocene) Middle River (EWTA 1984; Entrix 1986;Wilson et al. 2009). In general terms, the valley morphology is controlled by erosion-resistant bedrock outcrop in reaches MR-1 (gneiss), MR-2 (metasediments and gneiss), MR-3 (granite), MR-4 (granite) and MR-5 (metasediments) and thus the valley widths are narrow (<1000 ft) and sediment storage potential within the reaches in the form of bars, islands, floodplain and terraces is low (Tetra Tech 2013b). In contrast, in reaches MR-6 and MR-7 the valley morphology is controlled primarily by the presence of more erodible Pleistocene-age moraines and outwash terraces that are inset within a wider valley bounded by metasediments (Tetra Tech 2013b,g). Valley floor widths are in excess of 2,000 ft and as a result there is higher sediment storage potential within these reaches in the form of bars, islands, floodplains and Holocene-age terraces. With the exception of reach MR-8 which is bounded by Pleistocene-age glacial, glacio-fluvial and glacio-lacustrine deposits, all of the sediment storage zones, including the Focus Areas, within reaches MR-6 and MR-7 are located upstream of valley floor constrictions created by a range of geomorphic features that include tributary alluvial fans, bedrock outcrop, moraines and outwash terraces in various combinations. Six of the 7 studied Focus Areas and Geomorphic Assessment Areas are located upstream of constrictions that create backwater conditions under high flows and are also zones of preferred ice-dam formation (HDR 2013a; HDR 2013b). The exception is FA-104 (Whiskers Slough), where the river is confined laterally by terraces that may be Holocene in age (last 10,000 years) (Labelle et al.1985) and the downstream boundary is the very wide (about 9,000 ft) combined floodplains of the Susitna and Chulitna rivers that are also areas of preferential ice-dam formation(HDR 2013a; HDR 2013b).

### 5.1.3.3. Development of Conceptual Geomorphic Models

Based on the research and field work conducted in 2013, two geomorphic conceptual models, geomorphic successions and channel evolution model, were developed and are presented below.

#### 5.1.3.3.1. Geomorphic Succession Model

A conceptual model of geomorphic succession within the alluvial reaches of the Middle River, that describes the vertical progression from gravel bars to vegetated island and floodplain surfaces, was developed from observations and measurements made primarily in the 7 FAs and GAAs. From a geomorphic perspective, the active floodplains and vegetated islands are formed and maintained by a suite of very similar processes. Islands can become attached to floodplains and floodplains can be dissected to form islands (Gurnell et al. 2001) and therefore, they are treated interchangeably. The conceptual model follows the generally accepted, time-dependent progression established for floodplain (Leopold and Wolman 1957; Leopold et al. 1964) and island (Gurnell et al. 2001) formation in alluvial rivers where the rates of vertical accretion, the size of the deposited sediment and the frequency and duration of inundation all diminish over time as the height of the surface increases to some limiting height as a result of sediment deposition. However, in the Middle River, ice processes have both constructive effects on floodplain and island building as well as destructive effects that lead to erosion and dissection that complicate the basic hydro-geomorphic model. Backwater effects from ice-jams and short-duration flood surges associated with ice-jam failures (Gerard and Devar 1995; Beltaos 1995) can significantly modify the magnitude and frequency of inundation as well as sedimentation. Intimately associated with the physical construction of the geomorphic surfaces is the riparian vegetation, that itself follows successional pathways that in turn affect the depositional and erosional processes on the geomorphic surfaces by varying the hydraulic roughness (Helm and Collins 1997; Edwards et al. 1999; Kollmann et al. 1999). The riparian vegetation successional pathways can also be modified by ice processes and animal browsing (Helm and Collins, 1997; Collins and Helm 1997; Kevin Fetherston, R2, personal communication).

The conceptual geomorphic model is shown in Figure 5.1-5. The model shows a genetically-linked suite of geomorphic surfaces. It integrates the height of the identified surfaces above a summer season (June–August) 70th percentile flow (~18,000 cfs at Gold Creek gage) (Tetra Tech 2013d) water-surface datum, the materials that comprise the surfaces, the associated vegetation types and succession pathways and the approximate minimum age of the surfaces based on reported dendrochronology for the Susitna River (Helm and Collins 1997) and tree cores collected and counted from both balsam poplars and white spruces during the field data collection. Refinement of the elevations of the surfaces will be made with indexed LiDAR – based topography. Changes in the riparian vegetation distribution, and to some extent the successional process, can also be verified from the aerial photographic comparisons of the 1980s and 2012 images (Tetra Tech 2013g), which provide a roughly 30 year visual record of change in the Middle River. A more precise estimation of the minimum ages of the surfaces will be provided by dendrochronologic data from the Riparian Instream Flow Study (RSP Section 8.6) and it is possible that radiometric dating based on $Cs_{137}$ and $Pb_{210}$ isotopes will provide estimates of vertical accretion rates (Kevin Fetherston, R2, personal communication).

The primary unit of all the geomorphic surfaces is the unvegetated gravel bar (GB) (Labelle et al. 1985; Osterkamp 1998; Gurnell et al. 2001; Harvey et al. 2003) that on average is 2 to 3 ft high. When shrub-type vegetation (willows, alders) becomes established on the exposed gravel bar surface, the hydraulic roughness increases which promotes about 1-2 ft of deposition of primarily sand-size sediment on top of the gravel core. The vegetation roots provide effective cohesion to the essentially cohesionless sands and gravels and promote stability of the vegetated bar (VB). Within a 10-20 year period, dense stands of balsam poplars (diameter less than 0.5 ft) establish and attain a height of up to about 30 ft, provided that ice processes and moose browsing (Collins and Helm 1997) do not reset the vegetation succession.

Within 50 to 60 years there is an additional approximately 2 ft of primarily sand deposition on the VB surface that creates a young floodplain surface (YFP) that is on average 5 to 6 ft high. The density of the balsam poplars on the YFP surface is reduced but the diameter of the individual trees increases (approximately 1 ft) and white spruce trees become established under the poplar canopy on sand deposits. At about 80 years, there is an additional approximately 1 ft of primarily sand deposition on the YFP surface that creates a mature floodplain surface (MFP) that is on average 6-7 ft high. Balsam poplars are 70-80 ft high and the density of the trees is low with individual trees having diameters in excess of 2 ft. White spruce trees are up to 40 ft in height and ostrich ferns are ubiquitous as an understory species, especially where there is evidence of recent sand deposition.

After about 100 years, there is little increase in the height of the MFP surface, but there is a change in the vegetation on the surface as a result of the natural successional pathway that is essentially independent of fluvial processes, which is then characterized as an old floodplain surface (OFP). Balsam poplar trees are decadent (they can be as old as about 150 years), white spruce trees have grown in height to 70-80 feet and paper birch trees have become established on the mineral soils exposed by the root balls of downed balsam poplars (Kevin Fetherston, R2 personal communication). Overall tree density is low and the understory tends to be dominated by ostrich ferns. Based on field observations and review of the time-sequential aerial photography (1951, 1983, 2012), as well as ice-breakup photography (HDR 2013a; HDR 2013b), it appears that the combined effects of low density of trees and the fact that the ostrich ferns have died back over the winter create relatively low overbank roughness pathways that may predispose ice scour and ice-jam affected overbank flows in the spring to create chute channels across the floodplain and islands that ultimately widen and lead to dissection and erosion of the OFP surfaces.

Holocene-age terraces and dissected terrace remnants with similar vegetation characteristics as the OFP surfaces are located throughout the Middle River. The terraces are distinguishable from the floodplain surfaces by the thickness of the exposed gravel cores which tend to be 2 to 3 times thicker than those of the floodplain surfaces and by their additional height (9-10 ft). The vegetation assemblage on the terraces is dominated by paper birch and white spruce with a few very large diameter (> 3 ft) decadent balsam poplars. Tree density is low and the understory is primarily composed of ostrich ferns. Based on the sizes of the largest spruce and paper birch trees growing on the terraces it is possible that the terraces are 300-400 years old (Kevin Fetherston R2, personal communication). If this is the case, which will be confirmed or refuted by dendrochronological data (Kevin Fetherston, R2, personal communication), it is likely that the terraces are related to Little Ice Age sedimentation that peaked in Alaska in the mid-1700s (Calkin et al. 2001; Motyka 2003; Reyes et al. 2006) and likely caused aggradation within the Middle River. If true, this then implies that there has been some degradation (3-4 ft) of the Middle River in the last 300-400 years, but the relatively constant thickness of the gravel cores in the identified floodplain surfaces (2-3 ft) and the relatively constant height of the MFP and OFP surfaces (6-7 ft) suggests that there has been little or no degradation within the last approximately 150 years. Comparison of thalweg data from the 1980s and 2012/2013 tends to support vertical stability within the Middle River, at least over the last 30 years (Figure 5.1-6). The terrace, floodplain and comparative thalweg data do not support the assertion of a degrading Middle River that was inferred from time-sequential aerial photograph comparison between the 1940s and 1980s (Labelle et al. 1985).

##### *5.1.3.3.2. Channel Evolution Model*

Channel types in the Middle River were defined and classified in the 1980s studies (EWTA 1984, 1985; Entrix 1986). The classifications were somewhat arbitrary (EWTA 1985) but have persisted and thus are used in the current studies. The channel types and their distinguishing characteristics are described as follows.

<u>Mainstem Channel (MC)</u>: This channel type may be single or split by the presence of vegetated islands and in general conveys more than 10 percent of the total flow during the summer open-water season. Except in the winter low-flow period it conveys turbid water.

<u>Side Channel (SC)</u>: This channel type conveys less than 10 percent of the total flow and is in general hydraulically connected to the mainstem channel for more than 50 percent of the time in the summer open-water season and thus conveys turbid water. Breaching flows (i.e. flows when the SC and MC are hydraulically connected) are in general <20,000 cfs, but during the late Fall-Winter low-flow season the channels can be dry or conveying clear groundwater because the gravel berm or lateral weir at the head of the channel is at a higher elevation than the water-surface in the MC.

Side Slough (SS): This channel type by definition conveys only clearwater and thus the breaching flow is >20,000 cfs and it is disconnected hydraulically from the mainstem for more than 50 percent of the time in the summer open-water season. The berms or lateral weirs formed by gravel deposition at the upstream end of the SS channels are not vegetated. By definition, when the breaching flow is exceeded, the SS becomes a SC, thus the classification of the SC and SS channel types is flow dependent.

Upland Slough (US): This channel type only conveys clearwater that is derived from local runoff, small tributaries and groundwater. The berms or lateral weirs at the upstream ends of the US channels are vegetated and are very rarely overtopped by mainstem flows. The US channels are often inhabited by beavers because they represent low energy zones.

Field observations in the Middle River geomorphic reaches and review of time-sequential aerial photography clearly indicate that the individual channel types are not static. Based on an analysis of the 1983 and 2012 aerial photography (Tetra Tech 2013g), in the nearly 30 years between the 2 sets of photography there has been a general increase in the MC category area in the three reaches and with the exception of the US category in MR-8, there has been a reduction in the area of the SC, SS and US categories in MR-6, MR-7 and MR-8. Based on field observations, a generalized geomorphic model can be developed to explain the changes in channel types over both time and space within the more alluvial reaches of the Middle River (MR-6, MR-7, MR-8).

Figure 5.1-7 presents a conceptual model of channel evolution for the alluvial reaches of the Middle River that is based on the concept of location-for-time substitution (Schumm et al. 1984; Harvey and Watson, 1986; Harvey, 1989). In general, in most locations there is an MC and a more or less parallel SC that are separated by a vegetated island or dissected floodplain segment (OFP) (Stage 1). Ice scour or ice-jam induced flooding across the less densely treed OFP surface leads to the development of an erosional channel, which is referred to as a Chute Channel (CC) that is a transitional stage that connects to the MC (Stage 2). Diversion of flow through the CC from the MC causes erosion and widening and development of an SC (Stage 3). As the SC widens, the amount of flow being lost from the MC increases which results in reduced local bed-material transport in the MC and deposition of a gravel/cobble bar (berm) in the flow expansion zone that effectively forms a lateral weir (berm) at the head of the SC (Stage 4). When the weir is overtopped (breached), very little or none of the coarser bed material is conveyed into the SC. However, sands in suspension are transported into and through the SC. The absence of coarse bed material in the flows leads to a coarsening of the bed material in the SC which enhances its vertical stability. With time, willows and alders become established on the berm (lateral weir) and the elevation of the weir increases thereby increasing the flow required to overtop (breach) the berm, which in turn reduces the amount of time that the SS is hydraulically connected to the mainstem (Stage 5). The bulk of the former SC located downstream of the berm (lateral weir) begins to infill with primarily sand-size material conveyed by flows that overtop (breach) the berm and these become vegetated thereby leading to further lateral and vertical accretion over time that effectively eliminates the bulk of the former SS and it morphs into an US (Stage 6). Ultimately, there is sufficient sand deposition at the head and along the margins of the former SC that only a remnant portion of the US is left in the downstream part which is hydraulically connected to the original parallel-to- the-mainstem SC (Stage 7). Based on the types and sizes of the vegetation that are associated with each of the stages, it appears that the evolutionary sequence can occur in about a 20-30 year period, which is supported by the results of the time-sequential aerial photographic analysis (Tetra Tech 2013g).

The role of ice is likely to be complex with respect to the evolutionary sequence. Ice, or ice-induced overbank flooding of higher elevation surfaces appears to be involved in the initiation of SCs, and a combination of fluvial and ice processes are responsible for widening of the SCs once they form. Ice may also be involved in resetting the evolutionary sequence as well. Reversion of SSs to SCs has been observed in the comparative aerial photographic analysis (Tetra Tech 2013g).Ice has been observed to cause significant erosion of fluvial deposits (MacKay et al. 1974; Smith 1980) and may be involved in periodic erosion of both the unvegetated lateral weirs (berms) at the heads of the SCs and vegetated bars at the heads of the SSs.

Based on this geomorphic model of channel evolution, the US channels within the Middle River should be the most long-lived, and this tends to be supported by the longevity of the USs that were initially identified in the 1980s (Entrix 1986). Elimination of USs is likely to only occur with erosion and destruction of the geomorphic surfaces within which they are inset, which tend to be either OFP or Holocene-age terrace surfaces. Based on the currently available dendrochronological data (Helm and Collins 1997), it appears that the USs could, therefore, persist for at least 50-100 years.

#### *5.1.3.4. Downstream Controls*

Within reaches MR-6 and MR-7 and MR-8 of the Middle River, all of the alluvial zones within which the FAs and GAAs are located, with the exception of the FA-104 (Whiskers Slough) area, are located upstream of geologically and geomorphically-created valley floor constrictions (Appendix A.1 Surficial Geology Mapping). The constrictions create hydraulic backwater conditions during high flows that induce sediment deposition upstream of the constriction (Harvey et al. 1993; Mussetter et al. 2001) and are preferred loci for the formation of ice-jams (Beltaos, 1995; HDR 2013a, b). Furthermore, the deposition (bars and islands) in the reach upstream of the constriction also promotes the formation of ice-jams that have the ability to modify both the geomorphic surfaces (Prowse 1995; Beltaos, 1995; HDR 2013a, b) and the vegetation (Helm and Collins 1997).

The characteristics of the constrictions for each of the FAs and GAAs in reaches MR-6, MR-7, and MR-8 are shown in Table 5.1-3.

#### *5.1.3.5. Geomorphic Mapping of FAs and GAAs*

Aerial reconnaissance, field observations and measurements of geomorphic surface heights above a water-surface datum, aerial photography (2012) and shaded relief mapping based on the MatSu LiDAR were used to develop geomorphic maps of the 7 FAs and GAAs that were studied in the Middle River. The geomorphic maps of the individual GAAs and FAs (based on shaded relief mapping from the Mat-Su LiDAR) show the downstream boundary conditions, the valley floor lateral constraints created by various combinations of bedrock outcrop, lateral moraines and outwash terraces on the surficial geology maps (Appendix A.1) and the distribution of valley floor alluvial surfaces (GB, VB, YFP, MFP, OFP, Holocene-age Terrace) and channel types (MC, SC, SS, US). Refinement of the geomorphic mapping may be required when indexed

LiDAR mapping and the results of 1-D and 2-D Bed Evolution modeling are available (Study 6.6). Where present, 2 additional channel types were recognized and mapped; Overbank Channel (OCH) and Paleo Channel (PC). The former represents periodically active erosional features that have no direct connection with the MC and are located on OFP and Holocene-age terrace surfaces and appear to be the result of concentration of overbank flows most probably generated by downstream ice jams. The latter represent former MC and probably SC channels that are located on Holocene-age terraces and are currently hydraulically disconnected from the MC, except under the most-extreme, most likely ice-jam generated flood events. Most of the channels have been filled in and support both wetland (alder, black spruce) and upland (river birch and white spruce) shrub and tree species. Local runoff and minor tributaries are the sources of water observed in these paleo-channels and in a number of locations they are occupied by large beaver-dam complexes, some of which are active and some of which appear to be abandoned. The geomorphic maps also show the locations of active bank erosion based on field observations at the individual FAs and GAAs as well as the locations of tributaries and lateral controls (berms) at the heads of SC and SS channels.

##### *5.1.3.5.1. Geomorphic Maps*

Geomorphic maps for each of the 7 mapped FAS and GAAs are provided in Appendix A.2.For discussion purposes, maps for contrasting FAs and GAAs are presented in Figure 5.1-8 (FA-104 Whiskers Slough) and Figure 5.1-9 (FA-128 Slough 8A). The downstream boundary for FA-104 (Whiskers Slough) is the very wide combined floodplain of the Susitna and Chulitna rivers that does not create upstream backwater, whereas the downstream boundary for FA-128 (Slough 8A) is a constriction caused by outcrop of the Kahiltna Flysch metasediments on the west and the Skull Creek fan on the east. Both FAs are, however, affected by ice jams (HDR, 2013 a,b).

The geomorphology of the FA-104 GAA (about 3.2 miles long and 4,000 ft wide) is dominated by the presence of Holocene-age terraces that are inset below older, Pleistocene-age outwash terraces. There are limited areas of active floodplain and island surfaces (VB, YFP, MFP) and a fairly extensive area of relatively inactive floodplain and island surface (OFP). At a flow of about 12,900 cfs at the Gold Creek gage (based on the 2012 aerials), the MC occupies about 14 percent of the GAA and the other channel types in total occupy about 12 percent of the GAA. The US channels are primarily associated with the extensive network of paleo-channels (PC). Lateral controls in the form of gravel bars (berms) are present at the heads of most of the SCs. Evidence of some fluvial and or ice-driven erosion is present on the banks of most of the higher elevation surfaces (MFP, OFP and Holocene-age terrace). In general the erosion is recognized by the presence of undercut and cantilevered root-reinforced upper bank sediments as opposed to bare banks.

The geomorphology of the FA-128 GAA (about 2.3 miles long and 3,000 ft wide) is quite different from the FA-104 GAA. The more upstream portion of the GAA is occupied by OFP surfaces that have been dissected by SC and SS channels. There is a relatively small portion of Holocene-age terrace within the GAA, which may suggest that more extensive areas have been eroded, or that there was little of it formed. An extensive network of OCH channels, with no direct connection to the MC, is present on the OFP surface, which suggests that more dissection of the area will occur in the future, probably as a result of ice-jam caused overbank flooding. The lower portion of the GAA is occupied by younger surfaces including VB, YFP and MFP types. At a flow of about 12,900 cfs at the Gold Creek gage, the MC occupies about 20 percent of the GAA and the other channel types in total occupy about 19 percent of the GAA. Lateral controls in the form of gravel bars (berms) are present at the heads of most of the SCs and the SS (Slough 8A). Evidence of some fluvial and or ice-driven erosion, is present on the banks of most of the higher elevation surfaces (MFP, OFP and Holocene-age terrace).

##### *5.1.3.5.2. Distribution of Channel Types in the GAA's*

The areal distribution of the various types of channels was developed from the geomorphic mapping of the individual GAAs (Figure 5.1-10). Clearly, at all of the GAAs the MC and SC channels form the bulk of the surface area with the SS, US, OCH and PC channels occupying a much smaller, but biologically significant, area (EWTA 1985; Entrix 1986). To provide a basis for comparison of the distributions among the GAAs, the individual channel type areas were normalized by dividing by the total area of the GAA (Figure 5.1-11). The MC accounts for between 18 percent (FA-104 Whiskers Slough) and 36 percent (FA-144 Slough 21) of the GAA. In MR-6 and MR-7, where the GAAs are located upstream of valley-floor constrictions, the MC accounts for about 20 percent, but the highest value (36%) is located in the narrowest valley (about 1,600 ft) (FA-144 Slough 21) and the lowest value (18.5%) is located in FA-115 (Slough 6A) which has a much wider valley (2,700 ft). The SC accounts for between 9 percent (FA-141 Indian River) and 21 percent (FA-113 Oxbow I) of the GAA. The GAAs which have the higher SC values, FA-113 Oxbow I (21%), FA-128 Slough 8A (17%) and FA-144 Slough 21 (19%) tend to be the most dynamic ones.

Because of the small areas accounted for by the other channel types, they are shown separately (Figure 5.1-12). SSs occupy between 0 percent (FA-115 Slough 6A) and 1.6 percent at FA-128 (Slough 8A). At the other GAAs the percentages are less than 1 percent. USs occupy between 0 percent (FA-113 Oxbow I) and 3.5 percent (FA-138 Gold Creek) of the GAAs. There is a high correlation between the presence of the USs and PCs (1 to 15%), which are in turn correlated with the presence of Holocene-age terraces within the GAAs. The percentages of OCHs (0.2 to 1.5%) also tend to be correlated with the presence of higher elevation geomorphic surfaces. Both active and inactive beaver dams appear to be located preferentially in low energy environments provided by the USs and related PCs (Table 5.1-4)

##### *5.1.3.5.3. Channel Widths*

Average channel widths were determined from the geomorphic mapping for each of the GAAs. With the exception of FA-144 (Slough 21), where the flow at Gold Creek was 17,000 cfs, the channel widths at the other GAAs were determined at a flow of 12,900 cfs at the Gold Creek gage (Table 5.1-5). The average MC widths, regardless of the width of the valley bottom in the individual GAAs were very similar, ranging from 476 ft (FA-113 Oxbow I) to 586 ft (FA-128 Slough 8A). The relatively similar width of the MC within the 7 GAAs, regardless of the geomorphic variability within the individual GAAs, suggests that the width of the MC channels is controlled by a range of bed-material transporting flows that are common to all the sites. Although there is little doubt that ice processes have both constructive and destructive effects within the GAAs, it is highly unlikely that the more random nature of the ice processes would be responsible for the equi-width nature of the MC. It is more likely that the ice processes would periodically modify the channels (Prowse 1995), but the fluvial processes would reset the morphology. The range of effective sediment transporting flows will be determined from the 1-D and 2-D Bed Evolution modeling (ISR Study 6.6 Section 4.1.2).

The widths of the SC channels are, as expected, highly variable because the SC channels represent a wide range of conditions. They can be relatively narrow because they are still in a widening phase, or they can be wide and ultimately heading for closure as the channel evolves through time. However, many of the more established SCs have very coarse bed materials and are overly wide, which suggests they are threshold channels (Parker 1978; Mussetter and Harvey 2001) that have widened in response to coarsening of the bed material over time. The coarse bed material represents lag deposits within the alluvial valley fill that has been derived from reworking over time of glacial and fluvio-glacial deposits and are rarely, if ever, remobilized by flows in the SCs. The implication of this is that the bulk of the bed-material load (gravels and cobbles) is transported through the MC and the lateral weirs (berms) that form in the flow expansion zones at the heads of the SCs limit the transport of bed material into and through the SCs which leads to their coarsening and widening. Large quantities of sand are transported into and through the SCs during the summer open water season when the MC and SCs are hydraulically connected. Extensive channel margin and in-channel sand deposits were observed throughout the Middle River prior to freeze-up. The relative roles of the MC and the SCs in transporting flow and sediment through the GAAs will be investigated through the 1-D and 2-D Bed Evolution modeling and the 2-D Hydraulic modeling as part of the Fluvial Geomorphology Modeling Study below Watana Dam Study (Study 6.6).

##### *5.1.3.5.4. Geomorphic Stability*

Geomorphic stability within the Middle River can be viewed at a number of scales. Within the GAAs there is little doubt that there is some bank erosion taking place, primarily in the vicinity of the higher elevation geomorphic surfaces such as the MFP, OFP, Holocene-age terraces and Pleistocene-age outwash terraces and lateral moraines. The bank erosion occurs as a result of both fluvial and ice processes, but the rates of bank erosion appear to be quite slow. There is clear evidence along many banks that ice processes have in fact reinforced the stability of the banks by depositing and consolidating large cobbles and boulders in the mid-bank region and along the toes (Prowse 1995). The minimum ages of the geomorphic surfaces provided by the dendrochronology data indicate that the rates of erosion cannot be high. Comparisons of banklines from the 1983 and 2012 aerial photographs (Tetra Tech 2013g) indicate that erosion rates have been low over the last 30 years and that in general there is more vegetated area in the Middle River in 2012 than there was in 1983. By way of contrast, vegetated islands in the flashy pluvio-nival flow regime unregulated, gravel-bed, Fiume Tagliamento River that drains the Italian Alps, rarely last more than 20 years (Gurnell et al. 2001).

Comparison of the 1980s and 2012 banklines with those in the 1950s aerial photography, which is currently underway, will provide a longer frame of reference. Review of the annual peak flows at the Gold Creek gage indicate that there were a number of large floods between the 1950s and 1980s (>80,000 cfs) and in the 1980s to 2012 period the peak flows have been relatively low (<60,000 cfs). Consequently, the relatively low erosion rates in the 1980s to 2012 period may reflect the peak flow hydrology of that timeframe.

Based on the 1982 and 2012 thalweg profiles (Figure 5.1-6) it appears that the Middle River has been vertically stable for at least the last 30 years. However, the presence of the Holocene-age terraces within the Middle River, that may be related to the Little Ice Age glacial advance that reached its maximum extent in the 1750s, implies that there has been some degradation (3-4 ft) of the Middle River in the last 300-400 years, but the relatively constant thickness of the gravel cores in the identified floodplain surfaces (2-3 ft) and the relatively constant height of the MFP and OFP surfaces (6-7 ft) suggests that there has been little or no degradation within the last approximately 150 years.

At a different scale, there is field and aerial photographic evidence that the older geomorphic surfaces (OFP and Holocene-age terraces) are being dissected over time. The dissection is likely related to ice processes that drive channel avulsion (MacKay et al. 1974; Smith 1980), at least initially. However, the rates of dissection must be quite slow because of the ages of the geomorphic surfaces, which could range from about 150 to over 300 years.

##### *5.1.3.5.5. Preliminary Hydrology and Hydraulics*

In most alluvial river systems, the bankfull flow is exceeded with a recurrence interval of between 2 and 5 years (Leopold and Wolman 1957; Leopold et al. 1964; Williams 1978). Thus, by definition, the floodplain should be inundated with the same recurrence interval. The duration of floodplain inundation is highly dependent on the flow regime and can range from a few days per year in snowmelt-dominated rivers to months in tropical low-gradient rainfall-dominated rivers (Dunne and Leopold 1978). Terraces, by definition, should be very rarely, if ever, inundated in a fluvial system (Leopold et al. 1964; Schumm 1977). Periodic flooding of the floodplain is a requirement for many critical riparian ecosystem processes (Poff et al. 1997; Chapin et al. 2002; Mussetter et al. 2007; Hupp and Osterkamp 1986; Hupp and Rinaldi 2007).

In order to evaluate the recurrence interval for the flows that overtop the identified geomorphic surfaces within the 7 FAs and GAAs, a preliminary investigation was conducted based on measured heights of surfaces in relation to a water-surface datum and stage-discharge rating curves developed from the preliminary open water flow routing model (R2 et al. 2013). The discharge on the day of measurement at the Gold Creek gage was used with the stage-discharge rating curves -to convert the field height measurements of the various geomorphic surfaces to elevations that could then be compared with the model-estimated water-surface elevations for a range of flows based on the flood frequency curve developed for the Gold Creek gage (Appendix A.3 and A.4). The mean elevations and standard deviations for each of the surfaces within the individual FAs and GAAs are presented in Table 5.1-6 (FA-104 Whiskers Slough), Table 5.1-7 (FA-113 Oxbow I), Table 5.1-8 (FA-115 Slough 6A), Table 5.1-9 (FA-128 Slough 8A), Table 5.1-10 (FA-138 Gold Creek), Table 5.1-11 (FA-138 Indian River) and Table 5.1-12 (FA-144 Slough 21). Bar graphs of the data (mean and standard deviation) for the individual FAs and GAAs are presented in Figure 5.1-13 (FA-104 Whiskers Slough) Figure 5.1-14 (FA-113 Oxbow I), Figure 5.1-15 (FA-115 Slough 6A), Figure 5.1-16 (FA-128 Slough 8A), Figure 5.1-17 (FA-138 Gold Creek), Figure 5.1-18 (FA-138 Indian River) and Figure 5.1-19 (FA-144 Slough 21).

In general, the elevation data for each of the FAs and GAAs indicate that there is a progressive increase in elevation between the identified geomorphic surfaces in the evolutionary sequence

(GB to MFP), and that the Holocene-age terraces are higher than the floodplain. The tables and bar graphs also indicate that there is quite a bit of variance in the data for individual surface heights, which could be due to naturally occurring topographic variation, imprecise measurements or to misclassification of the surface in the field. Indexing of the LiDAR imagery currently underway, will enable the elevations of the geomorphic surfaces to be refined and the sample size to be increased. On the whole, there is little difference in elevation between the MFP and OFP surfaces, which tends to confirm that the two surfaces are primarily differentiated by the successional stage of the vegetation.

Table 5.1-13 summarizes the recurrence intervals (based on the Gold Creek gage flood frequency curve) for overtopping flows for each of the geomorphic surfaces within the 7 FAs and GAAs. The VB surfaces are overtopped by flows with recurrence intervals ranging from 3 (FA-138 Indian River) to 23 (FA-104 Whiskers Slough) years. The YFP surfaces are overtopped by flows with recurrence intervals ranging from 4 (FA-128 Slough 8A) to >100 (FA-104 Whiskers Slough) years. The MFP surfaces are overtopped by flows with recurrence intervals ranging from 10 (FA-138 Indian River) to >100 (FA-144 Slough 21) years. The OFP surfaces are overtopped by flows with recurrence intervals ranging from approximately 60 (FA-128 Slough 8A) to >1,000 (FA-104 Whiskers Slough, FA-144 Slough 21) years. The Holocene-age terraces are overtopped by flows with recurrence intervals ranging from approximately 40 (FA-138 Indian River) to >1,000 years (FA-104 Whiskers Slough). The recurrence interval data in Table 5.1-13 indicate that for a given geomorphic surface there is a very wide range of values. This could be due to the combined effects of the preliminary nature of the hydraulics, the use of a single rating curve located in the middle of the FA to represent the entire FA, as well as the naturally occurring topographic variation, imprecise measurements or to misclassification of the surfaces in the field. However, if the lowest and highest values are removed for each surface within the evolutionary sequence, the average values are 8, 51, 66 and 87 years, respectively for the VB, YFP, MFP and OFP surfaces. The recurrence interval for overtopping of the Holocene-age terraces is, as expected, in the 100s of years. Refinement of the values will be possible when the LiDAR based topography and hydraulic results from the 1-D and 2-D Bed Evolution models become available.

Recognizing that there is substantial uncertainty in the averaged recurrence interval values, they are at least internally consistent and indicate that the frequency of overtopping the geomorphic surfaces within the Middle River, with the exception of the Holocene-age terraces, is much less than would be expected for an alluvial river (Leopold and Wolman 1957; Leopold et al. 1964; Williams 1978). Field observations in the FAs and GAAs of recent extensive sand deposits on the tops of the VB and YFP geomorphic surfaces is probably due to the 2013 peak flow of about 90,000 cfs (~ 50-yr RI) at the Gold Creek gage which is consistent with the range of estimated recurrence intervals for those surfaces. However, observed recent sand deposits on the tops of the higher elevation MFP and OFP surfaces are unlikely to have been deposited by the 2013 peak flow and thus another process is required to explain their presence.

Low-level aerial videography during the ice-break up period (HDR 2013a; HDR 2013b) clearly indicates that ice-jam flooding occurs within the Middle River in the alluvial sections (GAAs) located upstream of valley floor constrictions. Depending on the height and roughness of the breakup ice-jam, the upstream water-surface elevation (backwater) can increase many feet over open-water conditions (Beltaos 1995) thereby leading to inundation of surfaces at much lower flows and at a higher frequency than would be predicted by open-water hydraulics. Sand deposited in the channels and channel margins the previous year during the summer open-water season is the likely source of sand for deposition on the inundated geomorphic surfaces. More frequent, ice-jam initiated inundation and sedimentation may support the riparian ecosystem processes. Inundation of higher elevation surfaces can also occur as a result of short duration flood surges caused by ice-jam failures (Prowse 1995; Beltaos 1995). Quantification of the hydraulic influences of ice-jam formation will be provided by the River1D Ice Processes and River 2D Focus Area Ice models (Study 7.6) and modeling of backwater and dam break effects of ice jams in the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6). Direct deposition from ice of sand to cobble and boulder size material during breakup also occurs within the Middle River, but the volume of material transported and deposited by this process is unknown and is very difficult to determine. Many of the geomorphic surfaces where there is evidence of ice activity, such as ice scars on trees, also display levee-like features on the channel margins that are formed by both ice-scraping of upper bank materials and local deposition from the ice.

### 5.1.4. Electronic Data

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

- Geomorphic Reach Break shapefile
  - File name: ISR_6_5_GEO_GeomorphicReaches.shp

## 5.2. Study Component: Bed Load 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

Much of the effort associated with this study component was conducted in 2012 and reported on in the Technical Memorandum Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech2013a). This 2012 technical memo utilized historical sediment transport measurements and the extended USGS hydrologic record to empirically characterize the Susitna River sediment supply and transport conditions. The collection of the data described in this study component supplements sediment transport data collected in the 1980s.

The most recent sediment measurements were collected in WY2012 and WY2013 by the USGS in the Susitna Basin. Discharge, water quality, temperature, turbidity, suspended-sediment concentrations (including sediment-size distribution), and bed load measurements (including sediment-size distribution), and bed-material size distributions were finalized and published for the 2012 data (USGS 2013). This study component is tasked with reporting the suspended-load, bed load and bed-material measurements along with the associated discharge at the time of the measurements. The locations and dates for the 2012 suspended and bed load sediment data are presented in Tables 5.2-1 and 5.2-2, respectively. In 2012, sediment data were collected at the Susitna River near Talkeetna site instead of the Gold Creek gage to represent the downstream portion of the Middle River. On the Chulitna, sediment data were collected at the Chulitna River below Canyon (gage 15292410) in addition to the Chulitna River near Talkeetna (gage 15292400). The alternate locations were substituted for the original locations due to the presence of boulders on the bed at the original locations that complicated the data collection. In addition, the alternate sections are closer to the Three Rivers Confluence and provide a better estimate of conditions at the confluence.

The 2012 suspended-sediment measurements collected in this study component are presented in Table 5.2-1. Table 5.2-2 contains the analogous bed load measurements. The 1980s sediment discharge data and rating curves, in addition to 2012 suspended-sediment discharge and bed load discharge data, were plotted versus discharge in Figures 5.2-1 through 5.2-16. The rating curves were development and presented in Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a).

### 5.2.1. Electronic Data

Data for this study component is located on the USGS website at http://wdr.water.usgs.gov/.

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

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

Much of the effort associated with the first two subsections was conducted in 2012 and reported on in the technical memorandum entitled Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Segments (Tetra Tech2013a). This study used historical sediment data and hydrology records to estimate the annual sediment loads at three mainstem gages and three primary tributary gages. These loads were then compared to the estimated supply to the reach for both pre-Project and Maximum Load Following OS-1 conditions. Changes in the relative sediment balance will help provide an initial basis for assessing the potential for changes to the sediment balance in the Middle and Lower Susitna River segments, and the associated changes to geomorphology, because it will permit quantification of the magnitude in the reduction of sediment supply below the dam and an initial estimate of how that reduction will translate downstream through the Middle and Lower River segments.

### 5.3.1. Initial Sediment Balance Middle Susitna River Segment

Results from the analysis indicate that the total sediment load passing the gages varies significantly from year to year, depending primarily on the total runoff. For example, the estimated total annual load passing the Gold Creek gage over the 61-year period ranged from about 0.5 million tons per year to over 10.8 million tons per year (Figure 5.3-1). Similar variation occurs at the other gages (see Tetra Tech2013a for details).

Watana Dam and Reservoir will trap a significant percentage of the sediment supply to the Middle River. For purposes of this preliminary analysis, it was assumed that the trap efficiency for the silt/clay load will be on the order of 90 percent, and all of the sand and coarser sediment will be trapped. In addition to the effects on sediment supply, the dam will also modify the flow regime in the downstream river in a manner that will affect the transport capacity along the reach. Because of the nonlinear relationship between discharge and sediment transport rates, the changes in flow regime associated with the Project will result in a general decrease in the capacity of the river to transport sediment in each segment of the reach. Under Project conditions represented by Maximum Load Following OS-1, the annual gravel bed load at Gold Creek will decrease to about 4,000 tons, on average, compared to the pre-Project annual average of 66,000 tons, the sand load will decrease to 213,000 tons from 1,409,000 tons under pre-Project conditions and the silt/clay load will decrease to 285,000 tons from 1,800,000 tons under pre-Project conditions (Tables 5.3-1 and 5.3-2).

### 5.3.2. Initial Sediment Balance Lower Susitna River Segment

The results of the analysis for pre-Project conditions indicate that the Middle River supplies about 22 percent of the total sediment load to the Three Rivers Confluence, and the Chulitna and Talkeetna rivers supply about 66 and 12 percent of the total load, respectively (Figure 5.3-2). On a by-size-fraction basis, the relative contributions of silt/clay and sand are about the same as the total load; however, the Chulitna River supplies the bulk of the gravel load that is key to the channel morphology (about 86 percent of the total, compared to about 8 percent from the Middle River and 7 percent from the Talkeetna River). The total sediment load from the Yentna River represents about 46 percent of the total load and about 65 percent of the gravel load at Susitna Station.

The results for post-Project conditions indicate that the Middle River will supply only about 4 percent of the total sediment load to the Three Rivers Confluence, and the Chulitna and Talkeetna Rivers would supply about 81 and 15 percent of the total load, respectively, under Project conditions (Figure 5.3-3). On a by-size-fraction basis, the contributions of silt/clay from the Middle River would decrease from about 22 percent (pre-Project) to about 4 percent (Maximum Load Following OS-1). During the initial periods after closure of the dam, the Middle River would supply about 6 percent of the sand load (this value has been refined and was reported as 10 percent in Tetra Tech 2013a) and only about 0.5 percent of the gravel load to the Three Rivers Confluence. Yentna River would supply about 48 percent of both the total load and the gravel load to Susitna Station under post-Project conditions.

### 5.3.3. Characterization of Bed-Material Mobilization

Approximate discharges corresponding to bed-surface mobilization were presented for the USGS gaging stations at Gold Creek and Sunshine in Tetra Tech (2013c). At Gold Creek, using an estimated $D_{50}$ of 67 mm, bed material is mobilized at approximately 25,000 cfs; at Sunshine, using an estimated $D_{50}$ of 40 mm, the critical discharge is approximately 16,000 cfs. Bed-material sampling was also conducted downstream from PRM 146.1 (ISR Study 6.6 Section 5.1.9.1); however, hydraulic parameters necessary for estimating the critical discharge by geomorphic reach will not be available until completion of the 1-D Bed Evolution Model (ISR Study 6.6 Section 4.1.2.).

### 5.3.4. Effective Discharge

This section summarizes the effective discharge results developed using the methods described in Section 4 for the pre-Project and Maximum Load Following OS-1 conditions at the three main stem gages and three primary tributary gages. The analysis is described in more detail in Appendix B.

Under pre-Project conditions, the estimated effective discharges along the mainstem ranged from approximately 27,000 cfs at the Gold Creek/near Talkeetna gage to 66,000 and 124,000 cfs, respectively, at the Sunshine and Susitna Station gages. The effective discharge in the gaged tributaries ranged from 11,000 cfs in the Talkeetna River to 23,000 and 50,000 cfs in the Chulitna and Yentna rivers, respectively.

For the Maximum Load Following OS-1 condition, the estimated effective discharges in the mainstem ranged from 9,000 cfs at the Gold Creek/near Talkeetna gage to approximately 46,000 and 108,000 cfs at the Sunshine and Susitna Station gages, respectively. Based on these results, there will be a substantial reduction in effective discharge throughout the mainstem under post-Project conditions, with the relative magnitude of the change decreasing in the downstream direction. These effective discharges are preliminary estimates and will be refined during the next year of study as well as determined for other operational scenarios.

### 5.3.5. Electronic Data

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

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

Mapping of geomorphic features in the Middle and Lower Susitna River segments was performed under the 2012 studies and the results presented in the technical memorandum Mapping of Geomorphic Features within the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (Tetra Tech 2013g). Efforts to map these features from recently acquired 1950s aerials are currently underway. The analysis of channel change in the Middle and Lower River segments presented in the technical memorandum was based on comparison of the geomorphic features mapped on aerial photographs from the 1980s and 2012. The analysis looked at changes in the geomorphic form, such as channel width, alignment, lengths, size of features present, and types of features present, within each geomorphic reach. The analysis also identified geomorphic processes that resulted in channel change, including vegetation encroachment, bank erosion, lateral migration, and biogeomorphic processes such as beaver dam construction. One of the tools used to identify and quantify change is the tabulated area for the various geomorphic features within a reach. Comparative terms, such as increase and reduce, are a function of area differences (1950s vs. 2012 vs. 1980s) determined from the tabulated geomorphic feature areas.

Graphical results have been produced for the 1980sand 2012 aerials with examples for the respective eras presented in Figures 5.4-1 and 5.4-2 for the Middle River. Figures 5.4-3 and 5.4-4 present examples of the 1980s and 2012 geomorphic feature mapping for the Lower River.

Overlay maps were produced by superimposing the outlines of the geomorphic features mapped for the 1980s and 2012 eras over each other. Figures 5.4-5 and 5.4-6 illustrate the overlay mapping for the Middle and Lower River, respectively.

Mapping of geomorphic features from the 1950s aerials was recently completed for the 1950s within Focus Area 128 of the Middle River and geomorphic reach LR-1 in the Lower River. The example of the 1950s delineations for the Middle Susitna River segment is provided in Figure 5.4-7. The example of the 1950s geomorphic feature mapping for the Lower Susitna River segment site is provided in Figure 5.4-8.

The mapping of the 2012 geomorphic features, including the extended area on the Chulitna River is displayed in Figures 5.4-9 and 5.4-10. The geomorphic feature mapping, including the extended mapping for the Talkeetna River is included as Figure 5.4-11. The extended areas represent portions of the Chulitna and Talkeetna rivers, which were not mapped in the 2012 technical memorandum (Tetra Tech 2013g). The 1980s aerials are not available for these areas; therefore, geomorphic feature delineations were not performed.

The areas of each geomorphic feature type within each geomorphic reach within the Middle and Lower River segments were tabulated and presented in the technical memorandum (Tetra Tech 2013g) along with the percent change from the 1980s to 2012. Examples of these tables are provided in Table 5.4-1 for geomorphic reach MR-6 and in Table 5.4-2 for geomorphic reach LR-1. To help visualize and interpret the changes from these two eras, bar charts were presented in Tetra Tech (2013g). Figure 5.4-12 provides a bar chart for the 2012 Middle River segment geomorphic feature areas by geomorphic reach, with the 1983 and 2012 areas displayed side by side for comparison. Figure 5.4-13 contains a similar bar chart for the Lower River segment. Examples of pie charts from the technical memorandum (Tetra Tech 2013g) that show the relative proportion of the geomorphic feature areas within each geomorphic are provided for the Middle River in Figure 5.4-14 and for the Lower River in Figure 5.4-15.

### 5.4.1. Electronic Data

The following data produced in 2013 for Study Component 4 are available on the GINA website at http://gis.suhydro.org/reports/isr:

- 1980s Middle River Mapped Geomorphic Features
  - File name: ISR_6_5_GEO_1980sM_GeoFeAqMHab.shp
- 2012 Middle River Mapped Geomorphic Features
  - File name: ISR_6_5_GEO_2012M_GeoFeAqMHab.shp
- 1980s Lower River Mapped Geomorphic Features
  - File name: ISR_6_5_GEO_1983_L_GeomFeat.shp
- 2012 Lower River Mapped Geomorphic Features
  - File name: ISR_6_5_GEO_2012_Lower_AqMHab.shp

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

Mapping of aquatic macrohabitat types in the Middle Susitna River Segments was performed under the 2012 studies and the results were presented in the Technical Memorandum Mapping of Aquatic Macrohabitat Types at Selected Sites in the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (Tetra Tech 2013f). The habitat site analysis presented in the technical memorandum provided the areas of the various habitats types mapped on aerial photographs from the 1980s and 2012. It also compares the changes in habitat area and site conditions, to which some of the change can be attributed. Comparative terms, such as increase and reduce, are a function of area differences (2012 area vs. 1980s area) determined from the tabulated habitat areas.

### 5.5.1. Aerial Photography

Aerial photography was obtained for the 1980s, 2012, and 2013. Aerial photography of the 17 sites with the aquatic habitat types mapped was provided in Tetra Tech (2013f) as Appendix 1 for 1983 and Appendix 2 for 2012. The aerial photography within the 2013 AOI (Figure 4.5-1) has been acquired and is in the process of being orthorectified. This imagery will be used to update and improve mapping in portions of the Middle River.

### 5.5.2. Digitize Riverine Habitat Types

Examples of the 1983 and 2012 aquatic habitat mapping from Appendix 1 and 2 (Tetra Tech 2013f) are presented in Figures 5.5-1 and 5.5-2 for the Middle River. The tabulated areas for the 1980s and 2012 aquatic macrohabitat types for mapped habitat sites in the Middle River segment are provided in Tables 5.5-1 and 5.5-2, respectively. These areas represent the actual areas at the specific flows when the aerial photographs were obtained flown and have not been scaled to the flows mapped in the 1980s.

### 5.5.3. Riverine Habitat Analysis

The area of each aquatic macrohabitat type within each site was tabulated and presented in the technical memorandum (Tetra Tech 2013f) along with the percent change from the 1980s to the scaled 2012 areas. An example table for Site 7, Side Slough 8A is provided as Table 5.5-3. To help visualize and interpret the change between the two eras, bar charts were presented in Tetra Tech (2013f). Examples for Site 7, Slough 8A, are presented as Figures 5.5-3 and 5.5-4.

The changes in habitat area were also tabulated for sites with comparable flows (1 to 13) and for sites within a single geomorphic reach. The percent change in macrohabitat area by types from 1983 to 2012 for the summation of Sites 1 through 13 is presented in Table 5.5-4. A summation of areas by aquatic macrohabitat type for sites in each geomorphic reach was presented in the technical memorandum (Tetra Tech 2013f). An example is provided for MR-6, which includes Sites 6 through 13, in Table 5.5-5.

### 5.5.4. Electronic Data

The following data produced under Study Component 5 are available on the GINA website at http://gis.suhydro.org/home (Due to the size of these files they are not housed on the "reports/isr" link).

- 1950s Aerial Photography
- 2012 Aerial Photography
- 2013 Aerial Photography

The following data produced in 2013 for Study Component 5 are available on the GINA website at http://gis.suhydro.org/reports/isr:

- 1980s Middle River Mapped Aquatic Macrohabitat
  - File name: ISR_6_5_GEO_1980sM_GeoFeAqMHab.shp
- 2012 Middle River Mapped Aquatic Macrohabitat
  - File name: ISR_6_5_GEO_2012M_GeoFeAqMHab.shp

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

The initial efforts associated with the first three subsections were reported in the three technical memoranda listed in Section 4.6.2. These studies used historical sediment data and hydrology records to estimate the annual sediment loads at three main stem gages and three primary tributary gages. These loads were then compared to the estimated supply to the reach for both pre-Project and Maximum Load Following OS-1 conditions. This section summarizes the results from these technical memoranda. The fourth item, the literature review on downstream effects of dams, is ongoing. Appendix C provides the bibliography of references compiled as part of the literature review.

### 5.6.1. Stream Flow Assessment

This section briefly describes the monthly flow and the summary statistics, the flow-duration analysis results and the flood-frequency analysis results for both the pre-Project and the Maximum Load Following OS-1 conditions. Example figures and tables are included. Tetra Tech (2013d) provides a detailed description of the results and the complete set of figures and tables.

#### *5.6.1.1. Pre-Project*

The average annual discharge from the USGS (2012) extended record at Gold Creek is about 9,700 cfs (average annual volume of ~7M acre-feet), and is between 8,100 and 11,200 cfs in 80 percent of the years. Due, primarily, to inflows from the Chulitna and Talkeetna rivers that contribute 36 and 17 percent of the total, respectively, the average annual flow increases to about 24,000 cfs (~17.4M acre-feet) at the Sunshine gage, and is between 20,400 and 26,900 cfs in 80 percent of the years. At the Susitna Station gage, the average annual discharge is about

48,600 cfs (~35.2M acre-feet) and is between 42,500 and 55,600 cfs in 80 percent of the years. The Yentna and Skwentna rivers contribute 40 and 14 percent of the total flow at Susitna Station, respectively. Table 5.6-1 summarizes the pre-Project average monthly flows at each of the mainstem and tributary USGS gages.

The annual flow-duration curves indicate the expected increase in discharge from up- to downstream, consistent with the average annual flows discussed above. Figure 5.6-1 shows the pre-Project annual flow-duration curves for the mainstem gages based on the USGS extended record. The median annual flow (flow that is equaled or exceeded 50 percent of the time) increases from about 2,050 cfs at Cantwell to about 3,400 cfs at Gold Creek, 8,220 cfs at Sunshine and 19,000 cfs at Susitna Station. Similarly, the 90-percent exceedence flow increases from about 690 cfs at Cantwell, to about 1,200 cfs at Gold Creek, 2,830 cfs at Sunshine and 6,400 cfs at Susitna Station, and the 10-percent exceedence flow increases from 16,500 cfs at Cantwell to about 25,300 cfs at Gold Creek, 64,000 cfs at Sunshine, and 124,000 cfs at Susitna Station. Flow-duration curves were developed for each month at each of the stations, including the tributaries (Tetra Tech 2013d), and the values for specific exceedence durations are tabulated in Appendix C of Tetra Tech (2013d).

The pre-Project flood-frequency analysis was performed for each of the gages using a combination of the recorded instantaneous peak flow data and the USGS extended record. This was accomplished by first correlating the recorded peak discharges for the period of record with the mean daily discharges on the day of the peak discharge. The instantaneous peak discharges for the years in the extended record for which measured data are not available were then estimated by applying the resulting regression relationship to the maximum mean daily discharge. Flood-frequency curves developed using the HEC-SSP program with the resulting extended record of peak discharges indicates that the 2-year recurrence interval peak discharge is about 27,300 cfs at the Cantwell gage and about 43,500 cfs at Gold Creek (Table 5.6-2). The 2-year peak discharges at Sunshine and Susitna Station are substantially higher (106,000 and 170,000 cfs, respectively). The 2-year peak discharges in the Chulitna and Yentna River are 35,200 and 23,200 cfs, respectively (Table 5.6-3). The peak discharges for other events from the 1.25-year through the 100-year recurrence interval flows are also provided in Tables 5.6-2 and 5.6-3. The computed flood-frequency curves at each of the gages being considered in this analysis are provided Appendix E of Tetra Tech (2013d).

#### *5.6.1.2. Maximum Load Following OS-1*

The presence of the Watana Dam at PRM 187.1 will affect flows in the mainstem of the Susitna River downstream of the project site, but flows in the tributaries and the mainstem upstream from the reservoir will not be affected by the dam. The hydrologic analysis for the Maximum Load Following OS-1 scenario therefore only considered the three gages along the mainstem downstream from PRM 187.1 (i.e., Gold Creek, Sunshine, and Susitna Station).

The Project does not permanently add to or divert flows from the river. As a result, the simulated average annual discharge at the three gages under the Maximum Load Following Scenario OS-1 is essentially the same as under pre-Project conditions, ranging from about 9,700 cfs at Gold Creek to about 24,000 cfs at Sunshine and 48,500 cfs at Susitna Station, and the variability from year to year is also approximately the same. Average monthly flow releases under Maximum Load Following Scenario OS-1 are, however, more uniformly distributed throughout the year than under pre-Project conditions (Table 5.6-4). Tributary inflows between the dam and the Three Rivers Confluence are relatively small compared to the mainstem flows; thus, the distribution of average monthly flows at the Gold Creek gage is also relatively uniform. Unlike the smaller upstream tributaries, inflows from the Chulitna and Talkeetna rivers are significant compared to the upstream mainstem flows, which results in significant seasonal variability in the downstream river, even under the Maximum Load Following Scenario OS-1. Monthly flow summaries for the individual gages for each year in are provided in Appendix F of Tetra Tech (2013d).

The annual and monthly flow-duration curves also reflect the more uniform distribution of flows throughout the year under Maximum Load Following Scenario OS-1. Figure 5.6-2 shows the annual flow-duration curve and Appendix G of Tetra Tech (2013d) includes monthly flow-duration curves. The median flow at the Gold Creek gage, for example, increases from about 3,400 cfs under pre-Project conditions to about 8,800 cfs under Maximum Load Following Scenario OS-1, and the 90-percent exceedence flow increases from about 1,200 to 7,200 cfs, while the 10-percent exceedence flow decreases from about 25,300 to 12,300 cfs. Similar magnitude changes occur at the two downstream gages, but the relative change is smaller because of the influence of the tributary inflows.

The flood-frequency analysis for Maximum Load Following Scenario OS-1 was conducted using the simulated annual maximum hourly flows from the HEC-ResSim model. Based on the analysis, the 2-year peak discharge at Gold Creek would decrease to about 23,900 cfs under Maximum Load Following Scenario OS-1, and the 100-year peak discharge would decrease to about 66,400 cfs, reductions of 45 and 28 percent, respectively (Table 5.6-5). Consistent with the mean daily flows, the reduction at the two downstream gages is less significant.

### 5.6.2. Sediment Transport Assessment

Results from the analysis indicate that the total sediment load passing the gages varies significantly from year to year, depending primarily on the total runoff (Tetra Tech 2013a). Watana Dam and Reservoir will trap a significant percentage of the sediment supply to the Middle River. For purposes of this preliminary analysis, it was assumed that the trap efficiency for the silt/clay load will be on the order of 90 percent, and all of the sand and coarser sediment will be trapped. In addition to the effects on sediment supply, the dam will also modify the flow regime in the downstream river in a manner that will affect the transport capacity along the Middle River segment. Because of the nonlinear relationship between discharge and sediment transport rates, the changes in flow regime associated with the Project will result in a general decrease in the capacity of the river to transport sediment in each reach of the segment. The results of this analysis are discussed in study component 4 (Section 5.3) and the average annual sediment load for pre-Project and Maximum Load Following conditions are summarized in previously presented Tables 5.3-1 and 5.3-2.

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

The results of this analysis are detailed in the technical memorandum (Tetra Tech 2013c) filed with FERC in early 2013. The values of S* were computed directly from the results of the sediment loads analysis previously presented in Tables 5.3-1 and 5.3-2 for pre-Project and Maximum Load Following OS-1 conditions. $S^*$ for both sand and gravel loads is about 1 between the Dam site and the Three Rivers Confluence under pre-Project conditions, and is less than 0.2 for sand and 0.1 for gravel in this reach under Maximum Load Following OS-1 conditions. Downstream of the Three Rivers Confluence, pre-Project values of $S^*$ for sand increases to 5.2 for sand and even more dramatically for gravel to 15.6, indicated a much larger supply of sediment primarily from the major tributaries (primarily the Chulitna River) than from the Susitna River. For Maximum Load Following OS1 conditions this sediment supply disparity results in S* for sand of 4.2 and 14.5 for gravel. The similarity in the without and with-dam values could lead to the assumption that sediment impacts may not occur downstream of the Three Rivers Confluence.

Moving downstream to Sunshine gage, however, the $S^*$ for gravel drops to 2.5 for Maximum Load Following OS-1 compared to 5.0 for pre-Project. The results are indicative of the braided, aggradational area at and below the Three Rivers Confluence resulting primarily from the inflows from the Chulitna River. S* for sand remains very consistent between Three Rivers Confluence and Sunshine gage with 5.1 and 4.2 for pre-Project and Maximum Load Following OS-1 conditions. Therefore, the aggradation is predominantly associated with gravel sizes.

In the reach between Sunshine gage and Yentna River Confluence, the values of $S^*$ increase for both sand and gravel and for pre-Project and Maximum Load Following OS-1 conditions. Values of $S^*$ are similar for both conditions downstream of the Yentna River (Susitna Station gage) where Maximum Load Following OS-1 values are greater than 80 percent of pre-Project for both gravel and sand. The pre-Project values upstream of the Yentna River indicate a tendency toward accumulation of gravel in this reach.

For the sand load, an abrupt, but lower magnitude, increase in $S^*$ occurs for both pre-Project and Maximum Load Following OS-1 conditions at the Three Rivers Confluence. Unlike the gravel, values of $S^*$ always remain constant or increase in the downstream direction and the ratio of sediment transport (Maximum Load Following OS-1 conditions divided by pre-Project conditions) is greater than 0.8 for the Susitna River below the Three Rivers Confluence. This indicates that potential impacts related to sand are less significant than for gravel. Sand is almost certainly supply limited in the Middle River Segment, and likely transitions to capacity limited in the reach upstream of the Yentna River.

Values of critical discharge ($Q_{cr}$) were estimated as 25,000, 16,000 and 4,000 cfs for Gold Creek, Sunshine, and Susitna Station gages, respectively (Tetra Tech 2013c). Based on the flow-duration curves presented in Tetra Tech (2013d), the proportion of time flows exceed critical discharge was estimated. For purposes of this analysis, an estimated $Q_{cr}$ value of plus and minus 5,000 cfs was used at the Gold Creek and Sunshine gages to reflect the uncertainty in determining this incipient motion discharge. At the Susitna Station gage, a value of plus and minus 2,000 cfs was used. In the Middle River, $T^*$ is approximately 0.2 for the best-estimate and high and low values of $Q_{cr}$, indicating that bed mobilizing flows under Maximum Load Following OS-1 conditions would only occur for about 20 percent of the duration that they occur under pre-Project conditions. Downstream of the Three Rivers Confluence to Susitna Station, $T^*$ is at or slightly greater than 1.0 for the best- and high estimate of $Q_{cr}$, but could be as much as 1.5 at the Sunshine gage using the lower estimate of $Q_{cr}$.

### 5.6.4. Literature Review on Downstream Effects of Dams

A literature search of the downstream effects of dams on geomorphology has been performed to identify research, observations and case studies with an emphasis on boreal region rivers that experience ice cover over some portion of the year. The references from this search have been compiled in Appendix C as the initial phase of development of a technical memorandum on the topic. A preliminary synthesis of compiled information focuses on dam effects on streamflow, ice-related processes, riparian vegetation, channel stability (e.g., erosion/aggradation), sediment transport and effects of tributaries.

### 5.6.5. Electronic Data

The following data (report and 61-year extended daily flow record) for Study Component 6 are available on the USGS website at http://pubs.usgs.gov/sir/2012/5210/.

- Streamflow Record Extension for Selected Streams in the Susitna River Basin, Alaska (USGS 2012)
  - File name: **Report** PDF
- Extended and Observed Streamflow Records for Water Years 1950–2010 for Selected Streamgages, Susitna River Basin, Alaska
  - File name: **Appendix B** XLSX

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

Results for each task of this study component are presented in this section. Example figures and tables are included. More detailed results can be found in the Stream Flow Assessment (Tetra Tech 2013d), Synthesis of 1980s Aquatic Habitat Information (Tetra Tech 2013e), Mapping of Aquatic Macrohabitat Types at Selected Sites in the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (Tetra Tech 2013f) technical memoranda.

### 5.7.1. Change in River Stage Assessment

This section presents the results of the comparative stage-exceedence analysis for the pre-Project and the Maximum Load Following OS-1 hydrologic conditions at both the Sunshine Gage and the Susitna Station Gage. Note that the stage values presented in the graphs and tables in this section are unique to each gage location. In other words, a 5-foot stage at the Sunshine Gage is not equivalent to a 5-foot stage at the Susitna Station Gage.

Tables 5.7-1 through 5.7-3 present example tabular results of the stage-exceedence analyses of the pre-Project hydrologic condition as compared to those for the Maximum Load Following OS-1 hydrologic condition. Table 5.7-1 includes specific annual stage-exceedence ordinates for both gage locations. Tables 5.7-2 and 5.7-3 include monthly stage-exceedence ordinates for just the Sunshine Gage. Similar tables were developed for the Susitna Station gage and are presented in Tetra Tech (2013d). In each of these tables, the relative change in stage (either positive or negative) for each exceedence percentile is indicated.

Table 5.7-4 provides example results of the statistical analyses of monthly stages calculated for both the pre-Project hydrologic conditions and the Maximum Load Following OS-1 hydrologic conditions at Sunshine Gage. The maximum, median, average and minimum monthly stage values are presented, and the relative change in stage (either positive or negative) for each statistic is indicated. A similar table was developed for the Susitna Station gage and is presented in Tetra Tech (2013d).

At the two gage locations, annual stage-exceedence curves and monthly stage-exceedence curves were developed for both the pre-Project and the Maximum Load Following OS-1 conditions. To allow a direct comparison between the results for the two hydrologic conditions, the stage-exceedence curves were plotted together. The annual stage-exceedence curves for the Sunshine Gage are provided in Figure 5.7-1. The line representing the pre-Project conditions is solid; whereas, the line representing the Maximum Load Following OS-1 conditions is dashed. Figure 5.7-2 illustrates the monthly stage-exceedence curves for the month of May at Sunshine Gage. Appendix J of Tetra Tech (2013d) includes the complete set of plots of the pre-Project and the Maximum Load Following OS-1 annual and monthly stage-exceedence curves for the two locations. Similar figures are presented for the Susitna Station gage in Tetra Tech (2013d).

The results of the stage-exceedence analysis are also presented on representative cross-section plots at each gage location, after first converting river stage (feet) to water-surface elevation (feet, NAVD88). For this presentation, the 90-, 50- and 10-percent pre-Project and Maximum Load Following OS-1 stage-exceedence values were converted to water-surface elevations (see Tetra Tech 2013d) and were overlaid on the representative cross section geometry. Figure 5.7-3 graphically shows the results of the annual stage-exceedence analysis for the Susitna Station gage. Appendix K of Tetra Tech (2013d) includes similar figures showing the results of the monthly stage-exceedence analyses at both gages. This method of presentation provides a visual assessment of the relative changes in water-surface elevation between the pre-Project and the Maximum Load Following OS-1 hydrologic conditions. It also provides a visual assessment of the relationship between the water-surface elevations associated with the range of flows between the 10- and 90-percent stage-exceedence.

Plots of specific hydraulic properties (velocity, hydraulic depth and cross-sectional area) versus discharge were created for the ice-covered discharge measurements as well as the open-water discharge measurements. These plots were developed for only the Susitna River at Sunshine Gage as the hydraulic data (area, width and velocity) for the open-water measurements were not reported at the Susitna River at Susitna Station gage. The plots are included in Tetra Tech (2013d). Independent regression lines were drawn through the ice-covered data points and the open-water data points. These plots were used to evaluate the difference in the hydraulic properties under ice-covered conditions and open-water conditions.

### 5.7.2. Synthesis of the 1980s Aquatic habitat Information

The Stream Flow Assessment technical memorandum (Tetra Tech 2013d) prepared as part of the 2012 studies and filed in Q1 2013 developed average monthly flows, weekly flows, and monthly stage values for various probabilities of exceedence at the Susitna River Sunshine gage for both the pre-Project and Maximum Load Following OS-1 conditions. These flow and stage values were then applied with the log-linear relationships of aquatic macrohabitat type area versus flow developed (Tetra Tech 2013f) to assess potential post-Project effects on habitat areas. The relationships developed were expanded beyond the minimum discharge (13,900 cfs) and maximum discharge (75,200 cfs) used by R&M Consultants and Trihey & Associates (1985a) using the following three assumptions:

1. Wetted surface areas were assumed to be remain at zero if they were zero for the bounding discharge values of 13,900 and 75,200 cfs,
2. Wetted surface areas were assumed to remain constant at the bounding discharge value of 13,900 and 75,200 cfs, if the relationship indicated that wetted surface areas were increasing with decreasing discharge from 21,100 to 13,900 cfs or were increasing with increasing discharge from 59,100 to 75,200 cfs, and
3. Wetted surface areas were assumed to decrease log-linearly for discharge values less than 13,900 cfs and more than 75,200 cfs, if the previous relationship indicated that wetted surface areas were decreasing with decreasing discharge from 21,100 to 13,900 cfs or were decreasing with increasing discharge from 59,100 to 75,200 cfs.

The aquatic macrohabitat type of primary importance to salmon spawning in the Lower River, as identified by R&M Consultants and Trihey & Associates (1985b), was clearwater tributaries. As a result, clearwater tributaries were investigated and described by three aspects to establish pre-Project conditions and evaluate potential post-Project changes. The three aspects included tributary mouth backwater areas during both the open-water period (May through September) and ice-affected period (October through April), the ability of spawning salmon to gain access to tributaries during spawning migration from June through September, and geomorphic stability of the tributary mouth. Potential changes in seasonal discharge patterns associated with the post-Project flows were generalized by R&M Consultants and Trihey & Associates (1985b), and included:

- Tributary Mouth Backwater Area (Holding Area)—Decreased size of backwater areas for migrating fish resting and holding at tributary mouths,
- Tributary Access—Decreased water depth in tributary mouths that may prevent adult salmon access, and
- Tributary Mouth Stability—Decreased morphologic stability for tributary mouths or adjoining side channels that may inhibit tributary access.

Monthly habitat areas were accumulated for the general open-water period of May through September, the salmon spawning period of June through September, and the general ice-affected period of October through April (Tetra Tech 2013e). The relationships derived by R&M Consultants and Trihey & Associates (1985a) were applied for the open-water period only, and the hydraulic conditions used to develop the relationships varies substantially between the open-water and ice-affected periods. Therefore, the winter-period accumulative results should be used for relative comparisons rather than comparison of absolute differences in wetted surface areas between the pre-and post-Project conditions.

Three of the eight sites for which habitat area types versus flow relationships were developed (Tetra Tech 2013f) were selected for comparative analysis with data from R&M Consultants and Trihey & Associates (1985a). The three sites were SC IV-4 (Site 1), Willow Creek (Site 2), and Goose Creek (Site 3). Table 5.7-5 summarizes the potential percent change of habitat type area between the pre- and post-Project conditions for the open-water and ice-affected periods. With respect to tributary mouth area and during the open-water period, the results were mixed between Goose and Willow creeks, with SC IV-4 not having area categorized with the tributary mouth habitat type. During the salmon migration period which overlaps with part of the open-water period, for Goose Creek, the tributary mouth area may decrease by 19 percent from the pre-Project to the post-Project conditions and for Willow Creek the area may decrease by 26 percent from the pre-Project to the post-Project conditions as shown in Figure 5.7-4. During the ice-affected period, Goose Creek did not have tributary mouth habitat, whereas at Willow Creek an increase of 167 percent was indicated from the pre-Project to the post-Project conditions.

Estimated decreases from the pre-Project to the post-Project stages at Caswell Creek and Sheep Creek by R&M Consultants and Trihey & Associates (1985b) and for the Susitna River at Sunshine by Tetra Tech (2013d) yielded similar results. During the last week of June, decreases in stage were predicted as 1.2 feet for Caswell Creek, 1.4 feet for Sheep Creek, and 1.43 feet for the Susitna River at Sunshine. During the last week of August, decreases in stage were predicted as 0.6 feet for Caswell Creek, 0.6 feet for Sheep Creek, and 0.67 feet for the Susitna River at Sunshine. R&M Consultants and Trihey & Associates (1985b) indicated that these decreases in stage would not negatively impact the holding areas of these two tributary mouths. To build upon this work, tributary mouth habitat areas were summed for Willow and Goose creeks for the open-water period and compared for both the pre- and post-Project conditions (Tetra Tech 2013e). Reductions were estimated for both Willow Creek at 26 percent and Goose Creek at 19 percent.

Evaluation of morphologic stability of tributary mouth areas was determined by R&M Consultants and Trihey & Associates (1985b) by comparing aerial photographs from 1951 and 1983 for relative change, and did not include a detailed geomorphic assessment associating impacts of main channel discharge. Results of this evaluation indicated that the post-Project conditions would not decrease stability for the sites inspected and that stability would improve at five sites. Furthering this assessment, Tetra Tech (2013f) evaluated change between the 1983 and 2012 aerial photographs. For Willow Creek, the tributary mouth has remained relatively stable between 1983 and 2012, but the habitat area types connecting the tributary mouth to the main channel Susitna River changed from main channel in 1983 to secondary side channel in 2012 due to migration of the main channel. The tributary mouth of Goose Creek was rated as having fair morphologic stability by R&M Consultants and Trihey & Associates (1985b), indicating that changes were observed between the compared 1951 and 1983 aerial photographs. The Study Team's further evaluation of changes at the Goose Creek tributary mouth by comparing the 1983 and 2012 aerial photographs indicates that significant changes occurred due to main channel migration (Tetra Tech 2013f). Main channel migration has the potential to significantly change the characteristics of habitat areas, including tributary mouth area, within the study sites (Tetra Tech 2013e).

### 5.7.3. 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 approximately 36,600-cfs flow at Sunshine Gage to study in 2012. 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). The sites selected were all determined to be relatively stable. Quantitative comparison of the aquatic macrohabitat types mapped in the 1980s and for current conditions is presented in Section 5.7.4 to further assess the stability of these sites over the approximately 30-year period.

### 5.7.4. Aerial Photography Analysis, Riverine Habitat Study Sites (PRM 32 to PRM 102.4)

The 1983 aerial photographs used in this analysis of the Lower River were flown between PRM 0 and PRM 102 (RM 0 and RM 99) at 36,600 cfs, which includes Sites 1 through 5. The 2012 aerials were flown between PRM 33.5 and PRM 69 (RM 29.5 and RM 65), covering Sites 1 and 2 at 54,100 cfs; between PRM 69 and PRM 78 (RM 65 and RM 74), covering Site 3 at 47,400 cfs; and between PRM 78 and PRM 102 (RM 74 and RM 98), covering Sites 4 and 5 at 37,900 cfs. Summary tables and figures showing the areas for each habitat site can be found in the aerial photography analysis technical memorandum (Tetra Tech 2013f). Examples of aquatic macrohabitat type delineations for Site 2 in 1983 and in 2012 are shown in Figures 5.7-5 and 5.7-6, respectively. A master table of delineated habitat type areas for Sites 1 through 5 in the Lower River in 1983 and 2012 can be found in Table 5.7-6 for main channel and side channel habitat types and Table 5.7-7 for tributary and side slough habitat types. Areas from the 2012 aerials were scaled down to the 36,600-cfs level using the procedure identified in Section 4.7.2.4. Example bar charts for Site 2, comparing areas from the original 1980s study (R&M Consultants, Inc. and Trihey & Associates, 1985a), the digitized 1983 areas, and the scaled 2012 delineations are shown in Figures 5.7-7 and 5.7-8.

There were no uniform trends in area change throughout all of the Lower River habitat sites. For example, Clearwater/Side Slough habitat area decreased from 1983 to 2012 in Sites 1 and 4, but increased in Sites 2, 3, and 5. In the case of Site 3, and Clearwater/Side Slough habitat area increased from 947,000 sq. ft. in 1983 to 6,983,000 sq. ft. in 2012. Tributary habitat area increased in Sites 2 and 5, and decreased in Sites 3 and 4. In the case of Site 4, however, the large increase in Tributary Mouth area (1983 area = 21,000 sq. ft., 2012 area = 291,000 sq. ft.) may account for the change in Tributary area. More detailed results can be found in the aerial photography analysis technical memorandum (Tetra Tech 2013f).

### 5.7.5. Additional Aerial Photography Analysis, Riverine Habitat Study Sites (PRM 32 to PRM 102.4)

The decision was made to not pursue additional analysis of aquatic habitat versus flow relationships using analysis of aerial photography. This decision was made in coordination with the Fish and Aquatics Instream Flow Study (Study 8.5), Riparian Instream Flow Study (Study 8.6), Ice Processes in the Susitna River Study (Study 7.6), Characterization and Mapping of Aquatic Habitats Study (Study 9.9), and licensing participants. This task was identified as an optional task in the RSP. It is noted that geomorphic features have been mapped for the entire Lower River from PRM 102.3 to PRM 3.3 for both the 1980s and current conditions and are in the process of being mapped for 1950s using a set of aerials acquired in Q3 2013.

### 5.7.6. Electronic Data

The following data produced in 2013 for Study Component 7 are available on the GINA website at http://gis.suhydro.org/reports/isr:

- 1980s Lower River Mapped Aquatic Macrohabitat
  - File name: ISR_6_5_GEO_1983_Lower_AqMHab.shp
- 2012 Lower River Mapped Aquatic Macrohabitat
  - File name: ISR_6_5_GEO_2012_Lower_AqMHab.shp

## 5.8. Study Component: Reservoir Geomorphology

### 5.8.1. Reservoir Trap Efficiency and Sediment Accumulation Rates

Inflowing sediment loads from the mainstem Susitna River at the Watana Dam were estimated under pre-Project conditions using bed- and suspended-load measurements collected at Gold Creek (Tetra Tech 2013a). For an average annual water discharge of 5,803,000 acre-feet (Tetra Tech 2013a), the combined average annual wash load (silt and clay general size characterization) is 1,684,000 tons and the total bed-material load (sand and gravel general size characterization) is 1,252,000 tons. The input to the Brune (1953) method for estimating long-term, average annual trap efficiency and the resulting estimated trap efficiencies are provided in Table 5.8-1. Regarding the reservoir capacity, it is noted that this volume assumes a filled normal pool, which seems unlikely at the start of the spring freshet; thus, the trap efficiencies may be conservatively high. These trap efficiency estimates indicate that over the reservoir life, it is expected that 100 percent of the bed-material load (generally sand, gravel, and cobble) will be trapped in the reservoir, but 6 percent of the wash load (generally silt and clay) will pass through the reservoir to the Middle Susitna River Segment. Applying these estimates to the average annual sediment loading to the reservoir, the average annual sediment accumulation rates are estimated as 1,252,000 tons of bed material and 1,583,000 tons of wash load, producing a total average annual sediment accumulation rate of 2,835,000 tons. This total sediment accumulation rate corresponds to approximately 96 percent of the total average annual inflowing sediment load, which is consistent with the median trap efficiency estimate.

Using estimated initial unit weights of 97 pounds per cubic foot (pcf) for bed material and 48 pcf for wash load (assuming 50-percent silt (70 pcf) and 50-percent clay (26 pcf)), the average annual sediment accumulation as a percentage of reservoir capacity is 0.04 percent. This indicates that the longevity of the Watana Reservoir is approximately 2,500 years. Considering only the dead storage volume of 1,790,872 acre-feet, the estimated sediment accumulation rate would take approximately 850 years to fill this storage. Both of these longevity estimates are biased low because they do not account for consolidation of the silt and clay over the reservoir life. If a consolidated unit weight of 72.8 pcf (R&M Consultants, Inc. 1982) is used, the longevity of the reservoir increases to approximately 3,200 years and the longevity of the dead storage increases to about 1,100 years. These preliminary estimates of reservoir trap efficiency will be refined to address uncertainty.

Estimates of trap efficiency, sediment accumulation rates, and reservoir longevity based on the Einstein (1965) and Li and Shen (1975) methods (Section 4.8.2.1) have not yet been completed because these methods require input of general reservoir hydraulics (depth and velocity) that have not yet been calculated. Reservoir depth and velocity will be estimated by flow continuity (i.e., flow rate equals flow area multiplied by flow velocity) at representative cross sections derived from topographic mapping using inflows and reservoir water-surface elevations provided by the Reservoir Operation Model (ISR Study 8.5 Section 8.5.5.3). These calculations will be performed in in the next study year. The EFDC modeling results that will ultimately quantify the reservoir trapping will be completed during the next year of study.

### 5.8.2. Delta Formation

Due to access limitations during the 2013 field season, reconnaissance of the potential tributaries where deltas may form was postponed until the next year of study. Coordination with other studies has been ongoing (Study 9.12 Fish Passage Barriers Middle and Upper River; Study 8.5 Mainstem Open-water Flow Routing; Study 9.5 Fish Distribution and Abundance Upper River). Contributing drainage areas, watershed slopes, and slopes of the primary tributary channels are being developed as part of Study 8.5. These factors will be used to screen tributaries based on the premise that larger drainage areas with greater land slopes have greater potential to generate sediment, and drainage areas with steeper channels have greater capacity to transport sediment. Fish passage barriers have been identified as a part of Study 9.12. Tributaries without barriers or with barriers that are a long distance upstream of the normal reservoir pool elevation could be more substantially impacted should deltas form at the tributary mouth. Fish presence and abundance data have been collected as part of Study 9.5. The presence of Chinook salmon is of primary interest, so tributaries that are used by Chinook salmon will be prioritized for consideration of potential fish passage impacts caused by delta formation.

Long-term flow series will be developed for the selected tributaries as part of Study 8.5 Mainstem Open-water Flow Routing. The flow series are needed for use with the bed-material sediment-rating curves developed in this study to characterize sediment loading to tributary mouths where deltas may form.

### 5.8.3. Reservoir Erosion

The reservoir erosion assessment will take place during the next year of study and results will be reported in the USR.

### 5.8.4. Bank and Boat Wave Erosion downstream of Watana Dam

Field observations of bank stratigraphy throughout the Middle River and Lower River indicated that the banks are composite (Thorne and Tovey, 1981) with a coarse, gravel-cobble (with some boulders) armored toe and a finer, sand dominated upper portion (Figure 5.8.1). Armoring of the middle and lower bank regions results from the combined effects of fluvial and ice processes (Prowse, 1995; MacKay et al. 1974). Over the course of the 2013 open-water field season between July and the end of September, when flows at the Gold Creek Gage ranged from about 8,000 to 48,000 cfs, very little, or no bank erosion was observed as a result of fluvial or boat wake activity. Water-surface elevations for the range of observed flows did not overtop the mid-bank or toe armor and the bank materials are so coarse that excess pore-water pressures would not develop even with fairly rapid stage changes.

The analysis results are not available for this task within the Reservoir Geomorphology Study component as the analysis will be conducted in the next year of study. The analysis relies on both data collected and hydraulic modeling results from the Fluvial Geomorphology Modeling Study below Watana Dam Study (Study 6.6).

### 5.8.5. Electronic Data

No electronic data are presented for Study Component 8 on the GINA website.

## 5.9. Study Component: Large Woody Debris

The large woody debris analysis completed in 2013 included an inventory of wood from recent and historical aerial photographs and a field inventory of wood in 16 LWD sample areas in the Middle and Lower Susitna River to determine wood loading, input mechanisms, input and transport frequency, species, and function in the river. The aerial photograph and field inventory of LWD in the remaining 13 LWD sample areas will be conducted during the next year of study.

### 5.9.1. LWD Inventory from Aerial Photographs

LWD was digitized from 1983 and 2012 aerial photographs in portions of the Middle and Lower Susitna River.

#### *5.9.1.1. 2012 Aerial Photographs*

The 2012 digital aerial photographs used for digitizing LWD were taken under low-flow conditions, with flows of 12,900 cfs in the Middle River (flow at Gold Creek Gage, photos of PRM 102-143.6) and 38,200 cfs in the Lower River (flow at Sunshine gage, photos of PRM 75-102). There were deep shadows in some areas of the channel on the 2012 aerial photographs that made differentiation of LWD and log jams difficult, particularly along southern shorelines where tall trees or topography created shadows.

In the Lower River areas inventoried (PRM 75-102), a total of 981 individual pieces of LWD and 147 log jams were observed (Table 5.9-1). The majority of wood was located in three channel positions (1) on the side of unvegetated bars, (2) at the apex of bars/islands, and (3) on banks adjacent to vegetated areas. Some wood was also observed in the middle of wetted channels; the numerous shallow bars and channels in the braided sections of the Lower River allowed LWD to become lodged throughout the river system.

In the Middle River areas inventoried (PRM 102-143.6), 977 individual pieces of LWD and 57 log jams were digitized (Table 5.9-1). The majority of wood was located in three channel positions (1) on banks adjacent to vegetated areas, (2) on the sides of unvegetated bars, and (3) at the apex of bars. Some wood was also lodged in the middle of channels (mainstem and side channels) and at the head of side channels or spanning side channels. Twenty-three beaver dams/lodges were digitized, all in side slough or upland slough geomorphic features.

#### *5.9.1.2. 1983 Aerial Photographs*

A set of 1983 aerial photographs that was taken under low-flow conditions (16,000 cfs at Gold Creek gage/36,600 cfs at Sunshine gage) was used to evaluate historical LWD within the 2013 LWD sample areas. In the Lower River (downstream of PRM 102), the channel had changed so much that the 1983 river characteristics in the areas where the 2013 samples were taken were not representative of the same geomorphic/habitat types. Therefore, LWD was not assessed in the Lower River on the 1983 aerials.

A total of 530 individual pieces of wood and 18 log jams were digitized on the 1983 aerials within the 11 Middle River 2013 LWD sample areas. These data are discussed further in Section 5.9.2.3.

### 5.9.2. LWD Field Inventory

A total of 1,590 individual pieces of LWD over 20 feet in length and 306 log jams (containing 2,716 pieces of LWD) were inventoried within 16 LWD sample areas in 2013 (Appendix D.3).

#### *5.9.2.1. Individual Pieces of LWD*

##### *5.9.2.1.1. Wood Species and Size Characteristics*

The majority (58 percent) of the individual pieces of wood were balsam poplar (*Populusbalsamifera*), with 12-percent white spruce (*Piceaglauca*), 13-percent paper birch (*Betulaneoalaska*formerly*papyrifera*), 8-percent alder (*Alnus*sp.), and 9-percent of unknown species (Table 5.9-2). LWD distribution among species varied by sample area (Figure 5.9-1).

All wood over 20 feet in length was inventoried; average length of wood varied by species, diameter, and how recently the tree entered the channel (referred to as wood freshness in graphs and tables). In general, wood that still had leaves or twigs attached were the longest; wood that had no leaves or twigs left or was starting to decay was shorter (Table 5.9-3). Balsam poplar was the longest (average 54 feet), with white spruce and paper birch averaging 42 and 40 feet long, respectively. Alder was the shortest, with an average length of 25 feet. Half (50 percent) of wood was 12 to 24 inches in diameter (dbh, diameter breast height), nearly 30 percent was 6 to 12 inches, with 9 to 10 percent in the less than 6-inch diameter and 24- to 36-inch diameter classes, respectively. The distribution of wood by diameter class also varied by sample area (Figure 5.9-2). Two percent of the wood were over 36 inches in diameter; these occurred primarily in LWD sample areas between PRM 128 and PRM 104, potentially reflecting upon source areas for these mature balsam poplar trees.

Over half (54 percent) of the individual logs had root wads attached (defined as root balls over 3 feet in diameter). Mature balsam poplar had very large root wads, up to 8 to 10 feet in diameter that provided enough hydraulic resistance to make local scour holes several feet deep.

##### *5.9.2.1.2. Wood Location and Function*

The channel position of each piece of LWD was noted to determine where wood accumulates in the river system (Figure 5.9-3). The following categories were used:

- Bank adjacent (protruding into the channel with one end within the vegetated bank)—53 percent of wood, with particularly high amounts in sample areas dominated by main channels.
- Side of bar—25 percent of wood.
- Downstream end of bar (located at the middle or downstream side of an unvegetated bar)—4 percent of wood
- Apex bar (located at the head of a vegetated or unvegetated bar or island)—8 percent of wood.
- Middle of channel—10 percent of LWD pieces.
- Head of side channel—less than 1 percent of wood.
- Spanning a channel—less than 1 percent of wood.

Less than 40 percent of the pieces of wood were within the wetted channel at the time of the surveys; the remainder was within the bankfull channel. Sample areas with a larger proportion of straight, main channel areas had fewer trees within the wetted channel.

The geomorphic/habitat function of the majority (68 percent) of single pieces of wood was unclear, meaning that no specific geomorphic or fish/aquatic/riparian habitat function was obvious. Twenty-two percent of the wood provided obvious aquatic habitat (e.g., cover or hiding habitat) and 9 percent caused scour pools to form around root wads. Less than 1 percent of wood provided bank protection, caused bars to form, or controlled side-channel inlets.

##### *5.9.2.1.3. Wood Input Mechanisms*

Each piece of wood inventoried was assigned an input mechanism: bank erosion/masswasting, ice processes, wind-throw, beaver felled, or unknown if the input mechanism was unclear (Figure 5.9-4). Many (47 percent) of trees had unknown input mechanisms; as logs are transported down the river and as they decay, input causes are harder to determine. Of the logs with input mechanisms assigned, bank erosion/masswasting was the dominant source of wood (30 percent of all logs) followed by ice processes (13 percent). Few trees entered the river due to wind-throw (5 percent) or felling by beavers (4 percent).

##### *5.9.2.1.4. Wood Input Frequency*

The field inventory of wood showed that many of the pieces of wood observed on the 2012 aerial photographs had moved by the time of the 2013 field inventory, and new wood had moved into the sample areas (see maps in Appendix D.3). The presence or absence of leaves, twigs, and branches was noted during the field inventory to help determine how many of the pieces of wood had been delivered recently to the stream channel. Thirty-one percent of the wood was fresh, with leaves (23 percent) or twigs (8 percent) still attached indicating that the trees had entered the channel within the past year and had not been transported very far (Figure 5.9-5). Sixteen percent had branches still attached, and just over half (53 percent) were just boles with no leaves, twigs or branches, indicating either decaying logs or trees that had been transported long distances. The state of decay and condition of bark on each log was also noted to assist with further analysis when the full dataset is available next year.

Observations in the channel on August 21, 2013, during the rising limb of a high-flow event suggested that small woody debris began to move between 10 and 11 AM in Focus Area 128, corresponding to a flow of approximately 35,000 cfs at the Gold Creek gage. Large trees were observed to begin moving at approximately 3 PM on the same day, corresponding to a flow of approximately 42,000 cfs at the Gold Creek gage. Boat operators who were on the river the following day (August 22) on the descending limb of the hydrograph (overnight peak of 49,100 cfs) observed little debris in the river between Gold Creek and PRM 115 suggesting that most of the available loose wood/debris had moved on the previous day and overnight. Local boat operators reported that these observations were consistent with their experience; small debris starts to move at flows of approximately 30,000 cfs (Gold Creek gage) and larger trees start to move at approximately 40,000 cfs.

Several pieces of LWD that had been inventoried prior to August were missing from LWD sample areas in Focus Area 104, Focus Area 115, and PRM 135-136 during September visits to the areas, and several new pieces were noted, primarily on shallow bar features, indicating that wood on these features is relatively mobile.

#### *5.9.2.2. Log Jams*

A total of 306 log jams, defined as accumulations with three or more pieces of wood over 20 feet in length, were inventoried in the 2013 LWD sample areas. The log jams ranged in volume from 11 to 43,000 cubic yards and contained from 3to 90 pieces of visible wood (the largest jams contained additional pieces of wood hidden within the jam that were not included in the counts). A total of 2,716 pieces of wood, 911 with attached root wads, were counted in the jams. Some jams were open framework, with a few touching pieces of wood spread over a large area, and some were dense with many pieces of smaller, racked wood. Eighteen of the jams were beaver dams or lodges (labeled biogeomorphic).

Log jams, like the individual pieces of wood described in the previous sections, occurred most frequently along the banks (bank adjacent) and on the sides of unvegetated bars (Figure 5.9-6). Many jams also occurred at the apex of bars/islands with relatively few jams in the middle of channels or spanning channels.

Half of the jams intersected the wetted channel at the time of the inventory. The log jams formed scour pools (28 percent) and provided aquatic habitat (24 percent). Forty-one percent of the jams were pinned against boulders or live trees, 25 percent were stabilized by having parts of key members buried in sediment, and 34 percent of the jams were classified as unstable.

#### *5.9.2.3. Comparison of Aerial Photograph and Field Inventory*

The number and location of pieces of LWD and log jams was compared between the 1983 aerial photographs, 2012 aerial photographs, and 2013 field inventory (Appendix D.3). Differences among the three datasets are the result of movement of wood between sample periods, changes to channel morphology, and/or aerial photograph limitations. Limitations to the aerial photograph inventory of LWD included not being able to discern wood due to shadows and tree cover in some areas of the river, photo resolution on the historical photos, and difficulty determining if logs had root wads attached due to the 1-foot pixel resolution of current photos. Table 5.9-4 shows the comparison of the number of pieces of LWD and log jams counted within the 2013 LWD sample areas (note that wood was not inventoried in the Lower River on the 1983 photos due to major changes in channel configuration within the sample areas in the Lower River).

In the Lower River, there were fewer individual pieces of wood and log jams on the 2012 aerials than found during the 2013 field inventory, and there were also substantial changes within individual sample areas, likely due to movement of wood between sample periods and the greater ability to determine if logs or jams were present during field inventories.

In the Middle River, more individual pieces of LWD and log jams were inventoried on the 1983 than the 2012 aerial photographs over all, and there were substantial differences within individual sample areas. These differences were likely due to wood movement and fewer shadows on the 1983 aerial photographs. Many more individual pieces of wood and log jams were found in the 2013 field inventory than either of the aerial photograph series; some of the difference was due to wood being obscured by shadows and tree cover on the aerial photographs, but many of the pieces of wood also moved during high flows and ice breakup between 2012 and 2013 as seen on the maps in Appendix D.3.

### 5.9.3. Electronic Data

The following data produced in 2013 for Study Component 9 are available on the GINA website at http://gis.suhydro.org/reports/isr:

- 2013 Large Woody Debris Sample Area shapefile
  - File name: ISR_6_5_GEO_2013_LWD_SampAreas.shp
- 2013 Large Woody Debris Field Inventory Shapefile
  - File name: ISR_6_5_GEO_2013_LWD_Field.shp
- 2013 Log Jam Field Inventory
  - File name: ISR_6_5_GEO_2013_Log_Jam_Field.shp

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

The assessments of the geomorphology of stream crossings along transmission lines and access alignments will take place in the second year of study and results will be provided in the USR.

### 5.10.1. Electronic Data

No electronic data are presented for Study Component 10 on the GINA website.

## 5.11. Study Component: Integration of Fluvial Geomorphology Modeling below Watana Dam Study with the Geomorphology Study

The current results for this study component relate to results of study components 1 (Delineate Geomorphically Similar (Homogeneous) Reaches and Characterize the Geomorphology of the Susitna River), 2 (Bed load 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), and 3 (Sediment Supply and Transport Middle and Lower Susitna River segments). The other study products listed in Section 4.11.3 not covered by these study components will become available as the study progresses.

These results were used to establish cross section locations and reach boundaries for the 1-D Bed Evolution Model and roughness boundaries for the channel and overbank surfaces for both 1-D and 2-D Bed Evolution models. The results will be used to establish sediment input for the 1-D and 2-D Bed Evolution models. As the modeling progresses, these results and additional study products in section 4.11.3 will be used 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. For example, the process models that describe the formation and maintenance of lateral features (previously presented Figure 5.1-7) and floodplain features (previously presented Figure 5.1-5) will be used as a starting point for assessing the reasonableness of the 1-D and 2-D Bed Evolution model results and whether adjustments to the numerical or conceptual models are required.

### 5.11.1. Electronic Data

No electronic data are presented for Study Component 11 on the GINA website.

# 6. DISCUSSION

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

A significant portion of the effort associated with this study component was completed in 2012 and 2013. The 2012 effort was reported on in a technical memorandum (Tetra Tech 2013b) and included the completion of the first task, development of the geomorphic reach classification system and much of the second task, the geomorphic delineation. The third task, the geomorphic characterization of the Susitna River, has also seen considerable work effort performed in 2013 with the effort being documented in the ISR.

### 6.1.1. Identification and Development of Geomorphic Classification System

The geomorphic reach classification system has been developed and was presented in a technical memorandum (Tetra Tech 2013b) and was summarized in section 5.1.1. No modifications to the classification system are anticipated.

### 6.1.2. Geomorphic Reach Delineation

The geomorphic reach delineation has been performed for all three Susitna River segments. Refinements to the parameters that describe the reaches will be made as results of the field data collection efforts become available.

### 6.1.3. Geomorphic Characterization of the Susitna River

#### *6.1.3.1. Surficial Geology*

Previous field verification was conducted for the bedrock and lateral constraint mapping by helicopter in 2013 for all reaches. Additional field verification will be performed "on the ground" during the next year of study in reaches MR-1, MR-2, and MR-3. Additional updates to the mapping will be made throughout the system as observations are made during execution of other field work. Review of the areas covered by 2011 Mat-Su Borough topography on major tributaries away from the main channel will be performed to identify additional mass wasting that may be contributing large sediment loads.

#### *6.1.3.2. Geomorphic Surfaces and Processes*

##### *6.1.3.2.1. Adequacy of Data Collected to Date*

Data collected in the 7FAs in the Middle River that were used to support the geomorphic mapping have led to the development of a reasonably robust classification of the geomorphic surfaces in general. The heights of the individual geomorphic surfaces were determined in relation to a local water-surface datum at the time of the data collection. The heights were converted to elevations by reference to a single stage-discharge rating curve for each FA using the daily discharge recorded at the Gold Creek gage. The stage-discharge rating curve for each FA was developed from a preliminary open water flow routing model (R2 et al. 2013). The resulting estimated recurrence intervals for overtopping of the identified geomorphic surfaces are highly variable which could be the result of the combined effects of the preliminary nature of the hydraulics, the use of a single rating curve located in the middle of the FA to represent the entire FA, as well as the naturally occurring topographic variation, imprecise measurements or to misclassification of the surfaces in the field. The use of indexed LiDAR-based topography, and calibrated 1-D and 2-D Bed Evolution models (Study 6.6) will enable refinement of the geomorphic mapping and the frequency of overtopping of the individual surfaces. Field verification of mapping units will be required in the extended GAAs in the areas outside the FA boundaries where the bulk of the height data were collected.

During the 2013 field season geomorphic data were not collected at the 3 FAs located upstream of PRM 146 because of lack of land access. These included FA-151 Portage Creek (MR-5), FA-173 Stephan Lake Complex (MR-2) and FA-184 Watana Dam (MR-1). Provided that access can be secured, geomorphic surface identification, vegetation associations as well as bank heights will be included in the geomorphic mapping. Site boundary extensions beyond those currently identified for the FAs may be required to encompass all of the geomorphic processes within a GAA.

During the 2013 field season no geomorphic data were collected in the 6 reaches of the Upper River. Aerial reconnaissance of the Upper River indicated on the basis of observed landforms that in the wider valley reaches downstream of the Oshetna River confluence (UR-4 though UR-6) similar geomorphic processes to those observed in the Middle River were occurring. However, very few islands and very limited floodplain development were observed in the highly sinuous, flat gradient and bedrock and glacial till constrained meandering reach between the Oshetna and Maclaren River confluences (UR-1 through UR-3). However, large, low-relief sand and gravel bars were observed in these reaches during aerial reconnaissance at low-flow conditions in the early fall, which suggests that the sediment transport and supply in these reaches may be in equilibrium. Geomorphic evaluation of the processes operating in these reaches will assist in establishing the existing sediment load and sediment caliber delivered to the Middle River and the likely sediment supply to the reservoir.

Limited geomorphic data collection was carried out in the 6 reaches of the Lower River. Aerial reconnaissance and some ground-based observations suggest that the geomorphology of the Lower River is less affected by ice processes. Clearly ice jams form in the Lower River (HDR Alaska, Inc. 2013a; HDR Alaska, Inc. 2013b) but because of the overall widths of the multiple channels, regardless of whether they are very dynamic bar-braids or island-braids (LR-1 through LR-4) or relatively stable anabranches in the anastomosed reaches (LR-2 and LR-3) (Nanson and Knighton 1996; Knighton 1998) there is unlikely to be much backwater created by ice jams nor are there likely to be major flood surges related to ice dam failure. Ice processes may be involved in localized channel avulsions and floodplain dissection in the anastomosed reaches (MacKay et al. 1974; Smith; Nanson and Knighton 1996). Consequently it is more likely that the stage-discharge-frequency of inundation relationships for the floodplains and islands in the Lower River will more closely match those reported for alluvial rivers (Leopold and Wolman 1957; Leopold et al. 1964; Williams 1978; Hupp and Osterkamp 1985; Hupp and Osterkamp 1986). Stage-discharge –frequency of inundation relationships for the floodplain and vegetated islands will be developed for the individual reaches based on overbank topography and the output from 1-D hydraulic modeling (Study 6.6). Lateral stability and the rate of turnover of vegetated islands and floodplains in both the anastomosed and island braided reaches will be assessed from a combination of time-sequential aerial photograph comparisons (Tetra Tech 2013g) that provide a roughly 60 year timeframe between the 1950s and the present, field based-assessments of vegetation ages (Study 8.6) and field-based observations of erosional processes. In the delta reach (LR-6), aerial reconnaissance suggests that sand splay deposits resulting from overbank flows are common and are functionally responsible for natural levee formation along the distributary channels and riparian plant establishment and succession. Analysis of overbank topography, time-sequential aerial photography and mapping of the distribution and ages of riparian plants will be used to assess the dynamics of the delta.

#### *6.1.3.2.2. Summary of Findings to-date*

The geomorphic characterization and surface mapping in the Middle River that has been based on observations of the Middle River in general and detailed data collection and mapping in the FAs and extended GAAs, has resulted in a number of findings that will be important in assessing the Project impacts on the geomorphology of the Middle River. The primary findings include:

1. Development of a robust geomorphic surfaces classification that incorporates the evolutionary development of vegetated island and floodplain surfaces.

2. Development of a conceptual geomorphic model that describes the evolution of channel types over time and incorporates the role of lateral weirs (berms) that control the hydraulic connections and bed-material flux between the main channel (MC) and lower order channels (SC, SS, US).

3. Recognition of the role of geologic and geomorphically-controlled constrictions of the valley floor that form the downstream controls for the alluvial deposits that create the geomorphic surfaces within the GAAs and FAs. The valley floor constrictions as well as the channels between the vegetated islands are also preferred locations for ice-jam formation during ice break-up.

4. Speculation on the role of Little Ice Age glaciation on the formation of the Holocene-age terraces within the Middle River and conclusion that based on geomorphic and stratigraphic evidence that the Middle River is vertically stable, which is supported by a comparison of 1982 and 2012 thalweg elevations.

5. Recognition that the rates of geomorphic change within the Middle River are relatively slow based on comparison of time-sequential aerial photography and the minimum ages of geomorphic surfaces provided by dendrochronology which suggests that the Middle River may be relatively insensitive (sensu Schumm 1991) to changes in the driving forces.

6. Recognition that the recurrence interval of open-water flooding of geomorphic surfaces is abnormally high in comparison to other fluvial systems and that processes other than fluvial ones must be involved in both vertical construction and flooding of the surfaces at a frequency that supports the riparian ecosystem.

7. Recognition of the role of ice processes as both constructive and destructive geomorphic agents within the alluvial reaches. Ice-dam induced flooding may be responsible for both sedimentation and flooding of geomorphic surfaces at a frequency that supports the ecologic processes. Ice processes appear to be important in causing channel avulsions and dissection of older geomorphic surfaces where the tree density is low, as well as retarding vegetation succession on younger, lower elevation surfaces.

## 6.2. Study Component: Bed Load 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

Much of the effort associated with this study component was conducted in 2012 and reported on in the Technical Memorandum Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a). This 2012 technical memorandum utilized historical sediment transport measurements and the extended USGS hydrologic record to empirically characterize the Susitna River sediment supply and transport conditions. The collection of the data described in this study component supplements sediment transport data collected in the 1980s.

## 6.2.1. Adequacy of Available Data

The USGS has completed its sediment transport measurements for 2013. These data will be available for support of the Geomorphology Studies in early 2014. The USGS will continue to collect sediment measurements in next year of study. If the comparison performed in ISR Study 6.5 Section 4.2 indicates a shift in the sediment transport rating curves from the 1980s to present sediment transport conditions, the data will be used to revise the sediment-rating curves and sediment balance presented in the Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a). As the downstream extent of the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6) was extended below Sunshine, sediment transport measurements at Susitna Station and Sunshine were added. Sediment transport measurements on the Talkeetna were added to refine the analysis of the potential Project effects in the Three Rivers Confluence area and downstream to Sunshine. In 2013, it was decided to collect a third year of sediment transport measurements. The efforts were added to ensure the adequacy of the sediment transport data to meet support the Geomorphology Study (Study 6.5) and the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6)

## 6.2.2. Discussion of Results

The plots of the 2012 data are generally consistent with the historical sediment-rating curves. At the Chulitna River below Canyon near Talkeetna (USGS Gage No. 15292410), the 2012 bed load sand-and-gravel data fell below the historical rating curves. The 2012 Chulitna data appear to fall in the lower range of the 1980s data. For initial model development, the 1980s-based rating curves will still be applied for all locations. When the additional data set is available from 2013, these data will be added to the plots and the potential need to shift a specific rating curve will be reevaluated. The process will again be repeated in the next year of study as additional data becomes available.

In 2013, based on review of the 1980s sediment transport data, including the information previously presented in Table 4.2-1, 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 was conducted in 2013. This allowed for the direct determination of the sediment balance at the Three Rivers Confluence rather than assuming the load from the Talkeetna was the difference between the sum of the Susitna near Talkeetna and the Chulitna below Canyon and the downstream load of the Susitna River at Sunshine. This supports a 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).

Also, in Q2 2013, the decision was made to extend the 1-D Bed Evolution Model from below Sunshine Station (PRM 87.9) to just below Susitna Station (PRM 29.9). The modeling of the additional 58- mile length of the Lower River requires that the 1980s data for the Susitna River at Susitna Station and the Yentna River near Susitna Station be applied to support the modeling effort. Therefore, the collection of current data was undertaken in 2013 to support assessment of the applicability of the 1980s data to current conditions at these two locations, and if necessary, subsequent adjustment of the 1980s-based sediment-rating curves.

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

Much of the effort associated with the first subsection, Middle and Lower River sediment balance, was conducted in 2012 and reported on in Tetra Tech (2013a). As discussed in Section 4.3.2, changes in the relative sediment balance will help provide an initial basis for assessing the potential for changes to the sediment balance in the Middle and Lower Susitna River Segments, and the associated changes to geomorphology, because it will permit quantification of the magnitude in the reduction of sediment supply below the dam. The information on bed mobilization and effective discharge also provide further understanding of the Susitna River system and potential Project effect on key processes that help govern the morphology. As such, this information will help guide and interpret the modeling efforts conducted in Study 6.6, Fluvial Geomorphology Modeling below Watana Dam.

To facilitate this discussion of sediment balance, the Middle and Lower River segments are discussed together.

### 6.3.1. Initial Sediment Balance Middle and Lower Susitna River Segments

The effect of the Dam on the sediment loads in the Middle and Lower River segments was discussed in Section 6.3.1 of Tetra Tech (2013a) for the silt/clay, sand, and gravel components. It also discussed the sediment balance between supply and transport capacity of the loads for the Three Rivers Confluence to Sunshine portion and the Sunshine to Susitna Station. The Middle River reach from Watana Dam site to Gold Creek is discussed in the following paragraph.

The sediment-load analyses presented in Section 5.3 provide a basis for development of a preliminary sediment balance for the Middle and Lower Rivers. As discussed above, the dam would likely cut off on the order of 90 percent of the silt/clay supply and essentially all of the sand and gravel supply to the head of the Middle River. The effects on all components of the sediment load would diminish in the downstream direction due to contributions from the tributaries and entrainment of material that is currently stored in the channel.

At the lower end of the Middle River segment, the 84-percent reduction (1.8 to 0.29 million tons/year) in the silt/clay supply (Figure 6.3-1) and decreased frequency of floodplain inundation will reduce the amount of floodplain sedimentation. The sand portion is most likely supply-limited in the Middle River and in approximate sediment balance. Under Maximum Load

Following OS-1 conditions the average annual sand load at Gold Creek, would decrease by 85 percent (1.41 to 0.21 million tons/year) and remain supply-limited (Figure 6.3-2). Based on the gravel-transport curves, the unit gravel load at Gold Creek near Talkeetna is about 11 tons/mi$^2$/year. Assuming that the unit yields are similar, the average annual gravel load at the dam site is about 56,000 tons under pre-Project conditions and the gravel supply from the ungaged tributaries is about 11,000 tons (Figure 6.3-3).

The silt/clay load is carried almost exclusively in suspension. Considering the estimated contributions from the tributaries between the dam and the Three Rivers Confluence, the silt/clay load at the lower end of the Middle River would be only about 16 percent of the pre-Project loads (Figure 6.3-1). The effects of the dam on the silt/clay load below Three Rivers Confluence diminish significantly due to the large contributions from the Chulitna and Talkeetna Rivers. Based on the available information, the loads at Sunshine with the dam in-place would be about 82 percent of the pre-Project loads, and the contributions from the Yentna River and other tributaries between Sunshine and Susitna Station cause the effect to diminish even further so that the post-Project silt/clay loads would be about 92 percent of the pre-Project loads at Susitna Station. The changes in the silt/clay load in the Middle River are not anticipated to have a direct effect on active channel morphology in Middle River, and the smaller downstream changes are less likely to affect active channel morphology in the Lower River. The large reduction in the silt/clay load in the Middle River, along with decreased frequency of floodplain inundation, may have an effect on floodplain sedimentation processes.

During the initial period after closure of the dam, Project effects on the sand load in the lower part of the Middle River and the Lower River would result primarily from the change in flow regime, because there is currently sand moving through the system and it moves at a much slower rate than the flow. Over time, much of the stored sand will be depleted from the Middle River, and the load just upstream from the Three Rivers Confluence area will be consistent with the supply from the local tributaries. After this occurs, the sand load above the Three Rivers Confluence will be only about 15 percent of the pre-Project load (Figure 6.3-2). Similar to the silt/clay load, sand inflows from the Chulitna and Talkeetna Rivers will decrease the relative impact of the Project, with Maximum Load Following OS-1 sand-load conditions of about 82 percent of the pre-Project loads. Contributions from the Yentna River and other tributaries downstream from Sunshine will increase the sand loads to about 91 percent of the pre-Project loads at Susitna Station.

Except for the upstream portion of the Middle River, Project effects on gravel loads will derive primarily from the changes in flow regime. There appears to be a relatively significant supply of gravel and coarser material between the dam site and the Three Rivers Confluence, the local tributaries and bank erosion likely supply a significant amount of gravel to the river, and the response rate of upstream changes in supply will progress downstream relatively slowly compared to the sand. Based strictly on integration of the pre-Project gravel transport curves over the Maximum Load Following OS-1 flows, the gravel loads in the lower part of the Middle River will be only about 7 percent of the pre-Project loads (Figure 6.3-3). Based on the same assumptions, the gravel loads at Sunshine in the upstream portion of the Lower River will be about 51 percent of the pre-Project loads, and this increases to about 80 percent at Susitna Station.

Between the Three Rivers Confluence and Sunshine, the pre-Project and post-Project sediment balances indicate a difference for the gravel transport capacity compared to the sand transport capacity. The effects of the dam between the Three Rivers Confluence and Sunshine would decrease the excess sand supply (Figure 6.3-4). Under Maximum Load Following OS-1 conditions the results suggest the annual gravel load will likely increase its relative imbalance of aggradation by about 10 percent (from 592 to 667 tons). This will likely increase the amount of channel braiding in this reach.

From Sunshine to Susitna Station, the pre-Project and post-Project sediment balance also indicates a difference for the gravel transport capacity compared to the sand transport capacity. The effects of the dam below Susitna Station would increase the excess sand supply from 0.5 tons to 0.7 tons which is only 1.5 percent of the post-project supply (Figure 6.3-5). Under Maximum Load Following OS-1 conditions, the annual gravel load will likely remain aggradational, but the relative imbalance in gravel loads would decrease by about one-third from an excess of 252,000 tons under pre-project conditions to about 168,000 tons under Maximum Load Following OS-1 conditions.

### 6.3.2. Characterization of Bed-material Mobilization

While ranges of flows associated with bed-material mobilization by geomorphic reach have not yet been estimated, preliminary assessments at the Gold Creek and Sunshine gaging stations are presented in Tetra Tech (2013c). At the time of the assessment, no information was available to evaluate the estimated $D_{50}$ values used at both locations. Subsequently, surface gradations from historical samples were identified in Harza-Ebasco (1984). The estimated $D_{50}$ at Gold Creek of 67 mm is nearly identical to the $D_{50}$ of 65 mm sampled August 25, 1983, at Gold Creek (LRX-45 sample, Harza-Ebasco 1984). Harza-Ebasco also indicates that the $D_{50}$ in the reach of the Susitna immediately upstream of the Chulitna River confluence is about 40 mm, based on samples collected in August 1983. No sampling was conducted downstream of this reach in the 1980s.

Collection of bed-material samples located upstream of PRM 146.1 is planned during the next year of study. These samples are needed to quantify the bed-surface gradation for geomorphic reaches MR-1 through MR-3 and MR-5. Bed-material mobilization will not be characterized in Geomorphic Reach MR-4 because very little, if any, alluvial sediment is stored within this narrow and steep reach (i.e., Devils Canyon). Geomorphic reaches LR-6 and LR-5 are entirely and mostly, respectively, downstream of the downstream extent of the 1-D Bed Evolution Model, so a range of flows over which the bed surface is mobilized will not be characterized in these reaches, unless a decision is made to extend the 1-D Bed Evolution Model downstream of PRM 29.9.

### 6.3.3. Effective Discharge

The effective discharge analyses presented in the previous sections provide a basis for a preliminary comparison of the change in the range of flows that transport the most sediment between the pre-Project and Maximum Load Following OS-1 conditions. This, in turn, may provide insight into the effects of the dam on the sediment balance in the mainstem of the Susitna River.

As discussed in Tetra Tech (2013a), the dam would likely cut off at least 90 percent of the silt/clay supply and essentially all of the sand-and-gravel supply to the head of the Middle River. The effects on all components of the sediment load would diminish in the downstream direction due to contributions from the tributaries and entrainment of material that is currently stored in the channel. This is evident in the change in magnitude of the effective discharge between the pre- and post-Project condition represented by the Maximum Load Following OS-1 scenario. Gold Creek, about 47 miles downstream from the Dam site, will experience a greater reduction in the effective discharge on a percentage basis than the other three mainstem gages.

For the initial assessment at Gold Creek, the effective discharge decreases by about 67 percent from 27,000 to 9,000 cfs (Figure 6.1-1). At Sunshine, the effective discharge decreases by about 30 percent from 66,000 cfs under pre-Project conditions to 46,000 cfs under the Maximum Load Following OS-1 conditions. At Susitna Station, the effective discharge decreases by 13 percent from 124,000 cfs under pre-Project conditions to about 108,000 cfs under Maximum Load Following OS-1 conditions.

Wolman and Miller (1960) concluded that hydrologic events of moderate magnitude and frequency transport the most sediment over the long-term, and these flows are most effective in forming and maintaining the planform and geometry of a channel in an alluvial river. The overall decrease in effective discharge on the mainstem of the Susitna River provides an indication that the morphology of the channel may change because there is a reasonably well identified relationship between the effective discharge and the size of the channel. The sediment transport relationships used in this analysis may be updated based on a comparison with additional data collected by the USGS in 2013 and beyond. The detailed 1-D and 2-D Bed Evolution models of the Susitna River to be implemented between Sunshine and Susitna Station are key tools in making assessments as to how the channel morphology may change under Project conditions.

### 6.3.4. Adequacy of Data

The primary data supporting this analysis are the sediment transport measurements performed in the 1980s and currently being performed by the USGS. The USGS completed measurements and delivered the results for 2012 and has completed measurements and is developing the results for 2013. The 2013 data will be available for support of the Geomorphology Studies during the next year of study. The USGS will continue to collect sediment transport measurements. If the comparison performed in ISR Study 6.5 Section 4.2 indicates a change from the 1980s to present sediment transport conditions the data will be used to revise the sediment-rating curves and sediment balance presented in Tetra Tech (2013a). During the 2013 field season, data were collected to estimate the contributions to the sediment supply from mass wasting and bank erosion in the Upper Susitna River Segment, and from contributing tributaries downstream of the dam in the Middle River segment. The volume of sediment from bank erosion will be estimated by comparing channel location and areas from aerial photographs take in the 1950s, 1980s and 2012. The basic information for this estimate was developed in the "turnover analysis" of the Assess Geomorphic Change Middle and Lower Susitna River Segments study component (ISR Study 6.5 Section 6.4.1). Cross sections surveyed in the 1980s and in 2012 can also be used to compare channel dimensions to estimate Middle River sediment storage, aggradation, and degradation. Data collected during the 2013 field season will be used to model tributary sediment loading in the Middle River as part of the Fluvial Geomorphology Modeling below

Watana Dam Study (ISR Study 6.6 Section 4.1.2.6). Historical USGS sediment transport data from Knott et al. (1986) are available for Indian River and Portage Creek for comparison to the tributary model results. Additional suspended sediment-load measurements from the Susitna River at Tsusena gage in 2013 will be used in refining the estimated annual sand and wash load supply to the Middle River under pre-Project conditions.

The other primary data sets supporting this effort are the cross-sectional surveys and bed-material sampling described in Study 6.6. These data sets are extensive as they were developed to support 1-D and 2-D Bed Evolution Models and more than adequate to support this effort. Additional bed-material samples and cross-section surveys are planned for 2014 and will further contribute to the robust supporting data set.

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

Much of the effort associated with this study component was conducted in 2012 and reported on in the technical memorandum, Mapping of Geomorphic Features within the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (Tetra Tech2013g). This 2012 study effort utilized aerial photographs from the 1980s and 2012 to perform an analysis of channel change over the approximately 30-year period. The analysis included classification of various components of the system into geomorphic features. The geomorphic features have direct relationships to the aquatic habitat types that were studied in in the 1980s in the Middle River (Trihey & Associates 1985) and the Lower River (R&M Consultants, Inc. and Trihey & Associates 1985a). By creating this linkage between the habitat types and the geomorphic features, the assessment of channel change provides insight into how the features that comprise the important aquatic macrohabitats in the Middle and Lower Susitna River have changed or remained the same over the past three decades.

### 6.4.1. Adequacy of Available Data

The data collection effort in 2012 involved flying and processing current (2012) and acquiring historical 1980s aerial photographs for the Upper, Middle and Lower Susitna River segments. Based on comparison of the 1980s and 2012 aerial photographs along with comments received on the Proposed Study Plan, the decision was made to acquire available 1950s aerial photographs and extend the channel change analysis for an additional 30 years in the Middle and Lower segments. In 2013, the necessary 1950s aerials were identified, acquired from the USGS photo archives, and processed. It was also decided to acquire an additional set of current (in this case 2013) aerials photographs for the Upper, Middle and Lower Susitna River segments. These aerials were successfully flown in the summer and fall 2013 and were processed in Q4 2013. This decision was based on the desire to have aerial photo documentation of the condition in the Susitna River after the high flows that occurred in September 2012 and June 2013 and to acquire aerials in portions of the study area closer to the target flows. In addition, small portions of the Upper River segment were missing from the 2012 aerials.

With the successful acquisition of the 1950s and 2013 aerials, the currently available aerial photographic database is adequate for the Geomorphology Study needs and no further aerial acquisition is planned. This includes adequacy to perform the turnover analysis in the Middle and Lower River segments to further quantify channel change by identifying the rate at which floodplain is converted to channel and channel converted to floodplain.

### 6.4.2. Discussion of Results

Mapping of geomorphic features in the Middle and Lower Susitna River segments was performed under the 2012 studies and the results presented in the technical memorandum, Mapping of Geomorphic Features within the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (Tetra Tech 2013g). Efforts to map these features from recently acquired 1950s aerials are currently underway. The analysis of channel change in the Middle and Lower River segments presented in Tetra Tech (2013g) was based on comparison of the geomorphic features mapped on aerial photographs from the 1980s and 2012. The analysis looked at changes in the geomorphic form, such as channel width, alignment, lengths, size of features present, and types of features present, within each geomorphic reach. The analysis also identified geomorphic processes that resulted in change, including vegetation encroachment, bank erosion, lateral migration, and biogeomorphic processes, such as beaver dam construction. One of the tools used to identify and quantify change is the tabulated area for the various geomorphic features within a reach. Comparative terms, such as increase and reduce, are a function of area differences (1980s vs. 2012 vs. 1980s) determined from the tabulated geomorphic feature areas.

The results of the geomorphology study indicated that channel change has occurred between the 1980s and 2012 in both the Middle and Lower Susitna River segments, with the largest changes occurring in the Lower River. In both cases, an increase in vegetation has played an important role in defining the change. The discussion is divided into the Middle Susitna River segment and the Lower Susitna River segment. Additional discussion of the results is provided in (Tetra Tech (2013g), including changes for each of the geomorphic feature types mapped in the Middle and Lower River segments.

#### *6.4.2.1. Middle Susitna River Segment*

The largest changes in the Middle River occurred in the four reaches below Devils Canyon (MR-5 through MR-8) where establishment of new vegetation reduced the combined main and side channel area by an average of 200,000 sq. ft/mi. Encroachment of vegetation in the main and side channels occurred through enlargement of vegetated islands and along the channel banks. Vegetated islands increased overall for the Middle Susitna River Segment. Substantial increases occurred since 1983 within MR-6 (approximately 300,000 sq. ft /mile) and MR-7 (approximately 400,000 sq. ft /mile).

Another large change in the Middle River was the apparent conversion of side sloughs to side channels in geomorphic reaches MR-6, MR-7, and MR-8, where the reduction in side slough area averaged 220,000 sq. ft/mi (or 61 percent) since 1983. The change in classification from side slough to side channel results when the breaching flow changes from greater than 12,500 cfs (side slough) to less than 12,500 cfs (side channel). This can occur as a result of relatively minor changes, on the order of one foot or less of lowering, in the invert of the lateral weirs at the upstream entrance to the side channels and side sloughs that determine the breaching flow to these lateral features. Therefore, the changes in area of side channels versus side sloughs over the past 30 years are not necessarily associated with major geomorphic changes, but rather likely represent small adjustments in the elevation of the controls at the upstream entrance to these features. It is noted that Labelle et al. (1985) showed the opposite trend over the period from the 1949 to the 1982 with a net conversion of side channels to side sloughs over that period.

A qualitative assessment of the level of geomorphic change within each geomorphic reach of the Middle Susitna River segment was conducted. The most stable reach was MR-4 (Devils Canyon), followed by MR-1, MR-3, MR-2, and MR-5. Reaches MR-7 and MR-8 were more dynamic. MR-6 was the most dynamic, having the most significant level of bank erosion identified in the Middle River over the period of 1983 to 2012.

#### *6.4.2.2. Lower Susitna River Segment*

In the Lower River, channel change was on a larger scale than in the Middle River. All six reaches in the Lower River experienced an increase in the area of vegetated islands ranging from 0.3 million sq. ft/mi for LR-4 to 5.2 million sq. ft/mi for LR-6. The dominant form of vegetation encroachment in most reaches of the Lower River was the conversion of open bars to vegetated islands in bar island complexes. Another important finding in the Lower River involved tributaries in the Susitna River floodplain. The backwater habitat at the mouths of tributaries remained fairly constant between 1983 and 2012, except in cases where lateral migration or bank erosion in the mainstem altered the connection with the tributary. Clearwater features (US, TR, SS) had minor changes primarily due to vegetation encroachment, and larger changes due to main channel migration causing increased or decreased connectivity.

A qualitative assessment of the level of geomorphic change within each geomorphic reach of the Lower Susitna River segment was conducted. Reaches LR-4, LR-5, and LR-6 were assessed as being fairly or relatively stable. The remaining reaches, LR-1, LR-2, and LR-3 appeared to be more dynamic over the three decades studied.

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

Most of the effort associated with this study component was conducted in 2012 and reported on in the technical memorandum entitled Mapping of Aquatic Macrohabitat Types at Selected Sites in the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (Tetra Tech 2013f). The habitat site analysis presented in the Technical Memorandum provided the areas of the various habitats types mapped on aerial photographs from the 1980s and 2012. It also compares the changes in habitat area and site conditions, to which some of the change can be attributed. Comparative terms, such as increase and reduce, are a function of area differences (2012 area vs. 1980s area) determined from the tabulated habitat areas. Additional aerials were acquired in 2013 to fill in areas of missing coverage (Upper River segment) and to obtain aerials at a more consistent flow level than in 2012. The 2013 aerials also document conditions since the high flows in September 2012 and June 2013.

## 6.5.1. Aerial Photography

The data collection effort in 2012 involved flying and processing current (2012) and acquiring historical 1980s aerial photographs for the Upper, Middle and Lower Susitna River segments. Since the aerials collected in 2012 had some missing areas and inconsistent flows as well as high flows had occurred in both September 2012 and June 2013, it was decided to acquire an additional set of current, in this case 2013, aerials photographs for the Upper, Middle and Lower Susitna River segments. These aerials were successfully flown in the summer and fall of 2013 and were processed in Q4 2013. With the successful acquisition of the 2013 aerials, the aerial photographic database currently available is adequate for the Geomorphology Study needs and no further aerial acquisition is planned.

## 6.5.2. Discussion of Results

### *6.5.2.1. Aerial Photography*

The discussion of the acquisition of the aerial photographs was presented in the previous section as they represent the data to conduct this study component.

### *6.5.2.2. Digitize Riverine Habitat Types*

The areas delineated for main channel and side channel show considerable differences between 1983 and 2012. The inconsistency occurs because 10 percent of the total flow criterion that defines the difference between the main channels and the side channels cannot be accurately determined from aerial photography. A conservative approach was taken in 2012 to determine side channel flow conveyance based on a comparison of main and side channel widths and assumed similar depths. Comparisons between main channel and side channel habitat type from the 1983 and 2012 aerials are inconclusive. For this reason, tables and bar charts that display the combined main channel and side channel habitat types were developed (see Tetra Tech [2013f] Appendix 5 for the tables and Appendix 7 for the bar charts).

Aquatic macrohabitat types mapped from 2012 aerial photographs were compared to mapping performed in 1983 at a discharge of 12,500 cfs. This was accomplished by scaling the flows using the habitat versus flow relationships from the 1980s. Scaling the flows upstream of PRM 143.6 for Sites 14 through 17, where the flows of 17,000 cfs were considerably higher than 12,500 cfs reduces the accuracy of the comparisons. For the effort being completed in 2014 between PRM 187.1 and PRM 149, the results from the 2013 aerial photography at 6,200 cfs and the 2012 aerial photography at 17,000 cfs will be needed to interpolate to the 1983 aerial's target discharge of 12,500 cfs.

### *6.5.2.3. Riverine Habitat Analysis*

The results of the aquatic habitat study showed a number of appreciable differences in habitat areas from 1983 to 2012. Some of these differences are due to observed physical changes at the site from geomorphic and biogeomorphic processes. In other cases the differences may be attributable to the mapping process including: difficulty in differentiating between main and side channel classifications and the lack of 2012 aerial photography at some sites at flows similar to the 1980s aerial photography. To identify overall changes in the 1983 and 2012 areas by aquatic macrohabitat types, comparable flows in the Middle River (Sites 1 through 13) were summed (Table 5.5-4). To identify overall changes by geomorphic reach, 1983 and 2012 aquatic macrohabitat type areas were also summarized by geomorphic reach. The example for MR-6 is presented in Table 5.5-5.

Habitat changes in the Middle River due to changes in morphology were primarily related to the biogeomorphic processes of vegetation establishment and beaver dam building. Overall, these process contributed to a 42-percent reduction in side slough habitat and an18 percent reduction in upland slough habitat for Sites 1 through 13 (Table 5.5-4). Vegetation establishment has included both initial colonization of exposed substrate and subsequent succession. This is evident to some extent at each of the habitat Sites 1 through 17.

Apparent changes in tributary mouths were detailed in (Tetra Tech 2013f). From 1983 to 2012, for Sites 1 through 13 (Table 5.5-4), which had comparable flows of 12,500 and 12,900 cfs, tributary mouth area decreased by 20 percent from 1983 to 2012. The wide range of tributary mouth percent change may be attributed to the relative discharges of the tributary and the main channel.

Because of the changes identified in the area of the aquatic macrohabitat types mapped between the 1980s and 2012, the historical macrohabitat mapping is not sufficiently representative of current conditions in order to be used as the sole information source to support Focus Area selection or to quantify either pre- or post-Project aquatic macrohabitat. It is recommended that the 1980s habitat mapping not be used as the primary basis for extrapolation of habitat quantifications in unsampled areas.

However, the 1980s habitat mapping and data are still useful to the current studies. The data are extremely valuable for developing and understanding the long term temporal variability and evolution of aquatic macrohabitat in the Middle and Lower Susitna River segments. The geomorphology studies will work with the Ice Processes in the Susitna River Study (Study 7.6), Riparian Instream Flow Study (Study 8.5) and Fish and Aquatics Instream Flows Study (Study 8.6) to develop the understanding of the how and what physical processes are responsible for determining the behavior of the Susitna River and its important lateral habitats.

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

This study component used historical sediment data and hydrology records to estimate the annual sediment loads at three mainstem gages and three primary tributary gages. These loads were then compared to the estimated supply to the reach for both pre-Project and Maximum Load Following OS-1 conditions. Changes in the relative flow magnitudes and duration and in sediment balance provide an initial basis for assessing associated changes to channel geomorphology. A literature search on the downstream effects of dams is also being conducted to provide information from other systems, particularly those in cold regions.

### 6.6.1. Streamflow Assessment

The pre-Project hydrology analysis was conducted based on the USGS extended record data at the five mainstem gages and six tributary gages for which the data were available. Unregulated flows at the Watana Dam site were also developed using the HEC-ResSim model to provide a basis for directly comparing pre-Project and Maximum Load Following Scenario OS-1 flows at that location. Because the Project will not affect mainstem flows upstream from the reservoir or inflows from the downstream tributaries, the Maximum Load Following OS-1 analyses only considered the Gold Creek, Sunshine, and Susitna Station gages. Output from the HEC-ResSim model was used directly for the analysis at Gold Creek and Sunshine. Since the model domain only extends downstream to PRM 88, it was necessary to estimate Maximum Load Following Scenario OS-1 flows at Susitna Station using the simulated Sunshine flows, adjusted for the difference between the Sunshine and Susitna Station flows from the USGS extended record.

The Project will change the seasonal flow patterns by increasing flow during the typical low-flow season that occurs in late-fall, winter and early-spring under pre-Project conditions, and decreasing the flows during the pre-Project high-flow period between May and September (Figure 6.6-1). These changes also affect the annual mean daily flow duration curves by reducing the magnitude of flows in the high-flow range that occur 35 to 40 percent of the time, and increasing flows in the low flow (60 to 65 percent) range (Figure 6.6-2). In all cases, the relative magnitude of the changes is much greater in the Middle River above the Three Rivers Confluence, decreasing in the downstream direction because of the influence of the major tributary inflows.

Comparison of the flood-frequency curves developed from the 61-year record of flows from the HEC-ResSim model results indicates that the annual peak flows for equivalent recurrence intervals at the Watana Dam site would decrease by about 40 to 50 percent for frequent events (1.25- to 2-year) under Maximum Load Following Operation Scenario OS-1, with the relative change decreasing to approximately 27 percent at the 100-year peak discharge (Table 6.6-1). The relative change at Gold Creek is similar. At Sunshine, the relative magnitude of the change is somewhat smaller, ranging from about 25 percent for frequent events to about 23 percent at the 100-year peak, due primarily to inflows from the Chulitna and Yentna rivers. Tributaries downstream from Sunshine, including the Yentna and Skwentna rivers, cause a further decrease in the relative change at Susitna Station (17 to 18 percent for the frequent event to only about 5 percent at the 100-year peak).

These results can also be assessed by comparing the recurrence intervals of equivalent discharges under pre-Project and Maximum Load Following Operation Scenario OS-1 (Table 6.6-2). For example, the 2-year peak discharge of 34,200 cfs at the Watana Dam site under pre-Project conditions would occur only about once in 10 years, on average, and the 20-year flow of 57,600 cfs would occur only about once in 140 years, on average, with Maximum Load Following Operation Scenario OS-1. At Gold Creek, the 2-year peak discharge of 43,700 cfs would occur about once in 12 years on average and the 20-year flow of 72,300 cfs could occur very rarely (once in about 166 years, on average) under Maximum Load Following Operation Scenario OS-1. The 2-year peak discharge at Sunshine of 94,700 cfs would occur about once every 7 to 8 years, and the 20-year flow of 143,600 cfs would occur about once in 150 years, on average. The changes are less significant at Susitna Station, with the pre-Project 2-year flow of 170,300 cfs occurring about once in 5.2 years and the 20-year flow of 233,500 cfs occurring about one in 43 years, on average, with Maximum Load Following Operation Scenario OS-1.

### 6.6.2. Sediment Transport Assessment

The sediment load analyses presented in Section 5.3 provide a basis for development of a preliminary sediment balance for the Middle and Lower Rivers. The dam would likely cut off at least 90 percent of the silt/clay supply and essentially all of the sand-and-gravel supply to the head of the Middle River. The effects on all components of the sediment load would diminish in the downstream direction due to contributions from the tributaries and entrainment of material that is currently stored in the channel. Section 6.3 of study component 3 details the discussion and conclusions for the sediment balance for both the Middle River and Lower River segments.

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

The values of $S^*$ for gravel and $T^*$ values were plotted in the same conceptual format proposed by Grant et al. (2003) (Figure 6.6-3). Although the ranges of $S^*$ and $T^*$ axes are not meant to be absolute, the shaded area of "Effects Subtle" are from an example application by Grant et al. (2003) for three rivers (Deschutes River, Oregon; Green River, Utah; and Colorado River, Arizona). Although the term "subtle" was used in the paper, it is probably better to consider this area as being "not extreme" or "indeterminate," at least in applying this model to the Susitna River. The Middle River Segment plots near the ordinate where sediment supply and time of bed mobilization are each small compared to pre-Project conditions. In the area between the Three Rivers Confluence and Sunshine, the results plot in an area of more extreme potential change, where aggradation and textural shifts at confluences is indicated. As evident from the channel braiding this is already an area of significant sediment accumulation, so the result does not actually represent a significant change from pre-Project conditions. The best- and high estimate values for the Sunshine gage plot at the lower range of the "effects subtle" area, as defined by Grant et al. (2003), but the low estimate value plots somewhat below this area. At Susitna Station, the values plot in a cluster in the "effects subtle" area for all three values of $Q_{cr}$, largely due to the sand-bed character of this location.

Application of the Grant et al. (2003) conceptual model suggests that the impacts to the channel form in the Middle River segment would not be extreme, as both the sediment input and the frequency of mobilizing flows will be significantly reduced. The potential impacts of the significant reduction in the frequency and duration of gravel mobilization on side channel and instream habitat are, however, not directly addressed by this approach. In this segment the planned sediment transport modeling will provide more complete analysis of potential effects (AEA 2012b, Section 6.6).

The application of the Grant et al. (2003) conceptual model of channel change suggests that the potential for significant change in the Lower River downstream from Sunshine is indeterminate; thus, it cannot be concluded that the impacts of the Project would be acceptably small. The $S^*$ and $T^*$ values at Sunshine gage plot at the lower limit of "Effects Subtle" range of Grant et al. (2003), indicating that the portion of the Lower River segment above Sunshine will continue to be aggradational with respect to the gravel load, but is likely to see little impact related to sand transport. Although these results are not extreme, the $S^*$-$T^*$ values indicate that the portion of the Lower River Segment below Sunshine could tend toward degradation and channel narrowing. Because the bed material is presumed to be predominantly sand at Susitna Station (the single sample available was dominated by sand), the results would indicate minor impact at this location because $T^*$ is 1.0 at Susitna Station and $S^*$ is nearly unchanged between pre-Project and Maximum Load Following OS-1 conditions.

The conceptual model of downstream impacts proposed by Grant et al. (2003) is a relatively simple way to assess the potential channel change impacts downstream of a dam. This model incorporates sediment transport magnitude and duration to identify areas of large potential impact. It is not, however, a complete analysis of the potential impacts of channel change. Considering the borderline results of the Grant et al. (2003) model for the Lower River between Sunshine and the Yentna River confluence and the results from the stream flow assessment (Tetra Tech 2013d) and initial sediment transport assessment (Tetra Tech 2013a), AEA will investigate the potential Project-related effects downstream to just below the Susitna Station gage (PRM 29.9). This investigation will include bed-material and bed load sampling, as well as 1-D Bed Evolution modeling to quantify and clarify the potential magnitude of the Project-related impacts.

### 6.6.4. Literature Review on Downstream Effects of Dams

From 2013 field observations of the effects of ice processes (ISR Study 6.6 Section 4.1.2.9), including eroded banks, ice-scarred trees, vegetation retardation and sand deposition on the floodplain, particular interest has been identified to synthesize information on the downstream effects of dams related to ice processes, riparian processes and geomorphology. Thus, collaboration of this effort with the Riparian Instream Flow Study (Study 8.6) and Ice Processes in the Susitna River Study (7.6) is being conducted.

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

The outcome of these efforts informed the decision to expand the Susitna River 1-D Bed Evolution Model as described in the Fluvial Geomorphology Modeling Approach technical memorandum (Tetra Tech 2013h) and to conduct more in-depth studies of Deshka River, Trapper Creek, Birch Creek, Sheep Creek, and Caswell Creek, as described in the Selection of Focus Areas and Study Sites in the Middle and Lower Susitna River for Instream Flow and Joint Resource Studies – 2013 and 2014 (R2 2013a).

Originally planned to extend from the Watana Dam site at PRM 187.1 to PRM 79, the 1-D Bed Evolution Model was expanded from the dam site to a new downstream limit just below Susitna Station at PRM 29.9. The 1-D Bed Evolution Model is being used to assess reach-scale sediment transport conditions, potential changes in bed and water-surface elevations, changes in channel profile, and potential changes in bed-material gradation (Tetra Tech 2013h).

Data collected in the five selected tributaries include stage and flow measurements, cross-sectional surveys, and thalweg profiles (data were collected at Trappers Creek and the Deshka River in 2013). Data collected at the tributary mouths will be used to develop HEC-RAS models to describe the relationship between mainstem flow and tributary water-surface elevations (R2 2013a) to assist in the Fish and Aquatics Instream Flow Study (Study 8.5) in determination of potential changes in tributary access for spawning adult salmon and in habitat conditions at the tributary mouths.

### 6.7.1. Change in River Stage Assessment

The stage-discharge ratings published by the USGS do not include the effect that ice has on river stage. For this reason, the results of the stage-exceedence analyses through the winter months should consider this limitation.

The tables and figures presented in Section 5.7.1 and in Tetra Tech (2013d) indicate that the magnitude of change in stage (or water-surface elevation) from the pre-Project condition to the Maximum Load Following OS-1 condition varies somewhat between the two gage locations. The results also indicate that the changes in stage vary considerably by season (i.e., month) at each of the two gage locations.

Regarding the sensitivity to location, it was found that for a given exceedence percentile and a given month, the magnitude of change in stage from the pre-Project hydrologic condition to the Maximum Load Following OS-1 hydrologic condition was often quite different between the two gage locations. As seen in Table 6.7-1, the relative change in flow between the two hydrologic conditions for the 50-percentexceedenceis roughly equivalent between the Sunshine Gage and the Susitna Station Gage. However, the change in stage between the two hydrologic conditions for a given annual exceedence percentile is not the same for the two gaging stations. For flows lower than the 50-percent exceedence (lower flows), the change in stage is slightly greater at the Susitna Station Gage than at the Sunshine Gage. When the stage is greater than the 50-percent exceedence value; the change at the Sunshine Gage is greater than at the Susitna Station Gage. Since the change in flows is approximately the same for each exceedence probability, the explanation is due to the differences in the slope of the published stage-discharge ratings at the two sites. For higher flow conditions, an equivalent change in flow rate at the two locations is associated with a larger change in stage at the Sunshine Gage than at the Susitna Station Gage.

Regarding the sensitivity to seasonality, it was found that for a given exceedence percentile and a given month, the magnitude of change in stage from the pre-Project hydrologic condition to the Maximum Load Following OS-1 hydrologic condition was often quite different between the two gage locations. For example, for the high-flow season (i.e., the months of May through August, inclusive), the changes in stage at the Sunshine Gage were higher than at the Susitna Station Gage for all exceedence probabilities.

The magnitude of the change in flow in the Susitna River from the pre-Project to the Maximum Load Following OS-1 condition varies by month, as illustrated in the monthly flow-duration curves provided in Tetra Tech (2013d). This monthly variability is a product of the assumptions that were made for Watana Dam operating under the Maximum Load Following OS-1 hydrologic condition. Correspondingly, the magnitude of the change in stage also varies by month. This monthly variability was shown in the tables in the previous section and is further illustrated in monthly bar charts (Figures 6.7-1 and 6.7-2). These bar charts illustrate the change in stage, by month, at a specific location (either the Sunshine Gage or the Susitna Station Gage) for the 50-percentexceedence value. Similar figures were developed for the 90- and 10-percent exceedence values at both gage locations.

The months that exhibited the least pronounced absolute change in hydrologic conditions, and consequently in stage, were the months of August and September. At the Sunshine Gage, the change in stage for the exceedence percentiles summarized in Table 5.7-3 ranged from -1.00 to +0.27 feet. At the Susitna Station Gage, the change in stage for the exceedence percentiles ranged from -0.45 to +0.22 feet (Tetra Tech 2013d).

During the months of June and July, the entire flow exceedence relationship for the Maximum Load Following OS-1 hydrologic condition was lower than for the pre-Project condition at both gage locations. Therefore, stage values for the entire range of flows for these months were also reduced. For instance, as seen in Table 5.7-4, the median value of stage (50-percent exceedence) at the Sunshine Gage was reduced by 1.43 feet (June) and 1.21 feet (July). At the Susitna Station Gage, the reduction in the median value of stage was 0.87 feet (June) and 0.77 feet (July) (Tetra Tech 2013d). At both gage locations, the months of June and July exhibited the largest reduction in stage values, using the median value as the measure.

Overall, the largest changes in stage occurred during the winter/spring months of November through April. For each of these months, the median value of stage was increased by more than one foot at both of the gage locations. This observation is attributed to the fact that these months have the lowest magnitude flows of the year, and incremental changes in lower flows produce relatively larger changes in stage due to the steepness of the lower part of the stage-discharge ratings. However, as previously stated, it is noted that the stage-discharge ratings published by the USGS do not include the effect that ice has on river stage. Thus, interpretation of the calculated stages should consider this limitation.

In summary, the months of October through April exhibit increased stages at the Sunshine Gage for the entire range of exceedence probabilities, as illustrated in Tables 5.7-2 and 5.7-3. The month of May exhibits increased stages for the lower flow conditions and reduced stages for the higher flow conditions. The months of June and July show reduced stages at both gage locations for all flow conditions. The months of August and September showed increased stages for the lower flow conditions and reduced stages for the higher flow conditions. Similar behavior is presented in the results at the Susitna Station Gage location (Tetra Tech 2013d).

Regarding the evaluation of discharge effects on ice elevation/thickness, it was concluded in Tetra Tech (2013d) that the available flow measurement data at the Sunshine and Susitna Station gages does not provide sufficient information with which to draw defensible conclusions about the differences in hydraulic conditions between ice-covered and open-water conditions. Future discharge measurements under ice-cover conditions should include the elevation of the top of the ice and the static water-level to provide a basis for assessing the extent of pressure flow.

### 6.7.2. Synthesis of the 1980s Aquatic habitat Information

Results based on comparing pre- and post-Project hydrology presented in R&M Consultants and Trihey & Associates (1985b), were determined to be useful for the current Project analysis, since the pre- and post-Project hydrologies are very similar (Tetra Tech 2013e). Therefore, habitat area versus flow relationships were developed from R&M Consultants and Trihey & Associates (1985b) and applied to the current Project study. Reductions in tributary mouth wetted habitat areas were identified using this methodology for both Willow Creek and Goose Creek when comparing the pre- to the post-Project conditions. In R&M Consultants and Trihey & Associates (1985b), access and passage issues were identified for Goose, Trapper, Caswell, and Montana creeks; and, none of the tributary mouths investigated by inspection of aerial photographs in this study were identified as having decreased morphologic stability for the post-Project conditions. However, evaluation of aerial photographs presented in Tetra Tech (2013f) indicates significant changes in habitat types connecting tributary mouth habitats to the main channel habitat is possible due to main channel migration.

Utilizing the habitat area versus flow relationships to evaluate aquatic habitat area types at SC IV-4, Willow Creek, and Goose Creek for the post-Project median discharge for the open-water period indicated potential reductions in main channel, secondary side channel, and tributary mouth habitat. A total of 64 percent of the site and habitat type combinations evaluated resulted in a potential decrease in wetted surface area (Tetra Tech 2013e). Ice-affected period results were presented, but should be viewed with caution as there is less certainty since the associated effects of ice coverage on the river hydraulics and wetted area are not incorporated into the habitat area versus flow relationships.

As a result of the analysis presented in Tetra Tech (2013e) and in conjunction with the Fish and Aquatics Instream Flow Study (Study 8.5), five tributaries in the Lower River were selected for additional study to better understand potential Project-related effects on the wetted surface area of the defined aquatic macrohabitat types and related tributary access by spawning salmon. The five Lower River tributaries selected for further study were Deshka River and Caswell, Sheep, Birch, and Trappers Creeks. Work that was identified for inclusion in the further study of these five Lower River tributaries includes 1-D local-scale hydraulic model development with a spatial extent from each tributary's mouth to approximately one mile upstream. In addition, sediment-transport relationships will be determined for each tributary near its mouth. This modeling effort will support the evaluation of possible morphologic changes related to accessibility and stability of these lateral habitats that may occur under the post-Project scenarios, including:

- potential for accumulation of sediments at the mouth,
- potential for accumulation of fine sediment supplied during backwater connection with the mainstem, and
- potential for changes in riparian vegetation that could alter the width of lateral habitat units (Tetra Tech 2013h).

### 6.7.3. Site Selection and Stability Assessment

The five sites selected in the Lower Susitna River Segment under this task for aerial photography analysis of riverine habitat (see Section 4.7.2.4) were adequate to compare the relative stability of the Lower River habitat types between the 1980s and current conditions. 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). The sites selected were all determined to be relatively stable; however, the results in Table 5.7.4 indicated that there was considerable change in the areas associated aquatic macrohabitat types mapped for the 1980s and current conditions. The change in habitat areas is consistent with the dynamic nature of much of the Lower River documented in the comparison of geomorphic features mapped from 1980s and 2012 aerials (Tetra Tech 2013g).

### 6.7.4. Aerial Photography Analysis, Riverine Habitat Study Sites (PRM 32 to PRM 102.4)

In the Lower Susitna River Segment, five specific habitat locations were analyzed to identify the magnitude and sources of changes in the area of aquatic macrohabitat types from 1983 to 2012. Habitat classification changes were primarily caused by geomorphic processes in Sites 4 and 5. There were instances where it was difficult to interpret the delineations from the 1980s mapbook. Sources of changes could not be definitively determined at Sites 1 through 3, where the flows were not comparable to the target flow of 36,600 cfs. Although these issues make it difficult to compare the habitat areas between the two periods, sufficient indicators are present to conclude that there have been appreciable changes in the distribution and proportion of aquatic macrohabitat types in the Lower Susitna River Segment between the 1980s and 2012.

The relative proportion of each aquatic macrohabitat type within each site is shown in Table 6.7-2. Site 1, SC-IV-4, was the most stable of the five habitat sites. Site 2, Goose Creek, showed a complete transition of Main Channel habitat to Secondary Side Channel due to channel migration. However, the overall proportion of Secondary Side Channel habitat remained relatively constantly, due to a large side channel, which had been turbid in 1983, being classified as Tributary in 2012, since the water was clear at the time of the 2012 aerial photo acquisition. The source of this difference cannot be definitively identified, since the discharge in Little Willow Creek was not available in either year. Main channel migration was also seen in Sites 3 through 5. The main channel migrated into Sites 3 and 5, and away from Site 4. The largest change in relative proportion in Site 3 resulted from a large channel on the eastern edge of the site, which was turbid in 1983, running clear in 2012, thus changing classifications from Secondary Side Channel to Clearwater/Side Slough. Vegetation encroachment was also noted throughout each site. More detailed descriptions of the observed changes in individual channels can be found in Table 6.1-6 of the aerial photography analysis technical memorandum (Tetra Tech 2013f).

### 6.7.5. Additional Aerial Photography Analysis, Riverine Habitat Study Sites (PRM 32 to PRM 102.4)

The decision was made not to pursue additional analysis of aquatic habitat versus flow relationships using analysis of aerial photography. The aerial photography analysis approach assumes a relatively static river system and that changes in aquatic macrohabitat area are associated with flows and not changes in the geomorphic features that define the boundaries of the various habitat types. Instead, in conjunction with the Fish and Aquatics Instream Flow Study (Study 8.5), Deshka River and Caswell, Sheep, Birch, and Trappers creeks were selected from tributaries in the Lower River for further studies using hydraulic modeling and sediment-transport analysis to assist the Fish and Aquatics Instream Flow Study in assessing potential project related changes to habitat in these important areas. In addition the 1-D Bed Evolution

Model is being extended downstream in the Lower River to PRM 29.9 to help quantify potential Project effects on channel morphology and the associated aquatic habitat.

# 6.8. Study Component: Reservoir Geomorphology

## 6.8.1. Reservoir Trap Efficiency and Sediment Accumulation Rates

The reservoir trap efficiency estimate made used the Brune (1953) method provides a general basis for comparing to other methods as described in Section 4.8.2.1. Despite a nearly 50-percent decrease in the capacity of the Watana Reservoir relative to the 1980s APA licensing studies, the trap efficiencies estimated in this study are quite similar to the estimates presented in Harza-Ebasco (1984) and R&M Consultants, Inc. (1982). It is noteworthy that the Brune method was developed from normally ponded reservoirs located in the southeast U.S., so the trap efficiency estimates may not be directly applicable to the Watana Reservoir where ice cover will persist through the winter months. For example, year-around wind can mix the upper layers of water in a reservoir in the southeast U.S., keeping clay-sized sediment in suspension; once ice cover has formed on the Watana Reservoir, wind-driven mixing will not be able to influence the suspension of clay. Also, the sediment load entering Watana Reservoir contains glacial flour that is not presented in inflows to the reservoirs used by Brune to develop his empirical relationship. The advantage of using other methods to estimate trap efficiency, such as Einstein (1965) and Li and Shen (1975), is to account for the tendency of finer sediments to be kept in suspension due to turbulence. Therefore, these methods may provide better estimates of sediment accumulation rates and reservoir longevity.

The preliminary estimates of reservoir longevity will be refined as the sediment accumulation rates are refined. Inferring longevity from reservoir capacities and sediment accumulation rates presented in previous studies (Harza-Ebasco 1984; R&M Consultants, Inc. 1982) produces estimates similar to the preliminary estimate of around 2,500 years. This similarity is due because both the current reservoir capacity and inflowing sediment loads are approximately half of the values used in the previous studies.

The 3-D Reservoir Water Quality Model developed to evaluate water quality in the Watana Reservoir (ISR Study 5.6 Section 4) will simulate the settling, deposition, and re-suspension of a few sediment- size classes less than 0.063 mm in diameter (silts and clays). The results of the simulations will provide estimates of sediment accumulation rates that are representative of the specific conditions in the Watana Reservoir under various operational scenarios, and will be the final estimate of reservoir sediment-trapping efficiency used in evaluating reservoir longevity and sediment delivery to the Middle Susitna River Segment. The earlier described methods for determining trap efficiency will be used for initial evaluations before the 3-D Reservoir Water Quality Model results are available. Additionally, these estimates will be used to check the assumption that 100 percent of all sand and larger-sized sediment will be trapped so the supply to the Middle Susitna River Segment from the Upper Susitna River Segment will be zero. The fine sediment that passes through the reservoir will become the upstream sediment supply for the 1-D Bed Evolution model (ISR Study 6.6 Section 4.1.2.1) and the 2-D River Water Quality Model (ISR Study 5.6 Section 5.6.4.8).

### 6.8.2. Delta Formation

Selection of tributaries where delta formation will be investigated will occur by the end of March 2014. This timing is important so that the reconnaissance and field data collection can be carried out during the 2014 field season. The reconnaissance will provide a basis for an informed decision about the most appropriate method to estimate sediment yield. If reconnaissance reveals that the sediment yield relationships developed for tributaries to the Middle Susitna River Segment (ISR Study 6.6 Section 4.1.2.6) are not appropriate for tributaries to the Watana Reservoir, alternate methods such as regional sediment yield relationships (Guymon 1974) or numerical modeling of bed-material load rating curves and long-term flow series will be considered.

### 6.8.3. Reservoir Erosion

The reservoir erosion assessment will take place in 2014 and will be provided in the final study report. Analysis during 2014 will include integration with the Geology and Soils Characterization Study, the Riparian Vegetation Study Downstream of Watana Dam, and Recreation Resources Study. Ongoing coordination with these study leads indicates the anticipated data will be available for study integration as planned.

### 6.8.4. Bank and Boat Wave Erosion downstream of Watana Dam

Bank and boat-wave induced erosion was not observed in the Middle and Lower River during the open-water season when boat traffic occurs. Armoring of the lower- and mid-bank regions prevents either fluvial or boat wave induced erosion. Since flows within the open-water period of the year are likely to the lower under project conditions, it follows that the potential for bank and boat wave induced erosion will also be reduced. Comparison between pre- and post-Project water surface elevations from the open-water flow routing model (Study 8.5) will be conducted to verify the this relationship between water surface elevations. A typical cross section will be selected in each geomorphic reach from MR-5 downstream to LR-4 (area with the heaviest boat traffic) to perform the comparison. The pre- and post-Project water surface elevations will be plotted on the typical cross sections for the 5, 10, 25 and 50 percent exceedence flows. The flow exceedences will be based on the period of heaviest boat traffic from June through September. During Project operations in the winter months when there are likely to be higher flows for post-Project compared to pre-Project conditions, there is no boat traffic on the river and the river is typically frozen over.

Primary data include characterization of the coarse material along the banks of the Susitna River and estimates of water-surface elevations throughout the open-water period for both existing and with-Project conditions. Data collected in 2013 and proposed for 2014 in the Fluvial Geomorphology Modeling below Watana Dam Study (Study 6.6) are adequate to support this analysis effort. The results of data collected on the gradation of the surface material at the toe or lower portion of the banks in each geomorphic reach will be used to determine the extent of armoring for flows representative of the periods when boat traffic is on the river. This will be performed for the selected typical cross sections. The analysis will be completed in Q4 2014.

## 6.9. Study Component: Large Woody Debris

The 2013 field and aerial photograph inventory and field observations of LWD and log jams in the Middle and Lower Susitna River Segments provided data regarding the species, size, input mechanisms and frequency, transport frequency, channel storage, and function of large woody debris in the Susitna River. The following preliminary observations were made:

- The recent high flows (reported instantaneous peak of 72,900 cfs at the Gold Creek gage on September 21, 2012, and a provisional instantaneous peak of 90,700 cfs on June 2, 2013) resulted in abundant fresh wood in the river system and mobilized much of the previously stored wood.
- Bank erosion/masswasting and ice processes are the primary mechanisms for LWD input to the river system.
- Balsam poplar is the most abundant species of LWD, followed by white spruce and paper birch.
- The majority of wood in the Middle River is stored along the vegetated margins of the channels; additional wood is stored on the side of unvegetated bars and at the apex of vegetated and unvegetated bars. Relatively little wood is stored within the wetted area of main or larger side channels.
- Wood in active channel areas (main and side channels) moves during large peak flow events and/or when ice jams move. Small woody debris in the Middle River begins to move at approximately 30,000 cfs (measured at the Gold Creek gage) and large pieces of wood become mobile at approximately 40,000 cfs. These flows have a recurrence interval of 1 to 2 years suggesting less stable logs move frequently in the river system.
- Wood in side sloughs and upland sloughs appears to be primarily from local sources and is relatively stable. Beaver dams provide local hydraulic controls and aquatic habitat in some side/upland sloughs. Beavers fell large trees (up to 36-inch dbh balsam poplar) in localized areas in both the Middle and Lower River.
- Large balsam poplar trees with attached root wads and large log jams provide local roughness elements, scour pools, and aquatic cover habitat.

The methods used for the aerial photograph and field inventories were successful in capturing pertinent information to meet study objectives; no changes to methods are anticipated for the 2014 study effort. Analysis in the next study year will include integration with the Ice Processes in the Susitna River Study (Study 7.6) and the Riparian Vegetation Study Downstream of the Proposed Watana Dam (Study 11.6). Ongoing coordination with these study leads indicates the anticipated data will be available for study integration as planned.

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

The assessments of the geomorphology of stream crossings along transmission lines and access alignments will take place in 2014 and will be provided in the USR.

## 6.11. Study Component: Integration of Fluvial Geomorphology Modeling below Watana Dam Study with the Geomorphology Study

The development of 1-D and 2-D Bed Evolution models is being supported by the results of the Geomorphology Study, including geomorphic reach delineation, characterization of geomorphic processes, tributary sediment supplies, and sediment-load analyses that are currently available. The modeling results will be compared with observations to evaluate whether geomorphic processes are represented, especially as they relate to various habitat conditions. The integration process involves continuous coordination between the modeling and geomorphology studies so that the conceptual models of geomorphic processes can be informed by the model results and vice versa. For example, the model results will provide stage-discharge information that will be used to determine the frequencies of inundation for the types of floodplain surfaces, which will be used to better understand floodplain surface accretion rates and riparian habitat development.

# 7. COMPLETING THE STUDY

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

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# 9. TABLES

**Table 4.1- 1. Upstream and Downstream PRM Boundaries for Geomorphic Assessment Areas.**

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

**Table 4.2- 1. 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 | 0.9 | 0.054 | 1.76 |
| Total of the three stations near Talkeetna | 10,906 | 15,925,000 | 7.06 | 5.37 | 0.43 | 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 | 2.2 |

**Table 4.2- 2. Sediment Transport Data Summary.**

| Gage Number | Gage Name | Number of Samples | | | | | | | | Record |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Suspended Silt/Clay | | Suspended Sand | | Bed Load Sand | | Bed Load Gravel | | |
| | | Pre-1985 | Post-1985 | Pre-1985 | Post-1985 | Pre-1985 | Post-1985 | Pre-1985 | Post-1985 | |
| 15292000 | Susitna River at Gold Creek | 45 | 5 | 46 | 5 | 45 | 0 | 38 | 0 | 1962 - 1986 |
| 15292400 | Chulitna River near Talkeetna | 48 | 2 | 46 | 2 | 48 | 0 | 48 | 0 | 1973 - 1986 |
| 15292700 | Talkeetna River near Talkeetna | 53 | 23 | 56 | 22 | 45 | 0 | 40 | 0 | 1967 - 1995 |
| 15292780 | Susitna River at Sunshine | 52 | 2 | 53 | 2 | 50 | 0 | 50 | 0 | 1971 - 1986 |
| 15294345 | Yentna River near Susitna Station | 24 | 1 | 24 | 1 | 13 | 0 | 13 | 0 | 1981 - 1986 |
| 15294350 | Susitna River at Susitna Station | 37 | 9 | 35 | 9 | 13 | 5 | 13 | 3 | 1975 - 2003 |

**Table 4.2- 3. Summary of Samples Collected or Planned for 2012, 2013, and 2014.**

| Gage Number | Gage Name | Year of Collection | Discharge Gage Station (Y/N) | Number of Samples Collected (2012 and 2013) or Planned (2014) | | |
|---|---|---|---|---|---|---|
| | | | | Suspended Sediment | Bed Load Sediment | Bed Material |
| 15291700 | Susitna R above Tsusena Creek | 2012 | N | 6 | 5 | 1 |
| 15291700 | Susitna R above Tsusena Creek | 2013 | N | 7 | 2 | 1 |
| 15291700 | Susitna R above Tsusena Creek | Next year of Study | N | 5 | 0 | 0 |
| 15292000 | Susitna River at Gold Creek | 2012 | Y | 0 | 0 | 0 |
| 15292000 | Susitna River at Gold Creek | 2013 | Y | 5 | 0 | 0 |
| 15292000 | Susitna River at Gold Creek | Next year of Study | Y | 0 | 0 | 0 |
| 15292100 | Susitna River near Talkeetna, AK | 2012 | N | 5 | 6 | 0 |
| 15292100 | Susitna River near Talkeetna, AK | 2013 | N | 5 | 4 | 0 |
| 15292100 | Susitna River near Talkeetna, AK | 2014 | N | 5 | 5 | 1 |
| 15292400 | Chulitna River near Talkeetna, AK | 2012 | Y | 3 | 0 | 0 |

| Gage Number | Gage Name | Year of Collection | Discharge Gage Station (Y/N) | Number of Samples Collected (2012 and 2013) or Planned (2014) | | |
|---|---|---|---|---|---|---|
| | | | | Suspended Sediment | Bed Load Sediment | Bed Material |
| 15292400 | Chulitna River near Talkeetna, AK | 2013 | Y | 5 | 0 | 0 |
| 15292400 | Chulitna River near Talkeetna, AK | Next year of Study | Y | 0 | 0 | 0 |
| 15292410 | Chulitna River below Canyon near Talkeetna, AK | 2012 | N | 5 | 4 | 0 |
| 15292410 | Chulitna River below Canyon near Talkeetna, AK | 2013 | N | 1 | 4 | 0 |
| 15292410 | Chulitna River below Canyon near Talkeetna, AK | Next year of Study | N | 5 | 5 | 1 |
| 15292700 | Talkeetna River at Talkeetna, AK | 2012 | Y | 0 | 0 | 0 |
| 15292700 | Talkeetna River at Talkeetna, AK | 2013 | Y | 9 | 5 | 0 |
| 15292700 | Talkeetna River at Talkeetna, AK | Next year of Study | Y | 5 | 5 | 1 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 2012 | Y | 10 | 6 | 0 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 2013 | Y | 6 | 4 | 0 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | Next year of Study | Y | 5 | 5 | 1 |
| 15294345 | Yentna River near Susitna Station | 2012 | N | 0 | 0 | 0 |
| 15294345 | Yentna River near Susitna Station | 2013 | N | 5 | 4 | 0 |
| 15294345 | Yentna River near Susitna Station | Next year of Study | N | 5 | 5 | 1 |
| 15294350 | Susitna River at Susitna Station | 2012 | Y | 0 | 0 | 0 |
| 15294350 | Susitna River at Susitna Station | 2013 | Y | 5 | 4 | 0 |
| 15294350 | Susitna River at Susitna Station | Next year of Study | Y | 5 | 5 | 1 |

**Table 4.3- 1. Sediment Transport Data Summary.**

| Gage Number | Gage Name | Number of Samples | | | | | | | | Record |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Suspended Silt/Clay | | Suspended Sand | | Bed Load Sand | | Bed Load Gravel | | |
| | | Pre-1985 | Post-1985 | Pre-1985 | Post-1985 | Pre-1985 | Post-1985 | Pre-1985 | Post-1985 | |
| 15292000 | Susitna River at Gold Creek | 45 | 5 | 46 | 5 | 45 | 0 | 38 | 0 | 1962 - 1986 |
| 15292400 | Chulitna River near Talkeetna | 48 | 2 | 46 | 2 | 48 | 0 | 48 | 0 | 1973 - 1986 |
| 15292700 | Talkeetna River near Talkeetna | 53 | 23 | 56 | 22 | 45 | 0 | 40 | 0 | 1967 - 1995 |
| 15292780 | Susitna River at Sunshine | 52 | 2 | 53 | 2 | 50 | 0 | 50 | 0 | 1971 - 1986 |
| 15294345 | Yentna River near Susitna Station | 24 | 1 | 24 | 1 | 13 | 0 | 13 | 0 | 1981 - 1986 |
| 15294350 | Susitna River at Susitna Station | 37 | 9 | 35 | 9 | 13 | 5 | 13 | 3 | 1975 - 2003 |

**Table 4.3- 2. Summary of Sediment Load Relationships Used For the Analysis.**

| Gage Number | Gage Name | Suspended Load | | Bed Load | |
|---|---|---|---|---|---|
| | | **Silt/Clay** | **Sand** | **Sand** | **Gravel** |
| 15292000 | Susitna River at Gold Creek | 6.97E-10 $Q^{3.00}$ | 1.09E-11 $Q^{3.38}$ | 4.49E-9 $Q^{2.46}$ | 1.89E-20 $Q^{4.84}$ |
| | | | n = 51 (46/5), $R^2$ = 0.89 | 1.02E-11 $Q^{3.10}$ | |
| 15292400 | Chulitna River near Talkeetna | 1.12E-7 $Q^{2.66}$ | 1.01E-5 $Q^{2.14}$ | 5.1E-6 $Q^{2.09}$ | 2.6E-9 $Q^{2.80}$ |
| | | n = 50 (48/2), $R^2$ = 0.91 | n = 48 (46/2), $R^2$ = 0.86 | 3.51E-12 $Q^{3.63}$ | 1.23E-14 $Q^{4.22}$ |
| 15292700 | Talkeetna River near Talkeetna | 2.33E-8 $Q^{2.81}$ | 2.58E-6 $Q^{2.32}$ | 2.17E-5 $Q^{1.82}$ | Parker Equation |
| | | n = 76 (53/23), $R^2$ = 0.76 | n = 78 (56/22), $R^2$ = 0.86 | 1.43E-12 $Q^{3.99}$ | |
| 15292780 | Susitna River at Sunshine | 2.29E-8 $Q^{2.61}$ | 3.28E-6 $Q^{2.12}$ | 8.16E-4 $Q^{1.29}$ | 3.11E-17 $Q^{4.07}$ |
| | | n = 54 (52/2), $R^2$ = 0.82 | n = 55 (53/2), $R^2$ = 0.83 | | 3.68E-2 $Q^{0.820}$ |
| 15294345 | Yentna River near Susitna Station | 1.27E-7 $Q^{2.48}$ | 4.10E-6 $Q^{2.14}$ | 1.93E-4 $Q^{1.63}$ | 1.99E-9 $Q^{2.49}$ |
| | | n = 25 (24/1), $R^2$ = 0.94 | n = 25 (24/1), $R^2$ = 0.84 | | |
| 15294350 | Susitna River at Susitna Station | 4.49E-8 $Q^{2.46}$ | 3.31E-3 $Q^{1.46}$ | 4.45E-7 $Q^{2.04}$ | 4.85E-10 $Q^{2.47}$ |
| | | n = 46 (37/9), $R^2$ = 0.87 | n = 44 (35/9), $R^2$ = 0.87 | n = 18 (13/5), $R^2$ = 0.92 | n = 16 (13/3), $R^2$ = 0.92 |

from Knott et al (1987)

New Regression

Q = Water discharge in cfs

Sediment load in tons/day (tpd)

n = Total number of sample points (pre-1985 data/post-1985 data)

**Table 4.4- 1. 2012 Aerial Photo Summary.**

| Aerial Coverage (PRM) | | Date | Used for Mapping | Actual Discharge (cfs) | |
|---|---|---|---|---|---|
| From | To | | | Gold Creek | Sunshine |
| Upper River | | | | | |
| 265.2 | 231.7 | 10/20/2012 | | 7,410 | --- |
| 242.3 | 187.1 | 9/30/2012 | | 17,000 | --- |
| Middle River | | | | | |
| 187.1 | 143.6 | 9/30/2012 | X | 17,000 | --- |
| 143.6 | 141.4 | 9/30/2012 | | 17,000 | --- |
| 143.6 | 102.4 | 9/10/2012 | X | 12,900 | --- |
| 118.9 | 102.4 | 7/27/2012 | | 22,200 | --- |
| Lower River | | | | | |
| 102.4 | 63.1 | 7/27/2012 | | --- | 54,700 |
| 102.4 | 77.7 | 9/10/2012 | X | --- | 37,900 |
| 77.7 | 69 | 9/30/2012 | X | --- | 47,400 |
| 72.2 | 69 | 10/10/2012 | | --- | 54,100 |
| 69 | 33.5 | 10/10/2012 | X | --- | 54,100 |
| 33.5 | 22.5 | 9/30/2012 | X | --- | 47,400 |
| 22.5 | 0 | 10/10/2012 | X | --- | 54,100 |
| 77.7 | 0 | 9/30 - 10/1/2013 | X[1] | --- | 47,400 to 41,200 |

Notes:

1. The 9/30/2012 and 10/01/2012 photos were used tor coverage of the west (river right) floodplain of the Susitna River.

**Table 4.4- 2. Summary of 2013 Aerial Photography.**

| Aerial Coverage (PRM) | | Date | Discharge (cfs) | |
|---|---|---|---|---|
| From | To | (MM/DD/YYYY) | Gold Creek | Sunshine |
| Upper Susitna River Segment | | | | |
| 265.2 | 247.2 | 9/16/2013 | 19,200 | --- |
| 247.2 | 214.8 | 9/20/2013 | 15,300 | --- |
| 214.8 | 187.1 | 9/16/2013 | 19,200 | --- |
| Middle Susitna River Segment | | | | |
| 187.1 | 184.9 | 9/16/2013 | 19,200 | --- |
| 184.9 | 153.6 | 11/6/2013 | 6,200[1] | --- |
| 153.6 | 106.8 | 9/24/2013 | 11,300 | --- |
| 106.8 | 102.4 | 9/20/2013 | 15,300 | |
| Lower Susitna River Segment | | | | |
| 102.4 | 0 | 9/20/2013 | --- | 35,500 |

Notes:

1. USGS Gold Creek gage was not in operation on 11/6 due to ice cover, the average daily flow on 1/6 was extrapolated from the preceding week's daily discharges

**Table 4.4- 3. Summary of 1980s Aerials Used to Delineate Geomorphic Features.**

| Aerial Coverage (PRM) | | Date | Used for Mapping | Discharge (cfs) | |
|---|---|---|---|---|---|
| From | To | (MM/DD/YYYY) | | Gold Creek | Sunshine Station |
| Upper Susitna River Segment | | | | | |
| 251 | 187 | 7/19 and 7/20/1980 | | 35,800 & 31,600 | --- |
| Middle Susitna River Segment | | | | | |
| 187 | 154 | 7/19 and 7/20/1980 | X | 35,800 & 31,600 | --- |
| 154 | 102 | 9/11/1983 | X | 12,500 (12,200 published) | --- |
| Lower Susitna River Segment | | | | | |
| 102 | 0 | 9/6/1983 | X | --- | 36,600 |

**Table 4.4- 4. 1950s Aerial Photo Summary.**

| Aerial Coverage (PRM) | | Date | Used for Mapping | Discharge (cfs) | |
|---|---|---|---|---|---|
| From | To | (MM/DD/YYYY) | | Gold Creek | Sunshine[1] |
| Middle Susitna River Segment | | | | | |
| 191.5 | 187 | 8/15/1949 | | 25,800 | -- |
| 187 | 158.5 | 8/15/1949 | X | 25,800 | -- |
| 158.9 | 158.5 | 8/10/1949 | | 29,900 | -- |
| 158.5 | 151.8 | 8/10/1949 | X | 29,900 | -- |
| 151.8 | 140.9 | 8/10/1949 | | 29,900 | -- |
| 151.8 | 102 | 7/3/1951 | X | 19,000 | -- |
| Lower Susitna River Segment | | | | | |
| 102 | 33.4 | 7/3/1951 | X | (19,000)[2] | *45,100*[1] |
| 45.2 | 40 | 7/11/1954 | | (19,000) | *47,200* |
| 40[3] | 38.5[3] | 7/11/1954[3] | X[3] | (19,000) | *47,200* |
| 38.3 | 33.4 | 7/23/1953 | | (19,300) | *48,000* |
| 33.4 | 28.5 | 7/23/1953 | X | (19,300) | *48,000* |
| 31.3 | 28.5 | 7/25/1953 | | (20,000) | *49,800* |
| 28.5 | 27.4 | 7/25/1953 | X | (20,000) | *49,800* |
| 27.4 | 26 | 7/25/1953 | | (20,000) | *49,800* |
| 27.4 | 21.5 | 8/12/1952 | X | (24,400) | *61,400* |
| 21.5 | 20.6 | 8/12/1952 | | (24,400) | *61,400* |
| 21.5 | 0 | 9/2/1952 | X | (28,700) | *70,600* |

Notes:

1. Discharges shown in italics are synthesized flows from the extended flow record developed by the USGS (2013) and may not reflect actual flows
2. Discharges in parentheses are measured flows at Gold Creek and were used to develop the USGS extended flow record (USGS 2012)
3. 07/11/1954 Aerial photos only used on the river right floodplain

**Table 4.4- 5. 1950s Aerial Photography Parameters and Control Residuals.**

| USGS Project ID | Photo Block Parameters | | | | | | Control Residuals | | |
|---|---|---|---|---|---|---|---|---|---|
| | Date | # exposures | Camera ID | # ctl pts | Image Residuals (microns) | Orthophoto Tiles | $RMSE_x$ (ft) | $RMSE_y$ (ft) | $RMSE_z$ (ft) |
| ARBM137A | 25-Jul-53 | 2 | Unknown | 6 | 22.5 | 8 | 3.57 | 8.02 | 9.67 |
| ARBM4G18 | 11-Jul-54 | 4 | SF-269 | 19 | 14.7 | 30 | 13.23 | 6.88 | 7.43 |
| ARBM134A | 23-Jul-53 | 7 | AF41-4167 | 23 | 17.8 | 26 | 30.46 | 25.57 | 9.51 |
| ARBM0639 | 12-Aug-52 | 8 | AF41-4142 | 17 | 15.1 | 15 | 29.64 | 20.04 | 28.42 |
| ARBM0653 | 2-Sep-52 | 28 | AF41-4144 | 24 | 13.1 | 41 | 38.66 | 40.41 | 26.42 |
| ARBM0826 | 10-Aug-49 | 19 | AF41-4097 | 34 | 20.6 | 30 | 36.70 | 37.02 | 26.73 |
| ARBM0836 | 15-Aug-49 | 29 | AF41-4097 | 55 | 22.8 | 40 | 64.95 | 65.74 | 23.00 |
| ARBM0513 | 3-Jul-51 | 141 | AF41-4171 | 197 | 15.2 | 239 | 53.51 | 47.96 | 29.61 |

**Table 4.5- 1. Selected Aquatic Habitat Sites in the Middle Susitna River Segment.**

| Habitat Site | | Project River Mile | | Geomorphic Reach |
|---|---|---|---|---|
| Number | Name | Upstream | Downstream | |
| Middle Susitna River Segment | | | | |
| 23 | Below Dam[1] | 185.7 | 184.7 | MR-1 |
| 22 | MR-2 Island Bend[1] | 183.5 | 180.8 | MR-2 |
| 21 | MR-2 Tributary[1] | 179.7 | 178.7 | MR-2 |
| 20 | MR-2 Straight[1] | 177.8 | 176.1 | MR-2 |
| 19 | MR-2 Wide[1] | 175.4 | 173.6 | MR-2 |
| 18 | MR-2 Narrow[1] | 173 | 171.6 | MR-2 |
| 17 | Portage Creek | 152.3 | 151.8 | MR-5 |
| 16 | Fat Canoe Island | 151.0 | 149.9 | MR-5 |
| 15 | Slough 22 | 148.3 | 147.4 | MR-6 |
| 14 | Slough 21 | 145.8 | 143.1 | MR-6 |
| 13 | Indian River | 143.1 | 141.7 | MR-6 |
| 12 | Gold Creek | 141.6 | 140 | MR-6 |
| 11 | Slough 11 | 140 | 137.6 | MR-6 |
| 10 | Side Channel 10 | 137.6 | 136.3 | MR-6 |
| 9 | Side Channel 10A | 136.1 | 134.1 | MR-6 |
| 8 | Slough 9 | 132.8 | 131.3 | MR-6 |
| 7 | Slough 8A | 130.2 | 128 | MR-6 |
| 6 | Oxbow II | 124 | 122.7 | MR-6 |
| 6 | Oxbow II | 122.7 | 121.9 | MR-7 |
| 5 | Slough 8 | 119 | 116.9 | MR-7 |
| 4 | Slough 6A | 116.5 | 115.5 | MR-7 |
| 3 | Slough 5 | 112.1 | 110.7 | MR-7 |
| 2 | Slough 4 | 110.2 | 108.7 | MR-7 |
| 1 | Whiskers Slough | 105.9 | 104.4 | MR-8 |

Notes:

1 Site not studied in the 1980s

**Table 4.9- 1. Proposed Large Woody Debris (LWD) Sample Areas by Geomorphic Reach.**

| Geomorphic Reach | Reach Length (mi) | LWD Sample Areas (*Red italics- next study year*) | | | |
|---|---|---|---|---|---|
| | | Number Within Focus Areas | Focus Area IDs | Number Outside of Focus Areas | Locations (PRM) |
| UR-1 | 13 | - | | *1* | *250-251 or 259-260* |
| UR-2 | 14 | - | | *1* | *240-241* |
| UR-3 | 10 | - | | *1* | *231-233* |
| UR-4 | 17 | - | | *2* | *222-224,*<br>*211-214 or 208-210* |
| UR-5 | 5 | - | | *1* | *206-207* |
| UR-6 | 16 | - | | *2* | *196-197,*<br>*199-201* |
| MR-1 | 2 | *1* | *Focus Area 181* | | |
| MR-2 | 15 | *1* | *Focus Area 173* | *1* | *181* |
| MR-3 | 4 | - | | - | |
| MR-4 | 12 | - | | *-* | |
| MR-5 | 6 | *1* | Focus Area 151 | - | |
| MR-6 | 25 | 4 | Focus Area 144<br>Focus Area 141<br>Focus Area 138<br>Focus Area 128 | 2 | 126<br>135-136 |
| MR-7 | 16 | 2 | Focus Area 115<br>Focus Area 113 | 2 | 109-110<br>121-122 |
| MR-8 | 6 | 1 | Focus Area 104 | - | |
| LR-1 | 14 | - | | 1 | 92-93 |
| LR-2 | 22 | - | | 1 | 78-82 |
| LR-3 | 21 | - | | 1 | 47-51 |
| LR-4 | 13 | - | | 1 | 40-43 |
| LR-5 | 9 | - | | 1 | 26-28 |
| LR-6 | 20 | - | | *1* | *9-12* |

**Table 5.1- 1. Geomorphic Reach Delineations and Classifications.**

| Reach Designation | Reach Breaks ( PRM / *RM* ) | | Reach Classifi-cation | Slope (ft/mi) | Lateral Constraints |
|---|---|---|---|---|---|
| | Upstream | Downstream | | | |
| Upper Susitna River Segment (UR) | | | | | |
| UR-1 | 261.3 / *260.0* | 248.6 / *247.7* | SC2 | 4 | Quaternary Basin Fill |
| UR-2 | 248.6 / *247.7* | 234.5 / *233.0* | SC1 | 11 | Quaternary Basin Fill |
| UR-3 | 234.5 / *233.0* | 224.9 / *223.1* | SC1 | 20 | Quaternary Basin Fill |
| UR-4 | 224.9 / *223.1* | 208.1 / *205.7* | SC2 | 14 | Granodiorite |
| UR-5 | 208.1 / *205.7* | 203.4 / *200.8* | SC1 | 11 | Quaternary Basin Fill |
| UR-6 | 203.4 / *200.8* | 187.1 / *184.3* | SC2 | 10 | Quaternary Basin Fill |
| Middle Susitna River Segment (MR) | | | | | |
| MR-1 | 187.1 / *184.3* | 184.6 / *181.9* | SC2 | 9.4 | Tertiary-Cretaceous Gneiss |
| MR-2 | 184.6 / *181.9* | 169.6 / *166.4* | SC2 | 10.9 | Cretaceous Kahiltna Flysch Tertiary-Cretaceous Gneiss |
| MR-3 | 169.6 / *166.4* | 166.1 / *163.0* | SC2 | 11.0 | Paleocene Granites |
| MR-4 | 166.1 / *163.0* | 153.9 / *150.3* | SC1 | 30.6 | Paleocene Granites |
| MR-5 | 153.9 / *150.3* | 148.4 / *144.9* | SC2 | 12.1 | Cretaceous Kahiltna Flysch |
| MR-6 | 148.4 / *144.9* | 122.7 / *118.9* | SC3 | 10.8 | Cretaceous Kahiltna Flysch with undifferentiated Upper Pleistocene moraines, kames, lacustrine deposits |
| MR-7 | 122.7 / *118.9* | 107.8 / *104.1* | SC2 | 8.5 | Cretaceous Kahiltna Flysch with undifferentiated Upper Pleistocene moraines, kames, lacustrine deposits |
| MR-8 | 107.8 / *104.1* | 102.4 / *98.6* | MC1/SC3 (Reach is a transition from SC3 to MC1 as the Three Rivers Confluence is approached) | 7.3 | Upper Pleistocene moraines, outwash and Holocene Alluvial Terrace deposits |
| Lower Susitna River Segment (LR) | | | | | |
| LR-1 | 102.4 / *98.6* | 87.9 / *83.8* | MC1 | 6.0 | Upper Pleistocene Outwash, Moraine and Lacustrine deposits |
| LR-2 | 87.9 / *83.8* | 65.6 / *61.4* | MC2/MC3 | 5.0 | Upper Pleistocene Outwash, Moraine and Lacustrine deposits |
| LR-3 | 65.6 / *61.4* | 44.6 / *40.3* | MC3 | 4.1 | Upper Pleistocene Glaciolacustrine deposits |
| LR-4 | 44.6 / *40.3* | 32.3 / *28.3* | MC2 | 1.9 | Upper Pleistocene Glaciolacustrine deposits |
| LR-5 | 32.3 / *28.3* | 23.5 / *19.4* | SC2 | 1.3 | Upper Pleistocene Glaciolacustrine and Moraine deposits and Late Cretaceous granodiorite |
| LR-6 | 23.5 / *19.4* | 3.3 / *0.0* | MC4 | 1.5 | Upper Pleistocene Glaciolacustrine and Holocene Estuarine deposits |

**Table 5.1- 2. Summary of Geomorphic Parameters by Reach for the Middle and Lower Susitna River Segments.**

| Reach | Length (mi) | Gradient (ft/mi) | Sinuosity | Average Width (feet) | | | Entrench-ment Ratio[1,3] | Entrench-ment Ratio[2,3] | Median Bed Material Size (mm)[4] | Number of Bed Material Samples[4] | Channel Branching[6] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Active Channel | Valley Bottom[1] | Valley Bottom[2] | | | | | Avg Number Channels | Standard Deviation | Number of Sampled Transects |
| MR-1 | 2.5 | 9.4 | 1.03 | 655 | 782 | | 1.2 | | | | 1.2 | 0.5 | 18 |
| MR-2 | 15.0 | 10.9 | 1.06 | 715 | 1,512 | | 2.1 | | | | 1.4 | 0.8 | 111 |
| MR-3 | 3.5 | 11.0 | 1.02 | 594 | 781 | | 1.3 | | | | 1.1 | 0.3 | 32 |
| MR-4 | 12.2 | 30.6 | 1.03 | 312 | 370 | | 1.2 | | | | 1.0 | 0.2 | 207 |
| MR-5 | 5.5 | 12.1 | 1.03 | 512 | 851 | | 1.7 | | 70[5] | N/A[5] | 1.2 | 0.5 | 57 |
| MR-6 | 25.7 | 10.8 | 1.09 | 985 | 2,350 | 2,220 | 2.4 | 2.3 | 61 | 48 | 2.4 | 1.1 | 138 |
| MR-7 | 14.9 | 8.5 | 1.05 | 845 | 2,050 | 1,900 | 2.4 | 2.2 | 58 | 27 | 1.8 | 1.0 | 93 |
| MR-8 | 5.4 | 7.3 | 1.19 | 1,132 | 8,960 | 6,380 | 7.9 | 5.6 | 50 | 12 | 2.7 | 1.8 | 26 |
| LR-1 | 14.5 | 6.0 | 1.12 | 3,340 | 9,210 | 8,940 | 2.8 | 2.7 | 42 | 12 | 4.0 | 2.3 | 25 |
| LR-2 | 22.3 | 5.0 | 1.16 | 3,120 | 7,800 | | 2.5 | | 32 | 18 | 5.6 | 2.9 | 38 |
| LR-3 | 21.0 | 4.1 | 1.23 | 4,040 | 16,070 | | 4.0 | | 31 | 18 | 8.8 | 3.7 | 28 |
| LR-4 | 12.3 | 1.9 | 1.24 | 2,750 | 12,290 | | 4.3 | | 33 | 15 | 5.1 | 2.0 | 24 |
| LR-5 | 8.8 | 1.3 | 1.13 | 3,250 | 8,880 | | 2.7 | | 25 | 3 | 1.9 | 0.6 | 15 |
| LR-6 | 20.2 | 1.5 | 1.43 | 5,280 | 31,000 | | 5.9 | | | | 6.2 | 3.1 | 20 |

Notes:

1. Effects of manmade features, including railroad grade, levees, etc. not considered in valley bottom width.
2. Valley bottom width reflects confining effects of manmade features, including railroad grade, levees, etc.
3. Ratio of valley bottom width to active channel width.
4. Values calculated from 2013 collected bed-material data (i.e. surface samples).
5. Value from 1980s bed-material data
6. Number of channels separated by relatively stable, vegetated islands.

**Table 5.1- 3. Summary of Valley Floor Constriction Characteristics in MR-6, MR-7 and MR-8.**

| FA (GAA) | Nature of Constriction |
|---|---|
| FA-104 | Not applicable |
| FA-113 | Outwash terrace on the west and lateral moraine on the east |
| FA-115 | Granodiorite outcrop on west and lateral moraine on the east |
| FA-128 | Kahiltna Flysch metasediments on the west and Skull Creek fan on the east |
| FA-138 | Kahiltna Flysch metasediments on the west and outwash terrace on the east |
| FA-141 | Outwash terrace on the west and Gold Creek fan on the east |
| FA-144 | Outwash terrace on the west and un-named tributary fan on the east |

**Table 5.1- 4. Field Observed Beaver Dam Locations within Focus Areas.**

| Focus Area | Active | Height (ft) | Latitude | Longitude | Notes |
|---|---|---|---|---|---|
| FA-104 | YES | 5.5 | 62.38251 | -150.16148 | Large beaver dam in upland slough |
| FA-104 | UNKNOWN | n/a | 62.38379 | -150.15707 | True right bank of beaver pond across from side channel and upland slough |
| FA-113 | NO | n/a | 62.49256 | -150.11053 | Center of old beaver dam |
| FA-113 | NO | n/a | 62.51766 | -150.12950 | Abandoned beaver dam that has partially filled in -- raised water table |
| FA-113 | NO | n/a | 62.51711 | -150.12426 | Old beaver dam - intact but doesn't appear to be active |
| FA-115 | YES | n/a | 62.51861 | -150.12316 | Active beaver dam in upland slough |
| FA-115 | NO | 5.0 | 62.50936 | -150.11909 | Old abandoned breached beaver dam |
| FA-128 | YES | n/a | 62.66334 | -149.92648 | Upstream end of side slough - 2 beaver dams |
| FA-138 | NO | n/a | 62.76393 | -149.70025 | Downstream end of blown out beaver dam |
| FA-138 | NO | n/a | 62.76409 | -149.70043 | Blown out dam |
| FA-138 | YES | 1.5 | 62.75810 | -149.70290 | Beaver dam across side channel |
| FA-138 | YES | 2.0 | 62.75723 | -149.70461 | Beaver dam - head of coarse riffle |
| FA-138 | YES | 2.0 | 62.75803 | -149.70290 | Beaver dam on side slough |
| FA-138 | YES | 3.0 | 62.75481 | -149.70786 | Downstream end of beaver dam |
| FA-141 | UNKNOWN | 3.0 | 62.78940 | -149.64857 | Beaver dam across upland slough |
| FA-141 | YES | 4.5 | 62.78810 | -149.65013 | Active beaver dam in upland slough |
| FA-144 | YES | n/a | 62.81134 | -149.58243 | Confluence of side slough at beaver dam & channel coming in from mainstem |
| FA-144 | NO | n/a | 62.81362 | -149.57591 | Old beaver dam at mouth of side slough (backed up from beaver dam @ WP107) |

**Table 5.1- 5. Average Width for Geomorphic Surfaces within Geomorphic Assessment Areas from Digitized Aerial Photographs (2012) at Flows of 12,900 Cfs; Exception, GAA-Slough 21 was Digitized at 17,000 cfs.**

| Geomorphic Assessment Area | Average MC Width | Average Total Secondary Channel[1] Width | Average Valley Floor[2] Width | Ratio of Main Channel to Valley Floor Width |
|---|---|---|---|---|
| | ft | ft | ft | ft/ft |
| GAA-Whiskers Slough | 554 | 390 | 4083 | 0.1 |
| GAA-Oxbow I | 476 | 376 | 1771 | 0.3 |
| GAA-Slough 6A | 514 | 426 | 2731 | 0.2 |
| GAA-Slough 8A | 586 | 542 | 2903 | 0.2 |
| GAA-Gold Creek | 568 | 401 | 2564 | 0.2 |
| GAA-Indian River | 585 | 239 | 2353 | 0.2 |
| GAA-Slough 21 | 580 | 328 | 1600 | 0.4 |

Notes:

1. Total secondary channel width is a summation of the following geomorphic feature areas divided by the GAA length: Side Channel, Side Channel Gravel Bar, Side Slough and Upland Slough.
2. Valley floor width is comprised of the following geomorphic feature areas dived by the GAA length: Main Channel, Side Channel, Gravel Bars, Side Slough, Upland Slough, Overflow Channel, Vegetated Bar, Young Floodplain, Mature Floodplain, Old Floodplain, Terrace and Paleo Channel.

**Table 5.1- 6. Field Measured Geomorphic Surface Elevations and Standard Deviations for FA-104 Whiskers Slough.**

| FA-104 | | | | | | |
|---|---|---|---|---|---|---|
| | GB | VB | YFP | MFP | OFP | TCE |
| Sample Count | 1 | 7 | 2 | 9 | 8 | 20 |
| Mean Elevation (ft) | 374.4 | 377.4 | 379.3 | 378.9 | 382.7 | 384.1 |
| St. Dev (ft) | n/a | 1.6 | 1.8 | 1.3 | 1.3 | 2.8 |

**Table 5.1- 7. Field Measured Geomorphic Surface Elevations and Standard Deviations for FA-113 Oxbow I.**

| FA-113 | | | | | | |
|---|---|---|---|---|---|---|
| | GB | VB | YFP | MFP | OFP | TCE |
| Sample Count | 0 | 11 | 4 | 4 | 7 | 3 |
| Mean Elevation (ft) | n/a | 453.8 | 455.8 | 455.8 | 456.4 | 460.0 |
| St. Dev (ft) | n/a | 0.6 | 0.9 | 0.6 | 1.2 | 1.7 |

**Table 5.1- 8. Field Measured Geomorphic Surface Elevations and Standard Deviations for FA-115 Slough 6A.**

| FA-115 | | | | | | |
|---|---|---|---|---|---|---|
| | GB | VB | YFP | MFP | OFP | TCE |
| Sample Count | 1 | 7 | 0 | 13 | 8 | 4 |
| Mean Elevation (ft) | 460.8 | 464.6 | n/a | 467.4 | 468.0 | 469.7 |
| St. Dev (ft) | n/a | 0.9 | n/a | 1.4 | 1.0 | 1.6 |

**Table 5.1- 9. Field Measured Geomorphic Surface Elevations and Standard Deviations for FA-128 Slough 8A.**

| FA-128 | | | | | | |
|---|---|---|---|---|---|---|
| | GB | VB | YFP | MFP | OFP | TCE |
| Sample Count | 0 | 7 | 5 | 5 | 8 | 0 |
| Mean Elevation (ft) | n/a | 583.4 | 582.9 | 585.3 | 585.9 | n/a |
| St. Dev (ft) | n/a | 0.7 | 2.3 | 0.6 | 1.1 | n/a |

**Table 5.1- 10. Field Measured Geomorphic Surface Elevations and Standard Deviations for FA-138 Gold Creek.**

| FA-138 | | | | | | |
|---|---|---|---|---|---|---|
| | GB | VB | YFP | MFP | OFP | TCE |
| Sample Count | 4 | 10 | 3 | 10 | 1 | 9 |
| Mean Elevation (ft) | 680.6 | 682.4 | 685.1 | 685.4 | 685.8 | 686.7 |
| St. Dev (ft) | 1.6 | 0.7 | 0.4 | 0.8 | n/a | 1.6 |

**Table 5.1- 11. Field Measured Geomorphic Surface Elevations and Standard Deviations for FA-141 Indian River.**

| FA-141 | | | | | | |
|---|---|---|---|---|---|---|
| | GB | VB | YFP | MFP | OFP | TCE |
| Sample Count | 3 | 4 | 2 | 10 | 0 | 3 |
| Mean Elevation (ft) | 715.3 | 717.1 | 719.3 | 718.8 | n/a | 720.5 |
| St. Dev (ft) | 0.8 | 0.7 | 0.4 | 2.1 | n/a | 1.3 |

**Table 5.1- 12. Field Measured Geomorphic Surface Elevations and Standard Deviations for FA-144 Slough 21.**

| FA-144 | | | | | | |
|---|---|---|---|---|---|---|
| | GB | VB | YFP | MFP | OFP | TCE |
| Sample Count | 6 | 4 | 7 | 12 | 2 | 0 |
| Mean Elevation (ft) | 751.2 | 753.0 | 754.6 | 755.1 | 757.1 | n/a |
| St. Dev (ft) | 1.4 | 1.1 | 1.2 | 0.8 | 0.5 | n/a |

**Table 5.1- 13. Preliminary Analysis of Return Periods Associated with Geomorphic Surfaces.**

| Focus Area | Return Period (yr) | | | | |
|---|---|---|---|---|---|
| | VB | YFP | MFP | OFP | TCE |
| FA-104 | 23 | >100 | 82 | >1000 | >1000 |
| FA-113 | 9 | 38 | 38 | 61 | > 500 |
| FA-115 | 6 | n/a | 76 | >100 | > 500 |
| FA-128 | 6 | 4 | 35 | 59 | n/a |
| FA-138 | 6 | 73 | 97 | >100 | >300 |
| FA-141 | 3 | 14 | 10 | n/a | 37 |
| FA-144 | 13 | 82 | >100 | > 1000 | n/a |

**Table 5.2- 1. 2012 Suspended Sediment Transport Measurements.**

| Gage Number | Gage Name | Date of Collection | Time of Collection | Discharge | Suspended Sediment Concentration | Suspended Sediment Discharge, Qs | Suspended Sediment Percent finer than size indicated, in millimeters | | | | | | | | | | | | Silt and Clay | Sand | Sediment Discharge, Qs, Silt and Clay | Sediment Discharge, Qs, Sand |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (mg/L) | (tons/day) | 0.001 | 0.002 | 0.004 | 0.008 | 0.016 | 0.031 | 0.0625 | 0.125 | 0.25 | 0.5 | 1 | 2 | % | % | (tons/day) | (tons/day) |
| 15291700 | Susitna River above Tsusena Creek | 4/10/2012 | 13:50 | 0:00 | 3 | 9 | | | | | | | 54 | | | | | | 54 | 46 | 4.752 | 4.048 |
| 15291700 | Susitna River above Tsusena Creek | 5/10/2012 | 15:20 | 8610 | 321 | 7460 | 0 | 8 | 13 | 19 | 27 | 38 | 47 | 62 | 83 | 97 | 100 | 100 | 47 | 53 | 3506 | 3954 |
| 15291700 | Susitna River above Tsusena Creek | 6/3/2012 | 13:00 | 14200 | 151 | 5790 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 28 | 48 | 91 | 99 | 100 | 21 | 79 | 1216 | 4574 |
| 15291700 | Susitna River above Tsusena Creek | 7/2/2012 | 19:00 | 20600 | 283 | 15700 | 13 | 19 | 26 | 35 | 46 | 57 | 62 | 69 | 78 | 95 | 100 | 100 | 62 | 38 | 9734 | 5966 |
| 15291700 | Susitna River above Tsusena Creek | 8/7/2012 | 11:10 | 14000 | 184 | 6960 | 10 | 16 | 24 | 33 | 42 | 50 | 55 | 62 | 73 | 94 | 100 | 100 | 55 | 45 | 3828 | 3132 |
| 15291700 | Susitna River above Tsusena Creek | 9/14/2012 | 10:30 | 8170 | 44 | 971 | | | | | | | 35 | 46 | 67 | 91 | 99 | 100 | 35 | 65 | 340 | 631 |
| 15292100 | Susitna River near Talkeetna, AK | 5/23/2012 | 12:10 | 20000 | 498 | 26900 | 0 | 6 | 10 | 14 | 22 | 33 | 43 | 61 | 79 | 98 | 100 | 100 | 43 | 57 | 11,567 | 15,333 |
| 15292100 | Susitna River near Talkeetna, AK | 6/5/2012 | 11:30 | 30100 | 375 | 30500 | 0 | 6 | 10 | 13 | 18 | 26 | 34 | 50 | 80 | 99 | 100 | 100 | 34 | 66 | 10,370 | 20,130 |
| 15292100 | Susitna River near Talkeetna, AK | 7/10/2012 | 13:50 | 27900 | 334 | 25200 | 14 | 20 | 29 | 42 | 56 | 67 | 71 | 77 | 87 | 99 | 100 | 100 | 71 | 29 | 17,892 | 7,308 |
| 15292100 | Susitna River near Talkeetna, AK | 8/14/2012 | 16:50 | 17700 | 227 | 10800 | 29 | 40 | 52 | 65 | 77 | 84 | 87 | 91 | 94 | 99 | 100 | 100 | 87 | 13 | 9,396 | 1,404 |
| 15292100 | Susitna River near Talkeetna, AK | 9/25/2012 | 14:20 | 43700 | 857 | 101000 | 23 | 29 | 37 | 45 | 54 | 63 | 67 | 78 | 93 | 99 | 100 | 100 | 67 | 33 | 67,670 | 33,330 |
| 15292100 | Chulitna River near Talkeetna, AK | 5/17/2012 | 14:30 | 7940 | 244 | 5230 | | | | | | | 56 | | | | | | 56 | 44 | 2,929 | 2,301 |
| 15292400 | Chulitna River near Talkeetna, AK | 6/7/2012 | 16:20 | 19700 | 1120 | 59600 | | | | | | | 62 | | | | | | 62 | 38 | 36,952 | 22,648 |
| 15292400 | Chulitna River near Talkeetna, AK | 9/19/2012 | 17:40 | 34500 | 1510 | 141000 | | | | | | | 53 | | | | | | 53 | 47 | 74,730 | 66,270 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 5/17/2012 | 11:20 | 7950 | 244 | 5240 | 0 | 15 | 23 | 31 | 41 | 52 | 59 | 74 | 92 | 100 | 100 | 100 | 59 | 41 | 3092 | 2148 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 6/7/2012 | 13:50 | 19800 | 940 | 50300 | 0 | 29 | 41 | 52 | 61 | 66 | 70 | 81 | 91 | 98 | 100 | 100 | 70 | 30 | 35210 | 15090 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 7/11/2012 | 12:45 | 15800 | 416 | 17700 | 28 | 37 | 48 | 60 | 68 | 74 | 78 | 84 | 92 | 98 | 100 | 100 | 78 | 22 | 13806 | 3894 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 8/23/2012 | 16:55 | 15600 | 452 | 19000 | 26 | 33 | 42 | 51 | 61 | 69 | 74 | 80 | 90 | 99 | 100 | 100 | 74 | 26 | 14060 | 4940 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 9/19/2012 | 14:30 | 33600 | 944 | 85600 | 8 | 14 | 21 | 30 | 37 | 46 | 52 | 65 | 81 | 96 | 99 | 100 | 52 | 48 | 44512 | 41088 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 10/6/2011 | 16:10 | 13700 | 25 | 925 | | | | | | | 60 | | | | | | 60 | 40 | 555 | 370 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 1/31/2012 | 17:10 | 3580 | 8 | 77 | | | | | | | 26 | | | | | | 26 | 74 | 20 | 57 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 3/19/2012 | 19:30 | 2510 | 4 | 27 | | | | | | | 63 | | | | | | 63 | 37 | 17 | 10 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 5/22/2012 | 16:40 | 35100 | 421 | 39900 | 0 | 9 | 14 | 19 | 27 | 37 | 46 | 62 | 81 | 98 | 100 | 100 | 46 | 54 | 18354 | 21546 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 6/5/2012 | 20:30 | 63000 | 549 | 93400 | 0 | 13 | 19 | 26 | 33 | 42 | 47 | 63 | 81 | 95 | 100 | 100 | 47 | 53 | 43898 | 49502 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 7/10/2012 | 18:30 | 53900 | 383 | 55700 | 17 | 25 | 35 | 46 | 57 | 63 | 66 | 74 | 88 | 99 | 100 | 100 | 66 | 34 | 36762 | 18938 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 8/13/2012 | 18:30 | 43400 | 483 | 56600 | 30 | 39 | 52 | 64 | 75 | 82 | 84 | 90 | 95 | 100 | 100 | 100 | 84 | 16 | 47544 | 9056 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 9/17/2012 | 17:30 | 69200 | 823 | 154000 | 11 | 19 | 28 | 38 | 47 | 54 | 58 | 74 | 91 | 99 | 100 | 100 | 58 | 42 | 89320 | 64680 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 9/22/2012 | 14:30 | 154000 | 1680 | 699000 | 16 | 23 | 31 | 40 | 52 | 63 | 68 | 83 | 96 | 99 | 100 | 100 | 68 | 32 | 475320 | 223680 |
| 15292780 | Susitna River at Sunshine near Talkeetna, AK | 9/22/2012 | 15:30 | 154000 | 1680 | 699000 | 0 | 23 | 31 | 40 | 52 | 63 | 68 | 83 | 96 | 99 | 100 | 100 | 68 | 32 | 475320 | 223680 |

**Table 5.2- 2. 2012 Bed Load Sediment Transport Measurements.**

| Gage Number | Gage Name | Date of Collection | Time of Collection | Discharge | Bed Load Sediment Discharge, Qs | Bed Load Sediment, Percent finer than size indicated, in millimeters | | | | | | | | | | | | Sand | Gravel | Sediment Discharge, Qs, Sand | Sediment Discharge, Qs, Gravel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (tons/day) | 0.0625 | 0.125 | 0.25 | 0.5 | 1 | 2 | 4 | 8 | 16 | 31.5 | 63 | 128 | % | % | (tons/day) | (tons/day) |
| 15291700 | Susitna R above Tsusena Creek | 5/10/2012 | 14:40 | 9140 | 142 | 0 | 0 | 1 | 57 | 81 | 90 | 93 | 95 | 98 | 100 | 100 | 100 | 90 | 10 | 128 | 14 |
| 15291700 | Susitna R above Tsusena Creek | 6/3/2012 | 11:00 | 13700 | 900 | 0 | 0 | 1 | 40 | 70 | 79 | 83 | 87 | 92 | 94 | 100 | 100 | 79 | 21 | 711 | 189 |
| 15291700 | Susitna R above Tsusena Creek | 6/3/2012 | 11:50 | 13700 | 658 | 0 | 0 | 1 | 45 | 83 | 93 | 96 | 98 | 99 | 100 | 100 | 100 | 93 | 7 | 612 | 46 |
| 15291700 | Susitna R above Tsusena Creek | 7/2/2012 | 17:10 | 20600 | 488 | 0 | 0 | 0 | 45 | 79 | 89 | 94 | 97 | 99 | 100 | 100 | 100 | 89 | 11 | 434 | 54 |
| 15291700 | Susitna R above Tsusena Creek | 7/2/2012 | 18:00 | 20600 | 601 | 0 | 0 | 0 | 35 | 60 | 67 | 70 | 74 | 82 | 93 | 100 | 100 | 67 | 33 | 403 | 198 |
| 15291700 | Susitna R above Tsusena Creek | 8/6/2012 | 18:30 | 16000 | 328 | 0 | 0 | 0 | 48 | 82 | 92 | 95 | 98 | 100 | 100 | 100 | 100 | 92 | 8 | 302 | 26 |
| 15291701 | Susitna R above Tsusena Creek | 8/6/2012 | 19:00 | 16000 | 307 | 0 | 0 | 1 | 52 | 86 | 94 | 96 | 97 | 98 | 100 | 100 | 100 | 94 | 6 | 289 | 18 |
| 15291702 | Susitna R above Tsusena Creek | 9/13/2012 | 16:50 | 7650 | 31 | 0 | 0 | 0 | 44 | 78 | 91 | 94 | 96 | 96 | 100 | 100 | 100 | 91 | 9 | 28 | 3 |
| 15291703 | Susitna R above Tsusena Creek | 9/13/2012 | 17:30 | 7650 | 13 | 0 | 0 | 0 | 55 | 89 | 97 | 99 | 100 | 100 | 100 | 100 | 100 | 97 | 3 | 13 | 0.4 |
| 15292100 | Susitna River near Talkeetna, AK | 5/23/2012 | 12:30 | 20000 | 694 | 0 | 0 | 0 | 7 | 8 | 9 | 9 | 9 | 14 | 55 | 100 | 100 | 9 | 91 | 62 | 632 |
| 15292100 | Susitna River near Talkeetna, AK | 6/5/2012 | 13:30 | 30100 | 852 | 0 | 1 | 1 | 53 | 71 | 74 | 76 | 77 | 79 | 86 | 100 | 100 | 74 | 26 | 630 | 222 |
| 15292100 | Susitna River near Talkeetna, AK | 7/10/2012 | 14:50 | 27900 | 312 | 0 | 0 | 1 | 72 | 92 | 95 | 96 | 98 | 100 | 100 | 100 | 100 | 95 | 5 | 296 | 16 |
| 15292100 | Susitna River near Talkeetna, AK | 7/10/2012 | 15:30 | 27700 | 290 | 0 | 0 | 1 | 74 | 94 | 96 | 96 | 98 | 100 | 100 | 100 | 100 | 96 | 4 | 278 | 12 |
| 15292100 | Susitna River near Talkeetna, AK | 8/14/2012 | 15:50 | 17700 | 39 | 0 | 1 | 1 | 66 | 80 | 81 | 83 | 87 | 100 | 100 | 100 | 100 | 81 | 19 | 32 | 7 |
| 15292100 | Susitna River near Talkeetna, AK | 8/14/2012 | 16:20 | 17700 | 18 | 0 | 0 | 2 | 78 | 98 | 99 | 99 | 100 | 100 | 100 | 100 | 100 | 99 | 1 | 18 | 0.2 |
| 15292100 | Susitna River near Talkeetna, AK | 8/24/2012 | 10:30 | 16000 | 119 | 0 | 0 | 1 | 61 | 88 | 94 | 98 | 100 | 100 | 100 | 100 | 100 | 94 | 6 | 112 | 7 |
| 15292100 | Susitna River near Talkeetna, AK | 8/24/2012 | 11:05 | 16000 | 56 | 0 | 0 | 0 | 76 | 98 | 99 | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 1 | 55 | 1 |
| 15292100 | Susitna River near Talkeetna, AK | 9/25/2012 | 12:20 | 43700 | 52 | 0 | 2 | 4 | 79 | 87 | 88 | 88 | 90 | 95 | 100 | 100 | 100 | 88 | 12 | 46 | 6 |
| 15292100 | Susitna River near Talkeetna, AK | 9/25/2012 | 13:10 | 43700 | 347 | 0 | 1 | 18 | 59 | 68 | 71 | 73 | 79 | 89 | 100 | 100 | 100 | 71 | 29 | 246 | 101 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 6/7/2012 | 12:12 | 19800 | 836 | 0 | 0 | 2 | 38 | 67 | 73 | 77 | 82 | 87 | 96 | 100 | 100 | 73 | 27 | 610 | 226 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 7/11/2012 | 15:10 | 15800 | 1940 | 0 | 0 | 1 | 29 | 52 | 58 | 60 | 63 | 70 | 0 | 100 | 100 | 58 | 42 | 1125 | 815 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 7/11/2012 | 16:20 | 15800 | 1380 | 0 | 0 | 1 | 25 | 53 | 62 | 66 | 69 | 75 | 92 | 100 | 100 | 62 | 38 | 856 | 524 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 8/23/2012 | 15:05 | 15600 | 1120 | 0 | 0 | 0 | 13 | 21 | 26 | 36 | 57 | 83 | 0 | 100 | 100 | 26 | 74 | 291 | 829 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 8/23/2012 | 15:35 | 15600 | 1510 | 0 | 0 | 1 | 15 | 26 | 28 | 36 | 56 | 83 | 95 | 100 | 100 | 28 | 72 | 423 | 1087 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 9/19/2012 | 12:30 | 33600 | 3700 | 0 | 0 | 1 | 11 | 20 | 24 | 33 | 54 | 75 | 94 | 100 | 100 | 24 | 76 | 888 | 2812 |
| 15292410 | Chulitna R Below Canyon near Talkeetna, AK | 9/19/2012 | 13:20 | 33600 | 7750 | 0 | 0 | 1 | 8 | 15 | 18 | 29 | 47 | 70 | 91 | 100 | 100 | 18 | 82 | 1395 | 6355 |
| 15292780 | Susitna River at Sunshine | 5/22/2012 | 14:00 | 35100 | 957 | 0 | 0 | 1 | 41 | 54 | 55 | 55 | 56 | 58 | 64 | 90 | 100 | 55 | 45 | 526 | 431 |
| 15292780 | Susitna River at Sunshine | 5/22/2012 | 16:10 | 35100 | 779 | 0 | 0 | 0 | 11 | 13 | 14 | 14 | 16 | 23 | 40 | 100 | 100 | 14 | 86 | 109 | 670 |
| 15292780 | Susitna River at Sunshine | 6/5/2012 | 17:50 | 61300 | 1550 | 0 | 0 | 1 | 43 | 66 | 71 | 74 | 77 | 82 | 90 | 100 | 100 | 71 | 29 | 1101 | 450 |
| 15292780 | Susitna River at Sunshine | 6/5/2012 | 18:30 | 61300 | 1500 | 0 | 1 | 2 | 40 | 57 | 61 | 65 | 69 | 75 | 86 | 100 | 100 | 61 | 39 | 915 | 585 |
| 15292780 | Susitna River at Sunshine | 7/10/2012 | 19:00 | 53900 | 518 | 0 | 0 | 1 | 66 | 89 | 91 | 92 | 93 | 95 | 100 | 100 | 100 | 91 | 9 | 471 | 47 |
| 15292780 | Susitna River at Sunshine | 7/10/2012 | 19:40 | 53900 | 648 | 0 | 1 | 2 | 70 | 90 | 93 | 94 | 96 | 99 | 100 | 100 | 100 | 93 | 7 | 603 | 45 |
| 15292780 | Susitna River at Sunshine | 8/13/2012 | 15:40 | 43400 | 3700 | 0 | 0 | 0 | 14 | 25 | 33 | 55 | 81 | 96 | 100 | 100 | 100 | 33 | 67 | 1221 | 2479 |
| 15292780 | Susitna River at Sunshine | 8/13/2012 | 16:20 | 43400 | 2250 | 0 | 0 | 0 | 15 | 41 | 47 | 54 | 65 | 81 | 91 | 100 | 100 | 47 | 53 | 1058 | 1193 |
| 15292780 | Susitna River at Sunshine | 8/24/2012 | 13:08 | 37000 | 1340 | 0 | 1 | 1 | 36 | 50 | 51 | 55 | 67 | 89 | 98 | 100 | 100 | 51 | 49 | 683 | 657 |
| 15292780 | Susitna River at Sunshine | 8/24/2012 | 13:40 | 37000 | 579 | 0 | 0 | 1 | 43 | 69 | 73 | 74 | 77 | 87 | 100 | 100 | 100 | 73 | 27 | 423 | 156 |
| 15292780 | Susitna River at Sunshine | 9/17/2012 | 15:45 | 69200 | 1910 | 0 | 3 | 7 | 52 | 80 | 83 | 84 | 86 | 89 | 94 | 100 | 100 | 83 | 17 | 1585 | 325 |
| 15292780 | Susitna River at Sunshine | 9/17/2012 | 16:30 | 69200 | 1840 | 0 | 0 | 2 | 40 | 62 | 65 | 68 | 74 | 85 | 98 | 100 | 100 | 65 | 35 | 1196 | 644 |

**Table 5.3- 1. Comparison of Average Annual Sediment Loads under Pre-Project Conditions.**

| Gage | Drainage Area (mi²) | Water Discharge (acre-ft) | Average Annual Load (tons) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Wash Load | Bed Material | | | Total Load |
| | | | Silt/Clay | Sand | Gravel | Total | |
| Watana | 5,180 | 5,803,000 | 1,684,000 | 1,197,000 | 56,000 | 1,252,000 | 2,936,000 |
| *Ungaged Tributaries* | 980 | *1,242,000* | *117,000* | *213,000* | *11,000* | *223,000* | *340,000* |
| Supply above Gold Creek | 6,160 | 7,045,000 | 1,800,000 | 1,409,000 | 66,000 | 1,475,000 | 3,276,000 |
| Gold Creek/Susitna nr Talkeetna | 6,160 | 7,045,000 | 1,800,000 | 1,409,000 | 66,000 | 1,475,000 | 3,276,000 |
| Talkeetna | 1,996 | 2,938,000 | 940,000 | 866,000 | 57,000 | 923,000 | 1,863,000 |
| Chulitna | 2,570 | 6,231,000 | 5,264,000 | 3,917,000 | 748,000 | 4,665,000 | 9,929,000 |
| Supply above Sunshine | 10,726 | 16,213,000 | 8,005,000 | 6,192,000 | 871,000 | 7,063,000 | 15,067,000 |
| Sunshine | 11,100 | 17,426,000 | 10,012,000 | 6,101,000 | 279,000 | 6,380,000 | 16,392,000 |
| *Ungaged Tributaries* | 2,120 | *3,654,000* | *2,366,000* | *534,000* | *53,000* | *587,000* | *2,953,000* |
| Yentna | 6,180 | 14,102,000 | 7,162,000 | 8,205,000 | 180,000 | 8,385,000 | 15,547,000 |
| Supply above Susitna Station | 19,400 | 35,182,000 | 19,540,000 | 14,840,000 | 512,000 | 15,352,000 | 34,892,000 |
| Susitna Station | 19,400 | 35,182,000 | 19,534,000 | 14,278,000 | 260,000 | 14,538,000 | 34,072,000 |

**Table 5.3- 2. Comparison of Average Annual Sediment Loads under Maximum Load Following OS-1 Conditions.**

| Gage | Water Discharge (acre-ft) | Average Annual Load (tons) | | | | |
|---|---|---|---|---|---|---|
| | | Wash Load | Bed Material | | | Total Load |
| | | Silt/Clay | Sand | Gravel | Total | |
| Watana Dam | 5,785,000 | 168,000 | 0 | 0 | 0 | 168,000 |
| *Ungaged Tribs* | *1,209,000* | *117,000* | *213,000* | *11,000* | *223,000* | *340,000* |
| Supply above Gold Creek | 6,995,000 | 285,000 | 213,000 | 11,000 | 223,000 | 508,000 |
| Gold Creek | 6,995,000 | 285,000 | 213,000 | 4,000 | 217,000 | 502,000 |
| Talkeetna | 2,938,000 | 940,000 | 866,000 | 57,000 | 923,000 | 1,863,000 |
| Chulitna | 6,231,000 | 5,264,000 | 3,917,000 | 748,000 | 4,665,000 | 9,929,000 |
| Supply above Sunshine | 16,164,000 | 6,490,000 | 4,995,000 | 809,000 | 5,804,000 | 12,294,000 |
| Sunshine | 17,375,000 | 8,497,000 | 4,995,000 | 142,000 | 5,137,000 | 13,634,000 |
| *Ungaged Tributaries* | *3,654,000* | *2,366,000* | *534,000* | *53,000* | *587,000* | *2,953,000* |
| Yentna | 14,102,000 | 7,162,000 | 8,205,000 | 180,000 | 8,385,000 | 15,547,000 |
| Supply above Susitna Station | 35,131,000 | 18,025,000 | 13,734,000 | 375,000 | 14,109,000 | 32,134,000 |
| Susitna Station | 35,131,000 | 18,019,000 | 13,040,000 | 207,000 | 13,247,000 | 31,266,000 |

**Table 5.4- 1. Comparison of Mapped Geomorphic Feature Area from 1980s and 2012 in Middle River Geomorphic Reach 6.**

| MR-6 (PRM 148.4 to PRM 122.7) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Main Channel[1]** | **Total Side Channel[1]** | **Total Main Channel and Side Channel[1]** | **Total Side Slough[2]** | **Total Upland Slough[2]** | **Total Tributary[1]** | **Vegetated Island** | **Additional Open Water** |
| | **$ft^2$** | | | | | | | |
| **1983** | 85,064,000 | 45,830,000 | 130,894,000 | 14,573,000 | 700,000 | 1,472,000 | 66,124,000 | 523,000 |
| **2012** | 100,493,000 | 27,431,000 | 127,924,000 | 5,660,000 | 566,000 | 775,000 | 73,743,000 | 592,000 |
| **Percent Change** | 18% | -40% | -2% | -61% | -19% | -47% | 12% | 13% |

Notes:

1 Total Values are summation of the geomorphic feature's wetted region, exposed region, and tributary mouth (e.g., Main Channel + Exposed Main Channel + Main Channel Tributary Mouth).

2 Total values are a summation of the geomorphic feature's wetted region and exposed region

**Table 5.4- 2. Comparison of Mapped Geomorphic Feature Area from 1980s and 2012 in Lower River Geomorphic Reach 1.**

| LR-1 (PRM 87.9 to PRM 102.4) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Main Channel | Side Channel Complex | Bar Island Complex | Bar Attached Bar | Braid Plain¹ | Mainstem² | Upland Slough | Side Slough | Side Channel | Tributary | Tributary Delta | Vegetated Island (Main Channel) | Vegetated Island (Side Channel Complex ) | Vegetated Island (Bar Island Complex) | Vegetated Island (MC + SCC + BIC+ SC) |
| | ft² | | | | | | | | | | | | | | |
| 1983 | 73,434,000 | 22,858,000 | 163,389,000 | 0 | 236,824,000 | 308,867,000 | 615,000 | 1,190,000 | 5,579,000 | 634,000 | 0 | 77,000 | 32,781,000 | 16,328,000 | 93,727,000 |
| 2012 | 71,135,000 | 18,218,000 | 148,951,000 | 0 | 220,086,000 | 312,410,000 | 730,000 | 1,911,000 | 3,207,000 | 590,000 | 0 | 1,245,000 | 42,902,000 | 29,960,000 | 99,799,000 |
| Percent Change | -3% | -20% | -9% | 0% | -7% | 1% | 19% | 61% | -43% | -7% | 0% | 1517% | 31% | 83% | 6% |

Notes:
1 Braid Plain = Main Channel + Bar Island Complex
2 Mainstem = Main Channel + Bar Island Complex + Side Channel Complex

**Table 5.5- 1. Delineated Areas by Macrohabitat Habitat Types in the Middle River for the 1980s.**

| Habitat Site Number | Discharge (CFS) | Main Channel | Side Channel | Side Slough | Upland Slough | Tributary | Vegetated Island | Background | Exposed Main Channel | Exposed Side Channel | Exposed Side Slough | Exposed Upland Slough | Exposed Tributary | Another Other Water | Tributary Mouth | Total Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ | ft² x 10³ |
| 1 | 12,500 | 3,818 | 2,893 | 388 | 46 | 0 | 3,480 | 12,669 | 614 | 2,109 | 130 | 0 | 0 | 0 | 0 | 26,147 |
| 2 | 12,500 | 5,015 | 441 | 0 | 132 | 0 | 43 | 8,723 | 605 | 248 | 0 | 0 | 0 | 0 | 0 | 15,207 |
| 3 | 12,500 | 4,459 | 177 | 0 | 40 | 0 | 0 | 6,637 | 591 | 385 | 0 | 0 | 0 | 0 | 0 | 12,289 |
| 4 | 12,500 | 2,565 | 2,172 | 0 | 105 | 0 | 2,077 | 7,500 | 129 | 573 | 0 | 6 | 0 | 0 | 0 | 15,126 |
| 5 | 12,500 | 4,756 | 3,288 | 178 | 0 | 7 | 3,272 | 6,339 | 349 | 3,430 | 179 | 0 | 6 | 0 | 49 | 21,852 |
| 6 | 12,500 | 5,805 | 2,004 | 265 | 0 | 0 | 6,051 | 5,599 | 1,446 | 375 | 141 | 0 | 0 | 0 | 0 | 21,687 |
| 7 | 12,500 | 5,623 | 2,024 | 1,138 | 0 | 0 | 15,022 | 4,539 | 966 | 1,505 | 1,777 | 0 | 0 | 0 | 8 | 32,601 |
| 8 | 12,500 | 3,246 | 1,627 | 494 | 74 | 0 | 5,632 | 6,104 | 224 | 2,268 | 1,713 | 0 | 0 | 0 | 0 | 21,382 |
| 9 | 12,500 | 5,028 | 2,440 | 22 | 0 | 0 | 4,813 | 5,213 | 895 | 4,038 | 0 | 0 | 8 | 0 | 79 | 22,535 |
| 10 | 12,500 | 2,929 | 1,674 | 333 | 80 | 0 | 2,299 | 7,742 | 650 | 1,577 | 56 | 0 | 0 | 0 | 0 | 17,341 |
| 11 | 12,500 | 6,013 | 1,616 | 321 | 42 | 0 | 6,668 | 6,780 | 2,542 | 2,539 | 1,009 | 3 | 0 | 0 | 80 | 27,613 |
| 12 | 12,500 | 3,219 | 324 | 142 | 116 | 0 | 1,959 | 10,442 | 1,178 | 643 | 81 | 3 | 322 | 0 | 274 | 18,703 |
| 13 | 12,500 | 3,283 | 2,051 | 0 | 67 | 0 | 948 | 6,425 | 498 | 1,206 | 0 | 0 | 78 | 0 | 113 | 14,670 |
| 14 | 12,500 | 6,899 | 1,571 | 743 | 15 | 0 | 3,119 | 8,632 | 1,095 | 1,999 | 1,113 | 0 | 0 | 0 | 0 | 25,185 |
| 15 | 12,500 | 1,851 | 869 | 134 | 0 | 0 | 2,363 | 2,676 | 486 | 165 | 162 | 0 | 0 | 0 | 54 | 8,759 |
| 16 | 12,500 | 3,018 | 0 | 0 | 0 | 0 | 574 | 2,937 | 587 | 0 | 0 | 0 | 0 | 0 | 0 | 7,115 |
| 17 | 12,500 | 1,009 | 0 | 0 | 0 | 0 | 0 | 335 | 76 | 0 | 0 | 0 | 41 | 0 | 100 | 1,560 |
| Totals | | 68,533 | 25,171 | 4,157 | 717 | 7 | 58,321 | 109,291 | 12,931 | 23,060 | 6,360 | 12 | 454 | 0 | 757 | 309,773 |

**Table 5.5- 2. Delineated Areas by Macrohabitat Type in the Middle River for 2012 Conditions.**

| Habitat Site Number | Discharge (CFS) | Main Channel | Side Channel (SC) | Side Slough | Upland Slough | Tributary | Vegetated Island | Background | Exposed Main Channel | Exposed Side Channel | Exposed Side Slough | Exposed Upland Slough | Exposed Tributary | Another Other Water | Main Channel Trib. Mouth | Side Channel Trib. Mouth | Tributary Trib. Mouth | Total Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ | $ft^2 \times 10^3$ |
| 0 | 12,900 | 131,297 | 5,725 | 1,328 | 780 | 1,620 | 43,450 | 404,394 | 23,968 | 7,496 | 1,099 | 62 | 238 | 2,108 | 0 | 0 | 0 | 623,566 |
| 1 | 12,900 | 6,174 | 914 | 212 | 84 | 104 | 4,493 | 12,177 | 1,112 | 727 | 76 | 0 | 0 | 16 | 57 | 0 | 0 | 26,147 |
| 2 | 12,900 | 5,507 | 0 | 0 | 30 | 0 | 64 | 8,659 | 885 | 0 | 0 | 0 | 0 | 55 | 6 | 0 | 0 | 15,207 |
| 3 | 12,900 | 4,549 | 134 | 0 | 66 | 0 | 129 | 6,428 | 567 | 233 | 0 | 8 | 0 | 174 | 0 | 0 | 0 | 12,289 |
| 4 | 12,900 | 4,546 | 0 | 0 | 110 | 0 | 2,224 | 7,413 | 722 | 0 | 0 | 0 | 0 | 112 | 0 | 0 | 0 | 15,127 |
| 5 | 12,900 | 6,073 | 1,474 | 93 | 0 | 19 | 4,630 | 6,234 | 945 | 1,946 | 31 | 0 | 0 | 371 | 36 | 0 | 0 | 21,852 |
| 6 | 12,900 | 6,014 | 2,252 | 99 | 0 | 0 | 6,026 | 5,760 | 1,147 | 329 | 38 | 0 | 0 | 15 | 0 | 8 | 0 | 21,687 |
| 7 | 12,900 | 8,278 | 567 | 597 | 0 | 11 | 15,649 | 4,369 | 1,927 | 805 | 286 | 0 | 44 | 61 | 7 | 0 | 0 | 32,601 |
| 8 | 12,900 | 4,072 | 821 | 414 | 0 | 0 | 6,691 | 6,484 | 211 | 1,096 | 1,432 | 0 | 0 | 160 | 0 | 0 | 0 | 21,382 |
| 9 | 12,900 | 6,487 | 823 | 0 | 10 | 39 | 6,249 | 5,319 | 1,796 | 1,696 | 0 | 0 | 17 | 5 | 93 | 0 | 1 | 22,535 |
| 10 | 12,900 | 4,764 | 279 | 128 | 86 | 0 | 3,109 | 7,638 | 948 | 264 | 110 | 0 | 0 | 16 | 0 | 0 | 0 | 17,341 |
| 11 | 12,900 | 6,471 | 2,134 | 283 | 0 | 0 | 3,984 | 11,260 | 1,188 | 1,828 | 336 | 7 | 0 | 121 | 0 | 0 | 0 | 27,613 |
| 12 | 12,900 | 3,413 | 181 | 33 | 118 | 17 | 2,371 | 10,372 | 553 | 1,176 | 159 | 0 | 0 | 151 | 107 | 53 | 0 | 18,703 |
| 13 | 12,900 | 5,440 | 274 | 0 | 74 | 82 | 2,039 | 5,181 | 1,292 | 56 | 6 | 0 | 109 | 0 | 115 | 0 | 3 | 14,670 |
| 14 D/S | 12,900 | 1,910 | 0 | 9 | 33 | 0 | 192 | 1,873 | 455 | 0 | 13 | 8 | 0 | 0 | 0 | 0 | 0 | 4,495 |
| 14 U/S | 17,000 | 7,300 | 811 | 294 | 0 | 0 | 2,902 | 7,139 | 737 | 1,484 | 15 | 0 | 0 | 9 | 0 | 0 | 0 | 20,691 |
| 15 | 17,000 | 2,931 | 0 | 90 | 0 | 10 | 2,521 | 2,527 | 305 | 17 | 293 | 0 | 0 | 0 | 63 | 0 | 2 | 8,759 |
| 16 | 17,000 | 3,187 | 0 | 0 | 0 | 0 | 645 | 2,952 | 315 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7,115 |
| 17 | 17,000 | 1,139 | 0 | 0 | 0 | 0 | 0 | 293 | 67 | 0 | 0 | 0 | 32 | 0 | 17 | 0 | 12 | 1,560 |
| 18 | 17,000 | 3,893 | 17 | 50 | 0 | 0 | 748 | 4,131 | 537 | 101 | 498 | 0 | 0 | 24 | 0 | 0 | 0 | 10,001 |
| 19 | 17,000 | 4,883 | 0 | 534 | 0 | 0 | 3,647 | 5,483 | 825 | 0 | 2,614 | 24 | 0 | 61 | 0 | 0 | 0 | 18,071 |
| 20 | 17,000 | 4,860 | 143 | 0 | 32 | 0 | 80 | 14,795 | 761 | 453 | 0 | 258 | 0 | 32 | 0 | 0 | 0 | 21,414 |
| 21 | 17,000 | 2,285 | 0 | 0 | 16 | 234 | 132 | 9,170 | 444 | 0 | 0 | 0 | 49 | 114 | 31 | 0 | 9 | 12,485 |
| 22 | 17,000 | 9,148 | 9 | 110 | 0 | 0 | 4,396 | 10,783 | 2,440 | 86 | 722 | 0 | 0 | 28 | 0 | 0 | 0 | 27,722 |
| 23 | 17,000 | 2,653 | 222 | 0 | 0 | 0 | 179 | 860 | 802 | 377 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5,092 |
| Totals | | 247,272 | 16,780 | 4,274 | 1,440 | 2,136 | 116,549 | 561,693 | 44,950 | 20,189 | 7,732 | 367 | 489 | 3,633 | 532 | 61 | 27 | 1,028,124 |

**Table 5.5- 3. Comparison of Areas of Mapped Aquatic Habitat Types from 1983 to 2012 at Slough 8A.**

| Site 7, Slough 8A at 12,500 cfs | | | |
|---|---|---|---|
| Habitat Type | 1983 Digitized | 2012 Scaled | Percent Change |
| | (sq. ft) | | |
| Main Channel | 5,623,000 | 8,188,000 | 46% |
| Side Channel | 2,024,000 | 726,000 | -64% |
| Side Slough | 1,138,000 | 602,000 | -47% |
| Upland Slough | 0 | 0 | 0% |
| Tributary Mouth | 8,000 | 7,000 | -18% |

**Table 5.5- 4. Percent Change in Area by Aquatic Macrohabitat Types for Sites 1 through 13 Summed in the Middle River Segment.**

| Habitat Sites 1 - 13 | | | | |
|---|---|---|---|---|
| Year | Total Main Channel & Side Channel | Total Side Slough | Total Upland Slough | Total Tributary Mouth |
| | Wetted Habitat Area (sq. ft) | | | |
| 1983 | 78,488,000 | 3,281,000 | 702,000 | 603,000 |
| 2012 | 82,081,000 | 1,913,000 | 579,000 | 481,000 |
| Percent Change | 5% | -42% | -18% | -20% |

**Table 5.5- 5. Summation of Areas by Aquatic Macrohabitat Type for Sites 6 through 13 in Geomorphic Reach MR-6.**

| MR-6 (Sites 6 - 13)[1] | | | | |
|---|---|---|---|---|
| Year | Total Main Channel & Side Channel | Total Side Slough | Total Upland Slough | Total Tributary Mouth |
| | Wetted Habitat Area (sq. ft) | | | |
| 1983 | 48,905,000 | 2,715,000 | 379,000 | 554,000 |
| 2012 | 53,086,000 | 1,571,000 | 287,000 | 379,000 |
| Percent Change | 9% | -42% | -24% | -32% |

Notes:

1 Habitat Sites 14 and 15 are within this geomorphic reach however because they were classified at a higher flow (17,000 cfs), they were excluded from this summation.

**Table 5.6- 1. Average Monthly Flows (Cfs) at USGS Gages in the Susitna River Watershed for Pre-Project Conditions Based on the USGS Extended Record (Tetra Tech 2013d).**

| Period | Susitna River near Denali | Maclaren River near Paxson | Susitna River near Cantwell | Susitna River at Gold Creek | Chulitna River near Talkeetna | Talkeetna River near Talkeetna | Susitna River at Sunshine | Willow Creek Near Willow | Skwentna River near Skwentna | Yentna River near Susitna Station | Susitna River at Susitna Station |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Drainage Area (sq. mi.) | 950 | 280 | 4,140 | 6,160 | 2,570 | 1,996 | 11,100 | 166 | 2,250 | 6,180 | 19,400 |
| OCT | 1,330 | 465 | 3,800 | 6,320 | 5,750 | 2,840 | 15,900 | 332 | 4,780 | 13,400 | 36,000 |
| NOV | 503 | 182 | 1,600 | 2,670 | 2,260 | 1,160 | 6,490 | 153 | 2,020 | 5,350 | 14,400 |
| DEC | 326 | 125 | 1,130 | 1,890 | 1,550 | 801 | 4,490 | 105 | 1,400 | 3,640 | 9,510 |
| JAN | 263 | 102 | 938 | 1,590 | 1,300 | 655 | 3,720 | 84 | 1,160 | 3,020 | 7,910 |
| FEB | 229 | 88 | 820 | 1,420 | 1,140 | 553 | 3,260 | 71 | 1,020 | 2,650 | 7,080 |
| MAR | 212 | 81 | 755 | 1,300 | 1,060 | 502 | 2,960 | 60 | 916 | 2,400 | 6,510 |
| APR | 293 | 106 | 1,030 | 1,740 | 1,370 | 670 | 4,030 | 79 | 1,330 | 3,480 | 8,990 |
| MAY | 3,120 | 1,140 | 8,630 | 13,800 | 10,400 | 5,120 | 33,200 | 487 | 9,280 | 26,900 | 66,100 |
| JUN | 7,400 | 2,800 | 16,900 | 26,300 | 21,500 | 10,700 | 63,700 | 1,040 | 17,400 | 50,600 | 120,000 |
| JUL | 8,580 | 2,920 | 15,800 | 24,000 | 23,200 | 10,300 | 60,500 | 745 | 16,700 | 49,900 | 122,000 |
| AUG | 7,300 | 2,420 | 13,900 | 21,400 | 20,600 | 9,210 | 54,200 | 666 | 14,200 | 43,100 | 109,000 |
| SEP | 3,640 | 1,290 | 8,620 | 13,700 | 12,600 | 5,940 | 34,900 | 573 | 9,320 | 27,900 | 72,800 |
| Annual | 2,780 | 982 | 6,190 | 9,720 | 8,600 | 4,060 | 24,100 | 368 | 6,660 | 19,500 | 48,600 |

**Table 5.6- 2. Mainstem Susitna River Estimated Return Period Peak Flows (Cfs) for Pre-Project Conditions Based on the USGS Extended Record (Tetra Tech 2013d).**

| Return Period (years) | Flow (cfs) | | | | |
|---|---|---|---|---|---|
| | Denali | Cantwell | Gold Creek | Sunshine | Susitna Station |
| 1.25 | 11,300 | 23,100 | 35,100 | 90,200 | 152,000 |
| 2 | 13,500 | 27,300 | 43,500 | 106,000 | 170,000 |
| 5 | 17,200 | 33,400 | 56,200 | 129,000 | 197,000 |
| 20 | 23,100 | 41,900 | 74,600 | 160,000 | 233,000 |
| 50 | 27,500 | 47,600 | 87,500 | 181,000 | 258,000 |
| 100 | 31,200 | 52,100 | 98,000 | 197,000 | 276,000 |

**Table 5.6- 3. Susitna River Tributary Estimated Return Period Peak Flows (Cfs) for Pre-Project Conditions Based on the USGS Extended Record (Tetra Tech 2013d).**

| Return Period (years) | Flow (cfs) | | | | | |
|---|---|---|---|---|---|---|
| | Maclaren | Chulitna | Talkeetna | Willow | Skwentna | Yentna |
| 1.25 | 4,220 | 30,200 | 17,700 | 1,970 | 25,000 | 74,100 |
| 2 | 4,900 | 35,200 | 23,200 | 2,700 | 29,100 | 83,600 |
| 5 | 5,950 | 43,000 | 32,700 | 3,990 | 35,300 | 97,400 |
| 20 | 7,510 | 54,800 | 49,100 | 6,240 | 44,400 | 116,000 |
| 50 | 8,620 | 63,200 | 62,300 | 8,080 | 50,800 | 129,000 |
| 100 | 9,510 | 70,100 | 73,900 | 9,700 | 55,900 | 139,000 |

**Table 5.6- 4. Average Monthly Flows (Cfs) at Three USGS Gages in the Susitna River Watershed for Maximum Load Following Scenario OS-1, Based on the HEC-Ressim Model (Tetra Tech 2013d).**

| Period | Susitna River at Gold Creek | Susitna River at Sunshine | Susitna River at Susitna Station |
|---|---|---|---|
| Drainage Area (sq. mi.) | 6,160 | 11,100 | 19,400 |
| OCT | 8,240 | 18,000 | 38,100 |
| NOV | 7,990 | 11,900 | 19,800 |
| DEC | 8,750 | 11,300 | 16,300 |
| JAN | 9,140 | 11,300 | 15,500 |
| FEB | 9,750 | 11,600 | 15,400 |
| MAR | 7,460 | 9,190 | 12,700 |
| APR | 6,950 | 9,160 | 14,100 |
| MAY | 8,490 | 27,400 | 60,200 |
| JUN | 10,200 | 47,500 | 104,000 |
| JUL | 10,800 | 47,200 | 108,000 |
| AUG | 15,400 | 48,400 | 103,000 |
| SEP | 12,700 | 34,100 | 72,000 |
| Annual | 9,660 | 24,000 | 48,500 |

**Table 5.6- 5. Susitna River Estimated Return Period Peak Flows (Cfs) for Maximum Load Following OS-1 Conditions Based on the HEC-Ressim Model (Tetra Tech 2013d).**

| Return Period (years) | Flow (cfs) | | |
|---|---|---|---|
| | Gold Creek | Sunshine | Susitna Station |
| 1.25 | 16,900 | 60,500 | 125,000 |
| 2 | 23,900 | 72,000 | 142,000 |
| 5 | 34,300 | 88,200 | 169,000 |
| 20 | 48,800 | 110,000 | 209,000 |
| 50 | 58,600 | 125,000 | 238,000 |
| 100 | 66,400 | 137,000 | 261,000 |

**Table 5.7- 1. Annual Stage-Exceedance Ordinate (feet) Comparison for Pre-Project and Maximum Load Following OS-1 Hydrologic Conditions at Sunshine Gage and Susitna Station Gage (Tetra Tech 2013d).**

| Percentile | Sunshine Gage (USGS 15292780) | | | Susitna Station Gage (USGS 15292780) | | |
|---|---|---|---|---|---|---|
| | Annual Stage-Exceedance Value | | | Annual Stage-Exceedance Value | | |
| | Pre-Project | Max LF OS-1 | Delta [a] | Pre-Project | Max LF OS-1 | Delta [a] |
| **99%** | 10.93 | 11.08 | 0.15 | 2.59 | 3.03 | 0.44 |
| **95%** | 10.97 | 12.28 | 1.31 | 2.77 | 4.28 | 1.51 |
| **90%** | 10.99 | 12.40 | 1.41 | 2.93 | 4.43 | 1.50 |
| **75%** | 11.21 | 12.62 | 1.41 | 3.26 | 4.83 | 1.57 |
| **50%** | 12.17 | 13.02 | 0.85 | 5.53 | 6.21 | 0.68 |
| **25%** | 16.85 | 16.17 | -0.68 | 13.00 | 12.57 | -0.43 |
| **10%** | 18.60 | 17.42 | -1.18 | 14.77 | 14.04 | -0.73 |
| **5%** | 19.35 | 17.98 | -1.37 | 15.51 | 14.66 | -0.85 |
| **1%** | 20.81 | 19.22 | -1.59 | 16.77 | 15.85 | -0.92 |

Notes:

1. Delta calculated as Max LF OS-1 value minus pre-Project value, with negative values indicated in red text.

**Table 5.7- 2. Monthly (October through March) Stage-Exceedance Ordinate (feet) Comparison for Pre-Project and Maximum Load Following OS-1 Hydrologic Conditions at Sunshine Gage (Tetra Tech 2013d).**

| Sunshine Gage (USGS 15292780) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Percentile | October | | | November | | | December | | |
| | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta |
| **99%** | 11.57 | 12.65 | 1.08 | 10.99 | 12.36 | 1.37 | 10.97 | 12.29 | 1.32 |
| **95%** | 11.91 | 12.78 | 0.87 | 11.17 | 12.47 | 1.30 | 10.98 | 12.42 | 1.44 |
| **90%** | 12.15 | 12.88 | 0.73 | 11.30 | 12.53 | 1.23 | 10.99 | 12.50 | 1.51 |
| **75%** | 12.57 | 13.07 | 0.50 | 11.54 | 12.65 | 1.11 | 11.21 | 12.59 | 1.38 |
| **50%** | 13.09 | 13.42 | 0.33 | 11.75 | 12.75 | 1.00 | 11.40 | 12.70 | 1.30 |
| **25%** | 13.94 | 14.02 | 0.08 | 12.02 | 12.91 | 0.89 | 11.55 | 12.82 | 1.27 |
| **10%** | 14.81 | 14.86 | 0.05 | 12.34 | 13.10 | 0.76 | 11.69 | 12.91 | 1.22 |
| **5%** | 15.40 | 15.44 | 0.04 | 12.57 | 13.26 | 0.69 | 11.81 | 12.98 | 1.18 |
| **1%** | 16.85 | 16.64 | -0.21 | 13.00 | 13.52 | 0.52 | 12.22 | 13.13 | 0.91 |
| | | | | | | | | | |
| Percentile | January | | | February | | | March | | |
| | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta |
| **99%** | 10.95 | 12.28 | 1.33 | 10.91 | 10.95 | 0.04 | 10.90 | 10.95 | 0.05 |
| **95%** | 10.95 | 12.46 | 1.50 | 10.94 | 12.45 | 1.51 | 10.92 | 11.09 | 0.16 |
| **90%** | 10.97 | 12.51 | 1.54 | 10.95 | 12.51 | 1.56 | 10.94 | 12.18 | 1.24 |
| **75%** | 11.08 | 12.62 | 1.54 | 10.99 | 12.62 | 1.63 | 10.97 | 12.29 | 1.32 |
| **50%** | 11.20 | 12.72 | 1.52 | 11.09 | 12.77 | 1.68 | 11.00 | 12.40 | 1.40 |
| **25%** | 11.36 | 12.80 | 1.44 | 11.21 | 12.93 | 1.72 | 11.14 | 12.50 | 1.36 |
| **10%** | 11.46 | 12.91 | 1.45 | 11.35 | 13.06 | 1.71 | 11.25 | 12.60 | 1.35 |
| **5%** | 11.49 | 12.99 | 1.50 | 11.39 | 13.13 | 1.74 | 11.37 | 12.67 | 1.30 |
| **1%** | 11.64 | 13.12 | 1.48 | 11.51 | 13.32 | 1.81 | 11.46 | 12.78 | 1.32 |

Notes:

1. Delta calculated as Max LF OS-1 value minus pre-Project value, with negative values indicated in red text.

**Table 5.7- 3. Monthly (April through September) Stage-Exceedance Ordinate (feet) Comparison for pre-Project and Maximum Load Following OS-1 Hydrologic Conditions at Sunshine Gage (Tetra Tech 2013d).**

| Sunshine Gage (USGS 15292780) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Percentile | April | | | May | | | June | | |
| | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta |
| 99% | 10.91 | 10.97 | 0.05 | 11.03 | 11.60 | 0.57 | 15.22 | 14.81 | -0.41 |
| 95% | 10.94 | 11.10 | 0.17 | 11.58 | 12.44 | 0.86 | 16.03 | 15.36 | -0.67 |
| 90% | 10.95 | 12.09 | 1.14 | 11.93 | 12.62 | 0.69 | 16.42 | 15.62 | -0.80 |
| 75% | 10.98 | 12.26 | 1.28 | 13.01 | 13.24 | 0.23 | 17.39 | 16.32 | -1.07 |
| 50% | 11.15 | 12.37 | 1.22 | 15.37 | 14.76 | -0.61 | 18.56 | 17.13 | -1.43 |
| 25% | 11.35 | 12.47 | 1.12 | 17.12 | 16.00 | -1.12 | 19.44 | 17.71 | -1.73 |
| 10% | 11.70 | 12.62 | 0.92 | 18.76 | 17.18 | -1.58 | 20.34 | 18.29 | -2.05 |
| 5% | 12.08 | 12.77 | 0.69 | 19.54 | 17.78 | -1.76 | 20.98 | 18.69 | -2.29 |
| 1% | 13.41 | 13.58 | 0.17 | 20.34 | 18.28 | -2.06 | 22.88 | 19.71 | -3.17 |
| | | | | | | | | | |
| Percentile | July | | | August | | | September | | |
| | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta |
| 99% | 16.13 | 15.48 | -0.65 | 14.14 | 14.26 | 0.12 | 12.83 | 13.10 | 0.27 |
| 95% | 16.65 | 15.81 | -0.84 | 15.69 | 15.41 | -0.28 | 13.35 | 13.43 | 0.08 |
| 90% | 16.98 | 16.07 | -0.91 | 16.13 | 15.79 | -0.34 | 13.73 | 13.78 | 0.05 |
| 75% | 17.52 | 16.44 | -1.08 | 16.80 | 16.29 | -0.51 | 14.50 | 14.44 | -0.06 |
| 50% | 18.13 | 16.92 | -1.21 | 17.61 | 16.94 | -0.67 | 15.48 | 15.39 | -0.09 |
| 25% | 18.91 | 17.49 | -1.42 | 18.36 | 17.80 | -0.56 | 16.61 | 16.48 | -0.13 |
| 10% | 19.68 | 18.08 | -1.60 | 19.23 | 18.67 | -0.56 | 17.91 | 17.73 | -0.18 |
| 5% | 20.14 | 18.60 | -1.54 | 19.94 | 19.39 | -0.55 | 18.62 | 18.43 | -0.20 |
| 1% | 21.29 | 19.69 | -1.60 | 22.30 | 21.30 | -1.00 | 19.96 | 19.95 | -0.01 |

Notes:

1. Delta calculated as Max LF OS-1 value minus pre-Project value, with negative values indicated in red text

**Table 5.7- 4. Monthly Stage Statistics for Pre-Project and Max Load Following OS-1 Hydrologic Conditions at Sunshine Gage (Tetra Tech 2013d).**

| Sunshine Gage (USGS 15292780) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Statistic | Oct | | | Nov | | | Dec | | |
| | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta |
| Maximum | 22.15 | 20.39 | -1.76 | 14.25 | 14.23 | -0.02 | 12.53 | 13.32 | 0.79 |
| Median | 13.09 | 13.42 | 0.33 | 11.75 | 12.75 | 1.00 | 11.40 | 12.70 | 1.30 |
| Average | 13.33 | 13.68 | 0.34 | 11.80 | 12.80 | 0.99 | 11.39 | 12.70 | 1.32 |
| Minimum | 11.09 | 12.33 | 1.24 | 10.98 | 12.29 | 1.31 | 10.96 | 12.13 | 1.17 |
| | | | | | | | | | |
| Statistic | Jan | | | Feb | | | Mar | | |
| | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta |
| Maximum | 11.89 | 13.29 | 1.40 | 12.01 | 13.43 | 1.42 | 11.52 | 13.16 | 1.64 |
| Median | 11.20 | 12.72 | 1.52 | 11.09 | 12.77 | 1.68 | 11.00 | 12.40 | 1.40 |
| Average | 11.22 | 12.70 | 1.48 | 11.12 | 12.75 | 1.63 | 11.06 | 12.33 | 1.27 |
| Minimum | 10.94 | 10.96 | 0.01 | 10.89 | 10.95 | 0.06 | 10.90 | 10.95 | 0.05 |
| | | | | | | | | | |
| Statistic | Apr | | | May | | | June | | |
| | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta |
| Maximum | 17.25 | 15.85 | -1.40 | 22.01 | 19.13 | -2.88 | 25.51 | 21.19 | -4.32 |
| Median | 11.15 | 12.37 | 1.22 | 15.37 | 14.76 | -0.61 | 18.56 | 17.13 | -1.43 |
| Average | 11.28 | 12.32 | 1.04 | 15.28 | 14.77 | -0.51 | 18.49 | 17.05 | -1.45 |
| Minimum | 10.91 | 10.95 | 0.04 | 10.94 | 11.08 | 0.14 | 14.64 | 14.31 | -0.33 |
| | | | | | | | | | |
| Statistic | July | | | Aug | | | Sept | | |
| | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta | Pre-Project | Max LF OS-1 | Delta |
| Maximum | 24.89 | 21.86 | -3.03 | 25.57 | 23.26 | -2.31 | 21.65 | 21.02 | -0.63 |
| Median | 18.13 | 16.92 | -1.21 | 17.61 | 16.94 | -0.67 | 15.48 | 15.39 | -0.09 |
| Average | 18.25 | 17.02 | -1.23 | 17.65 | 17.11 | -0.54 | 15.67 | 15.59 | -0.08 |
| Minimum | 15.40 | 15.01 | -0.39 | 12.98 | 13.42 | 0.44 | 12.36 | 12.83 | 0.47 |

Notes:

1. Delta calculated as Max LF OS-1 value minus pre-Project value, with negative values indicated in red text.

**Table 5.7- 5. Summary of Potential Percent Change between Pre-Project and Post-Project Habitat Area Types at Each Site for the Open-Water (May-Sept) and Ice-Affected (Oct-Apr) Periods (Tetra Tech. 2013e).**

| Habitat Type | Site | | | | | |
|---|---|---|---|---|---|---|
| | SC IV-4 (Site 1) | | Willow Creek (Site 2) | | Goose Creek (Site 3) | |
| | Open Water (May-Sept) | Ice Affected (Oct-Apr) | Open Water (May-Sept) | Ice Affected (Oct-Apr) | Open Water (May-Sept) | Ice Affected (Oct-Apr) |
| **Main Channel** | -3 | 1 | -3 | 0 | -26 | 10 |
| **Primary Side Channel** | NA[1] | NA | NA | NA | NA | NA |
| **Secondary Side Channel** | -7.9 | 44 | -6.8 | 42 | -12 | 47 |
| **Turbid Backwater** | -27 | 0 | 8 | 148 | 5 | 93 |
| **Clearwater** | 43 | 0 | 10 | 0 | 36 | 0 |
| **Side Slough** | 0 | -14 | 0 | -14 | -6 | -2 |
| **Tributary Mouth** | NA | NA | 18.8 | 167 | -19.3 | 0 |
| **Tributary** | NA | NA | 14 | -1 | -5 | -5 |

**Table 5.7- 6. Delineated Habitat Types Areas in the Lower River in the 1980s (Tetra Tech 2013f).**

| Habitat Site Name | Habitat Site Number | Discharge (CFS) | Main Channel | Primary Side Channel | Secondary Side Channel | Turbid Backwater | Tributary | Tributary Mouth | Clearwater or Side Slough | Exposed Main Channel | Exposed Primary Side Channel | Exposed Secondary Side Channel | Exposed Tributary | Exposed Clearwater or Side Slough | Vegetated Island | Background | Total Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ |
| SC IV-4 | 1 | 36,600 | 6,071 | 0 | 5,906 | 79 | 0 | 0 | 293 | 1,594 | 0 | 3,901 | 0 | 102 | 22,022 | 8,378 | 48,346 |
| Willow Creek | 2 | 36,600 | 2,882 | 0 | 9,884 | 101 | 1,513 | 290 | 306 | 958 | 0 | 3,787 | 682 | 34 | 34,501 | 44,583 | 99,522 |
| Goose Creek | 3 | 36,600 | 3,473 | 0 | 3,995 | 252 | 425 | 52 | 947 | 2,846 | 0 | 6,629 | 199 | 3,228 | 44,566 | 22,128 | 88,739 |
| Montana | 4 | 36,600 | 3,729 | 0 | 555 | 0 | 250 | 21 | 283 | 2,115 | 0 | 466 | 365 | 903 | 7,816 | 3,583 | 20,086 |
| Sunshine Slough | 5 | 36,600 | 6,701 | 0 | 9,850 | 202 | 85 | 36 | 278 | 1,265 | 0 | 9,905 | 8 | 68 | 31,678 | 37,911 | 97,988 |
| | | Totals | 22,857 | 0 | 30,190 | 634 | 2,273 | 399 | 2,107 | 8,777 | 0 | 24,689 | 1,254 | 4,335 | 140,583 | 116,583 | 354,681 |

**Table 5.7- 7. Delineated Habitat Types Areas in the Lower River in 2012 (Tetra Tech 2013f).**

| Habitat Site Name | Habitat Site Number | Discharge (CFS) | Main Channel | Primary Side Channel | Secondary Side Channel | Turbid Backwater | Tributary | Tributary Mouth | Clearwater or Side Slough | Exposed Main Channel | Exposed Primary Side Channel | Exposed Secondary Side Channel | Exposed Tributary | Exposed Clearwater or Side Slough | Vegetated Island | Background | Additional Open Water | Total Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ | sq ft x $10^3$ |
| SC IV-4 | 1 | 55,000 | 7,061 | 0 | 7,836 | 256 | 0 | 0 | 66 | 1,875 | 0 | 710 | 0 | 0 | 22,218 | 8,295 | 28 | 48,318 |
| Willow Creek | 2 | 55,000 | 0 | 0 | 12,921 | 0 | 2,959 | 525 | 594 | 0 | 0 | 3,812 | 193 | 93 | 50,401 | 27,871 | 153 | 99,368 |
| Goose Creek | 3 | 48,000 | 7,280 | 0 | 3,316 | 97 | 82 | 99 | 1,732 | 1,731 | 0 | 1,462 | 10 | 413 | 50,563 | 21,575 | 380 | 88,360 |
| Montana | 4 | 38,200 | 3,637 | 0 | 1,882 | 0 | 68 | 347 | 29 | 1,004 | 0 | 1,408 | 132 | 0 | 7,952 | 3,544 | 84 | 20,003 |
| Sunshine Slough | 5 | 38,200 | 12,587 | 0 | 7,746 | 2 | 70 | 66 | 651 | 2,227 | 0 | 6,316 | 0 | 322 | 30,139 | 37,725 | 137 | 97,850 |
| | | Totals | 30,564 | 0 | 33,701 | 355 | 3,179 | 1,037 | 3,072 | 6,836 | 0 | 13,709 | 335 | 828 | 161,274 | 99,010 | 783 | 353,899 |

**Table 5.8- 1. Watana Reservoir Estimated Trap Efficiency Based on Brune (1953).**

| Reservoir Capacity (acre-feet)[1] | Average Annual Inflow (acre-feet)[2] | Capacity:Inflow Ratio | Trap Efficiency (Brune 1953) | | |
|---|---|---|---|---|---|
| | | | Lower Curve[3] | Median Curve | Upper Curve[4] |
| 5,169,963 | 5,803,000 | 0.89 | 94 | 96 | 100 |

Notes:
1 Total storage volume at a maximum normal pool elevation of 2,050 feet (NAVD88)
2 Scaled from Gold Creek gage using a ratio of drainage areas
3 The lower envelope curve is applicable to fine-grained sediment
4 The upper curve is applicable to coarse sediment

**Table 5.9- 1. Large Woody Debris (LWD) and Log Jams Inventoried on 2012 Aerial Photographs.**

| | Lower River (PRM 75-102) | | Middle River (PRM 102-143.6) | |
|---|---|---|---|---|
| Channel Position | Individual LWD Pieces | Log Jams | Individual LWD Pieces | Log Jams |
| Bank Adjacent | 245 | 1 | 459 | 8 |
| Side of Bar | 365 | 51 | 189 | 4 |
| Downstream end of Bar | 46 | 3 | 33 | 0 |
| Apex Bar | 135 | 74 | 138 | 15 |
| Middle of Channel | 180 | 15 | 95 | 1 |
| Head of Side Channel | 7 | 3 | 21 | 3 |
| Span Channel | 3 | 0 | 42 | 4 |
| Beaver Dam/Lodge | 0 | 0 | 0 | 23 |
| Total | 981 | 147 | 977 | 57 |

**Table 5.9- 2. Large Woody Debris (LWD) Counts by Species within LWD Sample Areas, 2013 Field Inventory.**

| LWD Sample Area | Balsam Poplar | White Spruce | Paper Birch | Alder | Unknown | Total |
|---|---|---|---|---|---|---|
| PRM 26-28 | 40 | 24 | 6 | 7 | 17 | 94 |
| PRM 40-43 | 70 | 19 | 15 | 7 | 16 | 127 |
| PRM 47-51 | 22 | 21 | 26 | 5 | 21 | 95 |
| PRM 78-82 | 74 | 4 | 3 | 5 | 17 | 103 |
| PRM 92-93 | 14 | 0 | 2 | 0 | 1 | 17 |
| FA-104 Whiskers Slough | 43 | 13 | 18 | 2 | 14 | 90 |
| PRM 109-110 | 14 | 4 | 9 | 2 | 7 | 36 |
| FA-113 Oxbow 1 | 49 | 15 | 11 | 11 | 12 | 98 |
| FA-115 Slough 6A | 29 | 6 | 6 | 3 | 7 | 51 |
| PRM 121-122 | 33 | 3 | 42 | 6 | 8 | 92 |
| PRM 126 | 54 | 6 | 15 | 10 | 3 | 88 |
| FA-128 Slough 8A | 175 | 8 | 13 | 39 | 2 | 237 |
| PRM 135-136 | 95 | 17 | 4 | 10 | 2 | 128 |
| FA-138 Gold Creek | 90 | 18 | 18 | 5 | 4 | 135 |
| FA-141 Indian River | 43 | 22 | 14 | 3 | 7 | 89 |
| FA-144 Slough 21 | 75 | 17 | 11 | 5 | 2 | 110 |
| Total<br>(Percent) | 920<br>(58%) | 197<br>(12%) | 213<br>(13%) | 120<br>(8%) | 140<br>(9%) | 1,590 |

**Table 5.9- 3. Average Length (ft) of Large Woody Debris (LWD) by Species and Freshness, 2013 Field Inventory.**

| Species | Leaves | Twigs | Branches | None | Average |
|---|---|---|---|---|---|
| Balsam poplar | 73 | 62 | 59 | 45 | 54 |
| White spruce | 52 | 47 | 37 | 32 | 42 |
| Paper birch | 49 | 41 | 40 | 31 | 40 |
| Alder | 27 | 25 | 24 | 25 | 25 |

**Table 5.9- 4. Comparison of Large Woody Debris (LWD) and Log Jams between Historical and Recent Aerial Photographs and Field Inventory.**

| | Number of Single Pieces of LWD | | | Number of Log Jams | | |
|---|---|---|---|---|---|---|
| LWD Sample Area | 1983 Aerials | 2012 Aerials | 2013 Field Inventory | 1983 Aerials | 2012 Aerials | 2013 Field Inventory |
| PRM 26-28 | n/a | 26 | 94 | n/a | 3 | 19 |
| PRM 40-43 | n/a | 68 | 127 | n/a | 4 | 36 |
| PRM 47-51 | n/a | 77 | 95 | n/a | 10 | 27 |
| PRM 78-82 | n/a | 75 | 103 | n/a | 16 | 26 |
| PRM 92-93 | n/a | 25 | 17 | n/a | 3 | 11 |
| **Total Lower River** | **n/a** | **271** | **436** | **n/a** | **36** | **119** |
| FA-104 Whiskers Slough | 45 | 23 | 90 | 4 | 12 | 20 |
| PRM 109-110 | 11 | 5 | 36 | 0 | 0 | 3 |
| FA-113 Oxbow 1 | 54 | 28 | 98 | 5 | 3 | 17 |
| FA-115 Slough 6A | 32 | 19 | 51 | 4 | 2 | 3 |
| PRM 121-122 | 37 | 21 | 92 | 0 | 1 | 10 |
| PRM 126 | 40 | 20 | 88 | 0 | 0 | 9 |
| FA-128 Slough 8A | 78 | 56 | 237 | 0 | 0 | 20 |
| PRM 135-136 | 42 | 53 | 128 | 5 | 2 | 33 |
| FA-138 Gold Creek | 47 | 30 | 135 | 0 | 0 | 19 |
| FA-141 Indian River | 50 | 34 | 89 | 0 | 0 | 16 |
| FA-144 Slough 21 | 27 | 20 | 110 | 0 | 0 | 37 |
| **Total Middle River** | **530** | **309** | **1,154** | **18** | **20** | **187** |

**Table 6.6- 1. Susitna River Estimated Return Period Peak Flow (Cfs) Comparison for Pre-Project and Maximum Load Following Scenario OS-1 (Tetra Tech 2013d).**

| Return Period (Years) | Watana Dam Site | | | | Gold Creek | | | | Sunshine | | | | Susitna Station | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-Project Flow (cfs) | Max LF OS-1 (cfs) | Difference (cfs) | Difference (%) | Pre-Project Flow (cfs) | Max LF OS-1 (cfs) | Difference (cfs) | Difference (%) | Pre-Project Flow (cfs) | Max LF OS-1 (cfs) | Difference (cfs) | Difference (%) | Pre-Project Flow (cfs) | Max LF OS-1 (cfs) | Difference (cfs) | Difference (%) |
| 1.01 | 21,100 | 12,800 | -8,300 | -39% | 25,400 | 12,600 | -12,800 | -50% | 64,000 | 47,600 | -16,400 | -26% | 131,700 | 109,500 | -22,200 | -17% |
| 1.25 | 27,800 | 14,100 | -13,700 | -49% | 35,100 | 14,400 | -20,700 | -59% | 80,200 | 60,500 | -19,700 | -25% | 151,600 | 124,900 | -26,700 | -18% |
| 1.5 | 30,700 | 15,800 | -14,900 | -49% | 39,000 | 19,100 | -19,900 | -51% | 87,000 | 65,800 | -21,200 | -24% | 160,400 | 132,900 | -27,500 | -17% |
| 2 | 34,200 | 20,700 | -13,500 | -39% | 43,700 | 23,900 | -19,800 | -45% | 94,700 | 72,000 | -22,700 | -24% | 170,300 | 141,900 | -28,400 | -17% |
| 5 | 43,700 | 28,700 | -15,000 | -34% | 55,800 | 34,300 | -21,500 | -39% | 115,400 | 88,200 | -27,200 | -24% | 197,000 | 168,900 | -28,100 | -14% |
| 20 | 57,600 | 40,200 | -17,400 | -30% | 72,300 | 48,800 | -23,500 | -33% | 143,600 | 110,400 | -33,200 | -23% | 233,500 | 209,400 | -24,100 | -10% |
| 50 | 67,300 | 48,200 | -19,100 | -28% | 83,400 | 58,600 | -24,800 | -30% | 162,500 | 125,100 | -37,400 | -23% | 257,600 | 238,200 | -19,400 | -8% |
| 100 | 75,100 | 54,600 | -20,500 | -27% | 92,100 | 66,400 | -25,700 | -28% | 177,300 | 136,700 | -40,600 | -23% | 276,300 | 261,400 | -14,900 | -5% |

**Table 6.6- 2. Recurrence Interval of Annual Peak Flows for Pre-Project and Maximum Load Following Scenario OS-1. (Tetra Tech 2013d).**

| Watana Dam Site | | | Gold Creek | | | Sunshine | | | Susitna Station | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge (cfs) | Pre-Project Return Period (yrs) | Max Load Following OS-1 Return Period (yrs) | Discharge (cfs) | Pre-Project Return Period (yrs) | Max Load Following OS-1 Return Period (yrs) | Discharge (cfs) | Pre-Project Return Period (yrs) | Max Load Following OS-1 Return Period (yrs) | Discharge (cfs) | Pre-Project Return Period (yrs) | Max Load Following OS-1 Return Period (yrs) |
| 21,100 | 1.01 | 2.1 | 25,400 | 1.01 | 2.2 | 64,000 | 1.01 | 1.4 | 131,700 | 1.01 | 1.5 |
| 27,800 | 1.25 | 4.5 | 35,100 | 1.25 | 5.4 | 80,200 | 1.25 | 3.1 | 151,600 | 1.25 | 2.7 |
| 30,700 | 1.5 | 6.4 | 39,000 | 1.5 | 7.8 | 87,000 | 1.5 | 4.6 | 160,426 | 1.5 | 3.6 |
| 34,200 | 2 | 9.8 | 43,700 | 2 | 12 | 94,700 | 2 | 7.4 | 170,300 | 2 | 5.2 |
| 43,700 | 5 | 30 | 55,800 | 5 | 39 | 115,400 | 5 | 27 | 197,000 | 5 | 13 |
| 57,600 | 20 | 136 | 72,300 | 20 | 166 | 143,600 | 20 | 149 | 233,500 | 20 | 43 |

**Table 6.7- 1. Annual Flow-Exceedance and Stage-Exceedance Comparison for the Pre-Project and Maximum Load Following OS-1 Hydrologic Conditions at Sunshine Gage and Susitna Station Gage (Tetra Tech 2013d).**

| Percentile | Sunshine Gage (USGS 15292780) Annual Flow Exceedence Value | | | Susitna Station Gage (USGS 15292780) Annual Flow Exceedence Value | | | Sunshine Gage (USGS 15292780) Annual Stage Exceedence Value | | | Susitna Station Gage (USGS 15292780) Annual Stage Exceedence Value | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-Project (cfs) | Max LF OS-1 (cfs) | Delta [a] (cfs) | Pre-Project (cfs) | Max LF OS-1 (cfs) | Delta [a] (cfs) | Pre-Project (ft) | Max LF OS-1 (cfs) | Delta [a] (ft) | Pre-Project (ft) | Max LF OS-1 (cfs) | Delta [a] (ft) |
| **99%** | 1,740 | 3,240 | 1,500 | 5,210 | 6,810 | 1,600 | 10.93 | 11.08 | 0.15 | 2.59 | 3.03 | 0.44 |
| **95%** | 2,310 | 8,840 | 6,530 | 5,840 | 12,300 | 6,460 | 10.97 | 12.28 | 1.31 | 2.77 | 4.28 | 1.51 |
| **90%** | 2,830 | 9,470 | 6,640 | 6,400 | 13,000 | 6,600 | 10.99 | 12.40 | 1.41 | 2.93 | 4.43 | 1.50 |
| **75%** | 3,750 | 10,800 | 7,050 | 7,710 | 15,100 | 7,390 | 11.21 | 12.62 | 1.41 | 3.26 | 4.83 | 1.57 |
| **50%** | 8,220 | 13,200 | 4,980 | 19,000 | 23,100 | 4,100 | 12.17 | 13.02 | 0.85 | 5.53 | 6.21 | 0.68 |
| **25%** | 45,000 | 38,400 | -6,600 | 94,000 | 87,400 | -6,600 | 16.85 | 16.17 | -0.68 | 13.00 | 12.57 | -0.43 |
| **10%** | 64,000 | 51,000 | -13,000 | 124,000 | 112,000 | -12,000 | 18.60 | 17.42 | -1.18 | 14.77 | 14.04 | -0.73 |
| **5%** | 72,800 | 57,100 | -15,700 | 138,000 | 122,000 | -16,000 | 19.35 | 17.98 | -1.37 | 15.51 | 14.66 | -0.85 |
| **1%** | 91,200 | 71,300 | -19,000 | 164,000 | 145,000 | -19,000 | 20.81 | 19.22 | -1.59 | 16.77 | 15.85 | -0.92 |

Notes:

1. Delta calculated as Max LF OS-1 value minus pre-Project value, with negative values indicated in red text

**Table 6.7- 2. Relative Proportion of Aquatic Macrohabitat Types for Sampled Sites in the Lower Susitna River Segment, 1983 and 2012 (Tetra Tech 2013f).**

| Proportion of Area for Aquatic Macrohabitat Type by Site (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Main Channel | | Secondary Side Channel | | Turbid Backwater | | Tributary | | Tributary Mouth | | Clearwater/Side Slough | |
| 1983 | 2012 | 1983 | 2012 | 1983 | 2012 | 1983 | 2012 | 1983 | 2012 | 1983 | 2012 |
| Site 1, SC IV-4 (LR-4) | | | | | | | | | | | |
| 49.2 | 51.3 | 47.8 | 47.8 | 0.6 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 2.4 | 0.5 |
| Site 2, Willow Creek (LR-3) | | | | | | | | | | | |
| 19.2 | 0.0 | 66.0 | 66.6 | 0.7 | 0.0 | 10.1 | 27.8 | 1.9 | 1.5 | 2.0 | 4.2 |
| Site 3, Goose Creek (LR-2) | | | | | | | | | | | |
| 38.0 | 34.2 | 43.7 | 17.9 | 2.8 | 0.9 | 4.6 | 0.5 | 0.6 | 0.4 | 10.4 | 46.1 |
| Site 4, Montana Creek (LR-2) | | | | | | | | | | | |
| 77.1 | 62.2 | 11.5 | 31.1 | 0.0 | 0.0 | 5.2 | 1.2 | 0.4 | 5.0 | 5.8 | 0.5 |
| Site 5, Sunshine Slough (LR-1) | | | | | | | | | | | |
| 39.1 | 59.1 | 57.4 | 37.1 | 1.2 | 0.0 | 0.5 | 0.4 | 0.2 | 0.3 | 1.6 | 3.0 |

# 10. FIGURES

[See separate file for figures.]

# PART A - APPENDIX A – STUDY COMPONENT 1

[See separate file.]

Appendix A.1: Surficial Geology Mapping in the Lower and Middle Susitna River Segments

Appendix A.2: Geomorphic Surface Mapping in 7 Focus Areas

Appendix A.3: Ratings Curves for 7 Focus Areas

Appendix A.4: Recurrence Interval Plots for 7 Focus Areas

# PART A - APPENDIX B: STUDY COMPONENT 3: INITIAL EFFECTIVE DISCHARGE ANALYSIS FOR THE MAINSTEM SUSITNA RIVER AND TRIBUTARIES

[See separate file.]

# PART A - APPENDIX C: STUDY COMPONENT 6: COMPILATION OF REFERENCES FROM LITERATURE SEARCH ON THE DOWNSTREAM EFFECTS OF DAMS

[See separate file.]

# PART A - APPENDIX D: STUDY COMPONENT 9

[See separate file.]

Appendix D.1: Large Woody Debris Aerial Photograph Digitizing

Appendix D.2: Large Woody Debris Field Inventory Protocol

Appendix D.3: Large Woody Debris Study Area Maps