Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River Segment

2012 Study 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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Abbreviation	Definition
AEA	Alaska Energy Authority
APA Project	Alaska Power Authority Susitna Hydroelectric Project
cfs	cubic feet per second
ER	Entrenchment Ratio
FERC	Federal Energy Regulatory Commission
ft/mile	feet per mile
ILP	Integrated Licensing Process
LiDAR	Light Detection and Ranging-based Topography
LR	Lower Susitna River Segment
MC	Multiple Channel Reach Classification
mi	mile(s)
mm	millimeter(s)
MR	Middle Susitna River Segment
NEPA	National Environmental Policy Act
OS	operational scenario
Project	Susitna-Watana Hydroelectric Project
PRM	Project River Mile (the current, Susitna-Watana Project river-mile system)
RM	River Mile (the 1980s APA Project river-mile system)
RSP	Revised Study Plan
SC	Single Channel Reach Classification
UR	Upper Susitna River Segment
USGS	United States Geological Survey

SUMMARY

This effort synthesized results from the Development of Sediment-Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments technical memorandum and the Stream Flow Assessment technical memoranda within an analytical framework to perform an initial assessment of potential Project-related changes in channel morphology of the Lower River. The overall goal was to determine whether portions of the Fluvial Geomorphology Modeling Study and other studies need to be extended downstream in the Lower River based on the potential for the Project to affect channel morphology. The 2012 reconnaissance level assessment involved analysis of pre-Project and post-Project conditions in the Susitna River below Watana Dam. The pre-Project condition was based on the extended flow record developed by the USGS. The post-Project condition was based on a hypothetical operational scenario (OS) referred to as Maximum Load Following OS-1.

The assessment of potential channel change in the Lower River was successfully completed. The limits of the one-dimensional sediment transport modeling effort were extended downstream based on the results of this study. The assessment procedure will be used in 2013 and 2014 to serve as check on the one-dimensional sediment transport modeling efforts conducted in the Middle and Lower Rivers.

Results from three aspects of the study were combined to reach the conclusion that the one-dimensional sediment transport modeling component of the Fluvial Geomorphology Modeling Study should be extended approximately 50 miles farther downstream to Susitna Station. The combination of the results from the stream flow assessment, the sediment balance, and the analytical assessment framework suggested sufficient possibility of Project-related channel change that more detailed analyses are warranted to further investigate potential Project effects below Sunshine.

The stream flow assessment estimated reduction in peak flows at Sunshine and Susitna Station of 24 percent and 17 percent, respectively, under the Maximum Load Following OS-1 compared with the pre-Project condition. The reductions were for flows in the channel forming range of the 1.5- to 5-year return interval. Discharges in this range are considered representative of the channel forming or effective discharge to which the bankfull channel capacity adjusts. Relationships between channel size and discharge suggest this level of peak flow reduction could result in narrowing of the channel width by slightly greater than 10 percent below Sunshine, and less than 10 percent below the Yentna River confluence.

The results of both the sediment balance and analytical framework were inconclusive as to whether significant channel change would occur as a result of the Project. The results indicate the portion of the Lower River above Sunshine will continue to be aggradational. The results of the analytical framework in Lower River segment below Sunshine fell within the “Effects Subtle” range suggesting the need for further investigation of the potential for channel change in this portion of the Lower Susitna River.

1. INTRODUCTION

The Alaska Energy Authority (AEA) is preparing a License Application that will be submitted to the Federal Energy Regulatory Commission (FERC) for the Susitna-Watana Hydroelectric Project (Project) using the Integrated Licensing Process (ILP). The Project is located on the Susitna River, an approximately 300-mile-long river in the South-Central Region of Alaska. The Project's dam site will be located at Project River Mile (PRM) 187.1. The results of this study will inform the 2013-2014 formal study program, and Exhibit E of a license application, and FERC's National Environmental Policy Act (NEPA) analysis for the Project license.

This report provides the results of the Integrated Sediment Transport and Flow Results into Analytical Framework subtask of the 2012 Reconnaissance-Level Geomorphic and Aquatic Habitat Assessment of Project Effects on Lower River Channel (AEA 2012a). This effort synthesizes results from the Sediment Load Comparison task and Stream Flow Assessment task 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. The downstream limit of the 1-D bed evolution model in the Revised Study Plan (RSP; AEA 2012b) is at PRM 79. This effort was conducted to help inform the need to continue studies further downstream in the Lower Susitna River Segment.

This effort compares pre-Project and post-Project conditions to identify potential Project effects, based on information developed in the 2012 Geomorphology Study and presented in the technical memoranda: Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a) and Stream Flow Assessment (Tetra Tech 2013b).

The pre-Project flows used for the analysis are based on the 61-year extended record developed by the USGS (2012). The post-Project condition is a hypothetical operations scenario referred to as Maximum Load Following Operation Scenario 1 (Maximum Load Following OS-1), a simulated flow record developed with the Project-conditions flow-routing model (MWH 2012) for the same 61-year period as the pre-Project records. Maximum Load Following OS-1 is based on the assumption that the load fluctuation of the entire Railbelt would be provided by the Susitna-Watana Project, and all other sources of electrical power in the Railbelt would be running at base load. This assumed condition is not realistic for an entire year, and the results of this condition should be conservative with respect to assessing downstream impacts of load following.

2. STUDY OBJECTIVES

The specific objective of the effort presented in this technical memorandum is to perform an initial assessment of anticipated Project effects on the Lower Susitna River Segment channel type and morphology. The assessment was performed using the data developed for the pre- and post-Project flood frequency, flow duration, and sediment load analyses to predict the geomorphic response of the Susitna River in an analytic framework proposed by Grant et al. (2003) along the longitudinal profile of the river system from the Middle Susitna River Segment downstream through the Lower Susitna River Segment, with particular emphasis on the effects of the Chulitna and Talkeetna rivers at and downstream from the Three Rivers Confluence.

This work performed for this Technical Memorandum integrates the results of several earlier tasks in the 2012 Reconnaissance-Level Geomorphic and Aquatic Habitat Assessment of Project Effects on Lower River Channel Study (AEA 2012a) with several broader study objectives including:

- Assess potential changes to channel morphology and aquatic habitat pre- and post-Project.
- Evaluate the relative magnitude of changes to the sediment regime pre- and post-Project, the potential impacts on sediment/substrate gradations, and the vertical and lateral stability of the channel.

This effort is one of several conducted to help evaluate the need to extend studies into the Lower River Segment by addressing the sixth item in the criteria outlined in the Fish and Aquatics Instream Flow Study (AEA 2012b, RSP Section 8.5.3). The criteria from the RSP are provided below:

> *This assessment will include a review of information developed during the 1980s studies and study efforts initiated in 2012, such as sediment transport (see Section 6.5), habitat mapping (see Sections 6.5 and 9.9), operations modeling (see Section 8.5.4.2.2), and the Mainstem Open-water Flow Routing Model (see Section 8.5.4.3). The assessment and the following criteria will be used to evaluate the need to extend studies into the Lower River Segment and if studies are needed, will identify which geomorphic reaches require instream flow analysis in 2013. The criteria include: 1) Magnitude of daily stage change due to load-following operations relative to the range of variability for a given location and time under existing conditions (i.e., unregulated flows); 2) Magnitude of monthly and seasonal stage change under Project operations relative to the range of variability under unregulated flow conditions; 3) Changes in surface area (as estimated from relationships derived from LiDAR and comparative evaluations of habitat unit area depicted in aerial digital imagery under different flow conditions) due to Project operations; 4) Anticipated changes in flow and stage to Lower River off-channel habitats; 5) Anticipated Project effects resulting from changes in flow, stage and surface area on habitat use and function, and fish distribution (based on historical and current information concerning fish distribution and use) by geomorphic reaches in the Lower River Segment; and 6) Initial assessment of potential changes in channel morphology of the Lower River (see Section 6.5.4.6) based on Project-related changes to hydrology and sediment supply in the Lower River. Results of the 2013 studies will then be used to determine the extent to which Lower River Segment studies should be adjusted in 2014.*

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. Specific Study Area

For the Susitna-Watana Hydroelectric Project licensing effort the Susitna River from Cook Inlet to the Maclaren River confluence at Project River Mile (PRM) 261.3, the river has been subdivided into three segments (Tetra Tech 2103c) 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 (Figure 3.2-1):

- 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)

In addition to the segment boundaries, Figure 3.2-1 also shows the locations of gaging stations where flow, and in some cases, sediment measurements are available. 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. The Middle River (MR) segment extends from the Watana Dam site 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 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.

The study effort presented in this Technical Memorandum is concentrated on the Lower Susitna River Segment. However, the study area also includes the Middle Susitna River Segment since it is the altered hydrologic and sediment supply conditions in the Middle River that are the drivers of potential channel change in the Lower River.

4. METHODS

4.1. Deviations from Study Plan

There were no deviations from the tasks in the 2012 study plan involving the Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River Segment.

4.2. Analysis

This section describes the methods used to evaluate potential channel change in the Lower Susitna River based on the frequency and magnitude of flows that mobilize and transport bed material sediment. The procedure is based on a relatively simple conceptual model relating downstream channel changes due to dams to hydrogeomorphic change and geologic control (Grant et al. 2003). The procedure is based on estimates of two ratios:

1. The ratio of sediment supply downstream of the dam to the above-dam sediment supply (S^*).
2. The ratio of time when flow exceeds the threshold for bed-load transport under pre-Project conditions to post-Project conditions (In this case, Maximum Load Following OS-1) (T^*).

The sediment supply ratio (S^*) was computed from the results of the sediment balance investigation (Tetra Tech 2013a). S^* was computed for both pre- and post-dam conditions. The time ratio (T^*) is computed using the flow-duration curves developed as part of the stream flow assessment (Tetra Tech 2013b). The additional information required for the time ratio is an estimate of the critical flow (Q_{cr}) for initiation of sediment transport. For this assessment, the critical flow was estimated by identifying the discharge that corresponds to a low, threshold bed load transport rate, as defined by Parker et al. (1982) and Wilcock and Crowe (2003) using the bed-load sediment discharge measurements from Knott et al. (1987) and more recent USGS sediment discharge, along with USGS flow measurements at the gages.

4.2.1. Stream Flow Assessment

In the stream flow assessment (Tetra Tech 2013b) flow-duration and flood frequency analyses were performed for Maximum Load Following OS-1 for the three mainstem Susitna River gages (Gold Creek PRM 140, Sunshine PRM 88 and Susitna Station PRM 30). Data used in the analysis were developed by MWH (2012) using the HEC-ResSim operations model of the Project that uses the USGS 61-year extended record of mean daily flows as a long-term reservoir inflow time series. The model run on which these data are based represents a preliminary operation scenario that was developed by placing the entire variability of the Railbelt electricity load on Susitna-Watana; thus, it represents a maximum (or worst-case) load-following scenario (John Haapala, personal communication, January 24, 2013). The model was used to route the reservoir outflows downstream through the Susitna River to the Sunshine Gage at PRM 88, providing a 61-year period of simulated flows for Maximum Load Following OS-1 at Gold Creek and Sunshine. A 61-year flow record for the Susitna Station gage was estimated by adding the difference between the flows at the Sunshine and Susitna Station gages from the

USGS (2012) extended record to the routed flows at Sunshine. Annual maximum hourly flows from the HEC-ResSim routings were used for the peak flood frequency analysis at Gold Creek and Sunshine as a surrogate for the instantaneous (15-minute) gage data that are typically used for this type of analysis, since the maximum temporal resolution of the model output is 1 hour. This approach is not considered to be a significant limitation in the analysis, since Susitna River is relatively large, and the difference between the peak 15-minute and maximum hourly flows is typically quite small. The frequency analysis for Susitna Station was performed based on the annual maximum mean daily flows because sufficient information is not available at this time to reliably estimate maximum flows at a higher temporal resolution. As will be shown in the analysis, this is also not a significant limitation at this location on the river.

The data used from the Stream Flow Assessment report (Tetra Tech 2013b) are flow-duration curves for the three mainstem gages (Gold Creek, Sunshine, and Susitna Station). The flow-duration curves for all three stations are compared for pre-Project and Maximum Load Following OS-1 in Figure 4.5-2 of the Stream Flow Assessment report (Tetra Tech 2013b). For each mainstem gage, the critical discharge is estimated for initiation of motion of the bed material. Once this discharge is estimated, the flow-duration curves are used to determine the amount of time this flow is exceeded.

4.2.2. Sediment-transport Supply and Balance

The sediment-transport supply and balance assessment (Tetra Tech 2013a) provides an initial sediment balance for the Susitna River system. The annual sediment loads at the three mainstem gages were developed by combining the flow duration results with rating curves of each of the major components of the sediment load (silt/clay, sand, and gravel). Sediment loads supplied from gaged tributaries were determined using the same procedure. The sediment loads at the Watana Dam site and the sediment supplied from ungaged tributaries was also estimated based on the unit sediment yields from the available data. These results provide the basis for computing the sediment supply ratio (S^*) for pre-Project and Maximum Load Following OS-1 conditions.

4.2.3. Initial Assessment of Downstream Effects

Grant et al. (2003) describes a simple conceptual model of downstream channel changes due to changes in sediment supply and duration of sediment-mobilizing flows caused by dams. The model uses two dimensionless ratios (Figure 4.2-1). S^* is the ratio of sediment supply below the dam (S_B) to the sediment supply upstream of the dam (S_A):

$$S^* = \frac{S_B}{S_A} \qquad (4.2\text{-}1)$$

For post-dam conditions, most of this sediment is trapped in the dam. For pre-dam conditions, S_A and S_B are equal immediately below the dam site, and both S_B and S^* increase as other sediment sources contribute downstream. For this analysis, it is assumed that 100 percent of the sand and gravel supply is trapped in the dam; thus, $S_B=0$ immediately below the dam under post-dam conditions. Similar to pre-dam conditions, the values of S_B and S^* increase in the downstream direction as other sources of sediment are introduced. Separate values of S_B and S^* were calculated for the sand and gravel loads, as each is the dominant factor in determining sediment-transport conditions and the morphology of the Susitna River in specific portions of the study area.

T^* is the ratio of fractional time that bed sediments are mobilized under pre- and post-dam hydrologic conditions. To compute T^*, the fraction of time, T, that flows mobilize bed sediments is computed separately for pre- and post-dam conditions:

$$T = \frac{\sum t_{(Q>Qcr)}}{\sum t_Q} \qquad (4.2\text{-}2)$$

For perennial channels the denominator of Equation 4.2-2 is the complete flow record, or 100 percent of the time in a flow-duration analysis. For ephemeral channel the denominator can change from pre- to post-dam conditions. T^* is then computed from the time fractions:

$$T^* = \frac{T_{post}}{T_{pre}} \qquad (4.2\text{-}3)$$

The channel adjustment model (Figure 4.2-1) shows three regions. Reaches of river with low values of S^* and high values of T^* indicate that the upstream supply is dominant and mobilizing flows occur frequently. These reaches will respond primarily by degrading (i.e., downcutting) and/or armoring. Conversely, in reaches of river with high values of S^* and low values of T^*, the downstream sediment supply is dominant but mobilizing flows occur infrequently under post-dam conditions. These reaches will respond through aggradation, especially at the tributary confluences, and, potentially, fining of the bed material. Along the central diagonal the effects of the altered sediment and flow characteristics are much less extreme. At the origin, although sediment supply is truncated, the frequency of sediment mobilizing flow is also truncated so there is neither the supply of sediment nor the energy to alter the channel form. Reaches that fall along the shaded diagonal may still adjust, but sediment supply and transport capacity are likely to remain more closely in balance. The effects of changing hydrology on T^* are obvious; changing flow durations will likely have an impact on the amount of time that flows mobilize bed material. Trapping sediment in a reservoir impacts the sediment supply at the dam, reducing S*. Downstream tributary sediment supply is unaffected by the dam. However, changing hydrology also impacts the mainstem transport capacity. In the case of the Susitna River, Maximum Load Following OS-1 decreases sediment loads because of the reduced magnitude of high flows, the corresponding increase in magnitude and duration of low flows, and the non-linear form of the sediment transport versus flow relationship. These reduced loads become the supply to reaches farther downstream.

4.2.3.1. Evaluation of the Sediment Supply Ratio, S^*

Tables 4.2-1 and 4.2-2 show the annual sediment loads for pre-Project and Maximum Load Following OS-1 conditions. These tables are the same as those presented in Tetra Tech (2013a), but also include an estimate of the sediment supply for ungaged tributaries between Sunshine and the Yentna River. This location was included because the supply of gravel above the Yentna River confluence exceeds the capacity of gravel transport at Susitna Station, which is just downstream of the Yentna River confluence. As a result, deposition of gravel is expected between Sunshine and the Yentna confluence, even under pre-Project conditions. The results also indicate deposition of sand between Sunshine and the Yentna River confluence. For both pre-Project and Maximum Load Following OS-1 conditions, S^* was computed using the pre-

Project sediment supply at Watana Dam (1,197,000 tons/year for sand and 56,000 tons/year for gravel) as the denominator of Equation 4.2-1. S^* for both sand and gravel through the Middle Susitna River is close to zero for the Maximum Load Following OS-1 condition and is between 1.0 and 1.2 for pre-Project conditions. This indicates that relatively little sediment supply comes from tributary sources in the Middle River segment. At the Three Rivers Confluence, S^* increases dramatically for both sand and gravel sizes. S^* for sand at this location is 5.2 for pre-Project conditions and 4.2 for Maximum Load Following OS-1 conditions. S^* for gravel at the Three Rivers Confluence is 15.6 under pre-Project conditions and 14.5 for Maximum Load Following OS-1 conditions. These large increases for both conditions result from sediment supplied primarily by the Chulitna River, although the Talkeetna River is also a significant source.

The area from the Three Rivers Confluence downstream nearly to Sunshine is braided and stores considerable amounts of gravel (Tetra Tech 2013a, Tetra Tech 2013c). This is evident in the significant drop in values of S^* for gravel at Sunshine to 5.0 for pre-Project conditions. Similarly, S^* decreases to 2.5 for Maximum Load Following OS-1 conditions at Sunshine gage.

Under pre-Project conditions , S^* for the sand load ranges between 5.1 and 5.5 between Sunshine and the Yentna River, then increases significantly to 11.9 downstream of the Yentna River. Under Maximum Load Following OS-1 conditions, S^* for the sand load ranges from 4.2 to 4.6 between Sunshine and the Yentna River, and increases to 10.9 downstream of the Yentna River. For pre-Project conditions, S^* for the gravel load ranges from 5.0 to 5.9 between Sunshine and the Yentna River, and decreases to 4.6 downstream of the Yentna River. For Maximum Load Following OS-1 conditions, S^* for the gravel load increases from 2.5 to 3.5 between Sunshine and the Yentna River, then increases slightly to 3.7 downstream of the Yentna River. This indicates that there may be a small amount of gravel accumulation upstream of the Yenta River under pre-Project conditions, but the results for Maximum Load Following OS-1 conditions are less certain.

4.2.3.2. Evaluation of the Transport Duration Ratio, T^*

The parameter T, from Equation 4.2-2, is the fraction of time that flows are transporting sediment related to the specific resource issue under consideration (Grant et al. 2003). For this Project, the primary concerns are Project effects on the channel form that could alter the important lateral habitats (side channels, side sloughs and upland sloughs), as well as on the margins of the main channel that are used for adult salmonid spawning and juvenile rearing. Since the study area is primarily gravel-bedded, effects on the gravel component of sediment transport are the most important in addressing the resource issues of concern. It is also important to note that gravel is not mobilized for all flows, perhaps only a small percentage of the time, while sand sizes are mobile at essentially all flows. Therefore, T^* can change considerably for the gravels and remain unchanged for sand.

As indicated by Grant et al. (2003), the actual calculation of T^* can be difficult and is generally based on empirical or theoretical sediment-transport equations that consider only the median (D_{50}) sediment size. Although determining a critical discharge for incipient motion of a specific D_{50} is useful, in practice, small amounts of sediment are typically in transport below this "threshold" value. As a result, it is customary to define the threshold for gravel mobilization based on a reference condition of very low transport rates (Parker et al. 1982, Wilcock 1988) based on the dimensionless transport rate given by:

$$W_i^* = \frac{(S-1)gq_{bi}}{F_i u_*^3} = f\left(\frac{\tau}{\tau_{ri}}\right) = f(\varphi) \tag{4.2-4}$$

where:

W_i^* = dimensionless transport rate,
s = specific gravity of the sediment,
g = gravitational acceleration,
q_{bi} = volumetric transport rate of bedload per unit width for size fraction i,
F_i = proportion of size fraction i in the size distribution,
u^* = shear velocity,
τ = boundary shear stress,
τ_{ri} = reference shear stress for size class i, and
phi (ϕ) = τ/τ_{ri}.

Parker et al. (1982) and Wilcock (1988) defined incipient motion as a W_i^* value of 0.002, for ϕ = 1.0.

Equation 4.2-4 was used to determine the critical discharge for bed mobilization (Q_{cr}) in Equation 4.2-2 using the available bed-load transport measurements at the Gold Creek/near Talkeetna and Sunshine gages. The computational procedure involved estimating the value of W^* and the corresponding value of ϕ for each gravel-bed load transport measurement, adjusting the assumed D_{50} of the bed material so that the expected relationship between W^* and ϕ, computed using the Parker et al. (1982) bed-load transport equation, fits through the data. The available measurements included the total bed-load transport rates and corresponding water discharge, but did not include the hydraulic parameters (flow width, depth, slope, and velocity) necessary to calculate the unit transport rates, shear stresses and corresponding values of ϕ. The values of these parameters for each measurement were estimated from hydraulic geometry relationships for velocity, depth and width as a function of discharge that were developed using data from the USGS measurements that have been taken to calibrate the stage-discharge rating curves at the gages. The gradient (S) at each of the gages that is required to estimate the shear velocity (u^*) was estimated based on the local slope from longitudinal profiles developed from the 2012-surveyed cross sections at Gold Creek and the LiDAR mapping at Sunshine.

At Gold Creek, the channel slope is approximately 10.5 ft/mile and a D_{50} of 67 mm positions the transport relationship through the measured data (Figure 4.2-2). The discharge, Q_{cr}, associated with ϕ=1 and W^* =0.002 is approximately 25,000 cubic feet per second (cfs). The channel slope at Sunshine is about 6 ft/mile, and a D_{50} of 40 mm positions the transport relationship through the data, resulting in Q_{cr} equal to about 16,000 cfs (Figure 4.2-3). While sufficient data are not available to verify the estimated D_{50} values, they appear to be reasonable for purposes of this preliminary analysis, based on field observations and the limited data that are available. Typical of bed-load transport data, the plots show a plus/minus one log cycle of scatter in the data. The plot for Gold Creek appears to be a better fit, in part because the range of ϕ values corresponding to the measured data is greater. The Sunshine site shows more scatter because the sediment supply is much more variable with sediment contributions from the three upstream rivers, and the data were collected over a smaller range of ϕ values.

A similar analysis could not be performed at the Susitna Station. For the sand-bed channel at this location probably all flows mobilized the bed. For comparison, a low discharge of 4,000 cfs was used as Q_{cr}.

The values of Q_{cr} for each location were used in combination with the flow duration curves to determine the amount of time sediment is mobilized for pre-Project and Maximum Load Following OS-1 conditions. The ratio of these durations may be more or less than 1.0 depending on the flow value. If Q_{cr} is high, then T^* is likely to be less than 1.0 because the duration of bed-mobilizing flows will be reduced. If Q_{cr} is low, then T^* will likely be greater than 1.0 because the duration of bed-mobilizing flows will increase. If Q_{cr} is very low, such as the conditions that are believed to occur at Susitna Station, T^* will be equal to 1.0 because the bed is mobile at essentially all flows under both pre-Project and Maximum Load Following OS-1 conditions.

5. RESULTS

5.1. Evaluation of the Sediment Supply Ratio, S^*

S^* was computed for both the gravel and sand loads for pre-Project and Maximum Load Following OS-1 conditions (Figures 5.1-1 and 5.1-2). S^* for both the sand and gravel loads is about 1 between the dam site and the Three Rivers Confluence under pre-Project conditions, but is essentially zero in this reach under Maximum Load Following OS-1 conditions. Downstream of Three Rivers, S^* for gravel increases dramatically to approximately 15, with a slightly higher value under pre-Project conditions. The ratio of S^* between the two conditions (right axis on Figure 5.1-1) exceeds 0.9 at the Three Rivers Confluence. The similarity in the without and with-dam values could lead to the assumption that sediment impacts may not occur downstream of this location. Moving downstream to Sunshine gage, however, S^* for gravel decreases to a value of 5 for pre-Project conditions, and even more dramatically to slightly less than 3 for Maximum Load Following OS-1 conditions, resulting in a ratio between the two conditions of about 0.5. The large spike in the S^* values corresponds with the braided, aggradational area at and below the Three Rivers Confluence resulting primarily from the inflows from the Chulitna River. The more dramatic decrease in S^* under Maximum Load Following OS-1 conditions results from a combination of the changes in hydrology that decrease the duration of bed-mobilizing flows (i.e., T^*) and the significant increase in sediment supply. The altered hydrology under Maximum Load Following OS-1 conditions reduces the transport capacity of the Lower Susitna River Segment that becomes the supply for downstream reaches.

Moving downstream to the reach between Sunshine gage and the Yentna River confluence, S^* increases to about 6 for pre-Project conditions and 3.5 for Maximum Load Following OS-1 conditions, increasing the ratio to about 0.6. Values of S^* approach 4 for both conditions downstream of the Yentna River (Susitna Station gage) and the ratio of the two approaches 0.8. The mild crest in the pre-Project curve upstream of the Yentna River indicates 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 (Figure 5.1-2). Unlike the gravel plot, 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.

5.2. Evaluation of the Transport Duration Ratio, T^*

Based on the flow-duration curves presented in Tetra Tech (2013b), the critical discharge (Q_{cr}) of 25,000 cfs in the Middle River Segment occurs about 11 percent of the time under pre-Project conditions, and this would decrease to about 1.8 percent of the time under Maximum Load Following OS-1 conditions, resulting in a best-estimate value of T^* of 0.16 (Table 5.2-1, Figure 5.2-1). Similarly, the estimated Q_{cr} of 16,000 cfs at Sunshine occurs about 38 percent of the time under pre-Project conditions, but would increase to about 44 percent of the time under Maximum Load Following OS-1 conditions due to the increased duration of flows at or above this relatively low level. Because of the uncertainty in determining incipient motion discharge (Q_{cr}), a lower and higher value of this discharge was also estimated. For purposes of this preliminary analysis, the estimated value of Q_{cr} at the Gold Creek and Sunshine gages was increased and decreased by 5,000 cfs to reflect this uncertainty. At the Susitna Station gage, a value of plus and minus 2,000 cfs was used. The resulting values of T^* are also summarized in Table 5.2-1. 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 at which 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}.

5.3. Integration of S^* and T^*

The values of S^* for gravel and T^* values were plotted in the same conceptual format proposed by Grant et al. (2003) (Figure 5.3-1). 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 applying this model to the Susitna River. The Middle River Segment plots near the ordinate with 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. 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 plot 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.

6. DISCUSSION

The results of applying the Grant et al. (2003) conceptual model suggest 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 impact of the significant reduction in the frequency and duration of gravel mobilization on side channel and instream habitat could, however, be significant. In this segment the planned sediment-transport modeling will provide more complete analysis of potential effects (AEA 2012b, Section 6.6).

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, at least in comparison to upstream, 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 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. It should be noted, however, that this conclusion is based on only one bed material sample, so there is considerable uncertainty in the results for this location.

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 2013b) and initial sediment transport assessment (Tetra Tech 2013a), AEA will investigate the potential Project-related effects downstream to the Susitna Station gage. This investigation will include bed material and bed-load sampling, as well as 1-D sediment-transport modeling to quantify and clarify the potential magnitude of the Project-related impacts.

6.1. Stream Flow Assessment

The primary basis for identifying the need to continue the 1-D bed evolution modeling effort below the initially proposed downstream extent is based on interpretation of the results of the potential changes in hydrology identified in the stream flow assessment technical memorandum (Tetra Tech 2013b). A comparison of the annual peak flow frequency results between the existing conditions and the Maximum Load Following Operations Scenario 1 indicates an appreciable reduction in flows in the 1.5- to 5-year range of recurrence intervals in the Lower River. Discharges in the range of the 1.5- to 5-year peaks are often representative of the channel forming or effective discharge to which the bankfull channel capacity adjusts in streams such as the Lower Susitna River Segment that have mobile bed material and a substantial sediment supply (Wolman and Miller 1960, Wolman and Gerson 1978, Williams 1978, Andrews 1980). For the 2-year event, the reduction at Sunshine and Susitna Station were estimated at 24 and 17 percent, respectively.

Numerous researchers have identified hydraulic geometry relationships (i.e., relationships between channel dimensions and discharge) that clearly demonstrate this linkage (Leopold and Maddock 1953; Langbein 1964; Emmett 1972; Parker 1979; Andrews 1984; Hey and Thorne 1986; Julien and Wargadalam 1995). The channel width is typically proportional to about the square-root of the discharge; thus, the indicated reductions in 2-year discharge suggest that the channel could narrow by slightly more than 10 percent in the portion of the Lower River segment below Sunshine, and less than 10 percent downstream from the Yentna River confluence. The narrowing could occur through a combination of vegetation encroachment and sediment deposition along the margins of the channel and by expansion of the mid-channel islands. Since the channel margins, including the side sloughs are key habitat units, changes in these areas could have implications to habitat.

6.2. Development of Sediment-Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments

Results from this technical memorandum (Tetra Tech 2013a) indicate that the portion of the Lower Susitna River Segment below Sunshine is aggradational under pre-Project conditions, and it would likely remain aggradational under Maximum Load Following OS-1 conditions, although the magnitude of the aggradational tendency would be somewhat reduced. The sediment balance results are inconclusive as to whether significant channel change would occur as a result of the Project. More accurate quantification of this change under Project conditions is necessary to provide a basis for understanding the potential implications of the change in sediment balance to both channel form and instream and channel-margin habitat. Extension of the 1-D bed evolution model downstream to Susitna Station will help provide this understanding.

6.3. Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River Segment

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 with certainty 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.

7. REFERENCES

AEA (Alaska Energy Authority). 2012a. 2012 Reconnaissance-level Geomorphic and Aquatic Assessment of Project Effects on Lower River Channel: Susitna-Watana Hydroelectric Project FERC Project No. 14241. May 2012. Anchorage, Alaska. http://www.susitna-watanahydro.org/type/documents/.

AEA. 2012b. Revised Study Plan: Susitna-Watana Hydroelectric Project FERC Project No. 14241. December 2012. Prepared for the Federal Energy Regulatory Commission by the Alaska Energy Authority, Anchorage, Alaska. http://www.susitna-watanahydro.org/study-plan.

Andrews E.D. 1980. Effective and bankfull discharges of streams in the Yampa River basin, Colorado and Wyoming. *Journal of Hydrology* 46: 311–330.

Andrews, E.D. 1984. Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. *Bull. Geol. Soc. Am*. 95: 371–378.

Emmett, W.W. 1972. The Hydraulic geometry of some Alaska streams south the Yukon River. U.S. Geological Survey Open-file Report 72-0108: 110 p.

Hey, R D., and C.R. Thorne. 1986. Stable channels with mobile gravel beds. *J. Hydraul. Eng*. 112.8: 671–689.

Julien, P.Y., and J. Wargadalam. 1995. Alluvial channel geometry: Theory and applications. *J. Hydraul. Eng.* 121.4: 312–325.

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

Knott, J.M., S.W. Lipscomb, and T.W. Lewis. 1987. Sediment Transport Characteristics of Selected Streams in the Susitna River Basin, Alaska: Data for Water Year 1985 and Trends in Bed-load Discharge, 1981-95. U.S. Geological Survey Open-File Report 87-229. Prepared in cooperation with the Alaska Power Authority. Anchorage, Alaska. 45 p.

Langbein, W.B. 1964. Geometry of River Channels. J. Hydraulics Div. ASCE 90, HY2, 301-312.

Leopold, L.B., and T. Maddock. 1953. The hydraulic geometry of stream channels and some physiographic implications. *U.S. Geological Survey Professional Paper 252*; 57 p.

MWH. 2012. Susitna-Watana Hydroelectric Project, Preliminary Susitna River Pre-Project and Post-Project Flow Stages, presented at Technical Work Group Meetings, October 23-25.

Parker, G., 1979. Hydraulic geometry of active gravel rivers. *Journal of the Hydraulics Division*. v. 105. no. HY9: 1185-1201.

Parker, G. P.C. Klingeman, and D.L. McLean. 1982. Bedload and size distribution in paved gravel-bed streams. *Journal of Hydraulic Engineering*, ASCE, 108(4), 544-571.

Tetra Tech, Inc. 2013a. Development of Sediment Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments. Susitna-Watana

Hydroelectric Project. 2012 Study Technical Memorandum. Prepared for the Alaska Energy Authority. Anchorage, Alaska.

Tetra Tech, Inc., 2013b.Stream Flow Assessment. Susitna-Watana Hydroelectric Project. 2012 Study Technical Memorandum. Prepared for the Alaska Energy Authority. Anchorage, Alaska.

Tetra Tech, Inc. 2013c. Initial Geomorphic Reach Delineation and Characterization, Middle and Lower Susitna River Segments. Susitna-Watana Hydroelectric Project. 2012 Study Technical Memorandum. Prepared for the Alaska Energy Authority. Anchorage, Alaska.

U.S. Geological Survey (USGS). 2012. Streamflow Record Extension for Selected Streams in the Susitna River Basin, Alaska, Scientific Investigations Report 2012–5210. 46 p.

Wilcock, P.R. 1988. Methods for estimating the critical shear stress of individual fractions in mixed-size sediment. *Water Resources Research*. 24(7) 1127-1135.

Wilcock, P.R. and J.C. Crowe. 2003. Surface-Based Transport Model for Mixed-Size Sediment. *Journal of Hydraulic Engineering*, ASCE, 129(2), 120-128.

Williams GP. 1978. Bankfull discharge of rivers. *Water Resources Research* 14: 1141–1154.

Wilson, F.H., C.P. Hults, H.R. Schmoll, P.J. Haeussler, J M. Schmidt, L.A. Yehle, and K.A. Labay. 2009. Preliminary Mapping of the Cook Inlet Region Alaska Including Parts of the Talkeetna, Talkeetna Mountains, Tyonek, Anchorage, Lake Clark, Seward, Iliamna, Seldovia, Mount Katmai, and Afognak 1:250,000 Scale Quadrangles. USGS Open-File Report 2009-1108. 54p plus maps.

Wolman, M.G., and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. *Journal of Geology* 68: 54–74.

Wolman, M.G., and R. Gerson. 1978. Relative scales of time and effectiveness of climate in watershed geomorphology. *Earth Surface Processes* 3: 189-208.

8. TABLES

Table 4.2-1. Average annual sediment loads and S* under pre-Project conditions.

Gage	Drainage Area (mi^2)	Water Discharge (acre-feet)	Average Annual Load, tons (and S*)				
			Wash Load	Bed Material			Total Load
			Silt/Clay	Sand	Gravel	Total	
Watana	**5,180**	**5,803,000**	**1,684,000**	**1,197,000 (1.0)**	**56,000 (1.0)**	**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 (1.18)**	**66,000 (1.18)**	**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 (5.17)**	**871,000 (15.55)**	**7,063,000**	**15,067,000**
Sunshine	**11,100**	**17,426,000**	**10,012,000**	**6,101,000 (5.10)**	**279,000 (4.98)**	**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*
Supply above Yentna	13,220	21,080,000	12,378,000	6,635,000 (5.54)	332,000 (5.93)	6,967,000	19,345,000
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 (11.93)**	**260,000 (4.64)**	**14,538,000**	**34,072,000**

Note: S* is computed by dividing annual loads by the supply at Watana (1,197,000 tons/year for sand and 56,000 tons/year for gravel).

Table 4.2-2. Average annual sediment loads and S* under Maximum Load Following OS-1 conditions.

Gage	Water Discharge (acre-ft)	Average Annual Load, tons (and S*)				
		Wash Load	Bed Material			Total Load
		Silt/Clay	Sand	Gravel	Total	
Watana Dam	**5,785,000**	**168,000**	**0 (0.0)**	**0 (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** **(0.18)**	**4,000** **(0.07)**	**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** **(4.17)**	**809,000** **(14.45)**	**5,804,000**	**12,294,000**
Sunshine	**17,375,000**	**8,497,000**	**4,995,000** **(4.17)**	**142,000** **(2.54)**	**5,137,000**	**13,634,000**
Ungaged Tributaries	*3,654,000*	*2,366,000*	*534,000*	*53,000*	*587,000*	*2,953,000*
Supply above Yentna	21,029,000	10,863,000	5,529,000 (4.62)	195,000 (3.48)	5,724,000	16,587,000
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** **(10.89)**	**207,000** **(3.70)**	**13,247,000**	**31,266,000**

Note: S* is computed by dividing annual loads by the pre-Project supply at Watana (1,197,000 tons/year for sand and 56,000 tons/year for gravel).

Table 5.2-1. Results for critical discharge estimates.

Location	Estimated Q_{cr} (cfs)	T_{pre}	$T_{Max\ LF\ OS\text{-}1}$	T*
Best Estimate				
Watana	25,000	11.0%	1.8%	0.16
Gold Creek	25,000	11.0%	1.8%	0.16
Sunshine	16,000	44.0%	50.0%	1.14
Susitna Station	4,000	100.0%	100.0%	1.00
Low Estimate				
Watana	20,000	20.0%	4.5%	0.23
Gold Creek	20,000	20.0%	4.5%	0.23
Sunshine	11,000	46.0%	70.0%	1.52
Susitna Station	2,000	100.0%	100.0%	1.00
High Estimate				
Watana	30,000	5.0%	0.7%	0.14
Gold Creek	30,000	5.0%	0.7%	0.14
Sunshine	21,000	38.0%	38.0%	1.00
Susitna Station	6,000	92.5%	99.2%	1.07

9. FIGURES

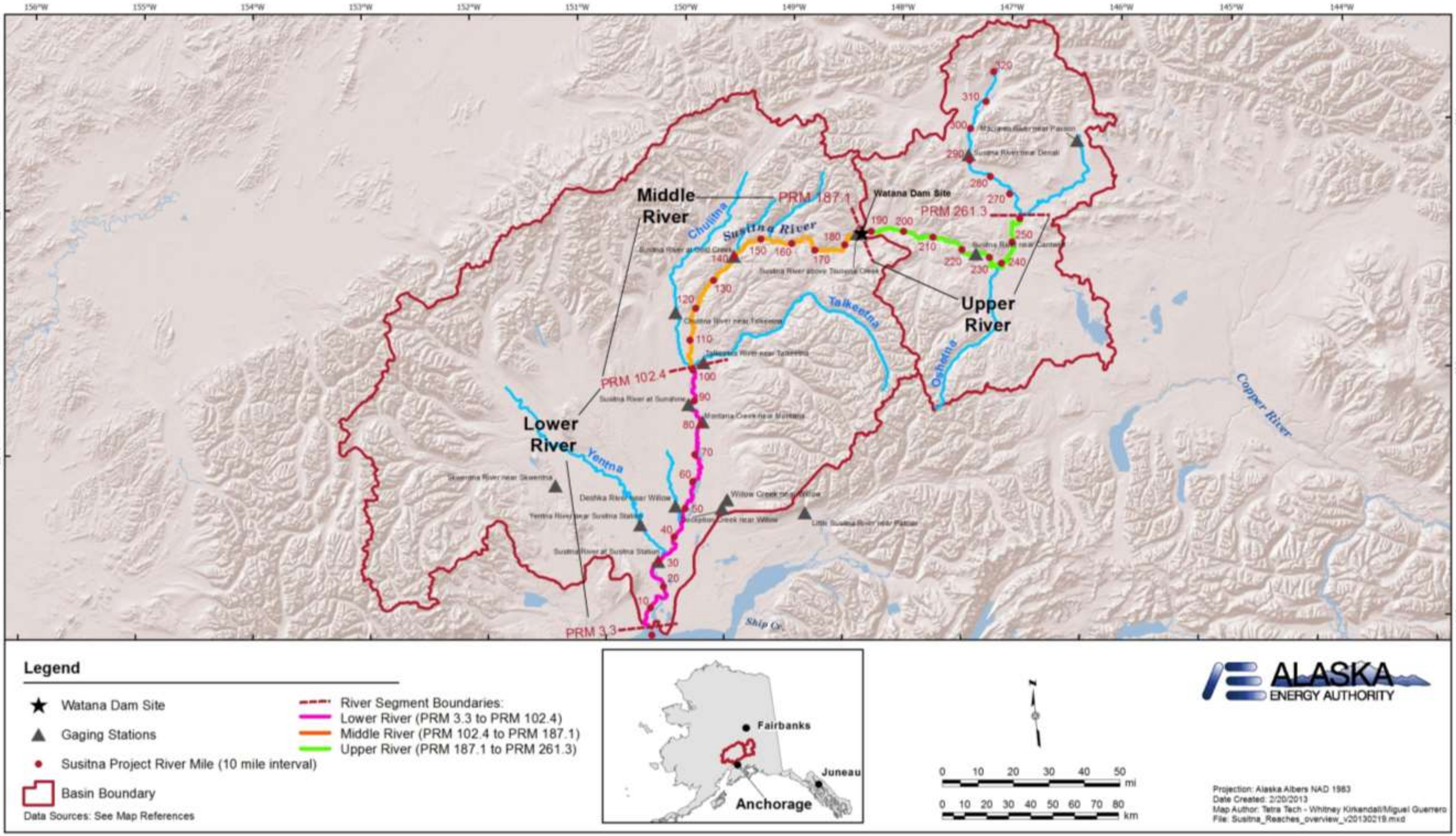

Figure 3.2-1. **Susitna River Geomorphology Study Area and Large-scale River Segments.**

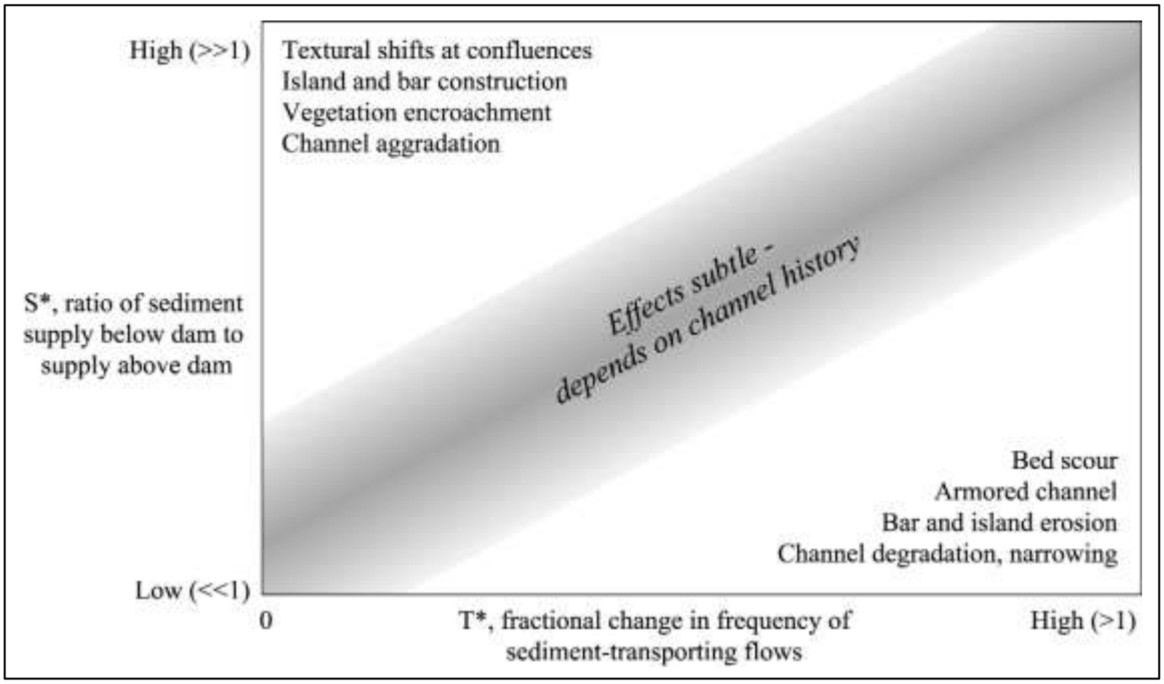

Figure 4.2-1. Response domain for predicted channel adjustments. (Grant et al. 2003).

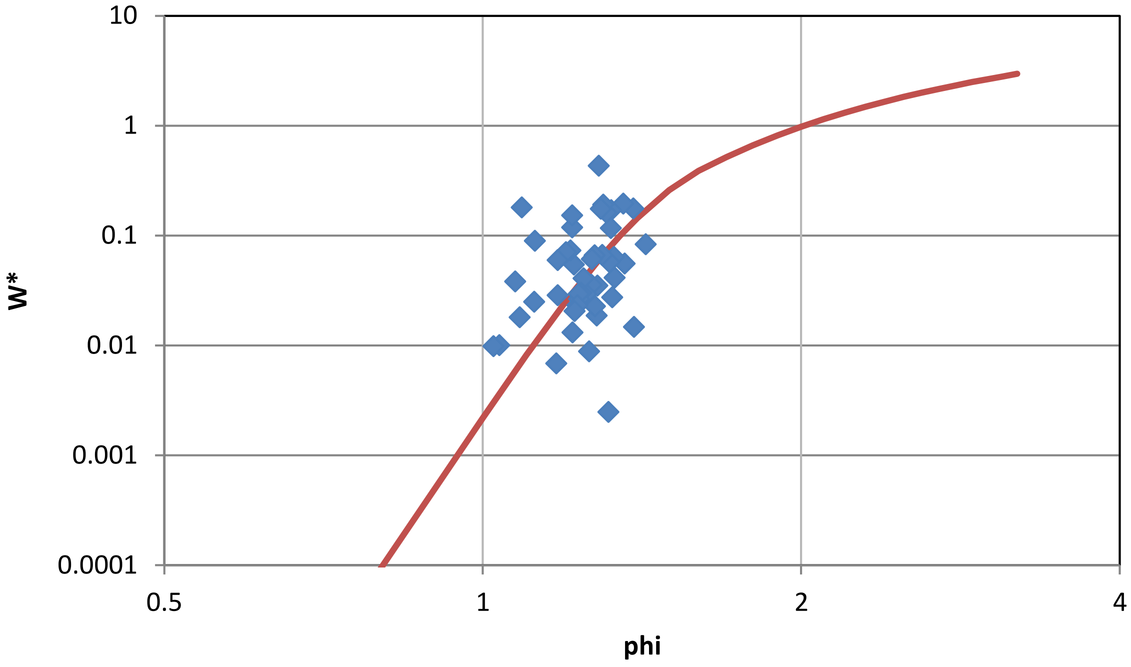

Figure 4.2-2. Gravel Bed-load Transport at Gold Creek Gage.

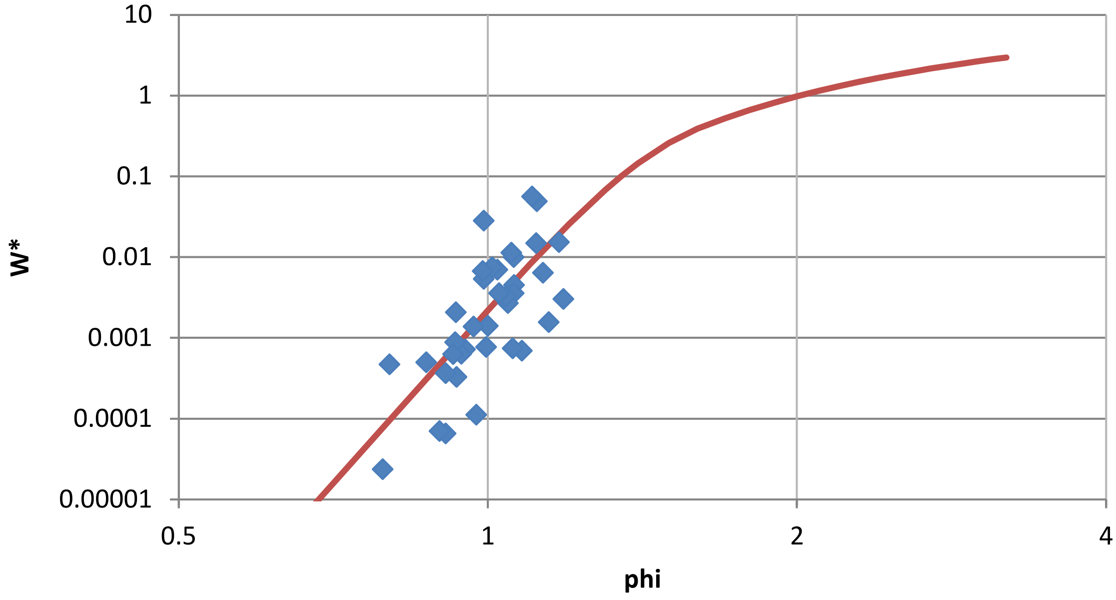

Figure 4.2-3. Gravel Bed-load Transport at Sunshine Gage.

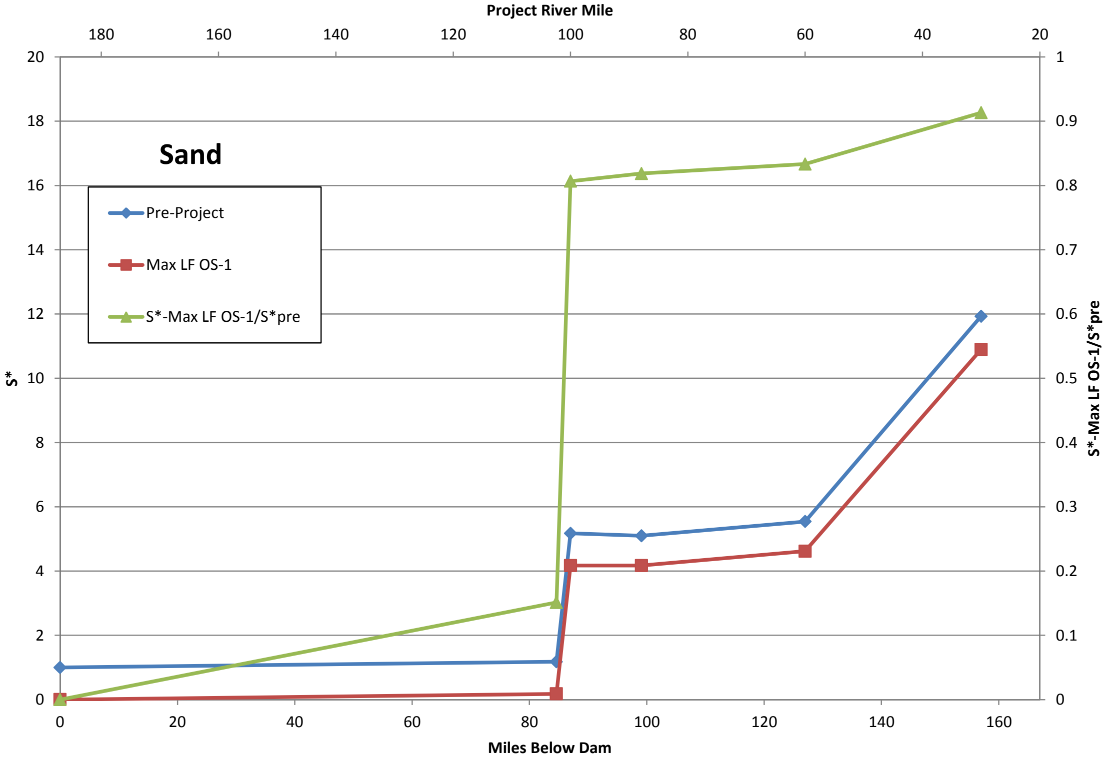

Figure 5.1-1. S* for gravel material on the Middle and Lower Susitna River Reaches.

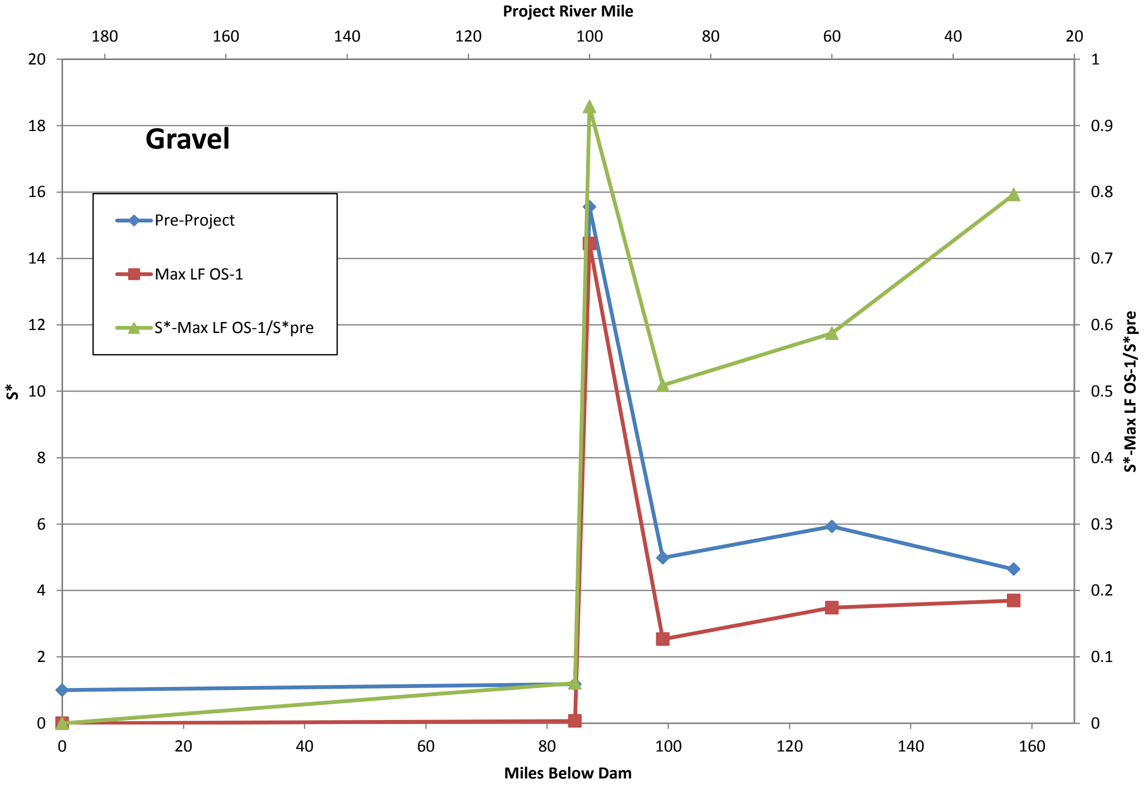

Figure 5.1-2. S* for sand material on the Middle and Lower Susitna River Reaches.

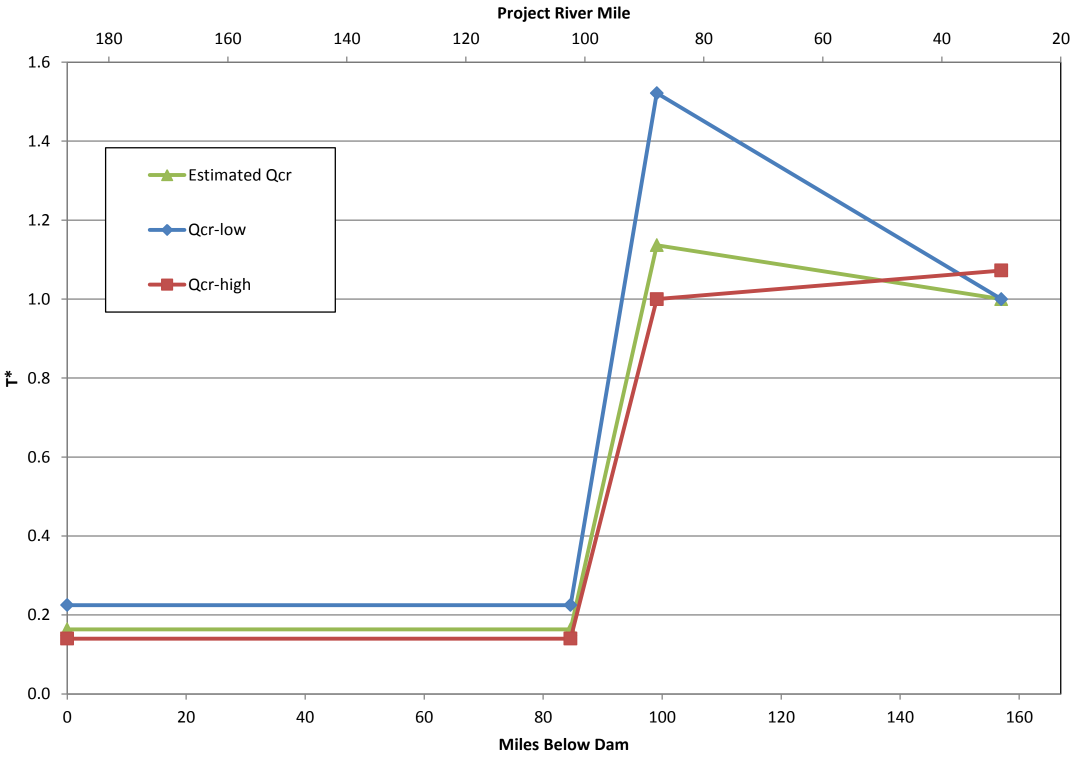

Figure 5.2-1. T* for the Middle and Lower Susitna River Reaches.

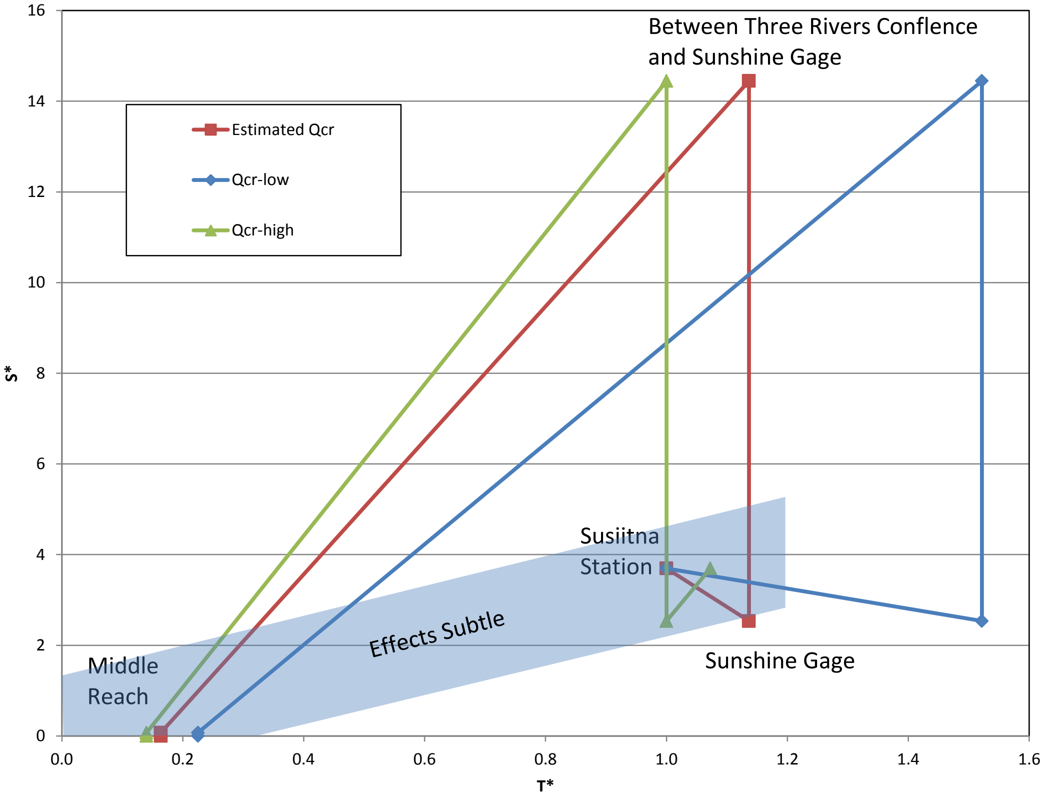

Figure 5.3-1. S* and T* on the Middle and Lower Susitna River Reaches.