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Susitna-Watana Hydroelectric Project
(FERC No. 14241)

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

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

February 2013

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LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
AEA	Alaska Energy Authority
cfs	cubic feet per second
FERC	Federal Energy Regulatory Commission
ILP	Integrated Licensing Process
M	million
mm	millimeter
MVUE	Minimum Variance Unbiased Estimator
NEPA	National Environmental Policy Act
NGVD	National Geodetic Vertical Datum
NWIS	National Water Information System
OS	Operation Scenario
PRM	Project River Mile
RM	River Mile
RSP	Revised Study Plan
sq mi	square mile
USGS	U.S. Geological Survey
WY	Water Year

SUMMARY

The purpose of the study effort was to make preliminary estimates of the overall sediment balance in the Middle and Lower River segments under pre-Project conditions and the potential magnitude of the changes that will occur under Maximum Load Following Operating Scenario (OS)-1 hydrologic conditions. A sediment balance is the determination of the difference between the inflowing sediment (supply) to a reach and the outflowing sediment from the reach (transport). If the sediment inflow to the reach is greater than the outflow, then sediment is stored within the reach. If the sediment supply into the reach is less than the sediment outflow from the reach, then sediment is removed from the reach. In the former case, the reach is considered depositional and in the latter case it is considered aggradational. If the sediment inflow and outflow are nearly equal, the reach is considered in balance with its sediment supply and transport.

Sediment transport relationships were developed at three locations on the mainstem Susitna River, Gold Creek, Sunshine and Susitna Station, and on its three largest tributaries, the Chulitna, Talkeetna and Yentna Rivers. Since the ability of the river to transport sediment and its response to the sediment being supplied varies greatly with the size of the sediment, relationships were developed for three sizes of sediment, wash load (silts and clay), sand load and gravel load. The relationships were applied to the long term hydrologic conditions represented by the Pre-Project and Maximum Load Following OS-1 scenarios. The sediment balance was computed for both conditions for the portion of the Susitna River from the Watana dam site to the Susitna Station gage approximately 30 miles upstream of the river's mouth.

The sediment transport relationships developed in the 2012 effort will be used in the 2013 and 2014 Geomorphology Studies to support detailed 1-D and 2-D bed evolution modeling of the Susitna River below Watana Dam. The relationships supported the assessment of 2012 study Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River Segment. The sediment transport relationships may be updated based on comparison with data collected by the U.S. Geological Survey (USGS) in 2012 and additional data to be collected in 2013.

For most of the Susitna River above Susitna Station, the gravel load plays the most significant role in determining the river's morphology. Under Maximum Load Following OS-1 conditions, the average annual gravel load at Sunshine will decrease to about 140,000 tons; thus, the total gravel supply above Susitna Station will decrease to about 370,000 tons/year. Based on integration of the gravel load rating curve over the Maximum Load Following OS-1 flow record, the average annual gravel load at Susitna Station would decrease to about 200,000 tons. This indicates that the reach between Sunshine and Susitna Station would remain aggradational, but the relative imbalance in gravel loads would decrease by about one-third from an excess of 250,000 tons under pre-Project conditions to about 170,000 tons under Maximum Load Following OS-1 conditions. Review of USGS data and the results of the sediment balance also indicated that at Susitna Station, the sand load may be the dominant factor in determining the morphology of the river. Sufficient information is not available at this time to identify the location of the transition zone from gravel to sand dominance, and specifically whether this occurs above or below the Yentna River confluence. This determination will be important in understanding potential Project effects. The 1-D sediment-transport modeling to be conducted in 2013 between Sunshine and Susitna Station will be a key tool in making these assessments.

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 Southcentral Alaska. The Project's dam site would be located at Project River Mile (PRM) 187.1. The results of this study will provide information that 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.

The G-S4: Reconnaissance-level Geomorphic and Aquatic Habitat Assessment of Project Effects on Lower River Channel study plan includes, among other objectives, a preliminary evaluation of the relative magnitude of changes in the sediment regime associated the Susitna-Watana Hydroelectric Project. This memorandum summarizes work performed under the *Sediment Load Comparison* section of the *Sediment Transport Assessment* task to meet this objective, including the development of sediment-transport relationships using the available sediment-transport data, and an initial sediment balance for the Middle and Lower Susitna River segments, based on the pre-Project hydrology and post-Project hydrology under an operations scenario referred to as Maximum Load Following Operation Scenario 1 (OS-1). These two hydrology scenarios were analyzed in detail in Tetra Tech (2013a). The pre-Project analysis was performed for six streamflow gages located in the Susitna Basin using 61 years of extended hydrologic records developed by the U.S. Geological Survey (USGS 2012) for the period from Water Year (WY) 1950 through WY2010. Three of the gages are located on the mainstem Susitna River and three of the gages are located on major tributaries (the Chulitna, Talkeetna and Yentna Rivers). The Maximum Load Following OS-1 hydrology is 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 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.

The main components of the sediment-transport analysis include the following:

- A review of previously published relationships between discharge and (1) suspended sediment load, (2) bed load, and (3) total sediment load (Knott et al. 1987), and refinement of those relationships where additional data were available.
- Application of selected relationships to both the pre-Project and Maximum Load Following OS-1 flow records to estimate annual sediment loads for suspended silt/clay (i.e., wash load), total sand load based on independent estimates of the amount of sand being carried in suspension and as bed load, and the gravel component of the bed load.
- Comparison of the estimated annual sediment loads to provide an approximate sediment balance in the river reaches between the mainstem gages in the Middle and Lower Rivers.

2. STUDY OBJECTIVES

The overall objective of this memorandum is to make preliminary estimates of the overall sediment balance in the Middle and Lower River segments under pre-project conditions and the potential magnitude of the changes that will occur under Maximum Load Following OS-1 hydrologic conditions, including the specific assessments of the following, interrelated topics:

- Determination of the suitability of previously published sediment transport relationships between discharge and sediment load and update the relationships if necessary.
- Selection of the most appropriate sediment transport relationships for use in the preliminary sediment balance.
- Use the selected sediment transport relationships to estimate the pre-Project and Maximum Load Following OS-1 annual loads. The sediment loads will be divided into wash load (silt and clay), sand load and gravel load.
- Comparison of estimated annual sediment loads at the three mainstem Susitna River gages to characterize the overall sediment balance under pre-Project conditions and the potential changes under Maximum Load Following OS-1 conditions.

A sediment balance is the determination of the difference between the inflowing sediment (supply) to a reach and the outflowing sediment from the reach (transport). If the sediment inflow to the reach is greater than the outflow, then sediment is stored within the reach. If the sediment supply into the reach is less than the sediment outflow from the reach, then sediment is removed from the reach. In the former case, the reach is considered depositional and in the latter case it is considered aggradational. If the sediment inflow and outflow are nearly equal, then the reach is considered in balance or in equilibrium in terms of sediment supply and transport.

3. STUDY AREA AND AVAILABLE DATA

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.

There are 14 USGS streamflow gages located in the Susitna River Basin plus one on the Little Susitna River that was used as an index station (Table 3.0-1 and Figure 3.0-1). The period of recorded data available for these gages ranges from 58 years at the Gold Creek gage to less than 10 years at gages such as the Yentna River at Susitna Station and the Susitna River at Sunshine gages. The data available from many of these gages may not adequately represent long-term streamflow conditions in the Susitna River Basin because of the short period of record and the distribution of years during which data were collected (USGS 2012). To provide a consistent long-term record, the USGS extended the record of 11 of these gages to 61 years (WY1950 – WY2010). WY1950 was selected for the start of the record because this was the first full water year of data collection for the primary index station at Gold Creek. The Montana Creek (Mont), Deception Creek (Decep), and the Deshka River (Desh) gages were not included in the extended record analysis because they could not be adequately correlated to any long-term index station for the entire study period (USGS 2012).

Three main stem gages and three primary tributary gages locations downstream of the Project site PRM 187.1 (Figure 3.0-1) were used to characterize the sediment-transport regime under the 61-year hydrology record for each portion of the reach, as follows:

- Main Steam Gages
  - Middle River Mainstem: Susitna River at Gold Creek Gage (15292000) and Susitna River near Talkeetna Gage (15292100)[1]
  - Lower River mainstem below Three Rivers Confluence: Susitna River at Sunshine Gage (15292780)
  - Lower River mainstem below Yentna River: Susitna River at Susitna Station Gage (15294350)
- Primary Tributary Gages
  - Tributary Supply to Three River Confluence (Chulitna River near Talkeetna Gage (15292400) and the Chulitna River below canyon near Talkeetna gage (15292410)[1)]
  - Talkeetna River near Talkeetna Gage (15292700)
  - Tributary Supply to Lower River: Yentna River near Susitna Station Gage (15294345)

The number and types of sediment samples, and the dates of sampling vary among the gages, but generally include both the magnitude and gradation of the suspended sediment and bed load for samples collected between the late-1970s and the late-1980s (Table 3.0-2). The bulk of these data that were collected through WY1985 were previously analyzed by Knott et al. (1987). As part of the current analysis, the available data for each of the gages were downloaded from the USGS National Water Information System (NWIS) website (http://waterdata.usgs.gov), and relevant data collected after 1985 were added to the data sets.

The post-Project hydrologic conditions of the Chulitna, Talkeetna and Yentna Rivers would be unaffected by the Maximum Load Following OS-1 condition; thus, the post-Project sediment supply from tributaries were assumed to be equivalent to the pre-Project supply.

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

4. METHODS

This section describes the methods used to select or develop relationships between discharge and sediment load for each component of the sediment load at the six USGS gaging stations, and apply these relationships, with the minimum variance unbiased estimator (MVUE) bias-correction technique, to the pre-Project and Maximum Load Following OS-1 extended flow records to estimate the annual sediment loads for each size range.

4.1. Deviations from Study Plan

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

4.2. Sediment Load Rating Curves

Knott et al. (1987) used the data collected through WY1985 at the six gages to characterize sediment-transport conditions in the reach. This included development of relationships between discharge and sediment loads from data for four components of the total sediment load collected during the period between October 1984 and September 1985, data collected from WY1981 through WY1984, and historical records (USGS 1953 to 1980):

- Suspended silt/clay
- Suspended sand
- Sand bed load,
- Gravel bed load

The Knott et al. (1987) relationships were of the power-function form:

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

where:

Q_s	=	sediment load (tons/day)
a	=	coefficient
b	=	exponent
Q	=	discharge (cubic feet/second)

For consistency with Knott et al. (1987) and standard practice in developing sediment load rating curves (USGS, 1992), power function relationships were also used for the current study.

As an initial step in the analysis, the available data through WY1985 in each size-range at each of the gages was plotted and compared with the data plots in Knott et al. (1987). This comparison revealed a limited number of available data points from the NWIS database that were not used in the Knott et al. (1987) analysis. No explanation was provided in their report for why these data points were not used. In an attempt to ascertain the reason(s), Mr. Gary Solin at the USGS Alaska Science Center, where the original data collection and analysis were performed, was contacted. Mr. Solin indicated that the individuals who performed the analysis were either retired and out of contact; thus, he was not able to provide specific information about the issue. He did, however, suggest that the data points used in the analysis were probably limited to those directly collected by the study team and/or for which the study team had specific knowledge. Based on this information, the decision was made to limit the WY1985 and earlier data to those data points used by Knott et al. (1987), under the assumption that their study team had the best knowledge of the quality and relevance of the data at that time; thus, their dataset represents the best-available data through WY1985.

After identifying the data points used by Knott et al. (1987), the data sets were updated by adding relevant data collected since WY1985. Power-function regression lines were then fit to the extended data sets using the least-squares regression technique and compared to the Knott et al. (1987) line-of-best-fit. Through analysis and inspection of the data and knowledge of the range of typical exponents for the different components of the sediment load, either the USGS line-of-best fit or the new regression equations were selected for this preliminary study (Table 4.1-1 and Appendix A). With the exception of the silt/clay load for the Gold Creek/near Talkeetna data set, new regression equations were developed for all of the suspended sediment loads to incorporate the post-WY1985 data points. The USGS equation was used for the Gold Creek/near Talkeetna data set because the new regression line significantly over-predicts the loads at flows less than about 20,000 cfs. It appears that Knott et al. (1987) also recognized this issue and visually fit a line to the data that provided better fit to data over the full range of discharges. Because of the significant scatter in the data and the typically limited range of flows over which the data were collected, regression equations do not provide reasonable relationships for most of the bed-load data sets. For this reason, the USGS equations were adopted for all of the data sets except for those at Susitna Station. Partly because of the influence of five newer sand bed load and three newer gravel bed load data points that were collected in 2003, the regression equations for both appear to fit the data better than the USGS equations, and the regression equations were, thus, used for both components of the bed load at this site.

4.3. Bias Correction and Annual Load Estimates

The selected relationships between discharge and the various components of the sediment load were then used with the MVUE bias-correction technique to estimate daily sediment loads for the entire 61-year record of mean daily flows for both pre-Project and Maximum Load Following OS-1 conditions. The MVUE technique was used to correct for the statistical bias that occurs in basic power-function regression, based guidance from USGS (1992). Previous studies have demonstrated that the bias occurs in the process of linearizing the data set by transforming it into the logarithmic domain and then back-transforming the resulting relationship into the arithmetic domain (Walling 1977b; Thomas 1985; Ferguson 1986). Various procedures are available to address the bias, including accounting for seasonal differences in sediment transport and accounting for hysteresis related to rising and falling limbs of flood hydrographs (Guy 1964; Walling 1974). Koch and Smillie (1986) and Cohn and Gilroy (1991) described methods of numerically correcting for the bias that depend on the expected distribution of errors. USGS (1992) endorsed the recommendations in Cohn and Gilroy (1991) to use the MVUE bias correction for normally distributed errors, or the Smearing Estimator (Duan 1983) when a non-normal error distribution is identified. The MVUE method was selected in this analysis to remove the bias from the log-transformed sediment loads because the errors are generally normally-distributed.

Annual sediment loads for each year in the pre-Project and Maximum Load Following OS-1 records were developed by summing the bias-corrected daily sediment loads.

5. RESULTS

This section summarizes the annual sediment yields developed using the methods described in Section 4 for the pre-Project and Maximum Load Following OS-1 conditions at the three main stem gages and three primary tributary gages. As noted above, Knott et al. (1987) divided the total sediment load into four components, primarily because of the manner in which the data are collected. It is, however, more meaningful from a river-process perspective to re-group these components into three components, consisting of the wash load (i.e., silt/clay that is almost exclusively carried in suspension), the sand component of the bed material load that consists of the sand that is carried both in suspension and as bed load, and the gravel component of the bed load. The sand load is being treated separately in this analysis because it may be strongly supply-limited, and thus more correctly categorized as part of the wash load in the Middle River and tributaries; however, in the Lower River in the area of Susitna Station and further downstream, the sand load may be transport limited.

5.1. Pre-Project

Under pre-Project conditions, the estimated total annual sediment loads at the Gold Creek/near Talkeetna gage average about 3.3 million (M) tons, varying from about 550,000 tons to nearly 11M tons (Figure 5.1-1). Of these amounts, the silt/clay, wash load accounts for about 55 percent (1.8M tons) of the total, on average, while the sand accounts for about 43 percent (1.4M tons) and the gravel bed load accounts for only about 2 percent (66,000 tons) of the total.

At the Sunshine gage, the average, pre-Project total annual sediment load increases to about 16.4M tons, ranging from about 4.7M to 26.8M tons (Figure 5.1-2). The relative proportion of wash load increases to about 61 percent (10.0M tons) of the total, with the sand and gravel loads accounting for about 37 and 1.7 percent (6.1M and 280,000 tons) of the total, respectively.

The annual total load at the Susitna Station gage averages about 34.1M tons, and ranges from 18.3M to 53.1M tons (Figure 5.1-3). The silt/clay load accounts for about 57 percent (19.5M tons), and the sand and gravel loads account for about 42 percent (14.3M tons) and less than 1 percent (260,000 tons) of the total, respectively, at this location.

The three primary tributaries supply a significant amount of the sediment to the mainstem. The annual load from the Chulitna River, for example, averages about 9.9M tons, ranging from 4.8M tons to 24.7M tons (Figure 5.1-4), and the Talkeetna River supplies an average of about 1.9M tons/year, ranging from about 380,000 to 6.9M tons/year (Figure 5.1-5). The Yentna River carries the largest total load of the three, averaging about 15.5M tons/year and ranging from 6.7M to 31.5M tons/year (Figure 5.1-6). The Chulitna River delivers a much larger percentage of gravel than either the mainstem or the other two major tributaries (about 7.5 percent versus 3.1 and 1.2 percent for the Talkeetna and Yentna Rivers, respectively). The Yentna River delivers the smallest relative percentage of wash load of the three tributaries (48 percent versus 53 and 50 percent for the Chulitna and Talkeetna Rivers, respectively).

Based on these results, the Middle River supplies about 22 percent of the total sediment load to the Three Rivers Confluence, and the Chulitna and Talkeetna Rivers supply about 66 and 12 percent of the total load, respectively (Figure 5.1-7). On a by-size-fraction basis, the relative contributions of silt/clay and sand are about the same as the total load; however, the Chulitna River supplies the bulk of the gravel load that is key to the channel morphology (about 86 percent of the total, compared to about 8 percent from the Middle River and 7 percent from the Talkeetna River). The total sediment load from the Yentna River represents about 46 percent of the total load at Susitna Station, and about 65 percent of the gravel load.

A tabulation of the estimated annual loads under pre-Project conditions for each component of the load at each of the six gages is provided Appendix B.1.

5.2. Maximum Load Following Operation Scenario 1

Watana Dam and Reservoir will trap a significant percentage of the sediment supply to the Middle River. For purposes of this preliminary analysis, it is assumed that the trap efficiency for the silt/clay load will be on the order of 90 percent, and all of the sand and coarser sediment will be trapped. In addition to the effects on sediment supply, the dam will also modify the flow regime in the downstream river in a manner that will affect the transport capacity along the reach. Tetra Tech (2013a) evaluated the changes in flow regime in the Middle and Lower River associated with Maximum Load Following OS-1 conditions that are based on the very conservative 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. Under these conditions, the total volume of flow will be essentially the same as under pre-Project conditions on an annual basis, but the distribution throughout the year will change, with a general increase in the winter base flows and decrease in the summer high flows. The effects are most significant in the Middle River, where tributary inflows are relatively small compared to the mainstem flows. The effects diminish significantly downstream from the Three Rivers Confluence due to the relatively large inflows from the Chulitna and Talkeetna Rivers, and they continue to diminish in the downstream direction as the relative contribution from local tributaries increases. Because of the nonlinear relationship between discharge and sediment-transport rates, the changes in flow regime associated with the Project will result in a general decrease in the capacity of the river to transport sediment in each segment of the reach.

Based only on the changes in flow regime (i.e., not accounting for the effects of sediment trapping the reservoir), the total sediment load at the Gold Creek/near Talkeetna gage would decrease to about 502,000 tons on an average annual basis, about 285,000 tons of which would be suspended silt/clay, 213,000 tons would be sand, and only about 4,400 tons would be in the gravel size-range (Figure 5.2-1). The supply of gravel from the tributaries between Watana Dam and Gold Creek/near Talkeetna gage is 11,000 tons if it is assumed to be in proportion with the intervening drainage area. If this assumption is reasonable, then gravel materials would tend to accumulate as fans at the mouths of the tributaries and within this reach or river. This amount could be more or less and will be investigated further. Because the bulk of the suspended silt/clay load is derived from upstream of the Watana Dam site, the trap efficiency of the reservoir will directly impact this component of the load throughout the Middle River immediately upon closure of the dam. Based on the preliminary estimate of 90 percent trap efficiency, and considering the estimated 117,000 tons contributed by the tributaries between the dam site and the gage, the average annual suspended silt/clay load at Gold Creek would, therefore, likely decrease to about 285,000 tons/year, an approximately 84-percent reduction from pre-Project conditions.

The relative contribution of the river upstream from the dam site to the sand load, compared to the contributions from within the channel and the intervening tributaries is not known at this time, but it is likely that the upstream contribution represents a relatively significant percentage of the total. During the initial period of a few to several years after closure of the dam, the average annual sand load passing the Gold Creek/above Talkeetna gage will likely be on the order of the 320,000 tons estimated using the pre-Project sand transport rating curves with the Maximum Load Following OS-1 flows, an approximately 77-percent reduction from pre-Project conditions. Based on these estimates, the year-to-year variability would range from only about 88,000 tons to about 1.3M tons. As the supply of sand that is available from the Middle River channel is depleted, the sand load in the vicinity of the Gold Creek/near Talkeetna gage will diminish relatively rapidly to a value that is consistent with the sand load from the intervening tributaries, or about 213,000 tons/year, an approximately 85-percent reduction from pre-Project conditions.

The gravel load at Gold Creek/near Talkeetna will likely remain at about the estimated 4,400-tons/year value for a significant period of time because of the slower overall response of gravel-sized material between the dam site and the gage. If the annual supply from the intervening tributaries is less than 4,400 tons then the response will be slow because of the relatively large reservoir of gravel-sized material between the dam site and the gages. If the annual supply is greater than 4,400 tons (preliminary estimate is 11,000 tons), then gradually through time the gravel materials will accumulate and the supply of gravel from the Middle River will tend toward the higher supply rate. The 4,400 tons/year represents an approximately 93-percent reduction from pre-Project conditions. Based on integration of the pre-Project gravel transport curve over the Maximum Load Following OS-1 flow record, the annual gravel loads would vary from about 50 to 42,300 tons on a year-to-year basis.

The total sediment load at Sunshine would diminish to about 13.6M tons on an average annual basis under Maximum Load Following OS-1 conditions, of which about 8.5M tons would be suspended silt/clay, 5.0M tons would be sand and about 142,000 tons would gravel (Figure 5.2-2). This represents an approximately 17-percent reduction in the total sediment load and a 15-percent reduction in the silt/clay load compared to pre-Project conditions. The average annual gravel load would diminish to about 142,000 tons, varying from about 67,000 to 377,000 tons on a year-to-year basis. The average annual gravel load represents a 49-percent reduction from pre-Project conditions.

Accounting for the effects of silt/clay trapping in the reservoir that would be seen very rapidly throughout the Middle and Lower Rivers, the average annual total load at Susitna Station would decrease to about 31.3M tons, of which about 18.0M tons would be suspended silt/clay (Figure 5.2-3). This represents an 8-percent reduction in both the total and silt/clay load. The effects of sediment trapping in the upstream reservoir on the sand-and-gravel supply to this portion of the lower river would not be seen for a relatively long period of time (likely, the life of the Project); however, as with the upstream gages, the changes in flow regime associated with the Project would change the transport capacities. Based on integration of the pre-Project sand transport rating curves over the Maximum Load Following OS-1 flows, the total sand load at Susitna Station would decrease to about 13M tons, an approximately 9-percent reduction from pre-Project conditions. The sand loads would vary from about 8.4M to 18.7M tons on a year-to-year basis. Similarly, the gravel loads would decrease to about 207,000 tons, an approximately 20-percent reduction from pre-Project conditions. The gravel loads would vary from 110,000 to 364,000 tons on an average annual basis.

Based on these results, the Middle River would supply only about 4 percent of the total sediment load to the Three Rivers Confluence under Maximum Load Following OS-1 conditions, and the Chulitna and Talkeetna Rivers supply about 81 and 15 percent of the total load, respectively (Figure 5.2-4). On a by-size-fraction basis, the contributions of silt/clay from the Middle River would decrease 4 percent of the total. During the initial periods after closure of the dam, the Middle River would supply about 10 percent of the sand load and only about 0.5 percent of the gravel load to the Three Rivers Confluence. The total sediment load from the Yentna River would supply about 48 percent of both the total load and the gravel load to Susitna Station under Maximum Load Following OS-1 conditions.

A tabulation of the estimated annual loads under Maximum Load Following OS-1 conditions for each component of the load at each the three mainstem gages is provided Appendix B.2.

6. DISCUSSION

The sediment load analyses presented in the previous sections provide a basis for development of a preliminary sediment balance for the Middle and Lower Rivers. The effects of the dam on the sediment balance vary between the silt/clay, sand and gravel loads.

As discussed above, the dam would likely cut off at least 90 percent of the silt/clay supply and essentially all of the sand and gravel supply to the head of the Middle River. The effects on all components of the sediment load would diminish in the downstream direction due to contributions from the tributaries and entrainment of material that is currently stored in the channel. The silt/clay load is carried almost exclusively in suspension. As a result, the effects of sediment trapping in the reservoir on downstream silt/clay loads would be felt within a very short time-frame (i.e., on the order of the travel time of the water) throughout the Middle and Lower Rivers after closure of the dam. Considering the estimated contributions from the tributaries between the dam and the Three Rivers Confluence, the silt/clay load at the lower end of the Middle River would be only about 16 percent of the pre-Project loads (Figure 6.0-1). The effects of the dam on the silt/clay load below Three Rivers diminish significantly due to the large contributions from the Chulitna and Talkeetna Rivers. Based on the available information, the loads at Sunshine with the dam in-place would be about 82 percent of the pre-Project loads, and the contributions from the Yentna and other tributaries between Sunshine and Susitna Station cause the effect to diminish even further so that the post-Project silt/clay loads would be about 92 percent of the pre-Project loads at Susitna Station. Even the very large changes in the silt/clay load in the Middle River are not anticipated to have a significant effect on active channel morphology in Middle River, and the smaller downstream changes are even less likely to affect active channel morphology in the Lower River. The significant reduction in the silt/clay load in the Middle River, along with decreased frequency of floodplain inundation, will have an effect on floodplain sedimentation processes.

During the initial period after closure of the dam, Project effects on the sand load in the lower part of the Middle River and the Lower River would result primarily from the change in flow regime, because there is currently sand moving through the system and it moves at a much slower rate than the flow. Over time, much of the stored sand will be depleted from the Middle River, and the load just upstream from the Three Rivers Confluence area will be consistent with the supply from the local tributaries. After this occurs, the sand load above the Three Rivers Confluence will be only about 15 percent of the pre-Project load (Figure 6.0-2). Similar to the silt/clay load, sand inflows from the Chulitna and Talkeetna Rivers will decrease the relative impact of the Project, with Maximum Load Following OS-1 sand-load conditions of about 82 percent of the pre-Project loads. Contributions from the Yentna River and other tributaries downstream from Sunshine will increase the sand loads to about 91 percent of the pre-Project loads at Susitna Station.

Except for the upstream portion of the Middle River, Project effects on gravel loads will derive primarily from the changes in flow regime. There appears to be a relatively significant supply of gravel and coarser material between the dam site and the Three Rivers Confluence, the local tributaries likely supply a significant amount of gravel to the river, and the response rate of upstream changes in supply will progress downstream relatively slowly compared to the sand. Based strictly on integration of the pre-Project gravel transport curves over the Maximum Load Following OS-1 flows, the gravel loads in the lower part of the Middle River will be only about 7 percent of the pre-Project loads (Figure 6.0-3). Based on the same assumptions, the gravel loads at Sunshine in the upstream portion of the Lower River will be about 51 percent of the pre-Project loads, and this increases to about 80 percent at Susitna Station.

The above information was used to develop a preliminary sediment balance for the Lower and Middle Rivers under pre-Project and Maximum Load Following OS-1 conditions (Tables 6.0-1 and 6.0-2). Ungaged tributaries between the Watana Dam site and the Gold Creek gage account for about 16 percent of the total drainage at Gold Creek, and ungaged tributaries between Sunshine and Susitna Station account for about 11 percent of the total drainage area at Susitna Station. Because they may contribute sufficient sediment to the mainstem to affect this balance, estimates of the ungaged tributary sediment inflows were made based on the unit yields of the various size-ranges of sediment from the available data. Based on these very preliminary estimates, the silt/clay load from ungaged tributaries contribute about 120,000 tons/year of silt/clay to the Middle River on an average annual basis, and the ungaged tributaries between Sunshine and Susitna Station contribute about 2.4M tons/year of silt/clay to the Lower River.

Assuming that the unit sand yield is approximately the same at the Watana Dam site as it is at the Gold Creek/near Talkeetna gages (~220 tons/mi^2/year), the average annual total sand load at the dam site is about 1.2M tons/year. Further assuming that the Middle River is supply limited with respect to the sand loads, the total sand load passing Gold Creek/near Talkeetna is the same as the total upstream supply and the ungaged tributaries in the Middle River deliver about 210,000 tons of sand to the river on an average annual basis. Based on these estimates, the total sand supply to Sunshine from the Middle River and tributaries under pre-Project conditions is about 6.2M tons, which is remarkably similar to the estimated pre-Project sand load at Sunshine, discussed above, of about 6.1M tons (Figure 6.0-4). Assuming that the ungaged tributaries between Sunshine and Susitna Station have unit sand yields that are similar to the ungaged tributaries to the Middle River, these tributaries deliver about 530,000 tons/year of sand to the Lower River. Based on the sum of the Sunshine, Yentna River and ungaged tributary inflows, the total sand load above Susitna Station is about 14.8M tons/year, very close to the average annual sand load at Susitna Station of 14.3M tons, estimated by integrating the Susitna Station sand-load rating curves over the 61-year pre-Project flow record. Collectively, these results indicate that the Middle and Lower Rivers are in approximate balance with respect to sand loads under pre-Project conditions.

Under Maximum Load Following OS-1 conditions, the sand supply to the upstream end of the Middle River will be essentially eliminated. As noted above, the sand loads in the lower part of the Middle River will remain about the same as they are under pre-Project conditions during the early period of Project operations, with the downstream sand loads decreasing over time to a level that is consistent with the tributary inflows as the sand that is currently stored within the mainstem river channel is depleted. After this occurs, the sand supply to the Three Rivers Confluence will diminish to about 5M tons. Since the sand load is most likely supply-limited in this part of the reach, the sand load at Sunshine will decrease to a level consistent with the supply (i.e., ~5M tons/year, on average).

The sand supply from the Yentna River and other ungaged tributaries between Sunshine and Susitna Station is estimated to be about 8.7M tons. Considering the 5M ton sand load at Sunshine, the total sand supply above Susitna Station under Maximum Load Following OS-1 is about 13.7M tons. The degree to which the sand load between Sunshine and the Yenta River confluence is supply-limited is not apparent from the available information. Based on the available data, however, the bed material at Susitna Station is primarily sand; thus, the sand load at this location is probably not supply-limited. This means that the quantity of sand transported in this part of the Lower River is controlled primarily by the flows and not by the upstream supply, and the Project effects on the sand load can be estimated by directly integrating the sand-load rating curves over the Project conditions flow record. Based on this integration, the average annual sand load at Susitna Station will decrease to about 13M tons. Considering the uncertainty in the sand-load estimates, the cumulative sand supply above Susitna Station and the load at Susitna Station are essentially the same (13.7M tons versus 13M tons); thus, this part of the reach would likely remain in approximate balance with respect to the sand load under Maximum Load Following OS-1 conditions.

Based on the gravel transport curves, the unit gravel load at Gold Creek/near Talkeetna is about 11 tons/mi^2/year. Assuming that the unit yields are similar, the average annual gravel load at the dam site is about 56,000 tons under pre-Project conditions and the gravel supply from the ungaged tributaries is about 11,000 tons (Figure 6.0-5). Based on these estimates and the estimated gravel loads from the Chulitna and Talkeetna Rivers presented above, the total gravel supply upstream from Sunshine under pre-Project conditions is about 870,000 tons, compared to the estimated loads at Sunshine of about 280,000 tons. Even considering the uncertainty in the transport relationships, these results strongly indicate that the river is aggradational between the Three Rivers Confluence and Sunshine. This conclusion is supported by the highly braided character of the river in this part of the reach. The gravel loads at Sunshine and the Yentna River from the results in the previous section equate to unit yields of about 27 and 25 tons/ mi^2/year, respectively. Assuming that the ungaged tributaries between Sunshine and Susitna Station have similar unit yields, these tributaries deliver approximately 53,000 tons of gravel to the mainstem on an average annual basis. The approximate gravel supply to the lower river from Sunshine, the Yentna River and the ungaged tributaries, therefore, averages about 510,000 tons/year. The average annual gravel load at Susitna Station under pre-Project conditions is about 260,000 tons, indicating that the portion of the Lower River between Sunshine and Susitna Station is also net aggradational. Similar to the Three Rivers Confluence to Sunshine portion, this result is consistent with the highly braided character of this part of the river.

Under Maximum Load Following OS-1 conditions, the average annual gravel load at Sunshine will decrease to about 142,000 tons; thus, the total gravel supply above Susitna Station will decrease to about 375,000 tons/year. Based on integration of the gravel load rating curve over the Maximum Load Following OS-1 flow record, the average annual gravel load at Susitna Station would decrease to about 207,000 tons. This indicates that the reach between Sunshine and Susitna Station would remain aggradational, but the relative imbalance in gravel loads would decrease by about one-third from an excess of 252,000 tons under pre-Project conditions to about 168,000 tons under Maximum Load Following OS-1 conditions.

As described in RSP Sections 6.5.4.3 and 6.6, and based on the above results, the following actions will be implemented:

1. New sediment load data that have been collected over the past few years by the USGS will be incorporated into the analysis to improve the sediment-transport rating curves.
2. The USGS will extend their sediment data collection program to include bed load, suspended sediment load, bed material and discharge to include Susitna Station and the Yentna River near Susitna Station to support the recent decision (Tetra Tech 2013b) to extend the 1-D sediment- transport model downstream to Susitna Station (PRM 29). The data from this effort will facilitate comparison with the 1980s data at these locations to check the validity of the earlier data, and it will also expand the data base that is available for development of sediment- transport relationships.
3. The updated sediment-transport rating curves for the mainstem gages will be used to calibrate the sediment-transport rates in the reach-wide 1-D sediment-transport model.
4. In the current analysis, sediment loading from all ungaged sources was lumped into the "ungaged tributary" category. In reality, sediment is also supplied to the river from bank erosion and mass wasting from unstable hillslopes. Estimates of the sediment loading from all of these sources, including the ungaged tributaries, will be segregated and improved based on field observations, evaluation of lateral bankline shifting and bed material measurements and transport capacity calculations in the lower end of a selected number of the larger ungaged tributaries. As described in RSP Section 6.6.4.1.2.6 (AEA 2012), sediment-load rating curves for the ungaged tributaries will be developed by surveying cross sections and collecting bed material samples in an appropriate reach near the mouth, developing 1-D hydraulic conditions using either step-backwater or normal depth calculations, as appropriate, and applying an appropriate bed material transport equations with the measured bed material gradations. For those tributaries that enter the river within the Focus Areas, the hydraulic and sediment-transport analysis to assess the response of the Susitna River channel to Project conditions will be performed using the 2-D model(s). For the selected tributaries outside the focus areas, the analysis will be performed using 1-D hydraulic modeling with relatively closely spaced cross sections in the vicinity of the confluence.
5. The tributary-specific sediment loads estimated in the previous task will be used to assess the potential impact of changes in flow and sediment load in the mainstem on the sediment-transport behavior at the tributary mouths. A key question to be answered by this analysis is

the extent to which the coarse-grained sediment from the tributaries will be entrained and transported downstream away from the tributary mouth versus building of the delta in a manner that could potentially affect fish passage into the tributary and/or constrict the river causing other impacts to water-surface elevations and channel stability. Similar to the sediment loading analysis, the analysis for those tributaries that are located within a Focus Area will be conducted using the 2-D mobile-boundary model. At the selected tributaries outside the Focus Areas, additional mainstem cross sections (typically 5 to 7, in total) will be surveyed in the vicinity of the mouth, and 1-D hydraulic modeling and sediment-transport calculations will used to perform the assessment.

6. Section 6.6.4.1.2.6., Tributary Delta Modeling of the RSP (AEA 2012), indicates that modeling of the sediment-transport dynamics at the Three Rivers Confluence may be necessary to understand the potential effects of Project operations. Based on the initial sediment balance presented above, the total gravel bed-load supply that is key to the behavior of this area would decrease by only about 7 percent from about 871,000 ton/year, on average, to about 810,000 tons/year under Maximum Load Following OS-1 conditions because of the overwhelming contribution from the Chulitna River and the large (relative to Middle River) contribution from the Yentna River. The transport capacity for gravel bed load past the Sunshine gage would decrease by about 50 percent from about 279,000 tons/year to about 142,000 tons/year under Maximum Load Following OS-1 conditions. As a result, the pre-Project gravel excess in this area will increase by about 12 percent from 592,000 to 667,000 ton/year. Under pre-Project conditions, the excess in gravel load corresponds to a net aggradational tendency that averages about 0.05 feet/year over the approximately 5,600-acre active channel between the confluence and the Sunshine gage. The aggradational tendency would increase modestly to about 0.055 feet/year under Maximum Load Following OS-1 conditions. (Of course, the aggradation depths will vary spatially within this area, with some locations changing significantly more than the average and some locations significantly less.) Because of the relatively small net change, however, it is our opinion that the potential impacts to this area can be adequately described based on the refined reach-wide sediment balance that will be developed from the 1-D mobile sediment-transport modeling, field observations, and knowledge of how rivers typically respond to modest changes in sediment load. As a result, additional 2-D mobile boundary modeling in this large and complex area is not warranted.

7. In spite of the above opinion that 2-D modeling of the Three Rivers Confluence is not warranted, AEA will extend the 1-D sediment-transport model downstream to at least Susitna Station (PRM 29) (Tetra Tech 2013b). Based on the limited bed material data that is available from the previous studies, the bed is primarily gravel with median (D_{50}) size in the range of 50 to 100 millimeters (mm), and only a small amount of sand (typically <5 percent) at Sunshine. In contrast, the bed material at Susitna Station is primarily sand (D_{50}~0.4 mm and nearly 90 percent <2 mm based on one sample). Based on this information, alone, the sediment load at Sunshine is almost certainly supply-limited with respect to sand, but is capacity-controlled with respect to sand at Susitna Station. From the above rating curve analysis, the reach between Sunshine and Susitna Station, and possibly through Susitna Station, is aggradational under pre-Project conditions with respect to both the sand and gravel loads (excess of ~250,000 and 562,000 tons/year, respectively). Under Maximum Load Following OS-1 conditions, that reach will remain aggradational for both components of the sediment load, but the magnitude of the excess in gravel supply will decrease by about one-

third to 168,000 tons/year, while the excess in sand load will increase by about 24 percent to 694,000 tons/year, due primarily to the reduced transport capacity associated with the change in flow regime. The Yentna River supplies about 55 percent of the sand load and 35 percent of the gravel load; thus is probably a significant factor in the mainstem dynamics at and downstream from Susitna Station. Sufficient information is not available at this time to identify the location of the transition zone from supply-limited to capacity-controlled in the Lower River, and specifically whether this occurs above or below the Yentna River confluence. This determination will be important in understanding potential Project effects. The sediment-transport behavior of mainstem at the tributary mouths will also be an important factor in understanding Project effects in the Lower River, particularly in the reaches upstream from the gravel-sand transition zone. The 1-D sediment- transport modeling will be a key tool in making these assessments.

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8. TABLES

Table 3.0-1. List of streamflow gages.

Gage Number	Gage Name	Drainage Area (sq mi)	Gage Datum (NGVD 29, feet)	Latitude	Longitude	Available Record	Extended Record	Main Stem River Mile
15290000	Little Susitna River near Palmer	63	917	61° 42' 37"	149° 13' 47"	1948 - 2011		-
15291000	Susitna River near Denali	950	2,440	63° 06' 14"	147° 30' 57"	1957 - 1966; 1968 - 1986	Yes	291
15291200	Maclaren River near Paxson	280	2,866	63° 07' 10"	146° 31' 45"	1958 - 1986	Yes	-
15291500	Susitna River near Cantwell	4,140	1,900	62° 41' 55"	147° 32' 42"	1961 - 1972; 1980 - 1986	Yes	223
15292000	Susitna River at Gold Creek	6,160	677	62° 46' 04"	149° 41' 28"	1949 - 1996; 2001 - 2011	Yes	136
15292400	Chulitna River near Talkeetna	2,570	520	62° 33' 31"	150° 14' 02"	1958 - 1972; 1980 - 1986	Yes	-
15292700	Talkeetna River near Talkeetna	1,996	400	62° 20' 49"	150° 01' 01"	1964 - 2011	Yes	-
15292780	Susitna River at Sunshine	11,100	270	62° 10' 31.3"	150° 10' 13.5"	1981 - 1986	Yes	84
15292800	Montana Creek near Montana	164	250	62° 06' 19"	150° 03' 27"	2005 - 2006; 2008 - 2011		-
15294005	Willow Creek near Willow	166	350	61° 46' 51"	149° 53' 04"	1978 - 1993; 2001 - 2011	Yes	-
15294010	Deception Creek near Willow	48	250	61° 44' 52"	149° 56' 14"	1978 - 1985		-
15294100	Deshka River near Willow	591	80	61° 46' 05"	150 20' 13"	1978 - 1986; 1998 - 2001		-
15294300	Skwentna River near Skwentna	2,250	200	61° 52' 23"	151 22' 01"	1959 - 1982	Yes	-
15294345	Yentna River near Susitna Station	6,180	80	61° 41' 55"	150 39' 02	1980 - 1986	Yes	-
15294350	Susitna River at Susitna Station	19,400	40	61° 32' 41"	150 30' 45	1974 - 1993	Yes	28

Table 3.0-2. Sediment-transport data summary.

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

Table 4.1-1. Summary of sediment load relationships used for the analysis.

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

from Knott et al (1987)

New Regression

Q = Water discharge in cfs

Sediment load in tons/day (tpd)

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

Table 6.0-1. Comparison of average annual sediment loads under pre-Project conditions.

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

Table 6.0-2. Comparison of average annual sediment loads under Maximum Load Following OS-1 conditions.

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

9. FIGURES

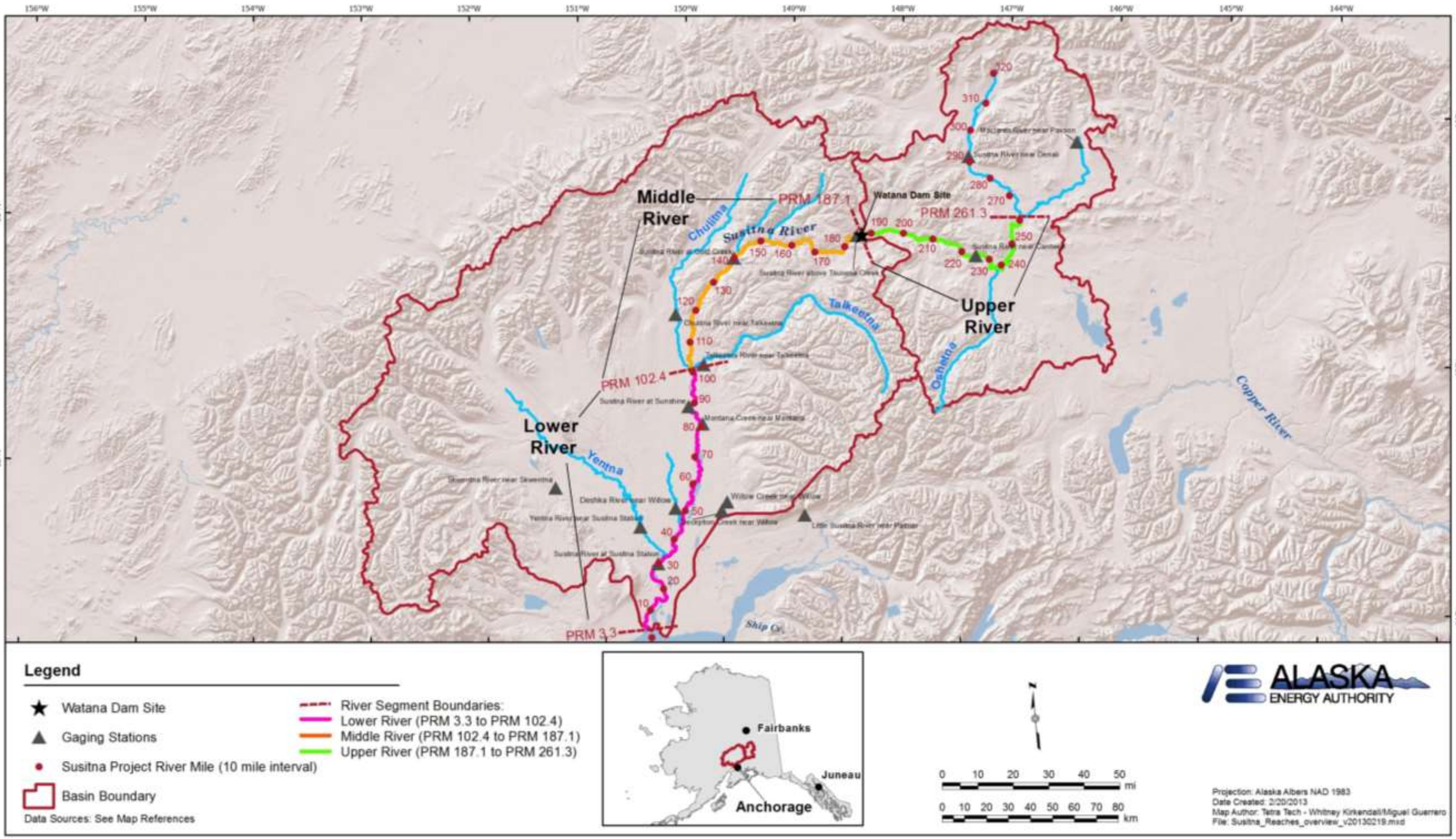

Figure 3.0-1. Susitna River study area and large-scale river segments.

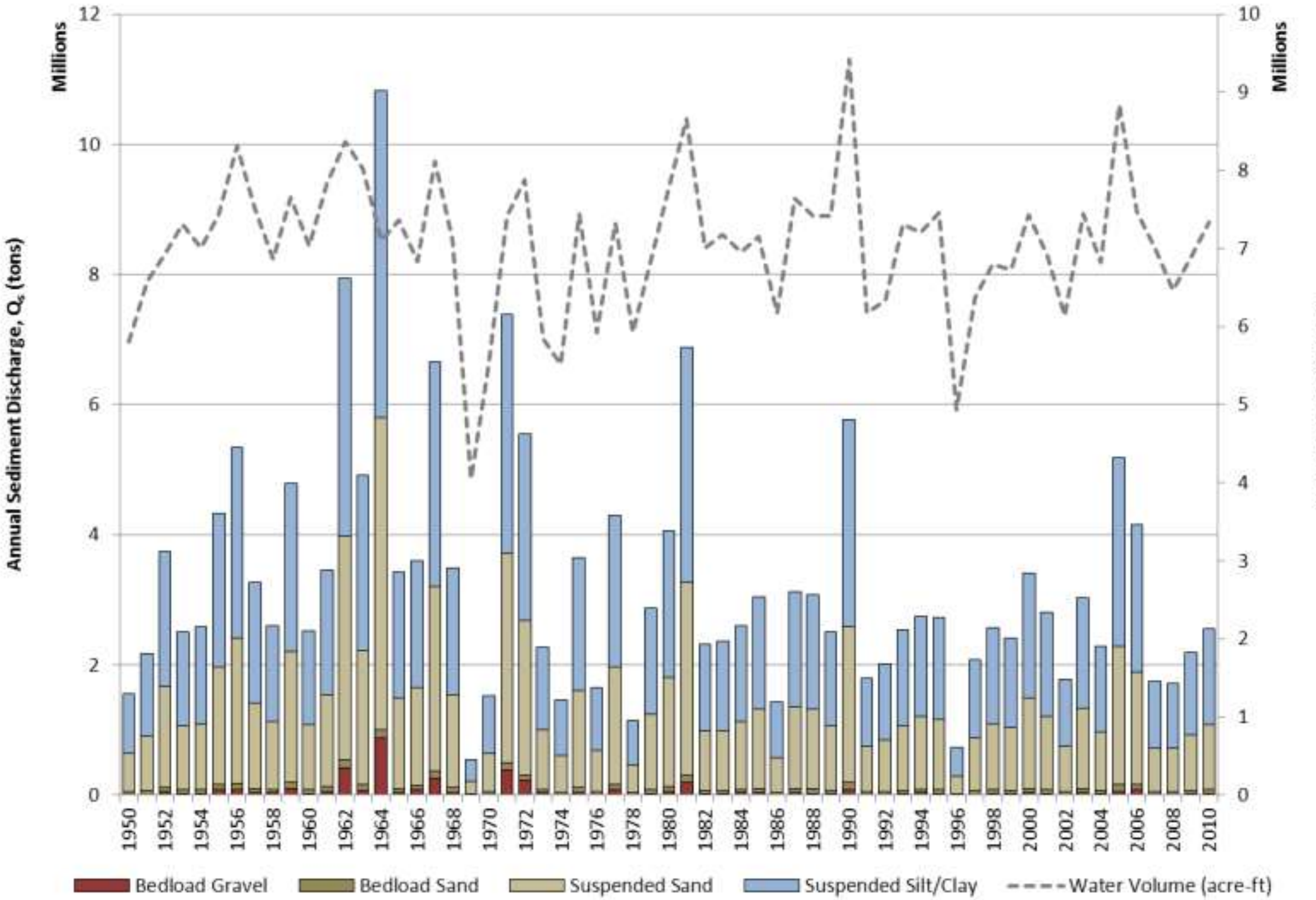

Figure 5.1-1. Estimated annual silt/clay, sand and gravel loads at the Gold Creek (Gage No. 15292000)/, Susitna River near Talkeetna (Gage No. 15292100) gage over the 61-year period of flows under pre-Project conditions. Also shown is the annual flow volume for each of the years.

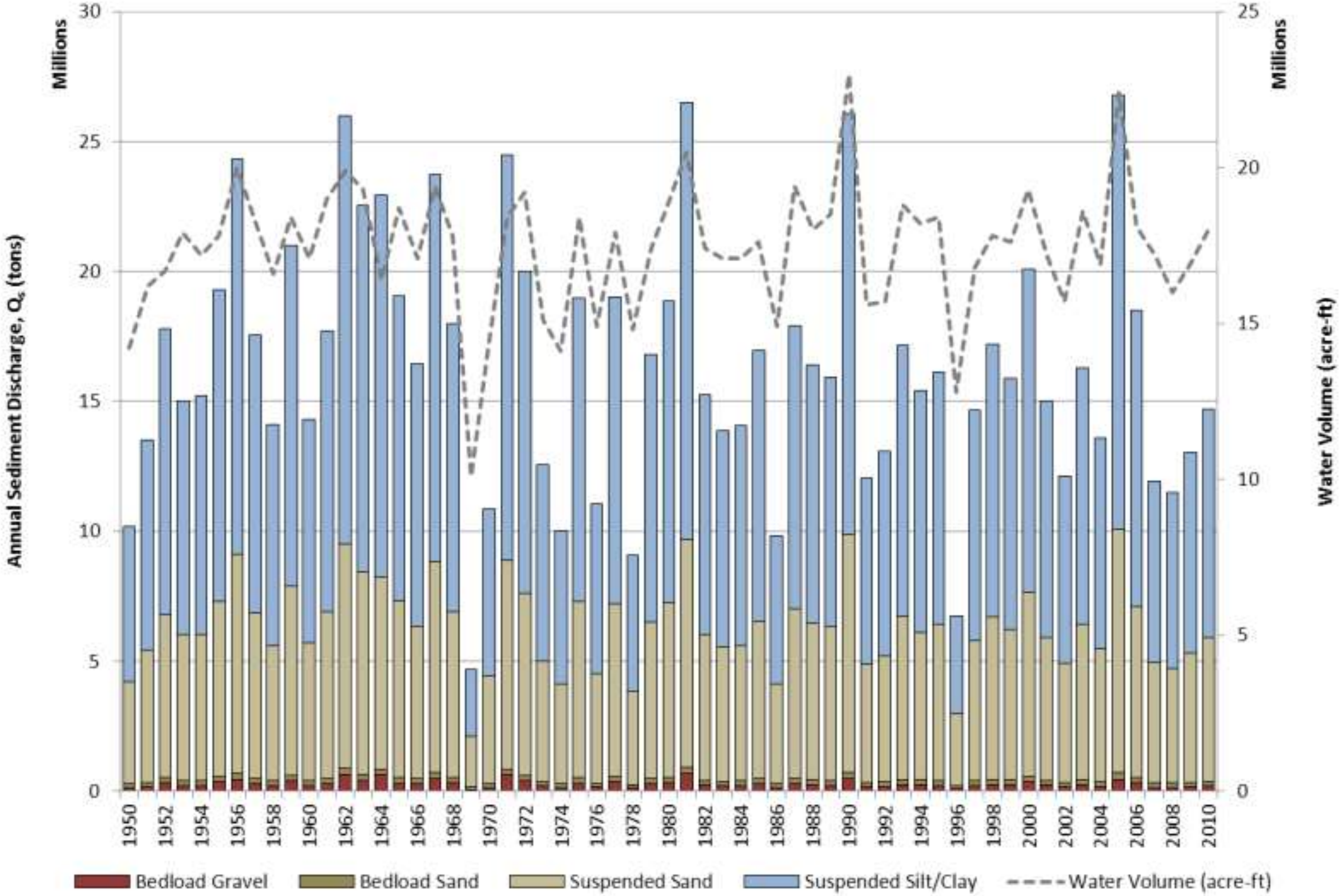

Figure 5.1-2. Estimated annual silt/clay, sand and gravel loads at the Susitna River at Sunshine (Gage No. 15292780) gage over the 61-year period of flows under pre-Project conditions. Also shown is the annual flow volume for each of the years.

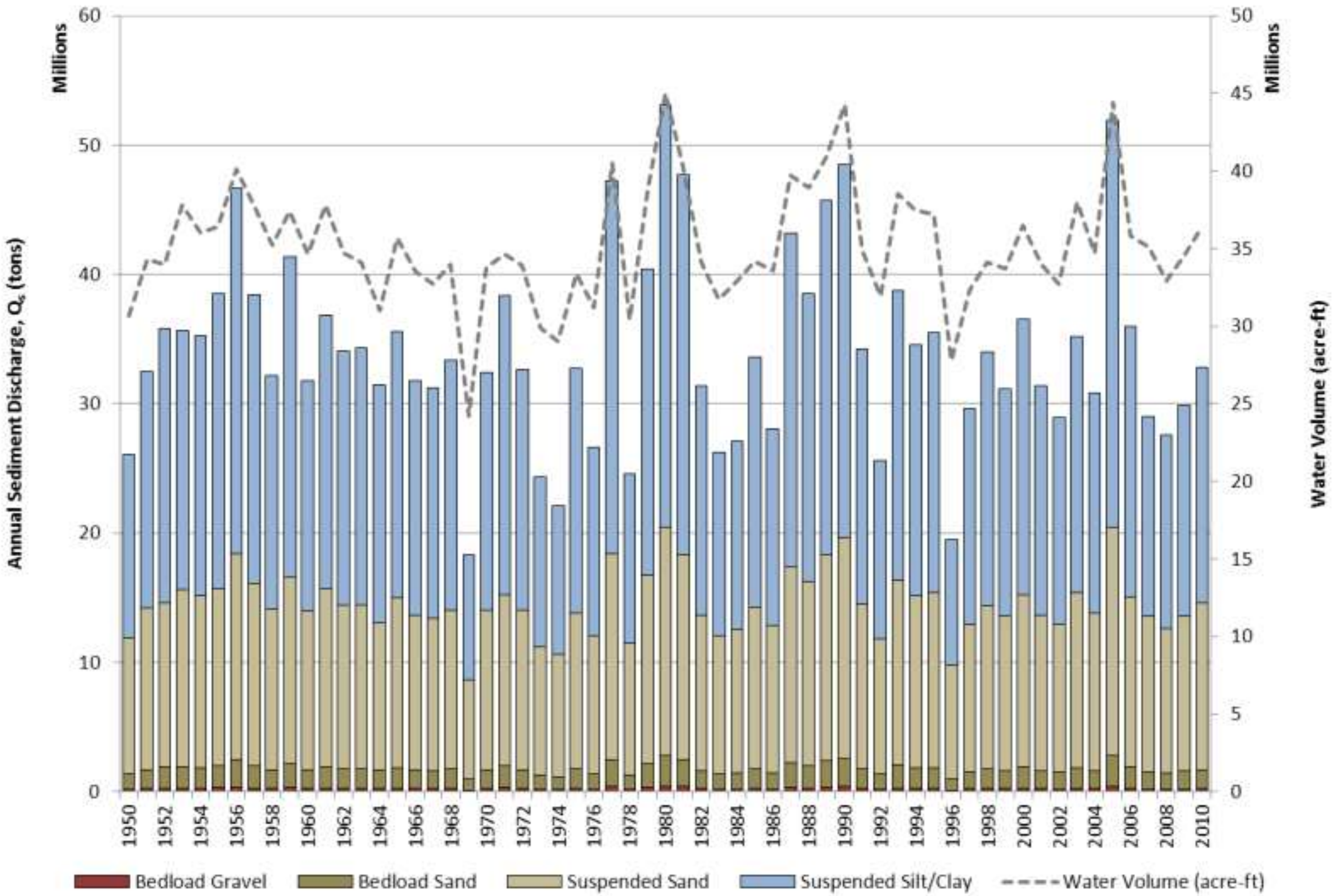

Figure 5.1-3. Estimated annual silt/clay, sand and gravel loads at the Susitna River at Susitna Station (Gage No. 15294350) gage over the 61-year period of flows under pre-Project conditions. Also shown is the annual flow volume for each of the years.

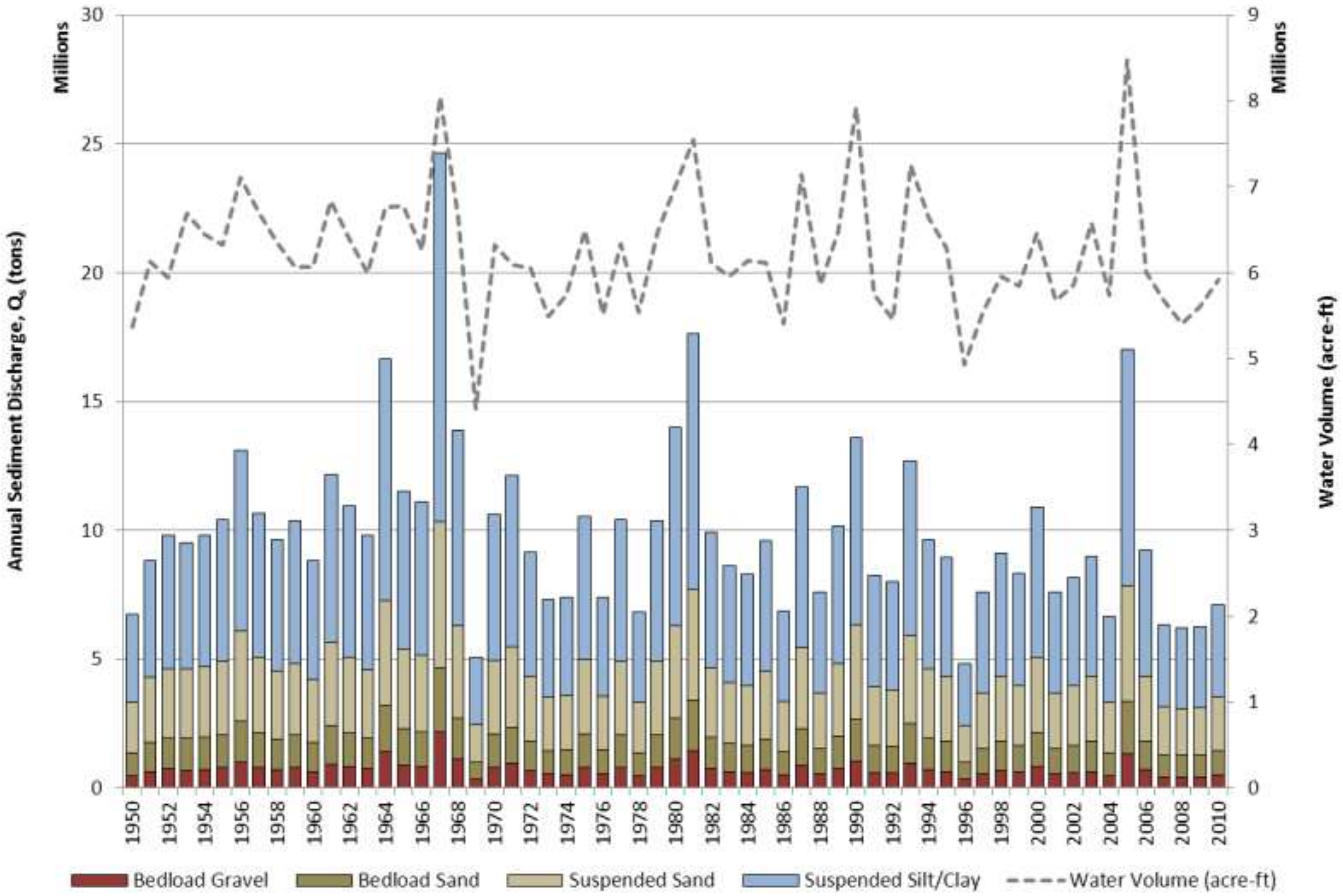

Figure 5.1-4. Estimated annual silt/clay, sand and gravel loads at the Chulitna River near Talkeetna (Gage No. 15292400), Chulitna River below Canyon near Talkeetna (Gage No. 15292410) gage over the 61-year period of flows under pre-Project conditions. Also shown is the annual flow volume for each of the years.

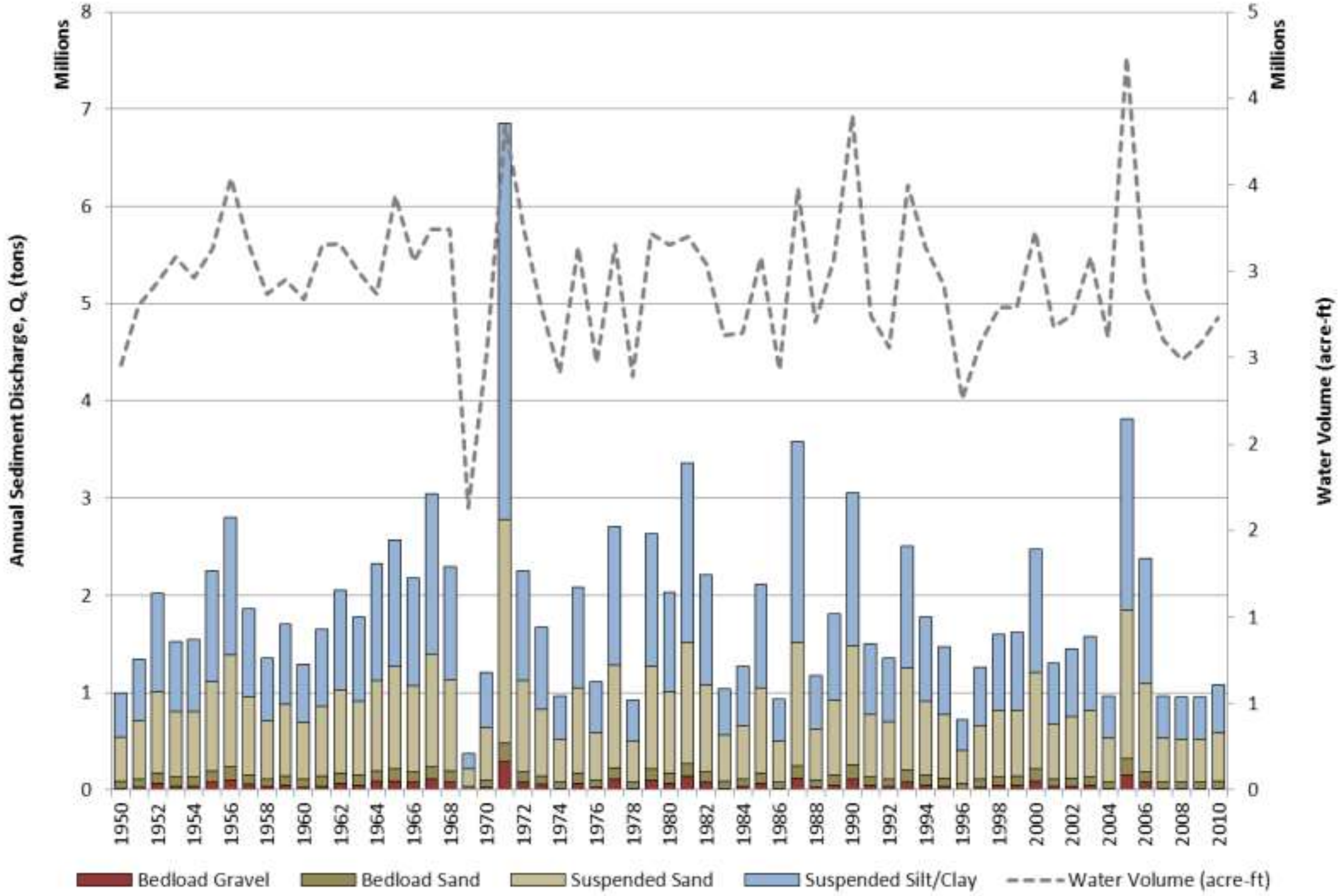

Figure 5.1-5. Estimated annual silt/clay, sand and gravel loads at the Talkeetna River near Talkeetna (Gage No. 15292700) gage over the 61-year period of flows under pre-Project conditions. Also shown is the annual flow volume for each of the years.

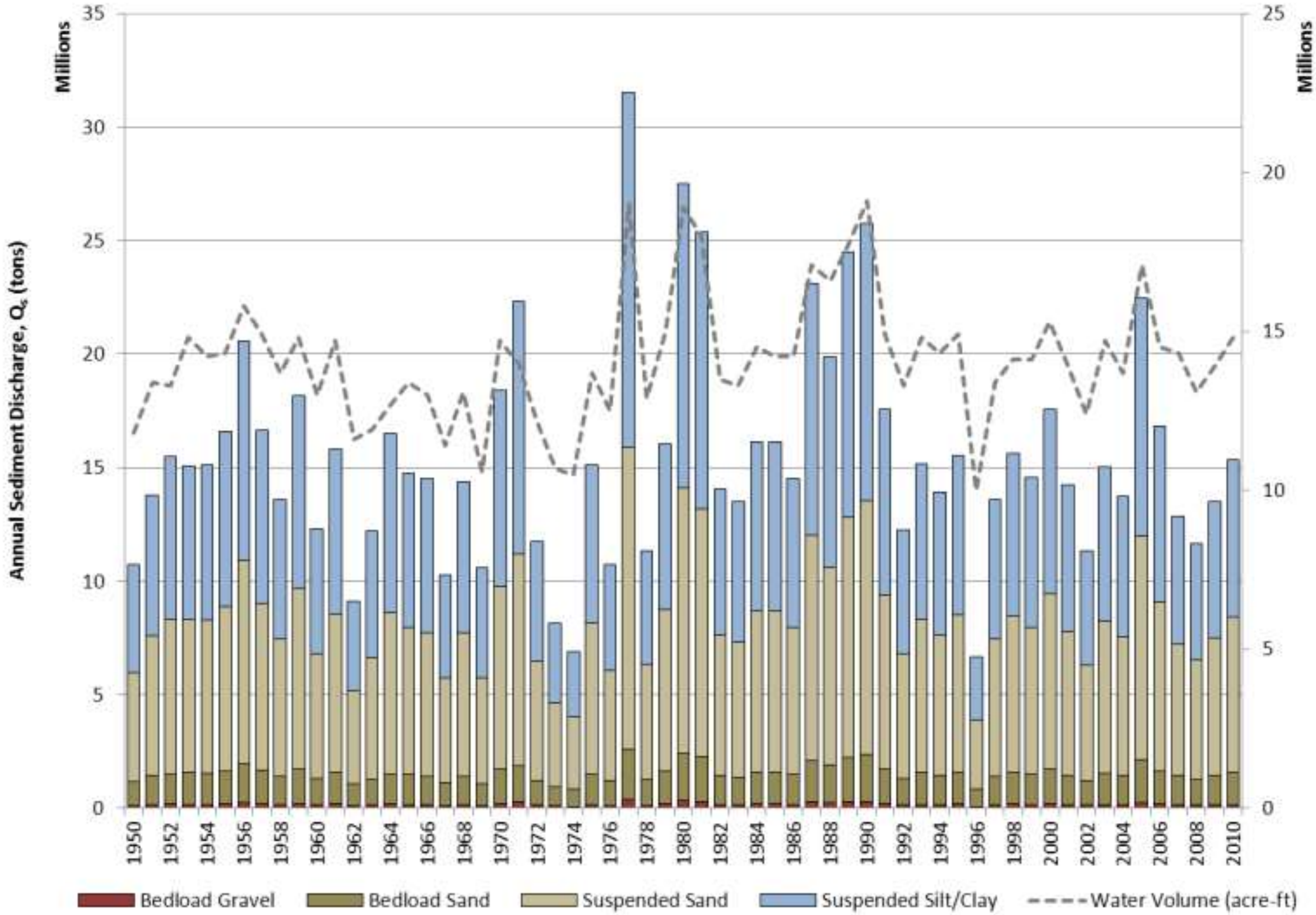

Figure 5.1-6. Estimated annual silt/clay, sand and gravel loads at the Yentna River near Susitna Station (Gage No. 15294345) gage over the 61-year period of flows under pre-Project conditions. Also shown is the annual flow volume for each of the years.

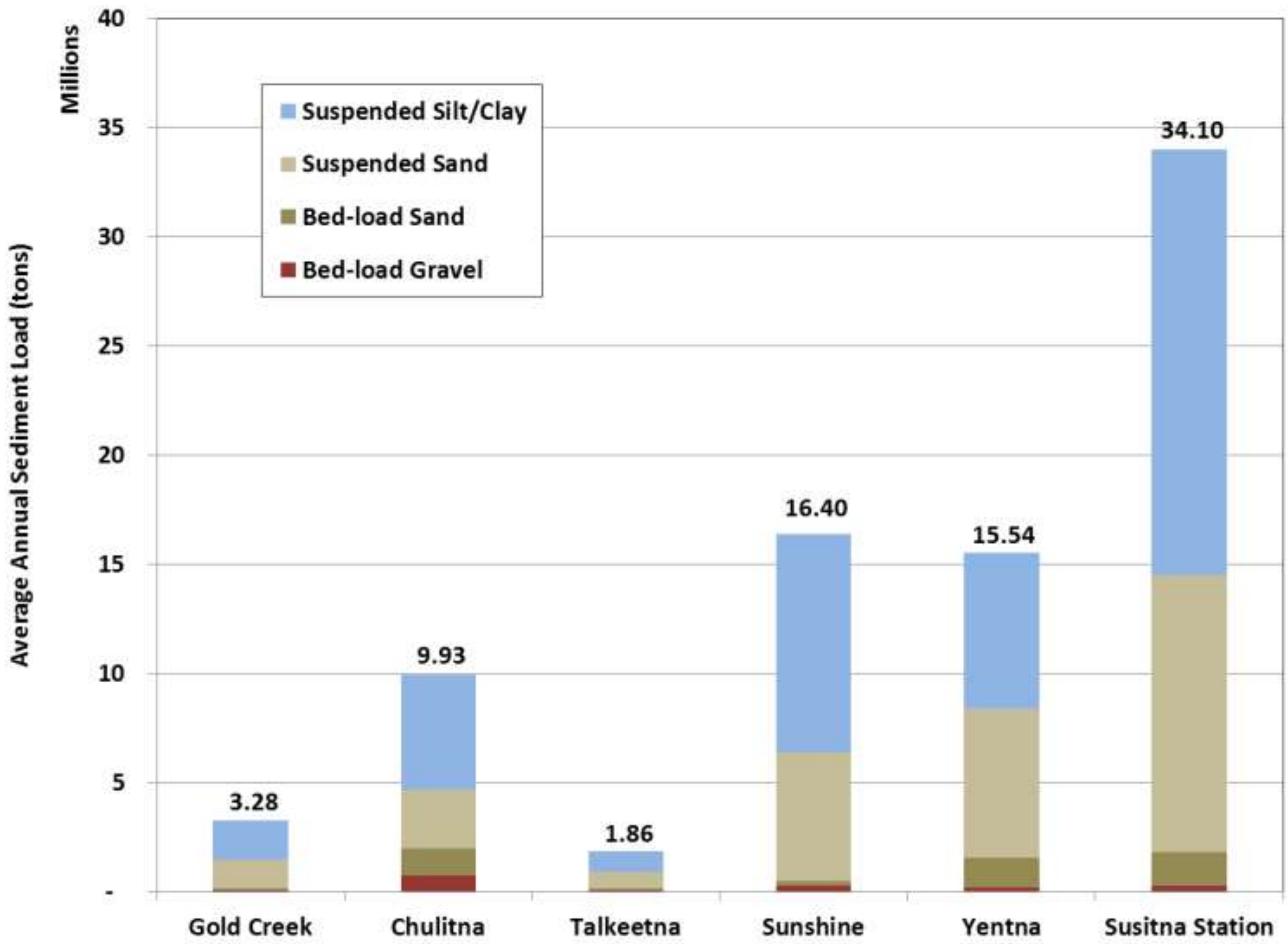

Figure 5.1.7. Average annual silt/clay, sand and gravel loads under pre-Project conditions for the three mainstem gages and three major tributary gages considered in the analysis.

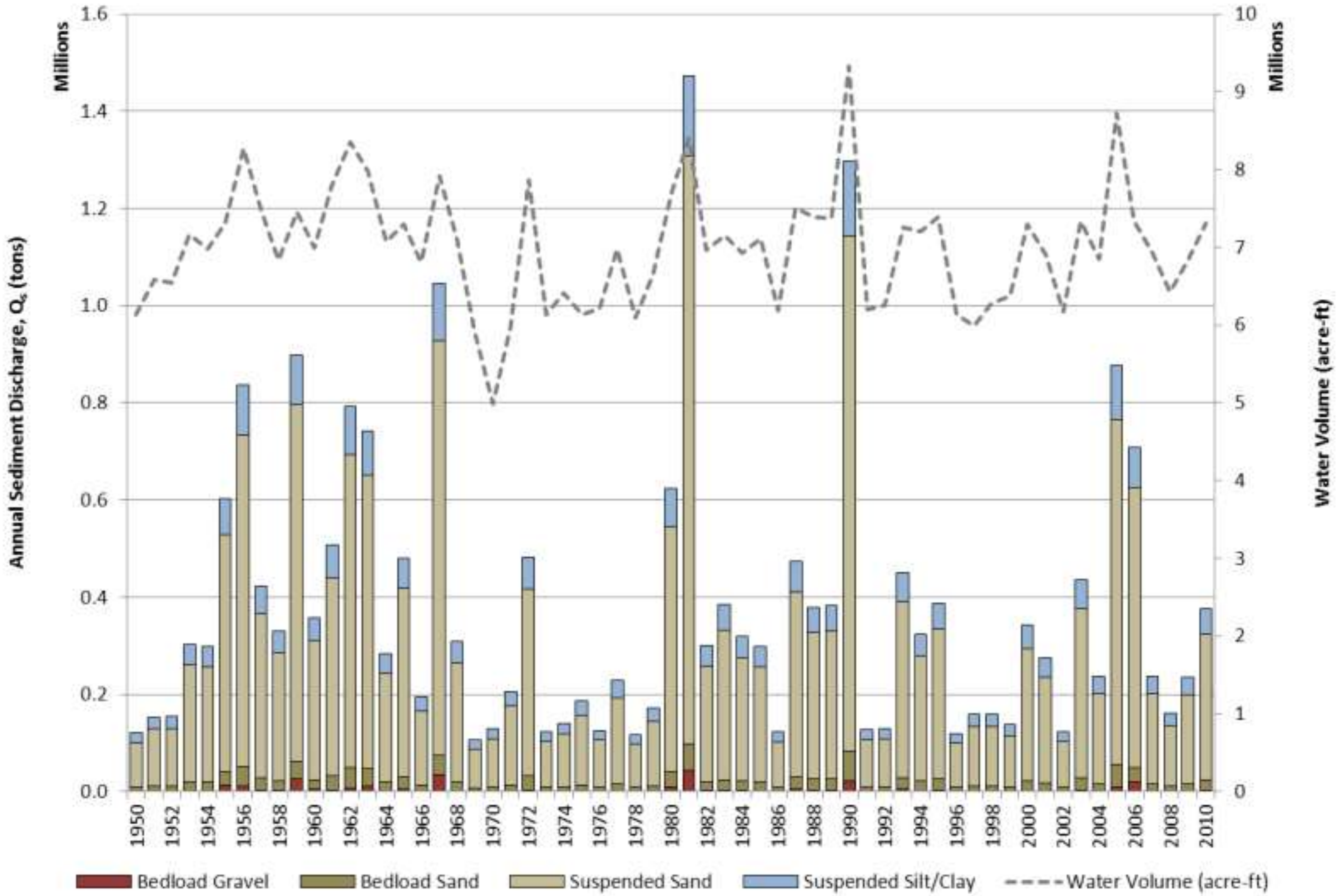

Figure 5.2-1. Estimated annual silt/clay, sand and gravel loads at the Gold Creek (Gage No. 15292000), Susitna River near Talkeetna (Gage No. 15292100) gage over the 61-year period of flows under Max LF OS-1conditions. Also shown is the annual flow volume for each of the years.

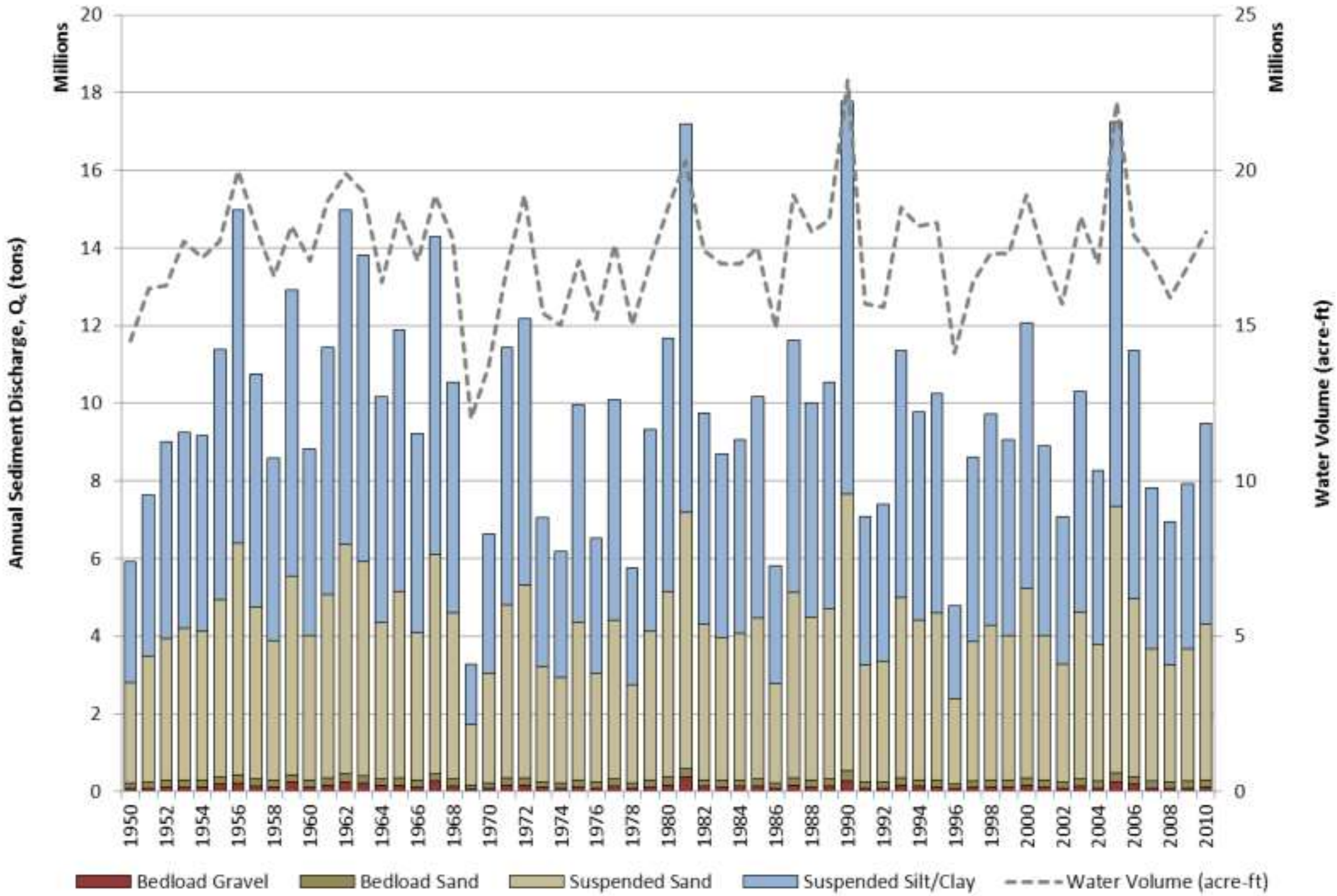

Figure 5.2-2. Estimated annual silt/clay, sand and gravel loads at the Susitna River at Sunshine (Gage No. 15292780) gage over the 61-year period of flows under Max LF OS-1conditions. Also shown is the annual flow volume for each of the years.

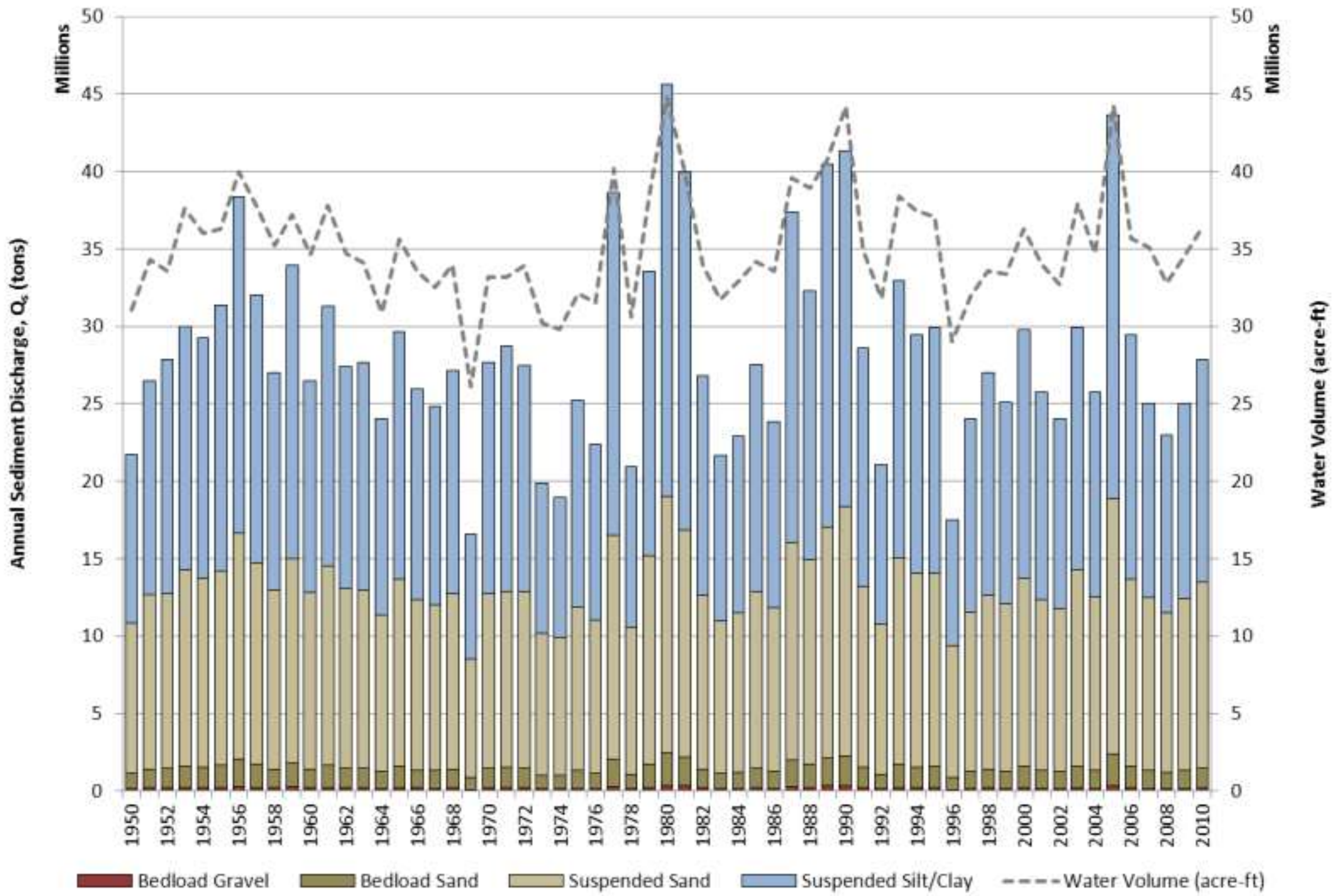

Figure 5.2-3. Estimated annual silt/clay, sand and gravel loads at the Susitna River at Susitna Station (Gage No. 15294350) gage over the 61-year period of flows under Max LF OS-1conditions. Also shown is the annual flow volume for each of the years.

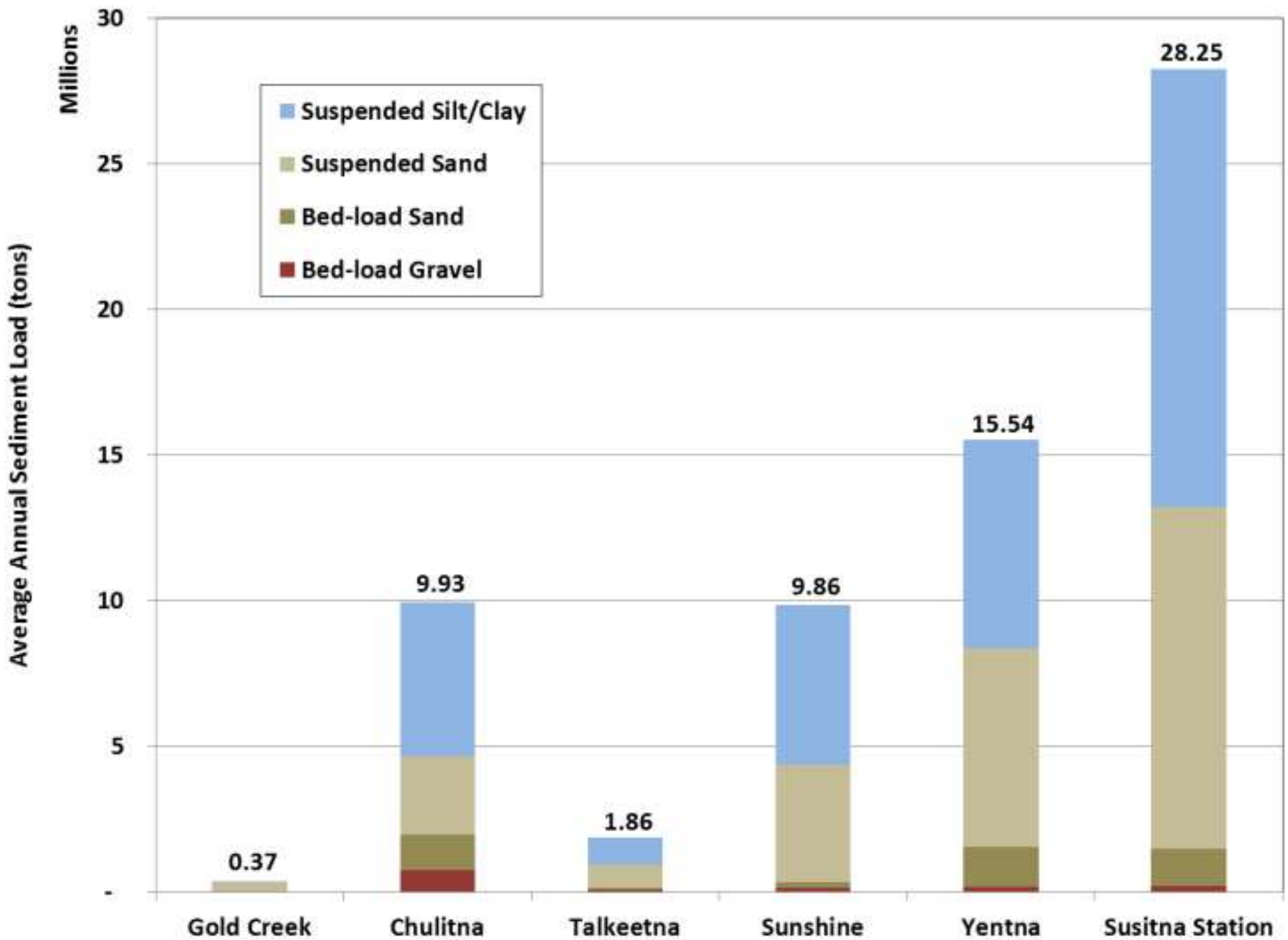

Figure 5.2.4. Average annual silt/clay, sand and gravel loads under Maximum Load Following OS-1 conditions for the three mainstem gages and three major tributary gages considered in the analysis. Note that the tributary loads are the same as pre-Project conditions.

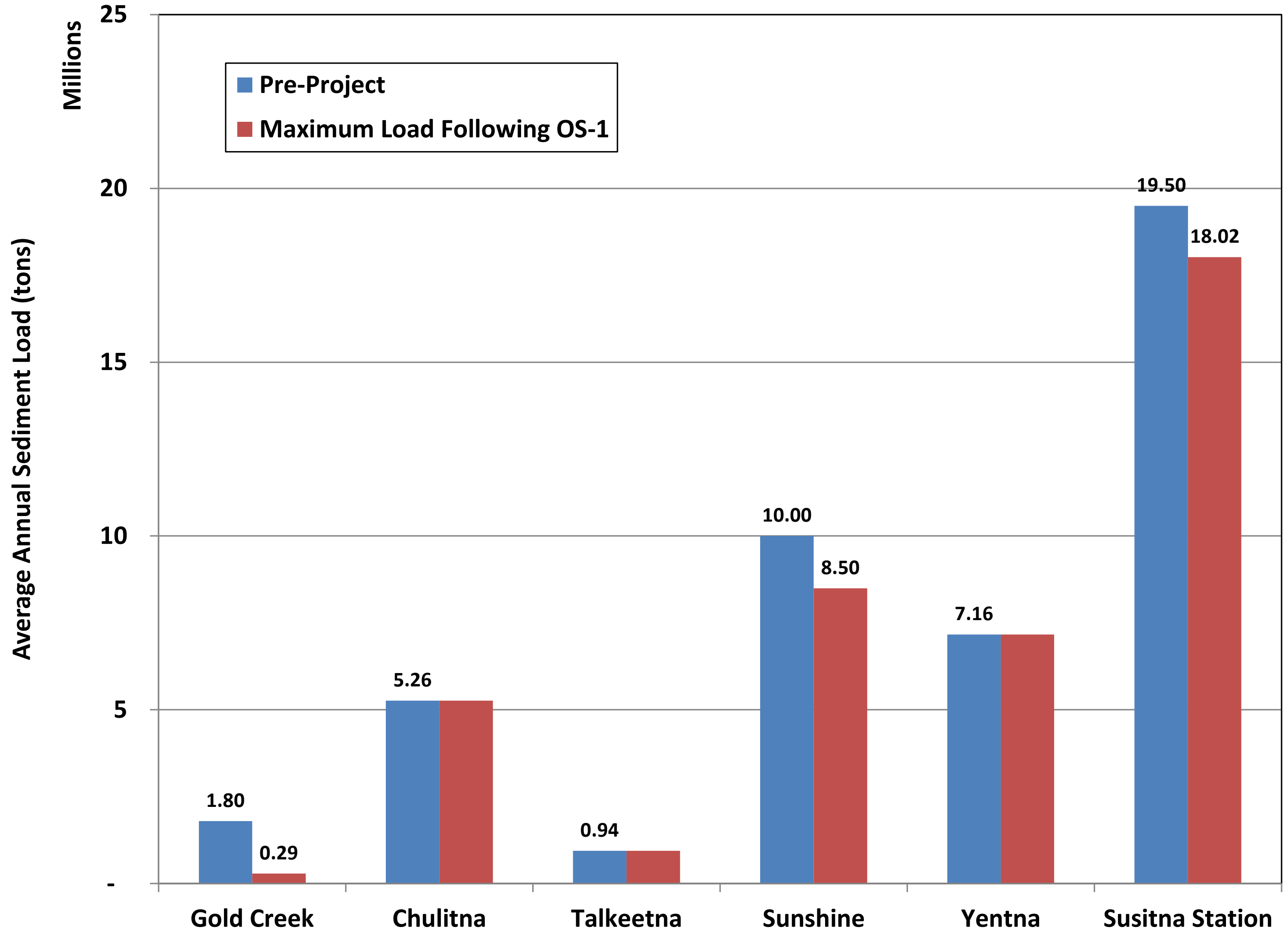

Figure 6.0-1. Average annual silt/clay loads at the three mainstem gages and the three primary tributary gages under pre-Project and Maximum Load Following OS-1 conditions.

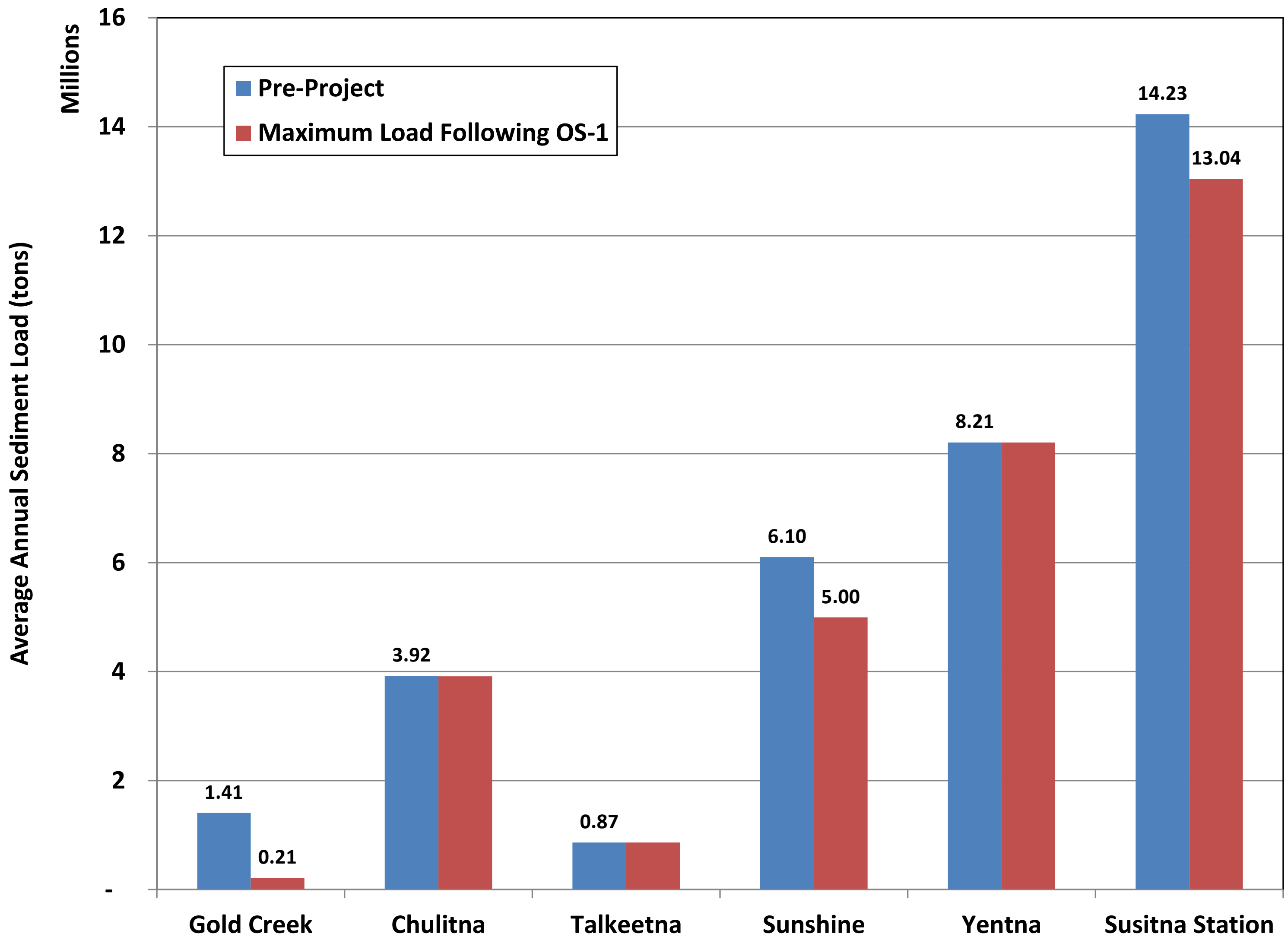

Figure 6.0-2. Average annual sand loads at the three mainstem gages and the three primary tributary gages under pre-Project and Maximum Load Following OS-1 conditions.

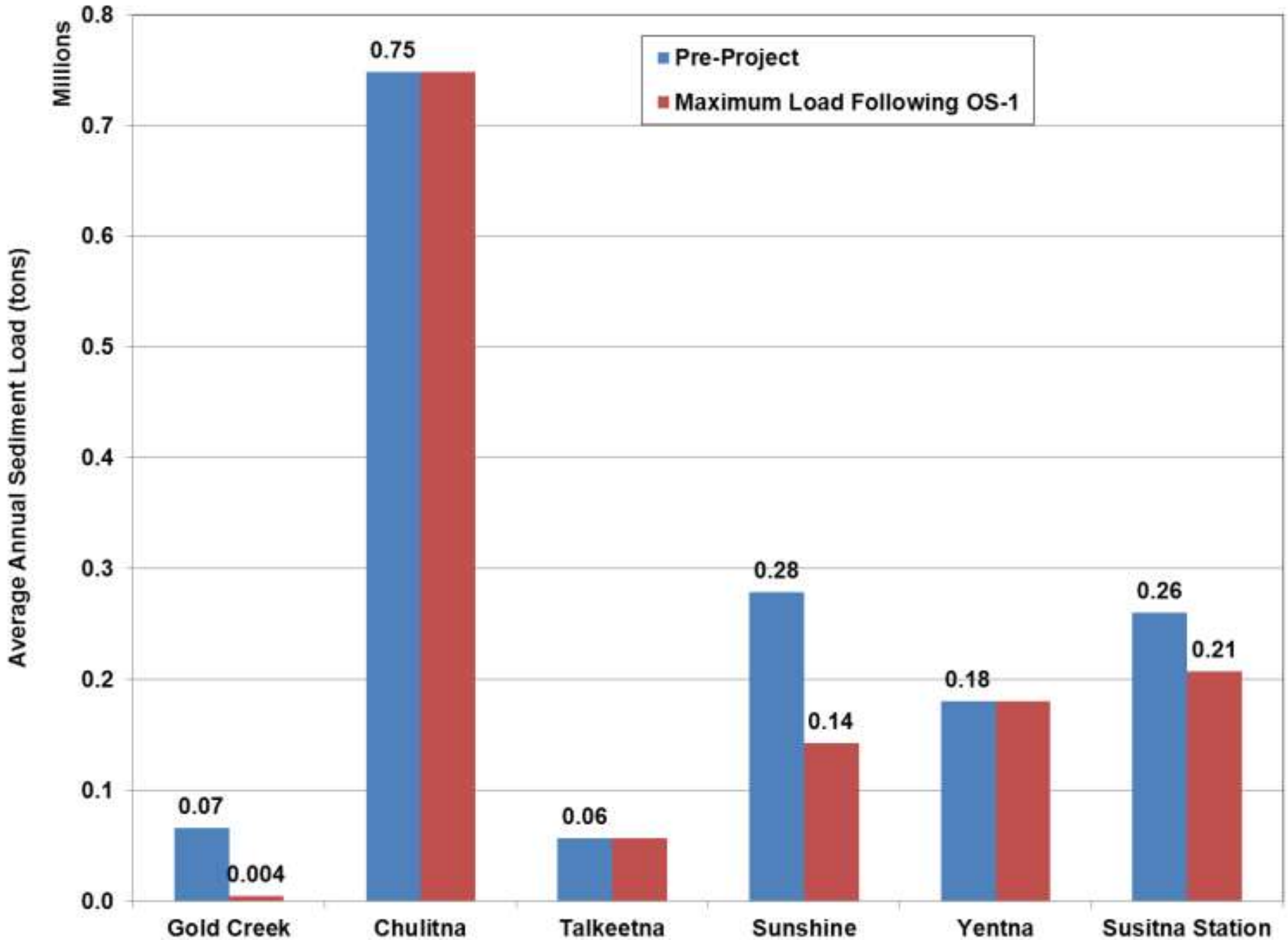

Figure 6.0-3. Average annual gravel loads at the three mainstem gages and the three primary tributary gages under pre-Project and Maximum Load Following OS-1 conditions.

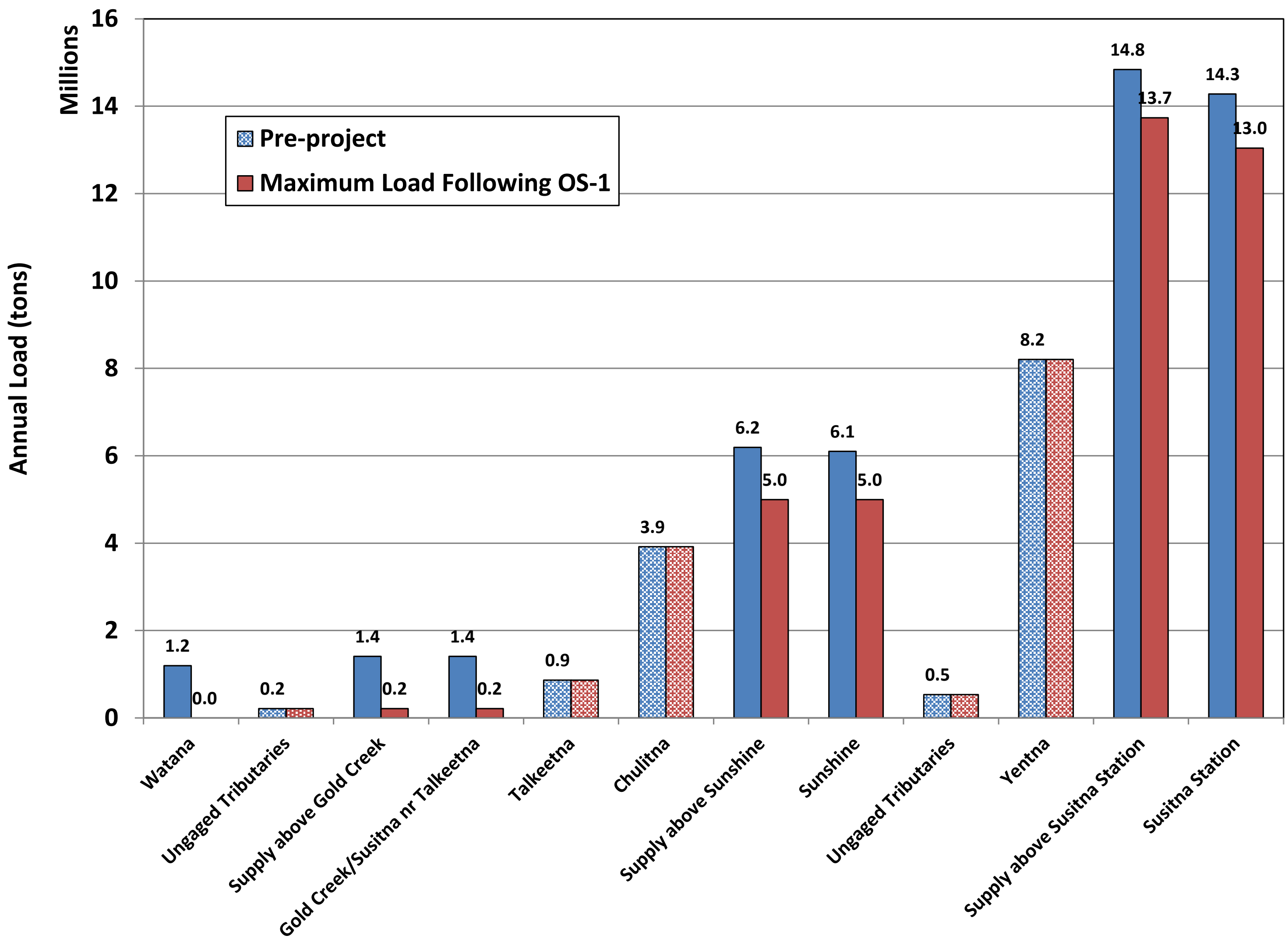

Figure 6.0-4. Average annual sand loads at the mainstem and tributary gages, along with the estimated annual sand load from ungaged tributaries, under pre-Project and Maximum Load Following OS-1 conditions. Also shown is the accumulated sediment supply to key points along the reach based on the gaged and ungaged sand loads.

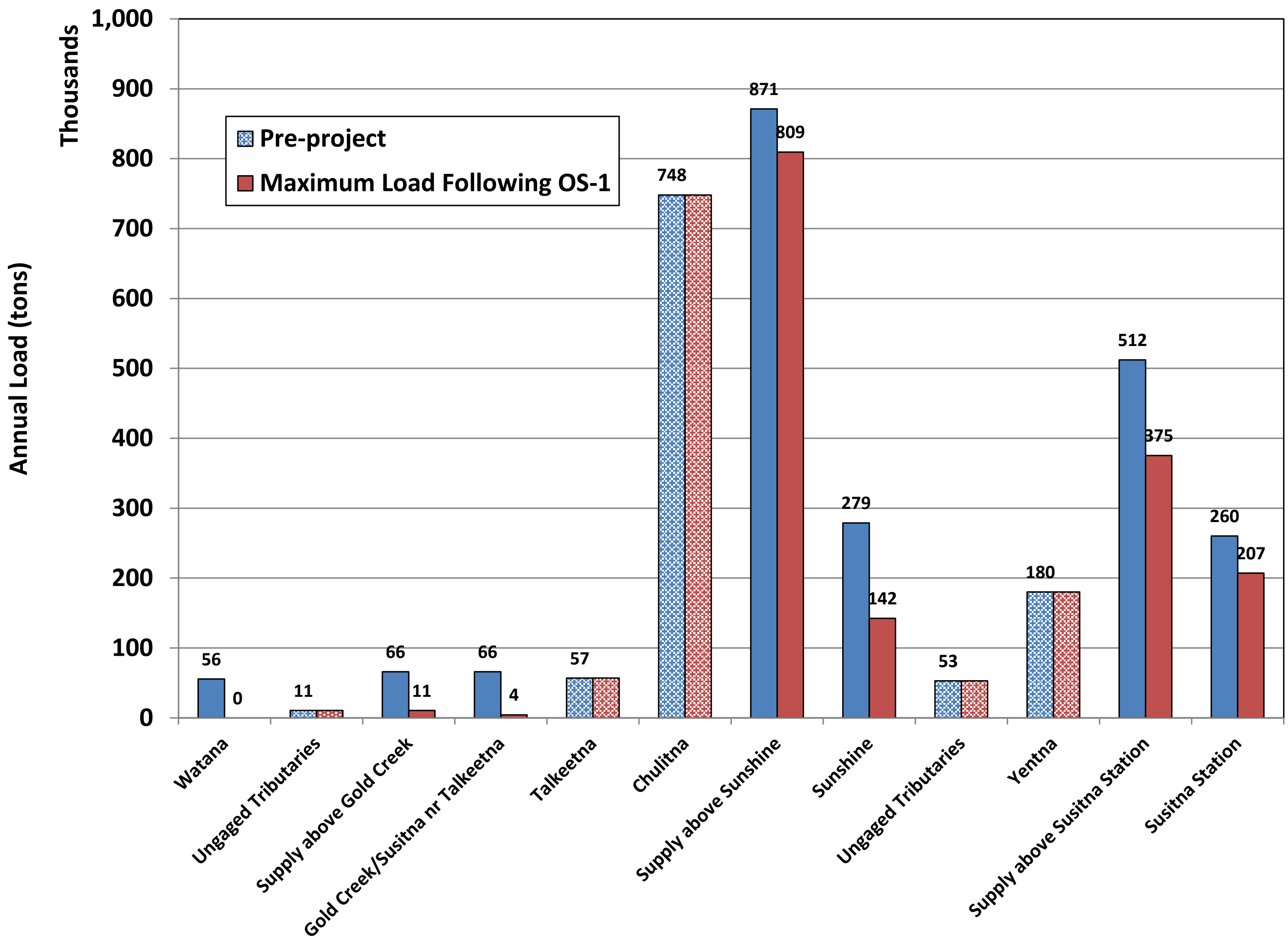

Figure 6.0-5. Average annual gravel loads at the mainstem and tributary gages, along with the estimated annual gravel load from ungaged tributaries, under pre-Project and Maximum Load Following OS-1 conditions. Also shown is the accumulated sediment supply to key points along the reach based on the gaged and ungaged gravel loads.