Susitna-Watana Hydroelectric Project

(FERC No. 14241)

Geomorphology Study

Study Plan Section 6.5

Study Implementation Report

Attachment 1

Geomorphic Reach Delineation and Characterization, Upper, Middle and Lower Susitna River Segments – 2015 Update Technical Memorandum

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

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LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
AEA	Alaska Energy Authority
ER	entrenchment ratio
FERC	Federal Energy Regulatory Commission
ft/mile	feet per mile
IfSAR	Interferometric synthetic aperture radar
ISR	Initial Study Report
LiDAR	Light Detection and Ranging-based Topography
LR	Lower Susitna River Segment
MC	Multiple Channel Reach Classification
mm	millimeter(s)
MR	Middle Susitna River Segment
M_W	moment magnitude
Project	Susitna-Watana Hydroelectric Project
PRM	Project River Mile (the current, Susitna-Watana Project river-mile system)
RM	River Mile (the 1980s Project river-mile system)
RSP	Revised Study Plan
SC	Single Channel Reach Classification
UR	Upper Susitna River Segment
USGS	United States Geological Survey

1. INTRODUCTION

This report (2nd Revision) provides an update to the *Updated Geomorphic Reach Delineation and Characterization, Upper, Middle, and Lower Susitna river Segments,* submitted in May 2014 (Tetra Tech 2014a). Tetra Tech (2014a) was an update (1st Revision) to the *Initial Geomorphic Reach Delineation and Characterization, Middle and Lower Susitna River Segments* 2012 Study Technical Memorandum presented in February 2013 (Tetra Tech 2013a). The 2012 study report presented the results of the Delineate Geomorphically Similar (Homogeneous) River Reaches tasks in the 2012 Aquatic Habitat and Geomorphic Mapping of the Middle River using Aerial Photography Study (G-S2) and the 2012 Reconnaissance-Level Geomorphic and Aquatic Habitat Assessment of Project Effects on Lower River Channel (G-S4), based on work outlined in the Revised Study Plan Section 6.5 (AEA 2012a).

This updated report adds geomorphic reach delineation and characterization for the Upper Susitna River Segment as well as updated median bed-material sizes collected during the 2014 field season in the Upper, Middle and Lower Susitna River geomorphic reaches as part of the Revised Study Plan (RSP) Study 6.6 (AEA 2012b). It is noted that the Project River Miles (PRMs) remain the same as those presented in the original report.

The information presented in this updated technical memorandum will be expanded as additional information is developed, including results of hydraulic modeling, additional cross-section surveys, bed material sampling, mapping of relic geomorphic features, and field observations made in executing future field seasons as part of the Geomorphology Study (RSP Study 6.5) and Fluvial Geomorphology Modeling below Watana Dam Study (RSP Study 6.6).

Data and analysis that supports the geomorphic reach delineation and characterization effort and was developed as part of the Geomorphology Studies (RSP 6.5 and 6.6) includes the following:

- 2012 Study Technical Memorandums:
    - Initial Geomorphic Reach Delineation and Characterization, Middle and Lower Susitna River Segments (Tetra Tech 2013a)
    - Mapping of Geomorphic Features and Assessment of Channel Change in the Middle and Lower Susitna River Segments from 1980s and 2012 Aerials (Tetra Tech 2013b)
    - Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013c)
    - Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River Segment (Tetra Tech 2013d)
- Initial Study Report 6.5 Sections 5.1.3.1 and 5.1.3.5 (AEA 2014):
    - Study Component 1: Delineate Geomorphically Similar (Homogeneous) Reaches and Characterize the Geomorphology of the Susitna River
        - Appendix A.1: Surficial Geology Mapping in the Lower and Middle Susitna River Segments
        - Appendix A.2: Geomorphic Surface Mapping in 7 Focus Areas
- Initial Study Report 6.6 Section 5.1.10 (AEA 2014):

- Study Component 1: Bed Evolution Model Development, Coordination, and Calibration
  - Surface Bed-material Electronic Data on the Middle and Lower Susitna Rivers

2. STUDY OBJECTIVES

The objective of the effort presented in this technical memorandum is to delineate large-scale geomorphic river reaches with relatively homogeneous characteristics (e.g., channel width, lateral confinement by terraces, entrenchment ratio, sinuosity, slope, bed material, single/multiple channel, and hydrology) for the purposes of stratifying the river into study segments.

This objective was stated within RSP Section 6.5.4.1 (Delineate Geomorphically Similar [Homogeneous] Reaches and Characterize the Geomorphology of the Susitna River) as well as within the 2012 Study Plan (2012 Aquatic Habitat and Geomorphic Mapping of the Middle River using Aerial Photography Study [G-S2] and 2012 Reconnaissance-Level Geomorphic and Aquatic Habitat Assessment of Project Effects on Lower River Channel Study [G-S4]). This technical memorandum presents the geomorphic reach delineation effort performed for both the Upper, Middle and Lower Susitna River segments.

More specific objectives of the geomorphic reach delineation tasks are as follows:

- Develop a geomorphic classification system for the Susitna River that considers both form and physical process;
- Apply the classification system for delineation of broad large-scale geomorphic segments and further delineation of segments into sub-reaches;
- Determine geomorphic parameters describing the physical characteristics for each of the identified geomorphic reaches.

3. STUDY AREA

3.1. General

The Susitna River, located in Southcentral Alaska, drains an area of approximately 20,010 square miles and flows about 320 miles from its headwaters at the Susitna, West Fork Susitna, and East Fork Susitna glaciers to the Cook Inlet (USGS 2012). The Susitna River basin is bounded on the west and north by the Alaska Range, on the east by the Talkeetna Mountains and Copper River Lowlands and on the south by Cook Inlet. The highest elevations in the basin are at Mt. McKinley at 20,320 feet while its lowest elevations are at sea level where the river discharges into Cook Inlet. Major tributaries to the Susitna River between the headwaters and Cook Inlet include the Chulitna, Talkeetna and Yentna Rivers that are also glacially fed in their respective headwaters. The basin receives, on average, 35 inches of precipitation annually with average annual air temperatures of approximately 29^{o}F.

3.2. Susitna River Segments

Within the study area that extends from Cook Inlet to the Maclaren River confluence at PRM 261.3, the river can be subdivided into three segments whose general characteristics are governed by the basin geology as described by Wilson et al. (2009). The segments are referred to as the Upper, Middle and Lower Susitna River segments and are identified on Figure 3.2-1 with the associated extents:

- Upper Susitna River Segment: Maclaren River confluence (PRM 261.3) downstream to the proposed Watana Dam site (PRM 187.1).
- Middle Susitna River Segment: Proposed Watana Dam site (PRM 187.1) downstream to the Three Rivers Confluence (PRM 102.4).
- Lower Susitna River Segment: Three Rivers Confluence (PRM 102.4) downstream to Cook Inlet (PRM 3.3).

The upstream-most segment, referred to as the Upper River (UR), extends from PRM 261.3 to PRM 187.1 at the Watana Dam site. The morphologic characteristics of this segment of the river are dominated by the products of Quaternary-age glaciation that overlie bedrock outcrop and a non-alluvially forced planform controlled by both bedrock outcrop and glacial deposits. The planform, which is quite sinuous in parts of the Upper River (i.e., UR-2), is antecedent but there is little evidence of significant lateral migration of the channel under current hydrologic and sedimentologic regimes. Over a very long period of time, the river has incised into the Jurassic-age igneous and metamorphic rocks to develop the current planform of the river. Pleistocene-age glaciations have periodically filled the valley with glacial and fluvio-glacial sediments but the river has re-incised into these deposits and reoccupied the bedrock-confined planform. Bedrock crops out in the bed of the river at PRM 233 at the downstream end of the sinuous reach, thus controlling baselevel for the upstream reach. The high inherited sinuosity in UR-2 could be the result of a change in lithology from coarser grained and possibly more erodible trondhjemite to finer-grained and less erodible granodiorite/quartz monzonite that occurs in the vicinity of the UR-3-UR-2 boundary (Wilson et al., 2009). Alternatively, it may be the result of a buried geologic structure that over time has raised the base level thereby reducing the valley slope and forcing an increase in channel sinuosity (Ouchi, 1985; Harden, 1990).

The Middle River (MR) segment extends from the Watana Dam site (PRM 187.1) to the Three Rivers Confluence at about PRM 102.4. The general characteristics of the river in this segment are heavily influenced by bedrock outcrop as well as Quaternary-age glaciations. The overall morphology of the MR is characterized by a series of valley floor constrictions formed by bedrock outcrop, horizontally-opposed tributary alluvial fans and various combinations of the above that have over time induced deposition of alluvial sediments upstream of the constrictions. The alluvial sediments upstream of the constrictions are stored in Pleistocene- and Holocene-age terraces as well as Holocene-age bars, islands and floodplain geomorphic units. The valley floor constrictions and the resulting upstream multi-channeled morphology tend to predispose the formation of ice dams and ice jams (HDR 2013a; HDR 2013b) and thus deposition on and erosion of the stored alluvial deposits is strongly ice process influenced, especially during the annual breakup.

The Lower River (LR) segment extends from the Three Rivers Confluence (PRM 102.4) to the tidal flats at Cook Inlet (PRM 3.3). The morphologic characteristics of the river in this segment are dominated by the sediment loading from the major tributaries and variable resistance to erosion of the Pleistocene-age, glacially-derived materials including tills (moraines), glacio-fluvial sediments in various elevation outwash-surfaces and glacio-lacustrine sediments that control the width of the valley. Valley width in the LR is about 3-4 times that of the MR because of the lower erosion resistance of the valley bounding sediments in the LR segment. Channel morphology varies from very active multi-channel braided between the Three Rivers Confluence and Sunshine (PRM 87.9) to relatively stable and vegetated multi-channeled anastomosed upstream of valley floor constrictions caused by tributary alluvial fans such as the Kashwitna and Yentna Rivers confluences. Downstream of Susitna Station (PRM 30), delta distributary channels discharge into Cook Inlet across a very wide delta.

4. METHODS

4.1. Deviations from Study Plan

There were no deviations from the tasks in the 2012 study plans or RSP (Study 6.5 Section 6.5.4.1) involving the delineation of the Upper, Middle, and Lower Susitna River segments into geomorphic reaches.

4.2. 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 was 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).

However, from a practical viewpoint, Schumm (2005) has suggested that rivers and streams can be divided into two principal types: regime and non-regime. Regime channels, which are defined as those that flow on and in sediments transported by the river during the present hydrologic regime, and whose morphology is controlled primarily by the interactions of the flow regime and the sediment supply (Leopold et al. 1964; Schumm 1977), can be further subdivided on the basis of patterns (straight, meandering, wandering, braided, anastomosing). Non-regime channels are defined as those whose channel morphology is not controlled by a balance between the sediment supplied and the ability of the flow-regime to transport it. Non-regime channels can be further subdivided into constrained, where the form of the channel is forced by non-alluvial factors such as bedrock, colluvium, glacial deposits or extreme flood deposits (Montgomery and Buffington 1997; Tinker and Wohl 1998; O'Connor and Grant 2003), or unstable, which can include degrading (Schumm et al. 1984; Darby and Simon 1999), aggrading (Schumm 1977) or avulsing (Schumm et al. 2000) channels.

Based on Schumm's (2005) classification scheme, the factors used in the 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, 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, hydraulic modeling
- Gradient and bed materials – derived from various sources of survey data 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

4.3. Geomorphic Parameters

The geomorphic parameters developed in this document include the following:

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

The procedures used to develop each of these parameters are described below.

Gradient (feet/mile): The gradient is defined as the change in elevation between the upstream to downstream limits of a reach divided by the reach length. The gradient is expressed in feet per mile (ft/mile). The reach lengths were developed from the stationing of the PRM line which was developed to follow the channel thalwegs. The elevations at the reach boundaries were taken from the best available information. For Upper River reaches UR-1 and UR-2 elevations were derived from Alaska 2010 IfSAR (Interferometric synthetic aperture radar), for reaches UR-3 through UR-6 elevations were taken from 2011 Mat-Su Borough LiDAR, for all Middle River reaches and Lower River reaches LR-1 through LR-4 elevations were derived from 2012/2013 cross section surveys, and for the remainder of the Lower River elevations were taken from the 2011 Mat-Su Borough LiDAR.

Sinuosity (dimensionless): Sinuosity is the ratio of the channel length to the valley length. It was determined using the reach length developed from the PRM line and a valley length developed by tracing a line up the general alignment of the valley as interpreted using the 2012 aerial photography. Note: the Upper River segment is an incised and confined river system (Jurassic –age metasediments) with an inherited plan form and is not laterally active; thus, sinuosity (ratio of channel length to valley length) equals one.

Active Channel Width (feet): The active channel width was defined as the width of the various channel features comprising the Susitna River as defined by their top of banks. The channel features in the Middle and Lower river segments were delineated in GIS as part of the 2012 G-S2 and G-S4 study efforts (Tetra Tech 2013c). Channel features that were considered part of the active channel included the main channel, side channels and side sloughs. Upland sloughs were not included as part of the active channel since they do not typically convey flows from the mainstem until channel banks have been overtopped. The average active channel width within a reach was determined by dividing the area of the channel features by the reach length previously developed for the sinuosity from the PRM line.

Valley Bottom Width (feet): The valley bottom width was used as an approximation of the area that is still subject to occasional flooding and potentially subject to lateral migration of the channel. It was defined using the 2011 Mat – Su Borough LiDAR and 2010 Alaska IfSAR (in the absence of LiDAR coverage) as the area within 20 feet vertically of the water surface elevation present at the time of the LiDAR survey (Matanuska-Susitna Borough 2011; GINA 2012). This typically meant the line defining the valley bottom intersected the slope of a terrace or the valley or canyon wall. At locations where a tributary crossed into the valley bottom, the valley bottom line was drawn across the tributary rather than following the contours up the tributary. In some locations, a second valley bottom line was defined based on manmade features, such as the railroad, that potentially constrain flooding and lateral migration of the river. The average valley bottom width for a reach was determined by dividing the area within the boundary of the valley bottom by the reach length previously developed from the PRM line for the determination of sinuosity.

Entrenchment Ratio (dimensionless): For the geomorphic reach delineation effort, the entrenchment ratio (ER) was defined as the average valley bottom width of a reach divided by the average active channel width of a reach. The entrenchment ratio is a measure of the vertical confinement of the stream. The higher the ratio, the wider the frequently flooded area adjacent to the river. Rivers with high entrenchment ratios generally dissipate proportionately more energy on the floodplain during large flood events and hydraulic forces, sediment transport and flow depth tend to increase less rapidly once bankfull flows are reached than for rivers with similar active channel characteristics with low entrenchment ratios.

Median Bed Material Size (mm): The median bed material size is the diameter of the bed material for which half is coarser than and half is finer. Since this parameter falls at the 50 percent point on the grain size distribution, it is also referred to as the D_{50}. The median bed material size was derived from several sources including Harza-Ebasco (1984), R&M Consultants (1982 and 1985) and USGS (2013). In this revised technical memorandum the median bed material size, where applicable, was updated to include 2013 collected field data derived from the Fluvial Geomorphology Modeling Study below Watana Dam Initial Study Report (ISR) Study 6.6 (AEA 2014).

Channel Branching Index (dimensionless): The channel branching index is defined as the average number of channel features present across the active channel within a reach. This was determined by counting the number of channels separated by relatively stable, vegetated islands at a series of approximately evenly spaced cross sections within each reach. Similar to the active channel width, the channel features included in the channel branching index included the main channel, side channels and side sloughs, but excluded upland sloughs. The branching index was determined in GIS for each reach by first drawing lines across the active channels at intervals equal to approximately one channel width and counting the number of channel features intersected by the line. The number of channel features intersected was totaled for the reach then divided by the number of lines sampled to determine the channel branching index.

5. RESULTS

5.1. Geomorphic Reach Delineation

Table 5.1-1 identifies the reach boundaries (PRM) and their individual geomorphic designations for each of the three Susitna River segments and also includes a brief description of the individual reach geology (Wilson et al. 2009). Figure 5.1-1 shows the longitudinal profile of the Susitna River from Cook Inlet to the headwaters. 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) and the bed material is dominated by sand. In the Upper River, between the Maclaren River (PRM 261.3) and the Watana Dam site (PRM 187.1), the channel boundary is composed of both Quaternary-age sediments and bedrock (meta-sediments and gneiss), the bed material is composed of gravels to boulders that are derived from erosion of both bedrock and glacial deposits and there is a fluctuating profile where the slope significantly increases from 4 to 20 ft/mile (between UR-1 and UR-3) and then steadily decreases (to 10 ft/mile). 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 8 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 with the bed material ranging in size from gravels to cobbles. The upper part of the Middle River Segment is bounded by primarily meta-sedimentary rocks, the middle by Pleistocene-age glacial deposits and the lower by Pleistocene- and Holocene-age alluvial terraces. In the Lower River Segment, 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 and the bed material is composed of gravels with a high proportion of sand.

5.2. Geomorphic Parameters

Table 5.2-1 summarizes the geomorphic parameters for each of the reaches that were derived from a number of different sources. The geomorphic parameters include (1) gradient (2) sinuosity, (3) average active channel width, (4) valley bottom width for both natural and man-modified conditions, (5) entrenchment ratio (ER), (6) average median bed material size where data were available, and (7) channel branching index.

The Initial Geomorphic Reach Delineation technical memorandum, submitted in February 2013 (Tetra Tech 2013a), provided geomorphic reach descriptions for the Middle and Lower River segments. The first revision of the technical memorandum delivered in May 2014 (Tetra Tech 2014a) was an updated version of the initial memorandum and included geomorphic reach descriptions for the Upper River Segment and median bed material sizes per geomorphic reach based on data collected during the 2013 field season as part of RSP Study 6.6. This second revision to the technical memorandum provides updated information based on the 2014 winter and summer field seasons. This includes a more thoroughly developed characterization of the river segments, primarily the Upper River Segment, in addition to bed material gradation data per geomorphic reach (ISR Study 6.5, Part C, Section 7; ISR Study 6.6, Part C, Section 7). Bed material gradation data were collected in the main channel (near the thalweg) during the winter of 2014 and collected at the heads of islands and bars during the summer of 2014. Data were collected in previously un-sampled geomorphic reaches (UR-1, UR-2, UR-4, UR-5, UR-6, MR-1, MR-2, MR-3, and MR-5). Further, additional gradation data were collected in the Lower River to supplement existing data.

5.3. Geomorphic Reach Descriptions for the Upper River (UR) Segment

Between Maclaren River confluence at PRM 261.3 and the Watana Dam site at PRM 187.1, six geomorphic reaches were identified and classified based on their geomorphic characteristics (Figure 5.3-1). A somewhat enlarged scale longitudinal profile of the Upper River Segment showing the reach boundaries is provided in Figure 5.3-2.

Overall the Upper River Segment is primarily bounded by Upper Pleistocene-age moraines, lacustrine and glacial outwash surfaces, Paleocene-age granitic rocks, and Jurassic-age meta-sedimentary rocks. It is a somewhat confined river segment with limited Holocene-age alluvial terraces and mid-channel vegetated bars and non-continuous bank-attached floodplain segments. Of the floodplain segments, surface heights tend to be high for a typical fluvial driven system. Ice-sheared banks, ice-stabilized banks, ice-paved channels, and boulders deposited on floodplain and terrace surfaces, indicate that this segment is likely an ice-driven system. Further, from a 2014 Upper River Segment reconnaissance (ISR Study 6.5, Part C, Section 7), a well-defined ice erosion line was present approximately 10 to 15 feet above the water-surface elevation (based on observations from 8/10/14 through 8/16/14). Additionally, with the absence of a local lateral coarse-grained sediment source, there was an absence of ice-paving.

Sediment inflows are derived primarily from landslide-induced moraine failures that could be the result of melting of permafrost or undercutting of the toes, or a combination of both factors as well as lateral erosion of glacio-lacustrine and glacial outwash surfaces. These surfaces are the primary source for sediment loading to the river. The contribution of sediment from tributaries through this segment is limited and is evidenced by the lack of tributary fans at many tributary mouths with the exception of tributaries identified for potential delta formation (ISR Study 6.5, Part C, Table 7.1-1).

At the end of this section, there is a description of the portion of the Susitna River upstream of the Maclaren confluence (PRM 261.3) to the Denali Highway Bridge (PRM 291.8). Although not part of the Upper River Segment or the study area at large, it is important to understand the section of river upstream of the Maclaren River confluence as it is the Upper River's source of sediment and flow.

5.3.1. Geomorphic Reach UR-1: PRM 261.3 to PRM 248.6; SC2

The Susitna River (819 feet active width) flows in a wider, approximately 1,100 feet wide, bedrock canyon from upstream of the Maclaren River Confluence to PRM 248.6. The reach is bounded by Upper Pleistocene-age moraines and glacial outwash surfaces. The relatively shallow slope (4.4 ft/mile) makes this reach have the most sediment storage potential in the Upper River Segment within some mid-channel bars and non-continuous bank-attached floodplain segments. The storage potential however is still limited, in part, due to the narrower valley bottom (ER=1.4). The Upper River segment is an incised and confined river system (Jurassic–age metasediments) with an inherited plan form and is not laterally active; thus, sinuosity (ratio of channel length to valley length) equals one. The average number of channels in the reach is 1.5+/-0.7. Based on 5 bar head samples collected in 2014 as part of ISR Study 6.6, the average median bed material size is 57 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 109 mm.

5.3.2. Geomorphic Reach UR-2: PRM 248.6 to PRM 234.5; SC1

The Susitna River flows (459 feet active width) through a narrow bedrock canyon formed in coarse-grained igneous rocks, 555 feet wide, between PRM 248.6 to PRM 234.5. The reach is further bounded by Upper Pleistocene-age moraines and glacial outwash surfaces. At the UR-1 and UR-2 reach break there are deep seated landslide failures in glacio-lacustrine deposits that are actively supplying a large quantity of fine-grained sediment to the river. There is little to no sediment storage (ER = 1.2) in this confined and moderately steep reach (11.5 ft/mile) due to the higher sediment transport capacity. Baselevel for UR-1 and the river above the Maclaren River is maintained by an igneous bedrock sill across the channel at PRM 243.5. The Upper River segment is an incised and confined river system with an inherited plan form and is not laterally active; thus, sinuosity (ratio of channel length to valley length) equals one. The average number of channels in the reach is 1.0+/-0.0. Based on 1 bar head sample collected in 2014 as part of ISR Study 6.6, the median bed material size is 46 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 162 mm.

5.3.3. Geomorphic Reach UR-3: PRM 234.5 to 224.9; SC1

The Susitna River flows (424 feet active width) through a narrow, approximately 565 feet wide, and steep (20.2 ft/mile) bedrock canyon formed in granodiorite/quartz monzonite from PRM 234.5 to PRM 224.9. In this reach there is little to no sediment storage (ER = 1.3) because of the higher sediment transport capacity. The Upper River segment is an incised and confined river system with an inherited plan form and is not laterally active; thus, sinuosity (ratio of channel length to valley length) equals one. The average number of channels in the reach is 1.0+/-0.2. No bed material samples were collected in 2014 as part of ISR Study 6.6 due to the lack of mid-channel or bank-adjacent gravel bars that were not ice-paved. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 171 mm.

5.3.4. Geomorphic Reach UR-4: PRM 224.9 to 208.1; SC2

The Susitna River flows (806 feet active width) through a relatively wider canyon, approximately 1,100 feet wide, from PRM 224.9 to PRM 208.1. The north side of the river segment is bounded by Jurassic-age metasediments and the south side by Upper Pleistocene-age moraines and glacial outwash surfaces. The reach has an asymmetric cross-valley profile and exposed altered bedrock that indicates the presence of a fault shear zone, hydrothermally altered zone, or both. There is some sediment storage (ER =1.4) in mid-channel bars, mid-channel islands, and non-continuous bank attached floodplain segments. The average slope of the reach is 14.2 ft/mile. The Upper River segment is an incised and confined river system with an inherited plan form and is not laterally active; thus, sinuosity (ratio of channel length to valley length) equals one. The average number of channels in the reach is 1.1+/-0.3. Based on 1 bar head sample collected in 2014 as part of ISR Study 6.6, the median bed material size is 68 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 91 mm.

5.3.5. Geomorphic Reach UR-5: PRM 208.1 to PRM 203.4; SC1

The Susitna River flows (575 feet active width) through a narrow valley, approximately 715 feet wide formed in Jurassic-age metasediments, from PRM 208.1 to PRM 203.4. The relatively steep slope (10.3 ft/mile) and confined valley (ER = 1.2) permit little sediment deposition. The Upper River segment is an incised and confined river system with an inherited plan form and is not laterally active; thus, sinuosity (ratio of channel length to valley length) equals one. The average number of channels in the reach is 1.1+/-0.3. Based on 1 bar head sample collected in 2014 as part of ISR Study 6.6, the median bed material size is 48 mm. No samples were collected in the winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b).

5.3.6. Geomorphic Reach UR-6; PRM 203.4 to PRM 187.1; SC2

The Susitna River flows (1,011 feet active width) through a wider valley approximately 1,200 feet wide bounded by Pleistocene-age moraines and glacial outwash surfaces, Tertiary to Cretaceous-age gneiss and Kahiltna Flysch metasediments from PRM 203.4 to the Watana Dam site (PRM 187.1). Despite the confined nature of this reach (ER=1.2) and moderate slope (9.7 ft/mile), the reach has some sediment storage in the form of mid-channel bars, mid-channel islands and discontinuous floodplain segments. The Upper River segment is an incised and confined river system with an inherited plan form and is not laterally active; thus, sinuosity (ratio of channel length to valley length) equals one. The average number of channels in the reach is 1.2+/-0.4. Based on 4 bar head samples collected in 2014 as part of ISR Study 6.6, the average median bed material size is 43 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 62 mm.

5.3.7. Upstream of Maclaren River Confluence: PRM 291.8 to 261.3

The section of the Susitna River upstream of the Maclaren River confluence to the Denali Highway Bridge is composed of a series of constrictions and expansion zones that can be divided into three subsections; (1) the Denali Highway Bridge at PRM 291.8 to a constriction at PRM 278.9, (2) PRM 278.9 to the start of the Clearwater Creek fan at PRM 266.7, and (3) PRM 266.7 to the Maclaren River confluence at PRM 261.3.

Subsection 1 is a roughly 13 mile long expansion zone confined laterally primarily by moraines. This expansion zone is a preferential zone of sediment deposition with numerous dynamic un-vegetated mid-channel braid bars composed primarily of medium-coarse sand. The largest observed surface bed-material grain size is about 22 mm (b-axis) on observations of bar heads during a 2014 reconnaissance (on 8/8/2014). Larger gravels and cobbles were only observed locally at periodic eroding sections of moraine where the larger grain sizes were introduced to the channel by both fluvial and ice erosion. The sand-dominated bed material located downstream of the glacial braid-plains is consistent with reported rapid downriver grain size fining below glaciers (Guymon, 1974).

Subsection 2, roughly 12 miles in length, contains both constrictions and expansion zones and is confined laterally primarily by moraines and some glacial outwash terraces. The constricted reaches within this subsection, roughly 9 miles in total, have a higher sediment transport capacity and transport sediments locally derived from erosion of tills (moraines) and outwash terraces (fine to medium gravels) to the downstream river. Surface sediments within this reach were too small to collect a surface sample (i.e pebble count) (see ISR Study 6.6 Section 4.1.2.9 for methodology), however one grab sample was collected. The resulting gradation curve indicated 62.0 percent gravel, 37.4 percent sand, and 0.6 percent silt/clay composition with a median bed material size of 4.2 mm. In the 25 miles downstream of Denali Highway Bridge (subsection 1 and 2) there is very little bank attached floodplain or vegetated islands. Sediment stored in this reach consists primarily of sand derived from upstream glacial sources and both fluvial and ice eroded glacio-fluvial deposits that contain some coarser gravels and cobbles. The sand dominance within the 2 subsections correlates with the absence of vegetated islands or bars because the bed material is mobile at all flows and the generally very shallow flow depths predispose the subsections to intensive ice activity during ice breakup in the Spring.

The confluence of Clearwater Creek with the Susitna River at PRM 266.7 (start of subsection 3) is a transition into the first stable sediment storage area downstream of Denali Highway Bridge. Numerous vegetated islands with basal gravel layers and upper sand layers have established in this wider valley floor reach. These relatively stable island surfaces, not present farther upstream, likely correspond to the influx of locally derived gravels that form a more stable platform for bars to vegetate. Most of the vegetation is composed of small willows that appear to be annually "mowed" by ice processes.

Overall, upstream of the Maclaren River confluence, there is a relatively mild slope of roughly 6 ft/mile, mostly fine-grained lateral sediment sources with some gravel and cobble, limited presence of mid-channel islands in expansion zones, with very-low sediment delivering, small tributaries. These geomorphic variables indicate that the sediment delivered to the Upper River Segment is mostly fine-grained (sand) and is derived from the upstream glaciers and erosion and mass failure of the glacial (till), glacio-lacustrine and glacio-fluvial deposits that form the channel banks for most of the section (Tetra Tech 2014c).

5.4. Geomorphic Reach Descriptions for the Middle River (MR) Segment

Between Watana Dam at PRM 187.1 and the Three Rivers Confluence at PRM 102.4, eight reaches were identified and classified based on their geomorphic characteristics (Figure 5.4-1). A somewhat enlarged scale longitudinal profile of the Middle River Segment showing the reach boundaries is provided in Figure 5.4-2.

Geomorphic reaches MR-1, MR-2 and MR-3 are primarily bedrock-bounded reaches with intermittent Pleistocene-age moraines and glacial outwash surfaces, and Holocene alluvial terraces. The constricted valley bottom allows for some, though limited, mid-channel bars and islands and bank attached floodplain surfaces, upstream of bed rock constrictions. Geomorphic reach MR-4 is a completely bedrock-bounded canyon. Geomorphic reaches MR-5 through MR-8 have banks composed of bedrock, Pleistocene-age moraines, glacial outwash surfaces and terraces, and Holocene alluvial terraces. The wider valley bottom allows for mid-channel bars, mid-channel islands, and bank-attached floodplain surfaces upstream of bedrock and alluvial fan constrictions. Ice-sheared banks and ice-deposits on floodplain and low terrace surfaces indicate that ice is a significant geomorphic driver through the Middle River Segment. While geomorphic surfaces appear to be higher than in a typical fluvial system (ISR Study 6.5, Section 5.1.3.3.1), they are lower than similar geomorphic surfaces present in the Upper River Segment which suggests that there has been less river incision in the Middle River. Armored bed-material, cantilevered banks, and lateral side channel gravel bar weirs, indicate that the Middle River Segment is still, in part, a fluvial driven system. Thus, the primary geomorphic drivers in this segment are both ice and fluvial processes.

Sediment sources in this segment include tributaries and eroding banks. Eroding banks typically range in sediment delivery potential from high to low as follows: floodplain surfaces, terraces, alluvial fans, outwash terraces, and moraines. While eroding banks through this segment provide some sediment loading, the majority is provided by tributaries.

5.4.1. Geomorphic Reach MR-1: PRM 187.1 to PRM 184.6; SC2

The Susitna River (655 feet active width) flows in a narrow, approximately 780 feet wide, bedrock-bounded canyon downstream of the Watana Dam site. The canyon is formed in Tertiary to Cretaceous-age gneiss. There is limited sediment storage potential in the reach because of the narrow valley bottom (ER=1.2) and relatively steep slope (9.2 ft/mile). Alluvial sediments are stored within vegetated and non-vegetated mid-channel bars that tend to be located in local hydraulic expansion zones. The sinuosity of the reach is 1.03, and the average number of channels in the reach is 1.2+/-0.5. Based on 11 samples collected in 2014 as part of ISR Study 6.6, the average median bed material size on the bar heads is 58 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 109 mm.

5.4.2. Geomorphic Reach MR-2: PRM 184.6 to PRM 169.6; SC2

The Susitna River (715 feet active width) flows in a wider, approximately 1,500 feet wide, bedrock-bounded canyon between the Tsusena Creek confluence and about PRM 173, where the canyon narrows to about 1,000 feet. The wider, upper part of the reach is formed in more erodible Cretaceous-age Kahiltna Flysch meta-sedimentary rocks and the narrower, lower part between PRM 173 and PRM 169.6 is formed in less-erodible Tertiary to Cretaceous-age gneiss. The average slope of the reach is 10.8 ft/mile. There are considerably more alluvial sediments stored in vegetated islands, mid-channel bars and in vegetated discontinuous floodplain segments in this reach with an entrenchment ratio of 2.1. This is particularly true of the wider, upper portion of this reach. Fog Creek, a south bank tributary, is a local source of sediment in the upper reach. In the lower, narrower part of the reach, alluvial sediments are stored within discontinuous vegetated floodplain segments and in unvegetated mid-channel bars. The sinuosity of the reach is 1.06 and the average number of channels in the reach is 1.4+/-0.8. Based on 36 samples collected in 2014 as part of ISR Study 6.6, the average median bed material size on the bar heads is 89 mm. Based on 2 samples collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the average median bed material size is 241 mm.

5.4.3. Geomorphic Reach MR-3: PRM 169.6 to PRM 166.1; SC2

The Susitna River (594 feet active width) flows in a narrow (about 780 feet wide), bedrock-bounded canyon from PRM 169.6 to PRM 166.1. The canyon is formed in Paleocene-age granitic rocks. Based on the abrupt change in the direction of the canyon at the head of the reach, which is part of an extensive NW-SE trending lineament, the reach is most likely fault-controlled. Because of the relatively narrow canyon (ER=1.3) and steep slope (12.3 ft/mile), the alluvial sediment storage potential in the reach is low. Alluvial sediments are stored within a few vegetated mid-channel bars in the reach, and there is little evidence of even discontinuous floodplain segments within the reach. The sinuosity of the reach is 1.02 and the average number of channels in the reach is 1.1+/-0.3. Based on 6 samples collected in 2014 as part of ISR Study 6.6, the average median bed material size on the bar heads is 77 mm. No samples were collected in the winter of 2014 in the reach as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b).

5.4.4. Geomorphic Reach MR-4: PRM 166.1 to PRM 153.9; SC1

The Susitna River (312 feet active width) flows in a very narrow (370 feet wide), very steep (30.6 ft/mile), bedrock-bounded canyon, referred to as Devils Canyon. The narrow canyon has formed in Paleocene-age granitic rocks that are probably not faulted given the very narrow width of the canyon. Because of the narrow canyon (ER=1.2) and steep slope, there is very little, if any, alluvial sediment stored within the reach. The sinuosity of the reach is 1.03 and the average number of channels in the reach is 1.0+/-0.2. No bed material samples have been collected in this reach as part of ISR Study 6.6 or Tetra Tech 2014b.

5.4.5. Geomorphic Reach MR-5: PRM 153.9 to PRM 148.4; SC2

The Susitna River (512 feet active width) flows through a slightly wider (about 850 feet), bedrock-bounded canyon from PRM 153.9 to PRM 148.4. The relatively narrow canyon has formed in Cretaceous-age Kahiltna Flysch meta-sedimentary rocks. The somewhat wider canyon and lower slope (12.3 ft/mile) compared to MR-4 (Devils Canyon) allow some alluvial sediment storage within the reach, primarily in a few vegetated mid-channel islands and discontinuous floodplain segments in the slightly wider parts of the reach (ER=1.7). The sinuosity of the reach is 1.03 and the average number of channels in the reach is 1.2+/-0.5. Based on a single sample collected in the 1980s, the median size of the bed material in the reach is about 70 mm. Based on 11 samples collected in 2014 as part of ISR Study 6.6, the average median bed material of the bar heads is 111 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the average median bed material is 116 mm.

5.4.6. Geomorphic Reach MR-6: PRM 148.4 to PRM 122.7; SC3

The Susitna River (985 feet active width) flows through a wider (2,350 feet wide without consideration of manmade features and 2,220 feet wide with consideration of manmade features), bedrock-bounded canyon from PRM 148.4 to PRM 122.7. The south side of the canyon is formed in Paleocene-age granitic rocks and the north side is formed in Cretaceous-age Kahiltna Flysch meta-sedimentary rocks that are overlain in many parts of the reach by undifferentiated Upper Pleistocene-age moraines, kames and lacustrine deposits. The wider valley may be due to the weakening effects of contact metamorphism between the older sedimentary rocks and the younger granites. In the wider parts of the reach, alluvial sediments are stored in continuous, vegetated floodplain segments and within numerous vegetated islands and bars, as well as in unvegetated mid-channel bars (ER=2.4 without manmade features, ER=2.3 with manmade features). Where the valley bottom is wider within the reach, the alluvial deposits tend to be more vegetated, and where the valley bottom is narrower, the alluvial deposits tend to be less vegetated. Channel slope is 10.7 ft/mile, sinuosity of the reach is 1.09 and the average number of channels is 2.4+/-1.1. The average median size of the bed material in the reach is 50 mm based on 17 samples that were collected in the 1980s. However, the average median size of the bed material is 64 mm based on 116 samples bar head samples collected in 2013 as part of ISR Study 6.6. Based on 4 samples collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the average median bed material size is 94 mm.

5.4.7. Geomorphic Reach MR-7: PRM 122.7 to PRM 107.8; SC2

The Susitna River (845 feet active width) flows through a bedrock-bounded canyon from PRM 122.7 to PRM 107.8 (2,050 feet wide without manmade features, 1,900 feet with manmade features). The canyon is formed in Cretaceous-age Kahiltna Flysch meta-sedimentary rocks that are overlain in many parts of the reach by undifferentiated Upper Pleistocene-age moraines, kames and lacustrine deposits. Because of the wider valley and lower slope (8.3 ft/mile), there is a reasonably high sediment storage potential within the reach (ER=2.4 without manmade features, ER=2.2 with manmade features). Alluvial sediments are stored primarily within continuous, vegetated floodplain segments and in vegetated islands and mid-channel bars. The sinuosity of the reach is 1.05 and the average number of channels in the reach is 1.8+/-1.0. Based on 7 samples collected in the 1980s, the average median size of the bed material in the reach is 40 mm. Based on 44 samples collected in 2013 as part of ISR Study 6.6, the average median bed material on the bar heads is 61 mm. Based on 3 samples collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the average median bed material size is 65 mm.

5.4.8. Geomorphic Reach MR-8: PRM 107.8 to PRM 102.4; SC3/MC1

This reach of the Susitna River (1,130 feet active width) extends from PRM 107.8 to above the Three Rivers Confluence at PRM 102.4. The valley floor (8,960 feet wide without manmade features and 6,380 feet with manmade features) above the confluence is confined by Upper Pleistocene–age moraines and glacial outwash surfaces as well as Holocene-age alluvial terraces. The average gradient of the river increases slightly to 8.8 ft/mile. In the upper part of the reach, alluvial sediments are stored within continuous floodplain segments, vegetated islands and mid-channel bars (SC3). Just upstream of the confluence, the bulk of the alluvial sediments are stored in active, un-vegetated braid bars (MC1). The large entrenchment ratio (ER=7.9 without manmade features and ER=5.6 with manmade features) is largely the result of the wide floodplain created by the confluence of the Susitna, Chulitna and Talkeetna Rivers. The sinuosity of the reach is 1.19 and the average number of channels is 2.7+/-1.8. Based on 18 samples collected in the 1980s, the average median size of the bed material in the reach is 63 mm. Based on 28 samples collected in 2013 as part of ISR Study 6.6, the average median bar head bed material size is 57 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material is 95 mm.

5.5. Geomorphic Reach Descriptions for the Lower River (LR) Segment

Between the Three Rivers Confluence at PRM 102.4.1 and Cook Inlet at PRM 3.3, six reaches were identified and classified based on their geomorphic characteristics (Figure 5.5-1). A somewhat enlarged-scale longitudinal profile of the Lower River segment showing the reach boundaries is provided in Figure 5.5-2. Throughout the Lower River Segment, the gradient of the Susitna River steadily decreases from 6 ft/mile below the Three Rivers Confluence to 1.5 ft/mile as it flows into the Cook Inlet. The character of the river changes dramatically below the Three Rivers Confluence as the width of the river more than triples from the widest portions in the Middle River Segment, and it adopts a braided channel form.

The Lower River Segment is predominantly bounded by Upper Pleistocene-age moraines, glacial outwash surfaces, and glacio-lacustrine deposits. Due to the lack of ice-scars on trees and ice deposits on the floodplain as well as geomorphic surface heights typical of a fluvial driven system, the main identified geomorphic driver for this segment is fluvial. Local sediment sources include tributaries as well as eroding moraines, outwash terraces, and glacio-lacustrine deposits. Downstream of the Deshka Landing, extensive active mass failures of the glacio-lacustrine terraces are possibly the result of the 1964 Alaska earthquake (9.3M_w). The presence of longitudinally-continuous but heavily vegetated slump blocks along the bases of the terraces suggests that they may have resulted from earlier earthquake-induced failures.

5.5.1. Geomorphic Reach LR-1: PRM 102.4 to PRM 87.9; MC1

This reach of the Susitna River (3,340 feet active width) includes the Three Rivers Confluence downstream of PRM 102.4 and extends downstream to a valley bottom constriction at PRM 87.9. The Susitna River triples its width in LR-1 compared with MR-8. This is the result of the added flow and sediment loads from the Chulitna and Talkeetna rivers. However, the width of the valley floor at approximately 9,200 feet wide without manmade features (with consideration of manmade features, the width is 8,940 feet) is nearly identical to MR-1 immediately upstream. LR-1 is confined on the eastside primarily by Upper Pleistocene-age moraines and glacial outwash surfaces and on the west side by Upper Pleistocene-age lacustrine deposits intercalated with glacial outwash surfaces. The average channel gradient for the reach is 6.2 ft/mile. In general, because of the combined sediment delivery from the Three Rivers Confluence, the reach is net aggradational and the bulk of the alluvial sediment is stored in active, unvegetated braid bars upstream of the valley floor constriction at PRM 87.9 (ER=2.8 without manmade features, ER=2.7 with manmade features). Within the reach, there are also locations where alluvial sediments are stored within vegetated islands and mid-channel bars, and the reach is bounded on each side by a vegetated floodplain of varying width. The sinuosity of the reach is 1.12 and the average number of channels is 4.0+/-2.3. Based on 24 samples collected in the 1980s, the average median size of the bed material in the reach is 47 mm. Based on 18 samples collected in 2013 and 2014 combined as part of ISR Study 6.6, the average median bed material size on the bar heads is 43 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 93 mm.

5.5.2. Geomorphic Reach LR-2: PRM 87.9 to PRM 65.6; MC2/MC3

This reach of the Susitna River (3,120 feet active width) can be further subdivided into upper and lower subreaches. The upper reach extends from the valley floor constriction formed by Upper Pleistocene-age glacial outwash on the south bank and Upper Pleistocene-age moraines on the north bank at PRM 87.9, down to about PRM 74.4. Within this subreach, the valley floor is confined on the east by Upper Pleistocene-age glacial outwash and on the west side by similar aged moraines. The valley floor width varies from about 4,000 to 5,200 feet and the alluvial sediments are primarily stored in vegetated islands, bars and continuous floodplain segments (MC2). Between PRM 74.4 and PRM 65.6, where there is a valley floor constriction most probably created by the Kashwitna River fan on the east bank and Upper Pleistocene-age moraines on the west bank, the planform of the river changes to anastomosed as a result of the imposed baselevel control (Smith and Smith 1980; Knighton and Nanson 1993; Makaske 2001).

The bulk of the alluvial sediments within the lower subreach are stored in longitudinally extensive, relatively stable, vegetated floodplain segments (MC3). The valley floor width is on the order of 8,000 feet upstream of the constriction. The east side of the valley is composed of Upper Pleistocene-age glacio-lacustrine deposits and the west side by similar-aged moraines. The greater width of the valley in the lower subreach suggests that the Upper Pleistocene-age glacial outwash that forms the east bank in the upper subreach is more erosion-resistant than the glacio-lacustrine deposits. The average slope of the channel is 4.9 ft/mile, the sinuosity is 1.16, the ER is 2.5, and on average there are 5.6+/-2.9 channels in the reach. Based on 18 samples collected in 2013 and 2014 combined as part of ISR Study 6.6, the average median bed material size on the bar heads is 32 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 36 mm.

5.5.3. Geomorphic Reach LR-3: PRM 65.6 to PRM 44.6; MC3

The Susitna River (4,040 feet active width) within this reach is bounded by Upper Pleistocene-age lacustrine deposits on both the east and west sides of the valley, the apparent reason for a wider valley floor (16,000 feet). A valley floor constriction at PRM 44.6 forms a downstream baselevel control for the river in this reach (Smith and Smith 1980; Knighton and Nanson 1993; Makaske 2001), and consequently, the river planform is anastomosed for most of the reach (MC3). The bulk of the alluvial sediments within reach are stored in longitudinally extensive, relatively stable, vegetated floodplain segments that are referred to as the Delta Islands (ER=4.0). The average slope of the channel in the reach is 4.7 ft/mile, the sinuosity is 1.23, and on average, there are 8.8+/-3.7 channels in the reach. Based on 19 samples collected in 2013 and 2014 combined as part of ISR Study 6.6, the average median bed material size on the bar heads is 32 mm. Based on 1 sample collected in the main channel in the area of the thalweg during winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b) the median bed material size is 39 mm.

5.5.4. Geomorphic Reach LR-4: PRM 44.6 to PRM 32.3; MC2

The Susitna River (2,750 feet active width) in this reach flows between Upper Pleistocene-age lacustrine deposits on both the east and west sides of the valley. Valley floor width is about 12,300 feet and a valley floor constriction is created by the Yentna River alluvial fan and the Upper Pleistocene-age moraine on the east side of the river and the moraine-draped, Late Cretaceous-age, granodiorite outcrop on the west side of the river at PRM 30 (Susitna Station downstream of the reach boundary). The bulk of the alluvial sediments in the reach are stored in vegetated islands and mid-channel bars and in continuous, vegetated floodplains on both sides of the river (ER=4.3). The average slope of the channel in the reach is 1.0 ft/mile, the sinuosity is 1.24, and on average there are 5.1+/-2.0 channels in the reach. Based on 15 samples collected in 2013 and 2014 combined as part of ISR Study 6.6, the average median bed material size on the bar heads is 33 mm. No samples were collected in the winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b).

5.5.5. Geomorphic Reach LR-5: PRM 32.3 to PRM 23.5; SC2

Between the Yentna River confluence at PRM 32.3 and PRM 23.5, the Susitna River (3,250 feet active width) is confined by Upper Pleistocene-age glacio-lacustrine deposits on the east bank as well as the Late Cretaceous-age granodiorite outcrop on the west side of the river at Susitna Station (PRM 30). The valley floor width is about 8,880 feet and the river slope is very low (1.3 ft/mile). The relatively constricted valley limits the sediment storage potential within the reach and the bulk of the sediment is stored in mid-channel bars, vegetated islands and discontinuous floodplain segments (ER=2.7). The sinuosity is 1.13 and on average there are 1.9+/-0.6 channels in the reach. Based on 5 samples collected in 2013 and 2014 combined as part of ISR Study 6.6, the average median bed material size on the bar heads is 31 mm. However, much of the exposed sediment through this reach is sand. The majority of observed gravel was at the heads of bars where sediment sampling was performed. No samples were collected in the winter of 2014 as part of the through-ice bed main channel sampling effort (Tetra Tech 2014b).

5.5.6. Geomorphic Reach LR-6: PRM 23.5 to PRM 3.3; MC4

From PRM 23.5 to the Cook Inlet at PRM 3.3, the Susitna River (5,280 feet active width) forms a delta-distributary system with longitudinally continuous, vegetated and relatively stable inter-distributary channel delta plain segments (ER=5.9). The delta is bounded to the east by Upper Pleistocene-age, glacio-lacustrine deposits and to the west by Holocene-age estuarine deposits. The active Castle Mountain Fault, with evidence of Holocene-age displacement (Labay and Haeussler 2001), crosses the river at the head of the reach. The width of the delta plain is about 31,000 feet and the river slope in the reach is extremely flat (1.5 ft/mile). The sinuosity is 1.43, and on average, there are 6.2+/-3.1 channels in the reach. No bed material samples have been collected in this reach as part of ISR Study 6.6 or Tetra Tech 2014b. Observed mid-channel bars were primarily composed of sands. In lieu of bar head material data, bank material data were collected. The lower bank material samples were collected in LR-6 at PRM 23.0 and PRM 22.4. The median particle size of the basal sediment layer is 0.127 mm (fine sand) at PRM 23.0 and is 0.3 mm at PRM 22.4 (fine to medium sand).

6. DISCUSSION

The geomorphic characteristics of the study area of the Susitna River between the Maclaren River confluence (PRM 261.1) and Cook Inlet (PRM 3.3) are predominantly the result of three factors. The first factor is the geologic setting and the relative erodibility of the channel bounding materials (Montgomery and Buffington 1997, Tinker and Wohl 1998, O'Connor and Grant 2003). In general, the Upper River segment reflects the effects of Pleistocene- and ongoing, Holocene-age glaciation and an inherited (antecedent) planform controlled by metamorphic and igneous rocks. The Middle River Segment is dominated by the presence of relatively erosion-resistant meta-sedimentary, gneissic and granitic rocks and the distribution of Pleistocene age glacially-derived materials. The Lower River Segment is primarily an alluvial system with a wide valley that is laterally constrained by Pleistocene-age, glacially-derived, materials that have variable resistance to erosion.

The second factor is the balance between the sediment supply and the potential for sediment storage within a reach. Extensive braidplains downstream of the active glaciers at the headwaters of the Susitna River buffer sediment supply to the Upper River segment and this is reflected in the general absence of both in-channel (bars and islands) and channel margin (floodplain) sedimentary deposits. Based on the available sediment record at the Gold Creek gage, the annual bed load and suspended sediment load in the Middle River are relatively low, and this is reflected in the somewhat limited sediment storage potential within the Middle River reaches where the entrenchment ratios, with the exception of geomorphic reach MR-8, are low (<2.5). In contrast, the combined bed-load and suspended sediment loads delivered to the Lower River segment from the Chulitna, Talkeetna and Yentna rivers are relatively high, and this is reflected in the extensive sediment storage potential in the Lower River Segment where the entrenchment ratios, with the exception of geomorphic reach LR-5, are high (>4). The sediment transport rates, and hence the potential for sediment storage and remobilization within the Lower River geomorphic reaches, is reflected in the form of the channel. Where the coarse sediment supply is likely higher than the transport capacity, the channel form is primarily braided (e.g. LR-1), and where the coarse sediment transport capacity and supply are likely more balanced, the channel form is dominantly anastomosed (e.g., LR-3).

The third factor is the relative importance of fluvial and ice processes. In the Upper River segment ice processes tend to be dominant. Where coarse bed materials are present there is extensive paving of the banks and there are extensive coarse grained deposits on the tops of lower terraces and floodplain segments. An ice trim line on the vegetation is frequently 10 to15 feet above the low-water surface. In the Middle River Segment the form and dynamics of the various order channels, bars and islands as well as floodplains and terraces are the result of the combined effects of both ice and fluvial processes. Ice processes, including ice damming and ice-jam failures, appear to be more important in alluvial reaches located upstream of valley floor constrictions. In the Lower River Segment, while ice processes occur, the widths of the valley bottoms tends to mitigate their effects, and hence the segment is fluvially dominated.

The sediment balance is an important factor in determining the morphology and behavior of the Lower River. Sediment transport and the sediment balance in the Lower Susitna River were further investigated in the 2012 Study Technical Memorandum *Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments* (Tetra Tech 2013b). An initial assessment of potential Project effects on the morphology of the Lower River was presented in the 2012 Study Technical Memorandum *Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River Segment* (Tetra Tech 2013d).

7. REFERENCES

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8. TABLES

Table 5.1-1. Geomorphic Reach Boundaries in the Upper, Middle, and Lower Susitna River Segments.

Reach Designation	Reach Breaks (PRM / *RM*)		Reach Classification	Slope (ft/mi)	Lateral Constraints
	Upstream	Downstream			
Upper Susitna River Segment (UR)					
UR-1	261.3 / *260.0*	248.6 / *247.7*	SC2	4.4	Quaternary Basin Fill
UR-2	248.6 / *247.7*	234.5 / *233.0*	SC1	11.5	Quaternary Basin Fill
UR-3	234.5 / *233.0*	224.9 / *223.1*	SC1	20.2	Quaternary Basin Fill
UR-4	224.9 / *223.1*	208.1 / *205.7*	SC2	14.2	Granodiorite
UR-5	208.1 / *205.7*	203.4 / *200.8*	SC1	10.3	Quaternary Basin Fill
UR-6	203.4 / *200.8*	187.1 / *184.3*	SC2	9.7	Quaternary Basin Fill
Middle Susitna River Segment (MR)					
MR-1	187.1 / *184.3*	184.6 / *181.9*	SC2	9.2	Tertiary-Cretaceous Gneiss
MR-2	184.6 / *181.9*	169.6 / *166.4*	SC2	10.8	Cretaceous Kahiltna Flysch Tertiary-Cretaceous Gneiss
MR-3	169.6 / *166.4*	166.1 / *163.0*	SC2	12.3	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	12.3	Cretaceous Kahiltna Flysch
MR-6	148.4 / *144.9*	122.7 / *118.9*	SC3	10.7	Cretaceous Kahiltna Flysch with undifferentiated Upper Pleistocene moraines, kames, lacustrine deposits
MR-7	122.7 / *118.9*	107.8 / *104.1*	SC2	8.3	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)	8.8	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	6.2	Upper Pleistocene Outwash, Moraine and Lacustrine deposits
LR-2	87.9 / *83.8*	65.6 / *61.4*	MC2/MC3	4.9	Upper Pleistocene Outwash, Moraine and Lacustrine deposits
LR-3	65.6 / *61.4*	44.6 / *40.3*	MC3	4.7	Upper Pleistocene Glaciolacustrine deposits
LR-4	44.6 / *40.3*	32.3 / *28.3*	MC2	1.0	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 5.2-1. Summary of geomorphic parameters by reach for the Upper, Middle and Lower Susitna River Segments

Reach	Length (mi)	Gradient (ft/mi)	Sinuosity[1]	Average Width (feet)			Entrench-ment Ratio[2,4]	Entrench-ment Ratio[3,4]	Median Bed Material Size (mm)[5]	Number of Bed Material Samples[5]	Median Winter Bed Material Size (mm)[6]	Number of Winter Bed Material Samples[6]	Channel Branching[7]		
				Active Channel	Valley Bottom[2]	Valley Bottom[3]							Avg Number Channels	Standard Deviation	Number of Sampled Transects
UR-1	12.7	4.4	1	819	1121		1.4		34	5	109	1	1.5	0.7	82
UR-2	14.1	11.5	1	459	555		1.2		46	1	162	1	1	0	162
UR-3	9.6	20.2	1	424	563		1.3		N/A[6]	0	171	1	1	0.2	121
UR-4	16.8	14.2	1	806	1112		1.4		68	1	91	1	1.1	0.3	111
UR-5	4.7	10.3	1	575	714		1.2		48	1	N/A[8]	0	1.1	0.3	43
UR-6	16.3	9.7	1	1011	1194		1.2		43	4	62	1	1.2	0.4	86
MR-1	2.5	9.2	1.03	655	782		1.2		58	11	109	1	1.2	0.5	18
MR-2	15	10.8	1.06	715	1,512		2.1		89	36	241	2	1.4	0.8	111
MR-3	3.5	12.3	1.02	594	781		1.3		77	6	N/A[8]	0	1.1	0.3	32
MR-4	12.2	30.6	1.03	312	370		1.2		N/A[8]	0	N/A[8]	0	1	0.2	207
MR-5	5.5	12.3	1.03	512	851		1.7		111	11	116	1	1.2	0.5	57
MR-6	25.7	10.7	1.09	985	2,350	2,220	2.4	2.3	65	116	94	4	2.4	1.1	138
MR-7	14.9	8.3	1.05	845	2,050	1,900	2.4	2.2	60	44	65	3	1.8	1	93
MR-8	5.4	8.8	1.19	1,132	8,960	6,380	7.9	5.6	57	28	95	1	2.7	1.8	26
LR-1	14.5	6.2	1.12	3,340	9,210	8,940	2.8	2.7	43	13	93	1	4	2.3	25
LR-2	22.3	4.9	1.16	3,120	7,800		2.5		32	18	36	1	5.6	2.9	38
LR-3	21	4.7	1.23	4,040	16,070		4		32	19	39	1	8.8	3.7	28
LR-4	12.3	1	1.24	2,750	12,290		4.3		33	15	N/A[8]	0	5.1	2	24
LR-5	8.8	1.3	1.13	3,250	8,880		2.7		31	5	N/A[8]	0	1.9	0.6	15
LR-6	20.2	1.5	1.43	5,280	31,000		5.9		N/A[8]	0	N/A[8]	0	6.2	3.1	20

Notes:

1. The Upper River is an incised and confined river system with an inherited plan form and is not active. Thus, sinuosity equals one.
2. Effects of manmade features, including railroad grade, levees, etc. not considered in valley bottom width.
3. Valley bottom width reflects confining effects of manmade feature, including railroad grade, levees, etc.
4. Ratio of Valley bottom width to active channel width.
5. Values calculated from summer 2013 and summer 2014 bed material data (i.e. surface samples) collected primarily at the heads of bars and mid-channel islands.
6. Values calculated from winter 2014 bed material data (i.e. surface samples) collected within the main channel near the thalweg.
7. Number of channels separated by relatively stable, vegetated islands.
8. No samples were collected.

9. FIGURES

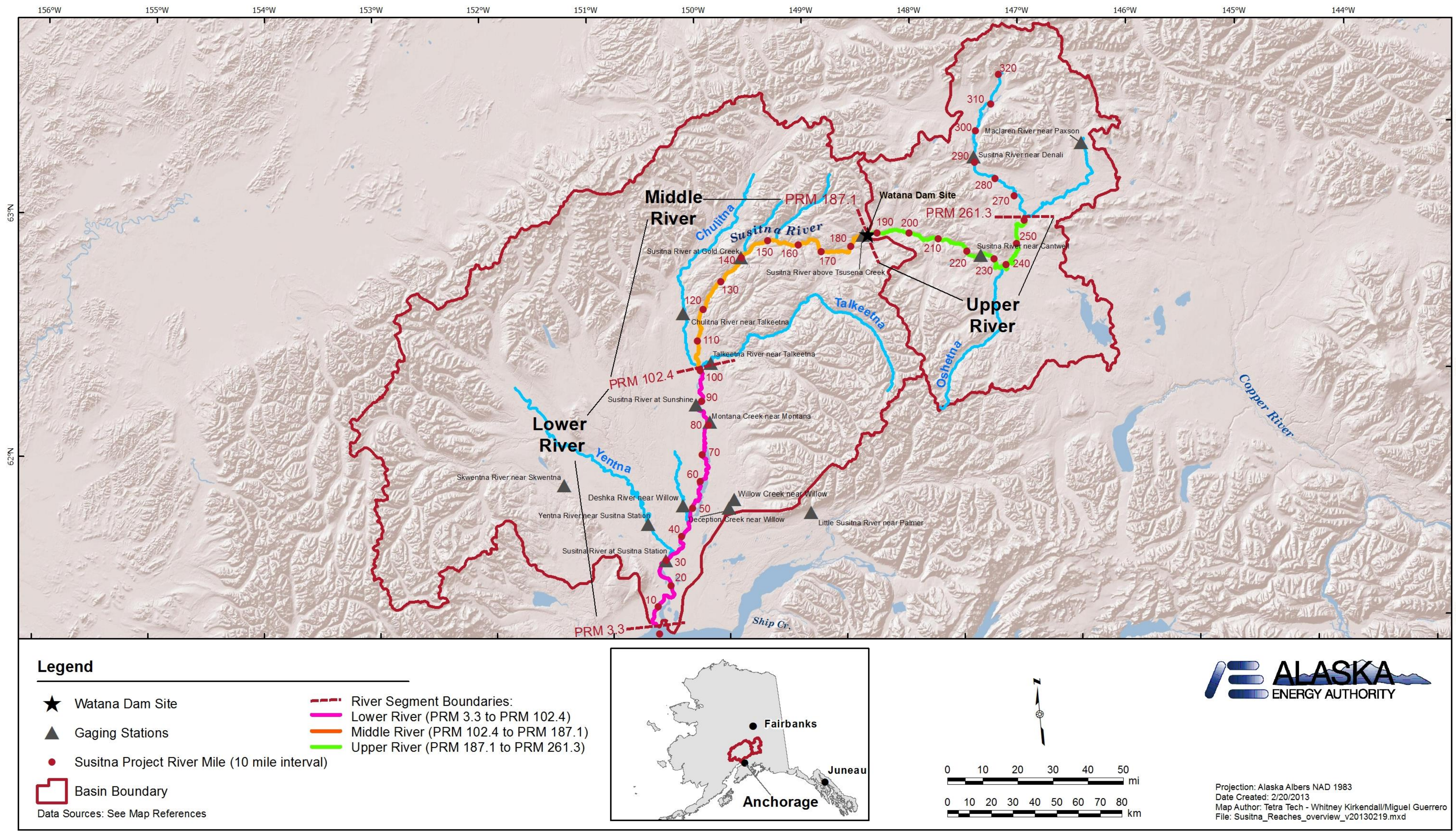

Figure 3.2-1 Susitna River Geomorphology Study Area and Large-scale River Segments.

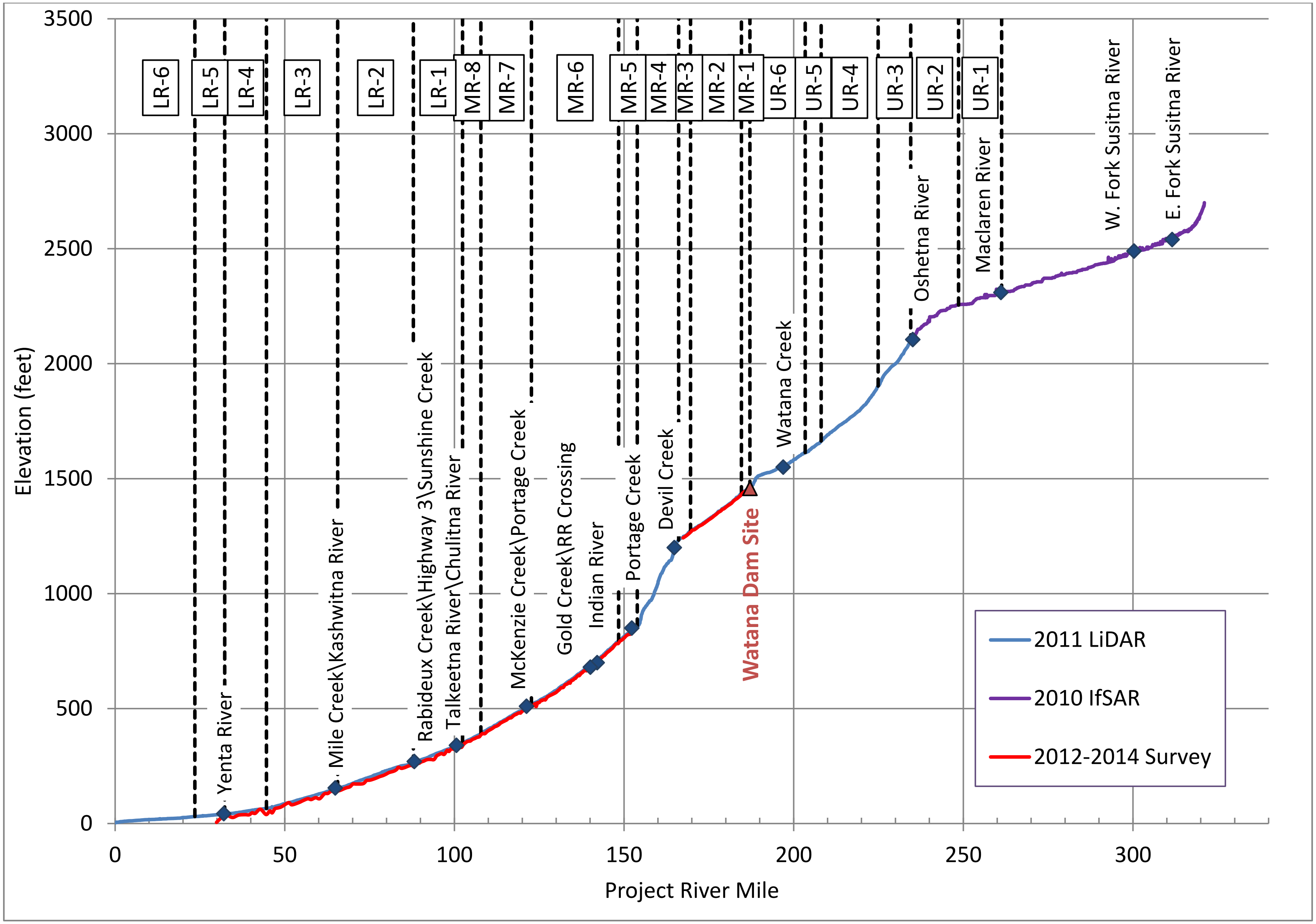

Figure 5.1-1 Longitudinal Profile of Susitna River from Cook Inlet to the Headwaters. Sources of data are shown on the figure. Reach boundaries are also included.

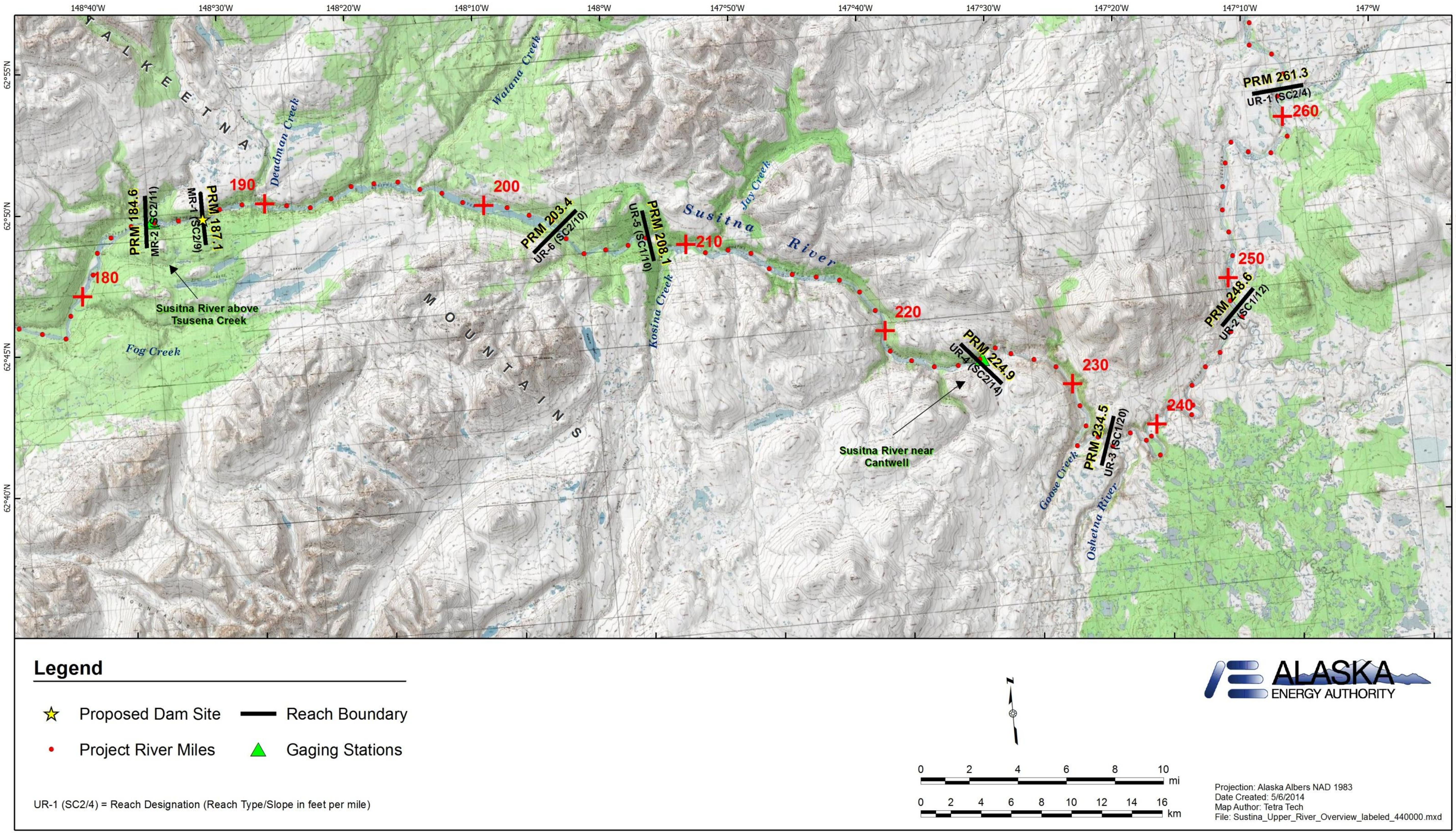

Figure 5.3-1 Map of the Upper Susitna River Segment showing the geomorphic reaches.

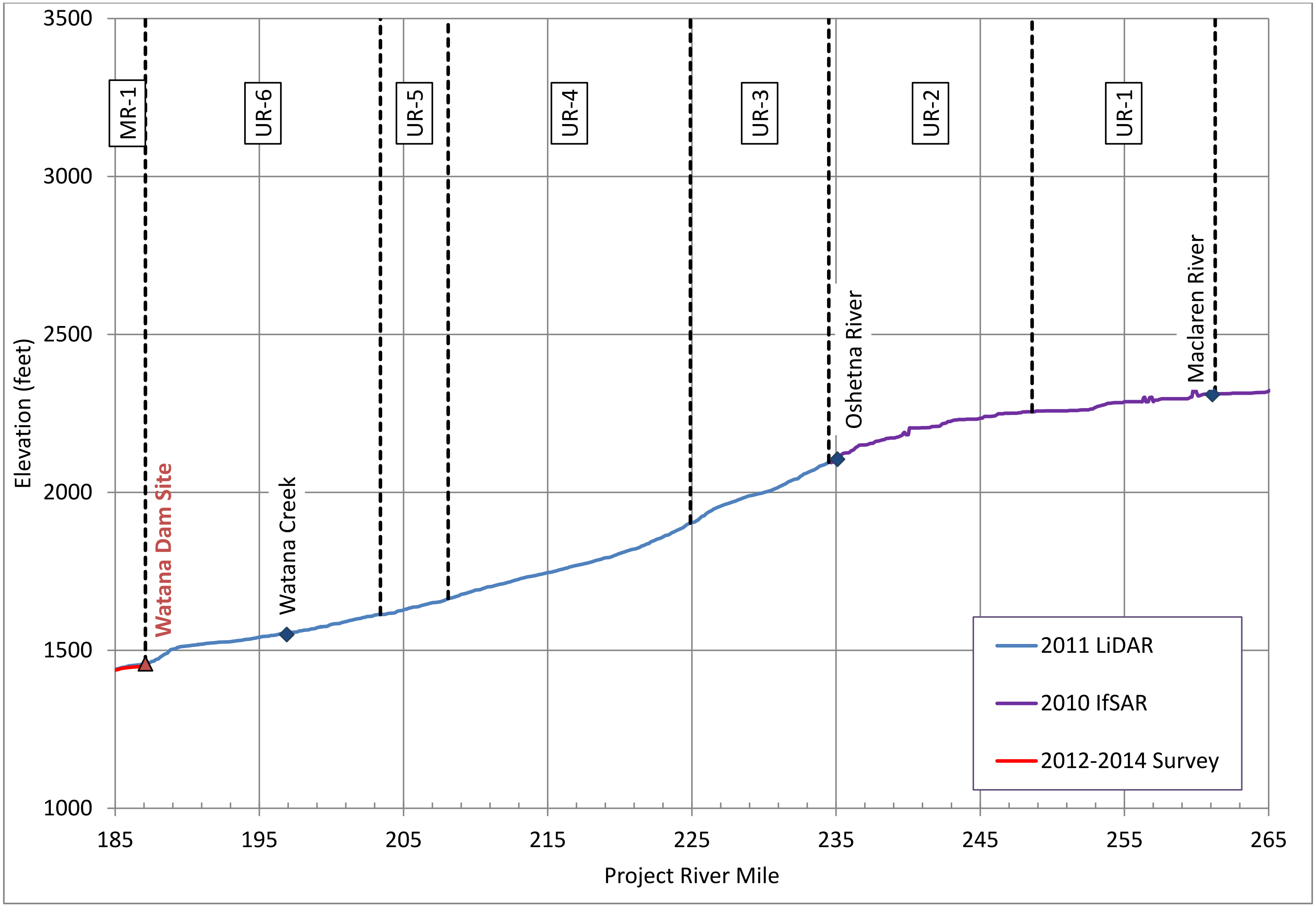

Figure 5.3-2 Longitudinal Profile of Susitna River in Upper River segment. Data Sources are shown on the figure. Reach boundaries are also included.

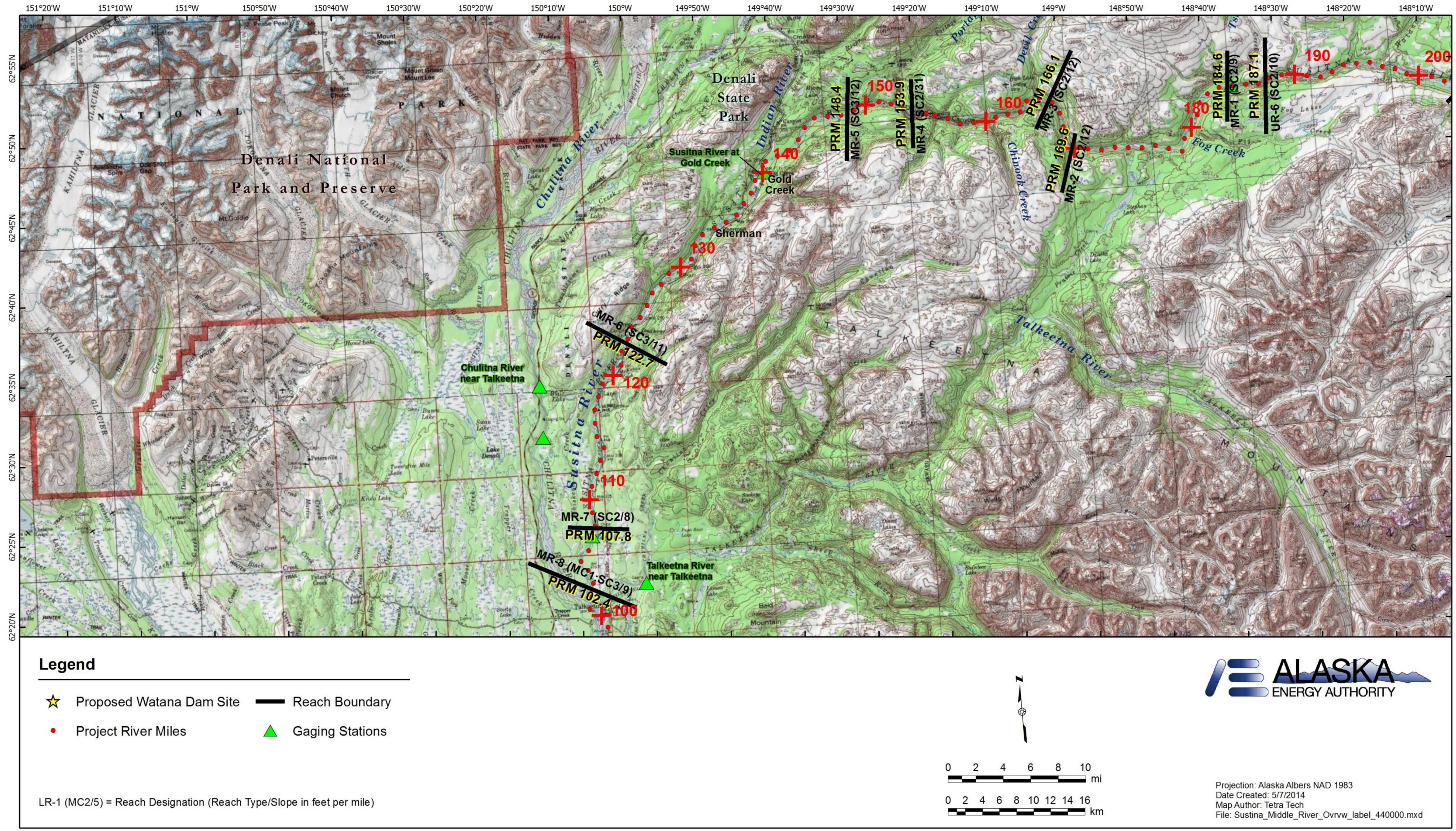

Figure 5.4-1 Map of Middle Susitna River Segment showing the Geomorphic Reaches.

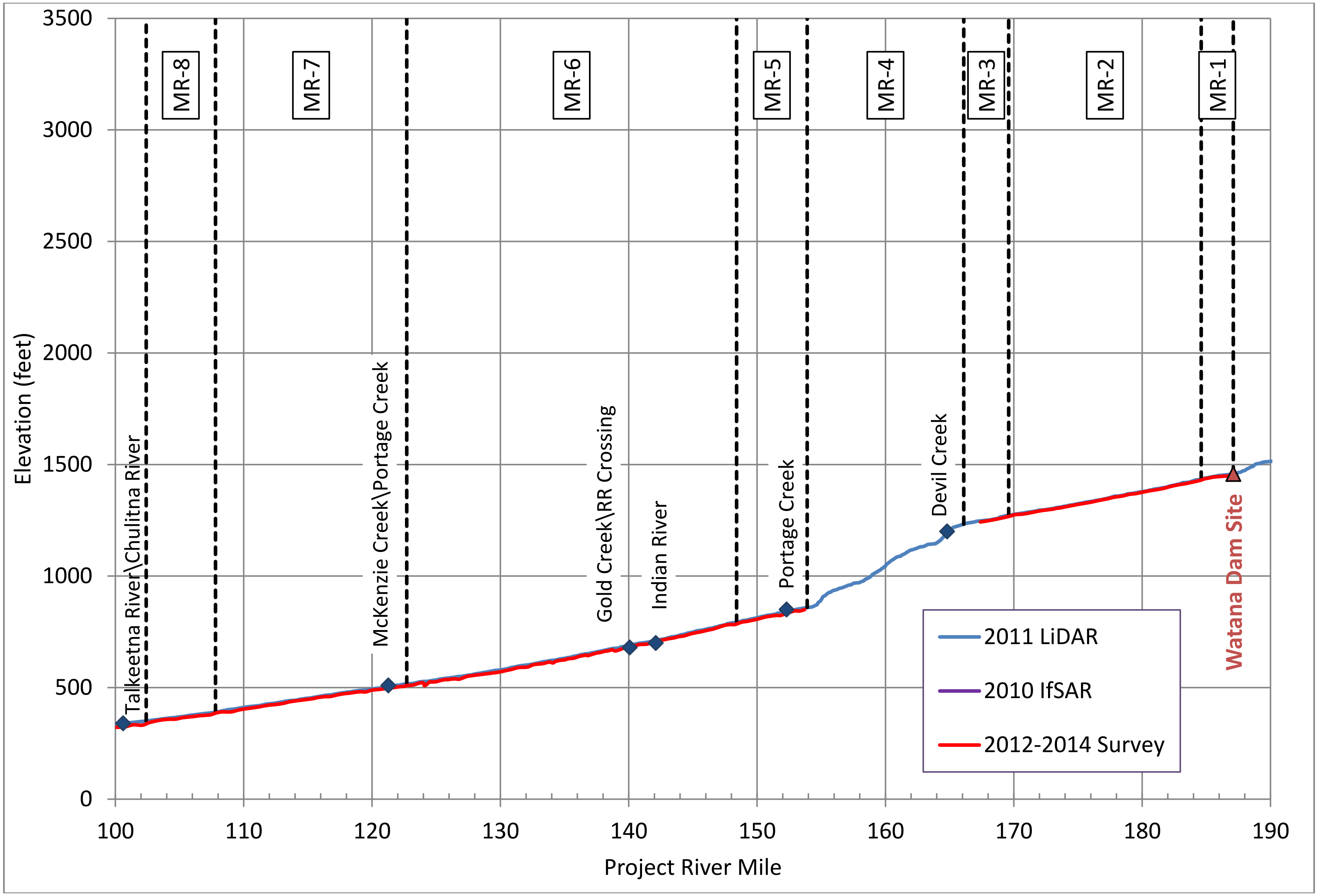

Figure 5.4-2 Longitudinal Profile of Susitna River in Middle River segment. Data sources are shown on the figure. Reach boundaries are also included.

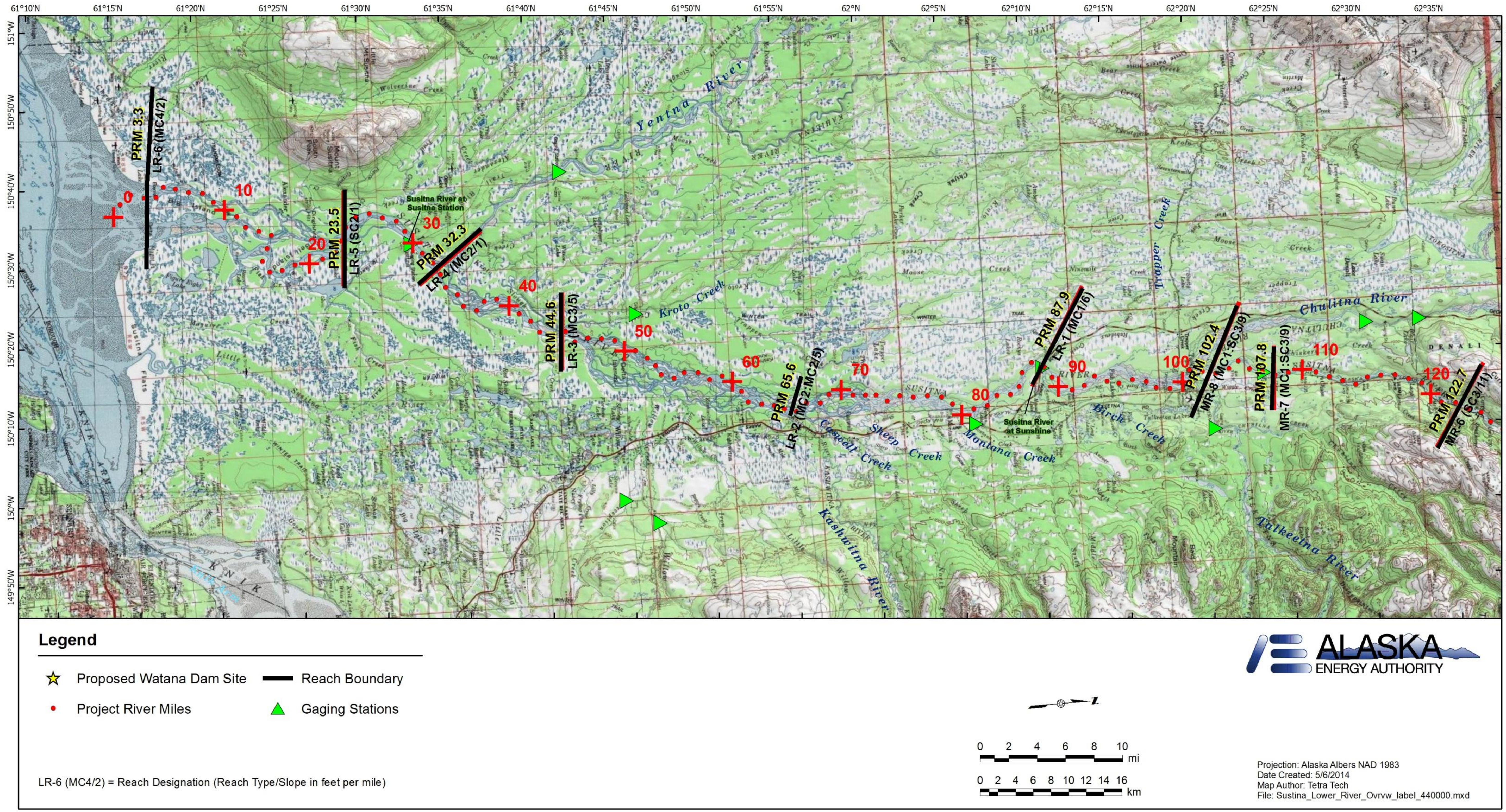

Figure 5.5-1 Map of Lower Susitna River Segment showing the Geomorphic Reaches.

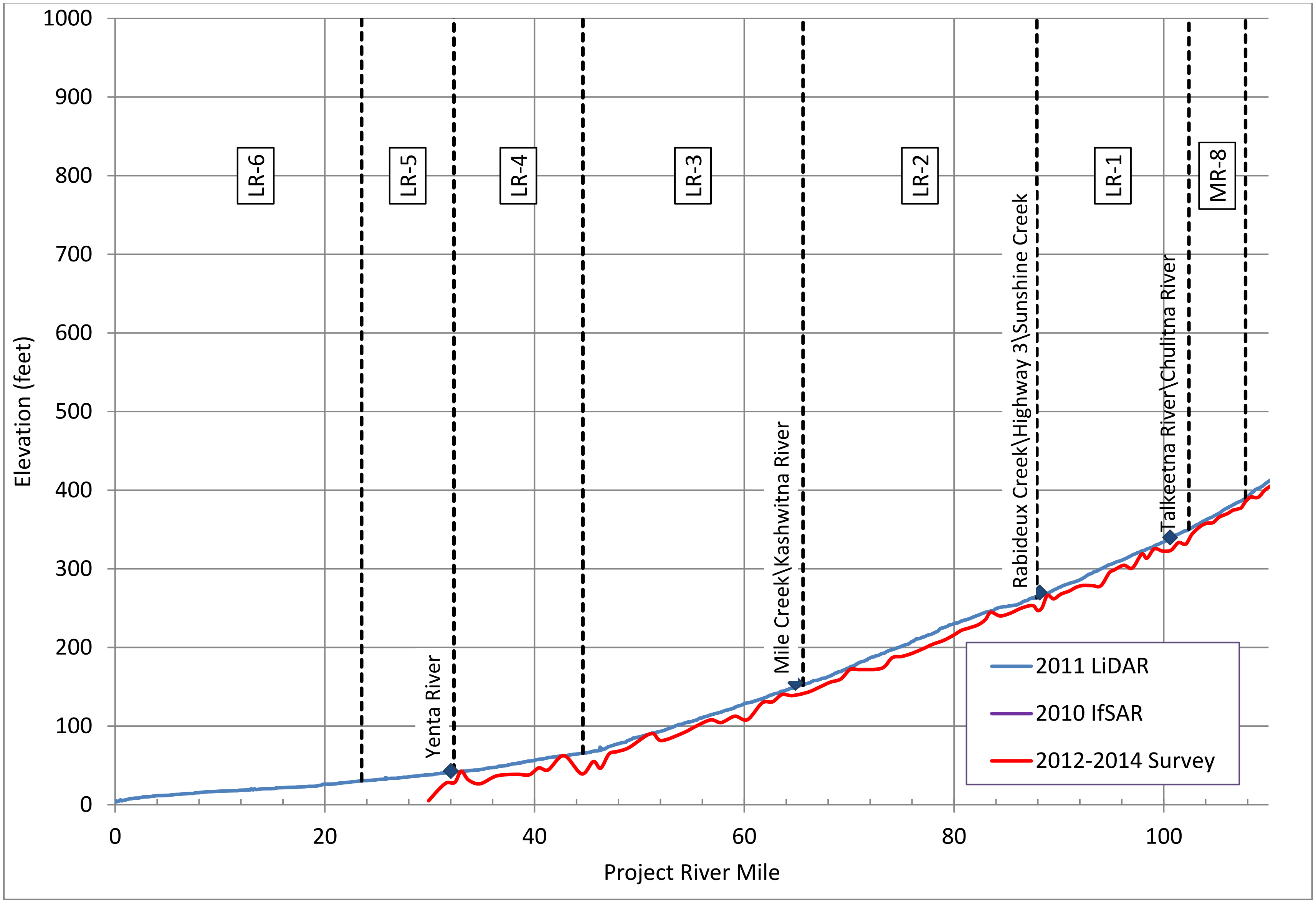

Figure 5.5-2 Longitudinal Profile of Susitna River in Lower River Segment. Sources of data are shown on the figure. Reach boundaries are also included.