PART A - APPENDIX A: STUDY COMPONENT 1:

APPENDIX A.1: SURFICIAL GEOLOGY MAPPING IN THE LOWER AND MIDDLE SUSITNA RIVER SEGMENTS

APPENDIX A.2: GEOMORPHIC SURFACE MAPPING IN 7 FOCUS AREAS

APPENDIX A.3: RATINGS CURVES FOR 7 FOCUS AREAS

APPENDIX A.4: RECURRENCE INTERVAL PLOTS FOR 7 FOCUS AREAS

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

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

PART A - APPENDIX D: STUDY COMPONENT 9:

APPENDIX D.1: LARGE WOODY DEBRIS AERIAL PHOTOGRAPH DIGITIZING

APPENDIX D.2: LARGE WOODY DEBRIS FIELD INVENTORY PROTOCOL

APPENDIX D.3: LARGE WOODY DEBRIS STUDY AREA MAPS

PART A - ATTACHMENT A: SUSITNA RIVER FLOW AEROTRIANGULATION SUMMARY

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Geomorphology Study (6.5)

Part A - Appendix A
Study Component 1

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

June 2014

TABLE OF CONTENTS

A.1: SURFICIAL GEOLOGY MAPPING IN THE LOWER AND MIDDLE SUSITNA RIVER SEGMENTS

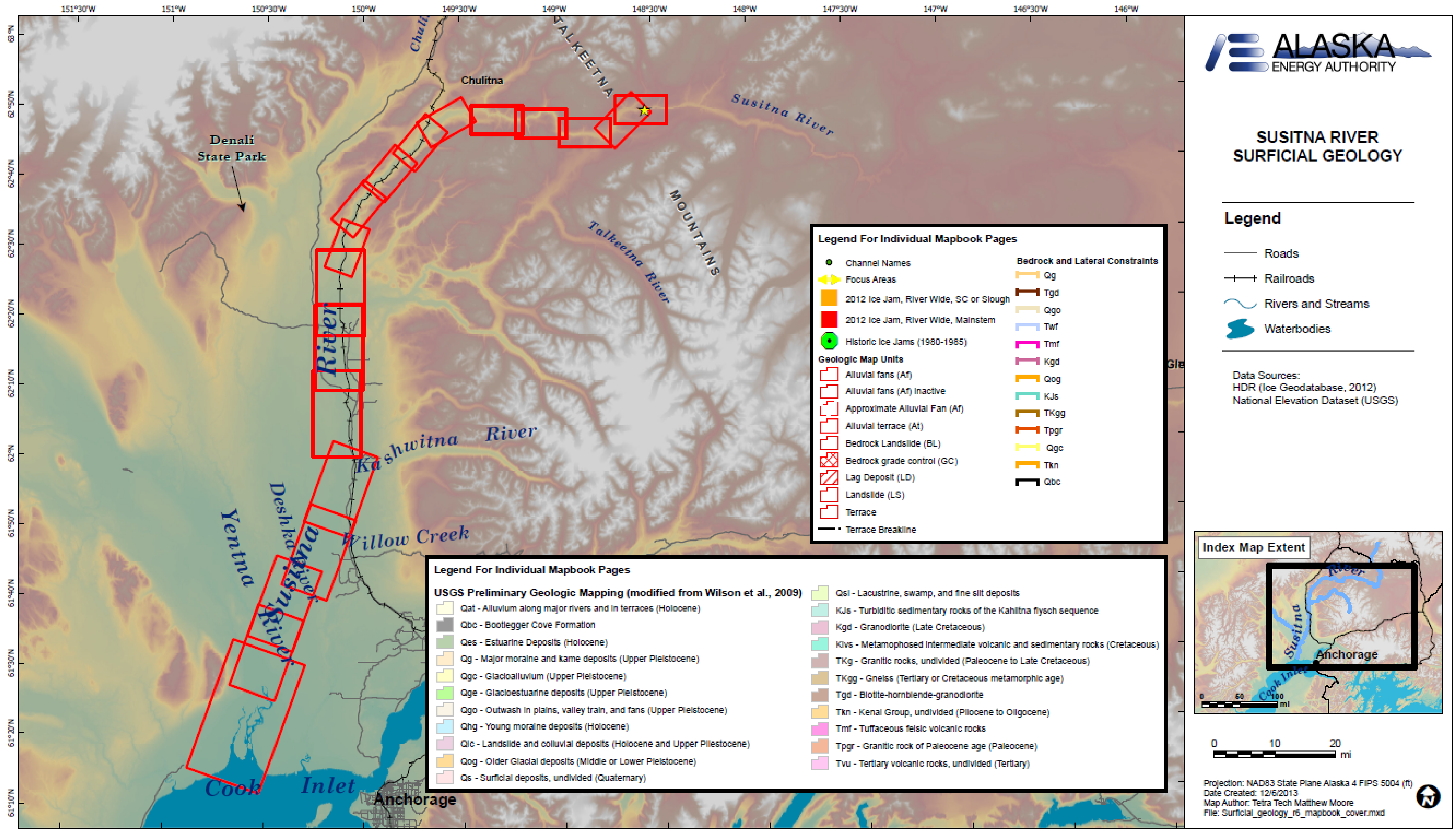

Figure A.1-1: Susitna River Surficial Geology Mapbook Cover Page.

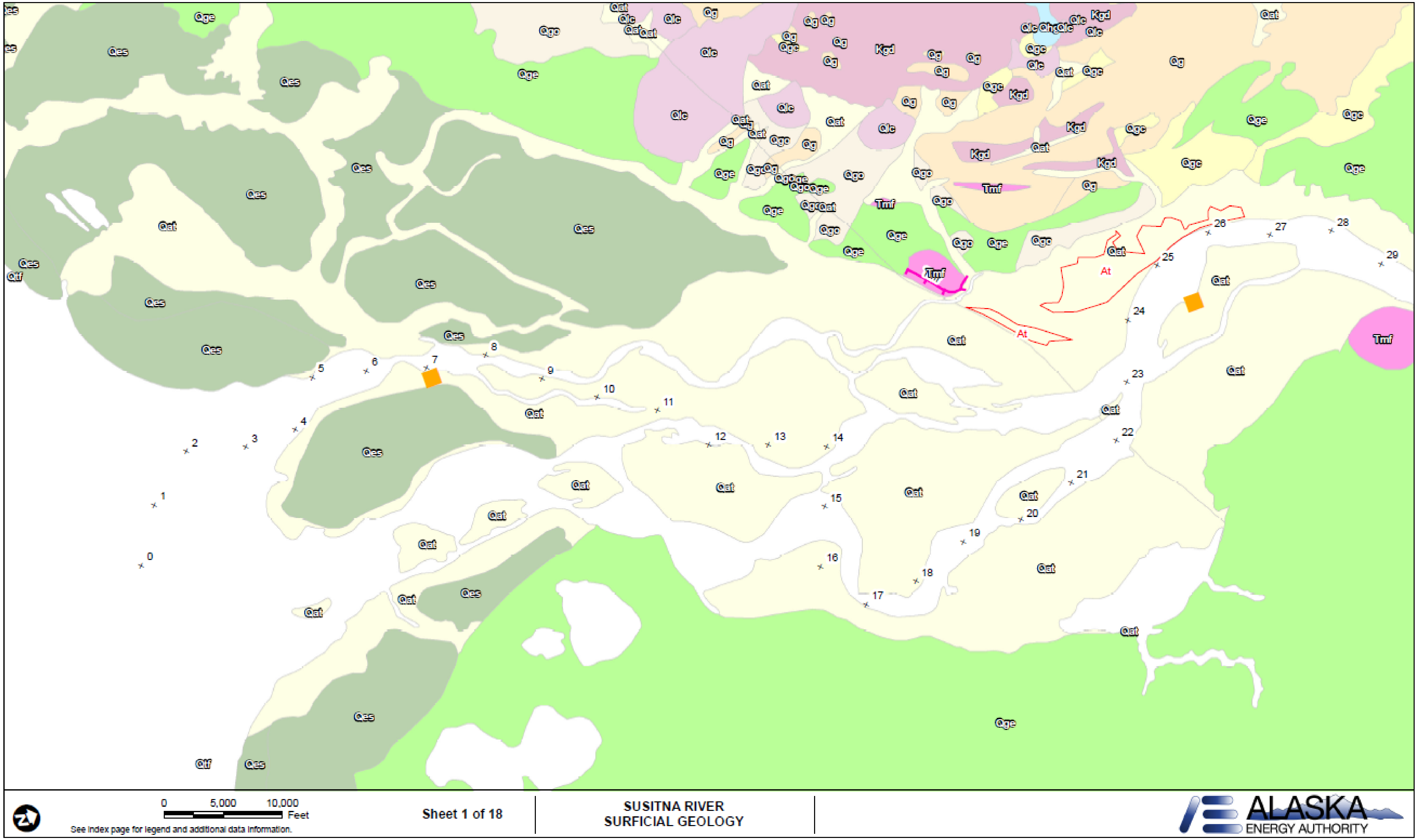

Figure A.1-2: Susitna River Surficial Geology Mapbook Sheet 1.

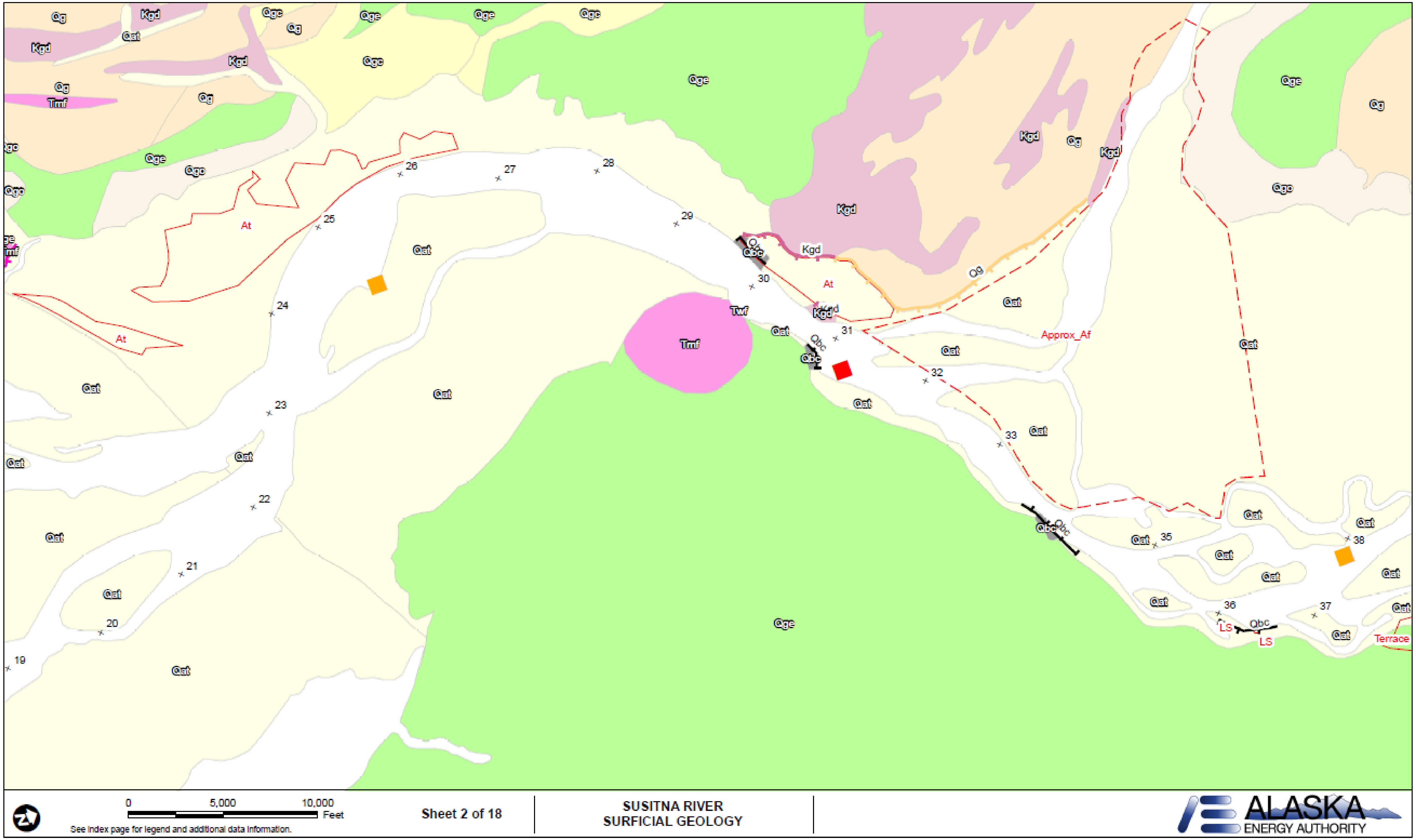

Figure A.1-3: Susitna River Surficial Geology Mapbook Sheet 2.

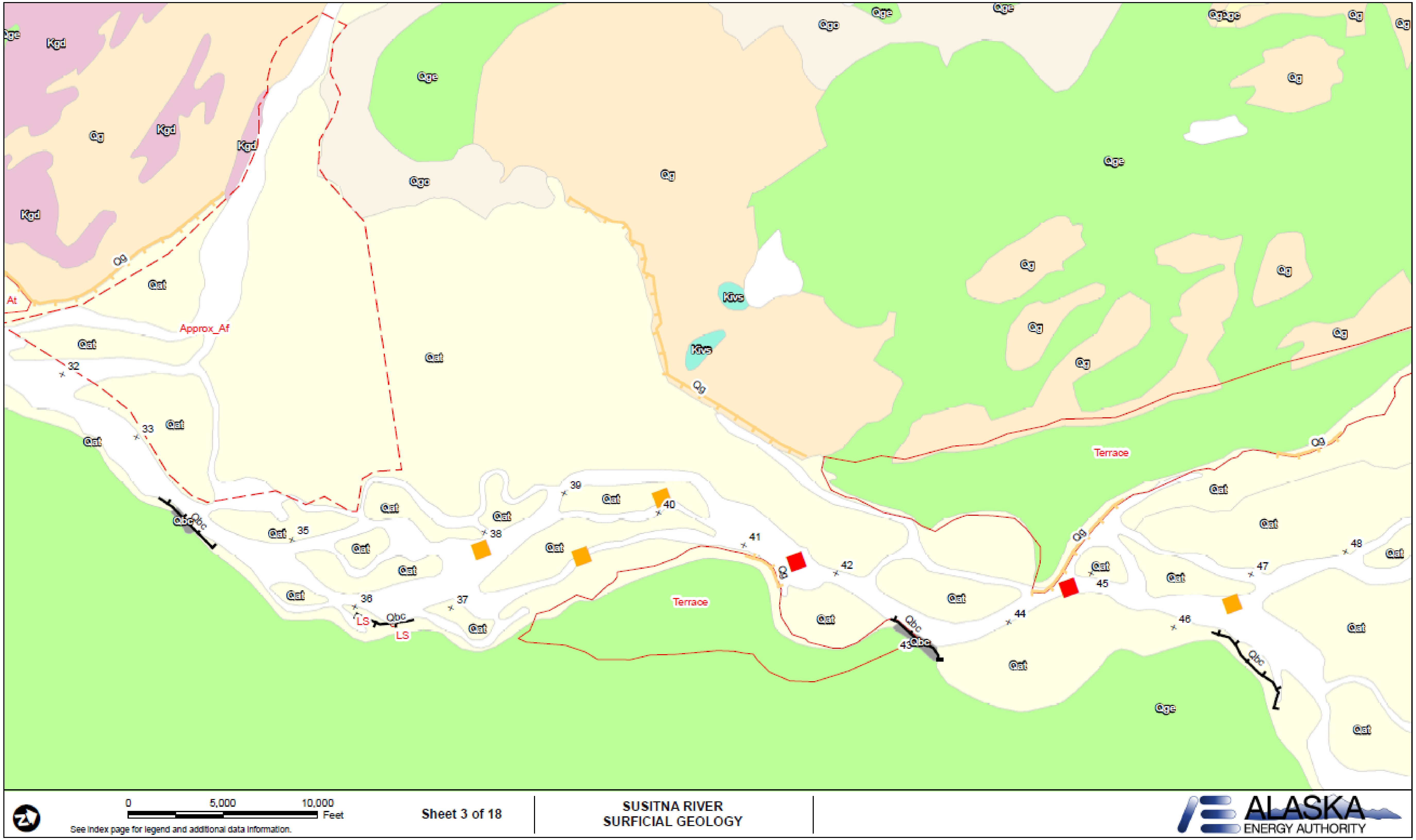

Figure A.1-4: Susitna River Surficial Geology Mapbook Sheet 3.

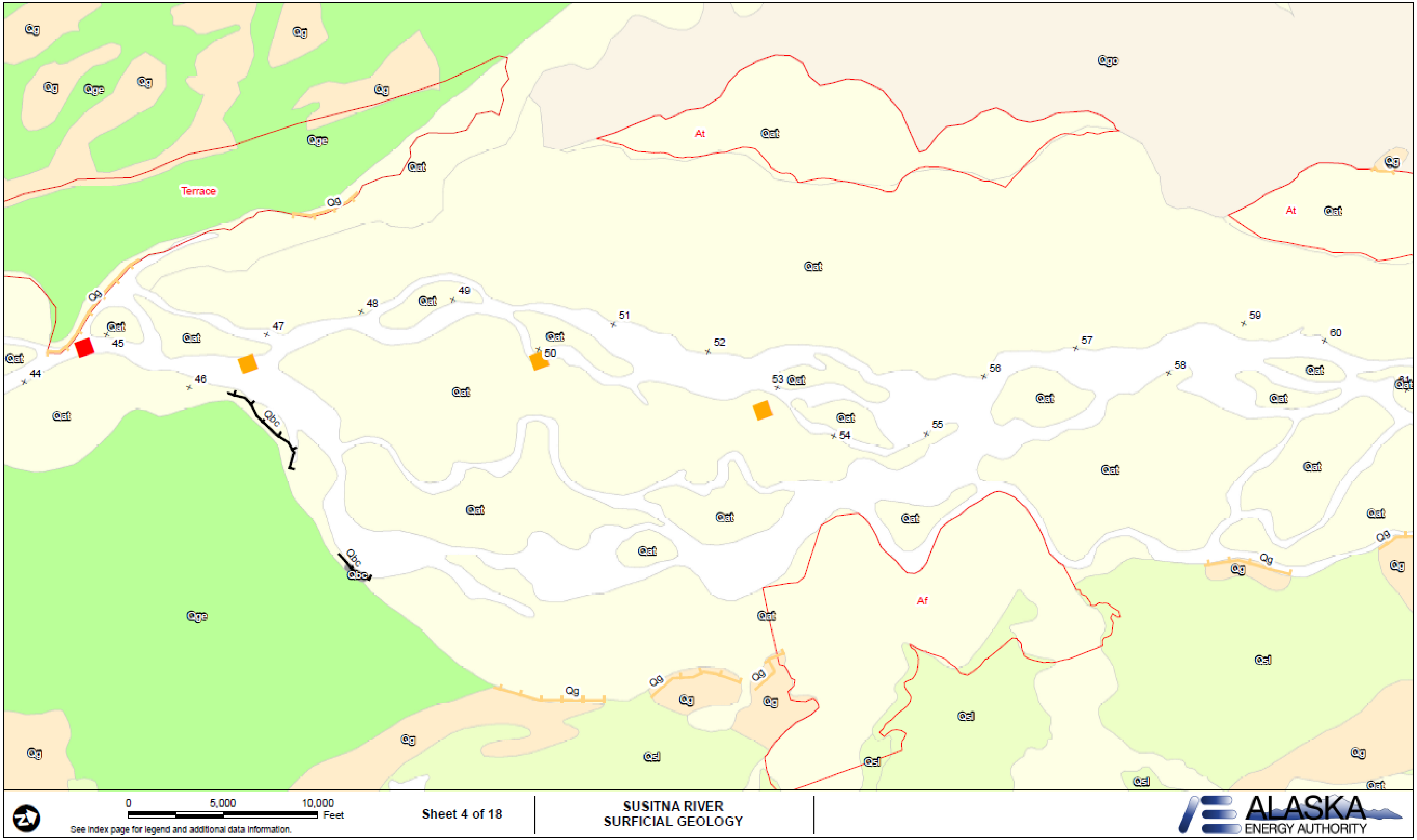

Figure A.1-5: Susitna River Surficial Geology Mapbook Sheet 4.

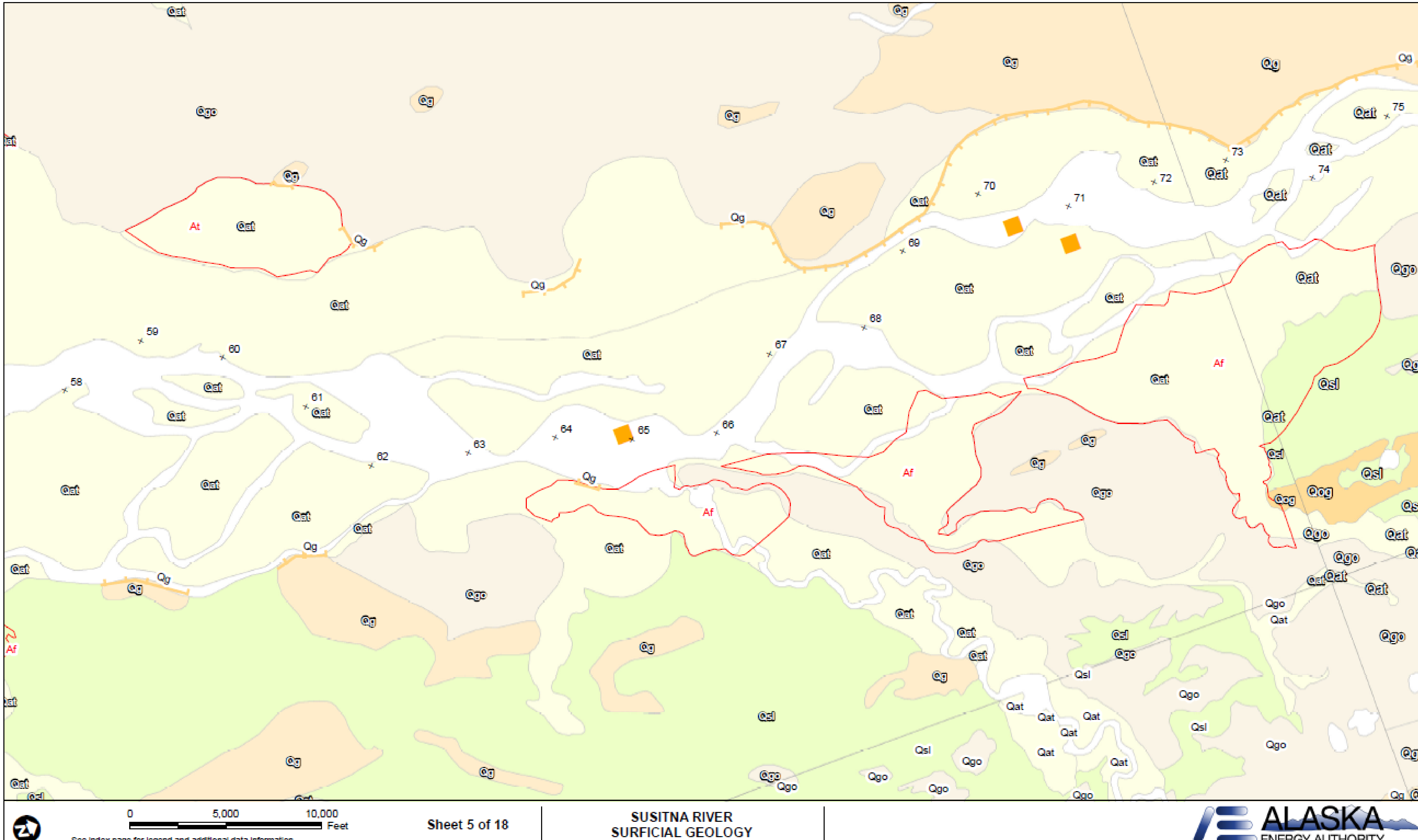

Figure A.1-6: Susitna River Surficial Geology Mapbook Sheet 5.

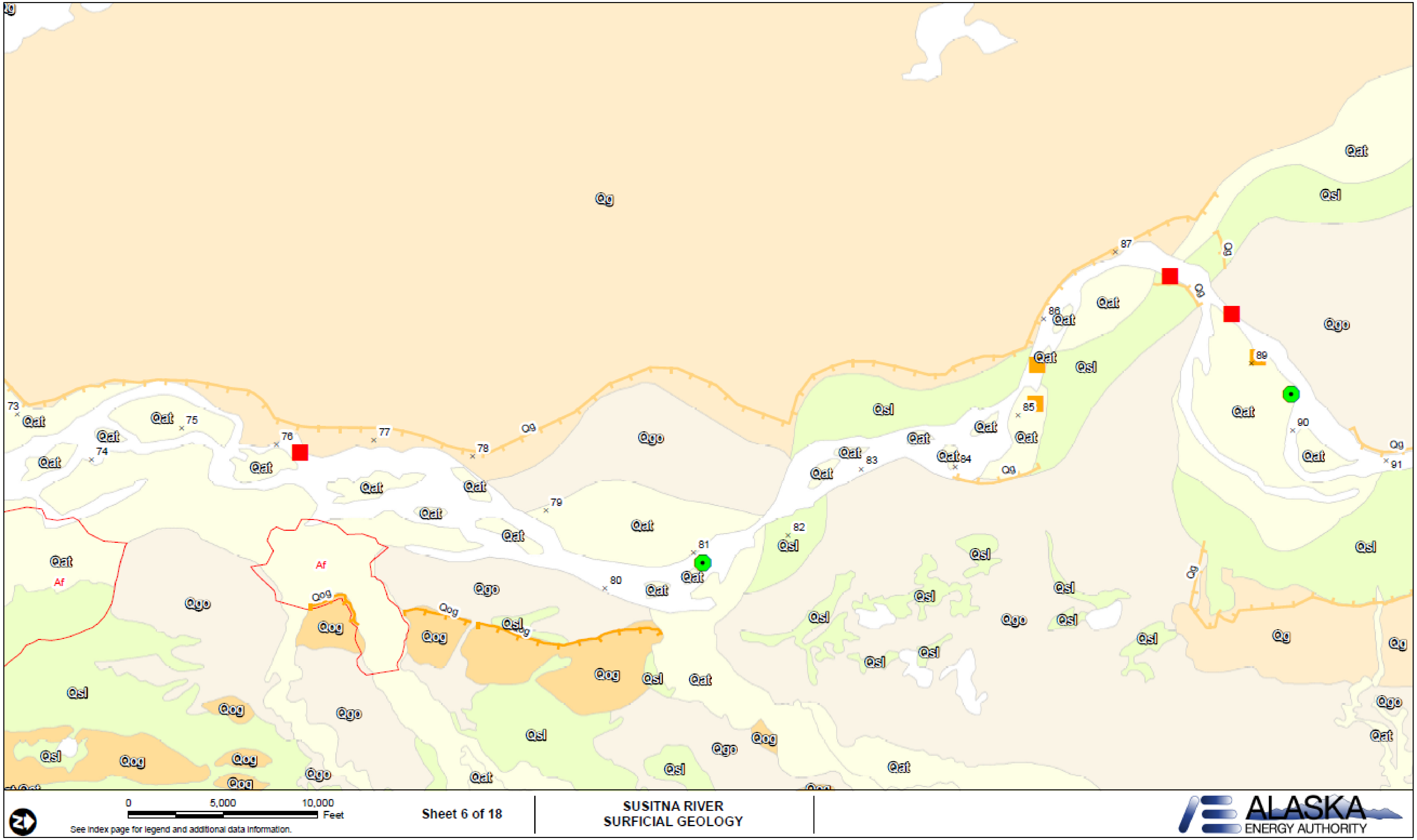

Figure A.1-7: Susitna River Surficial Geology Mapbook Sheet 6.

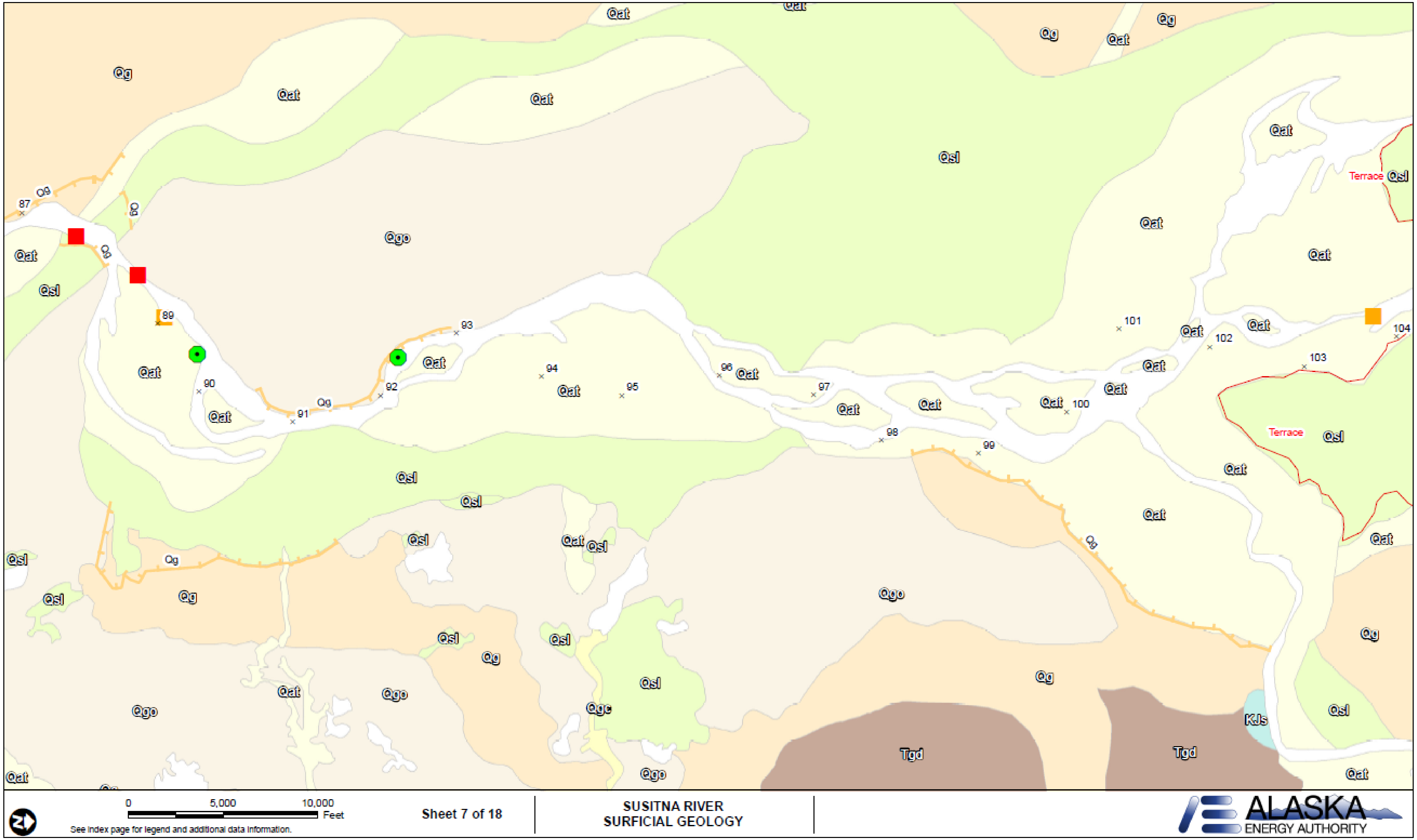

Figure A.1-8: Susitna River Surficial Geology Mapbook Sheet 7.

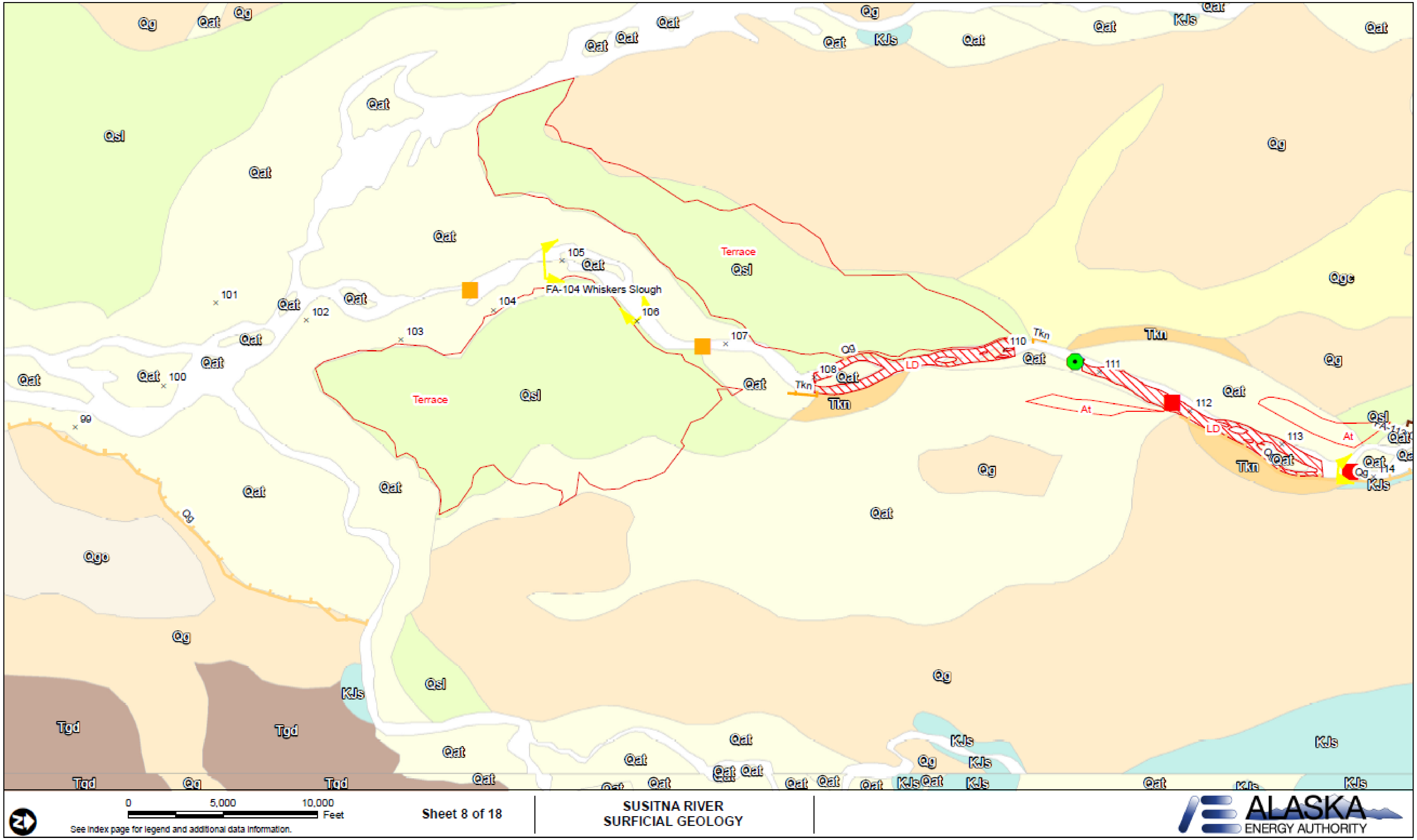

Figure A.1-9: Susitna River Surficial Geology Mapbook Sheet 8.

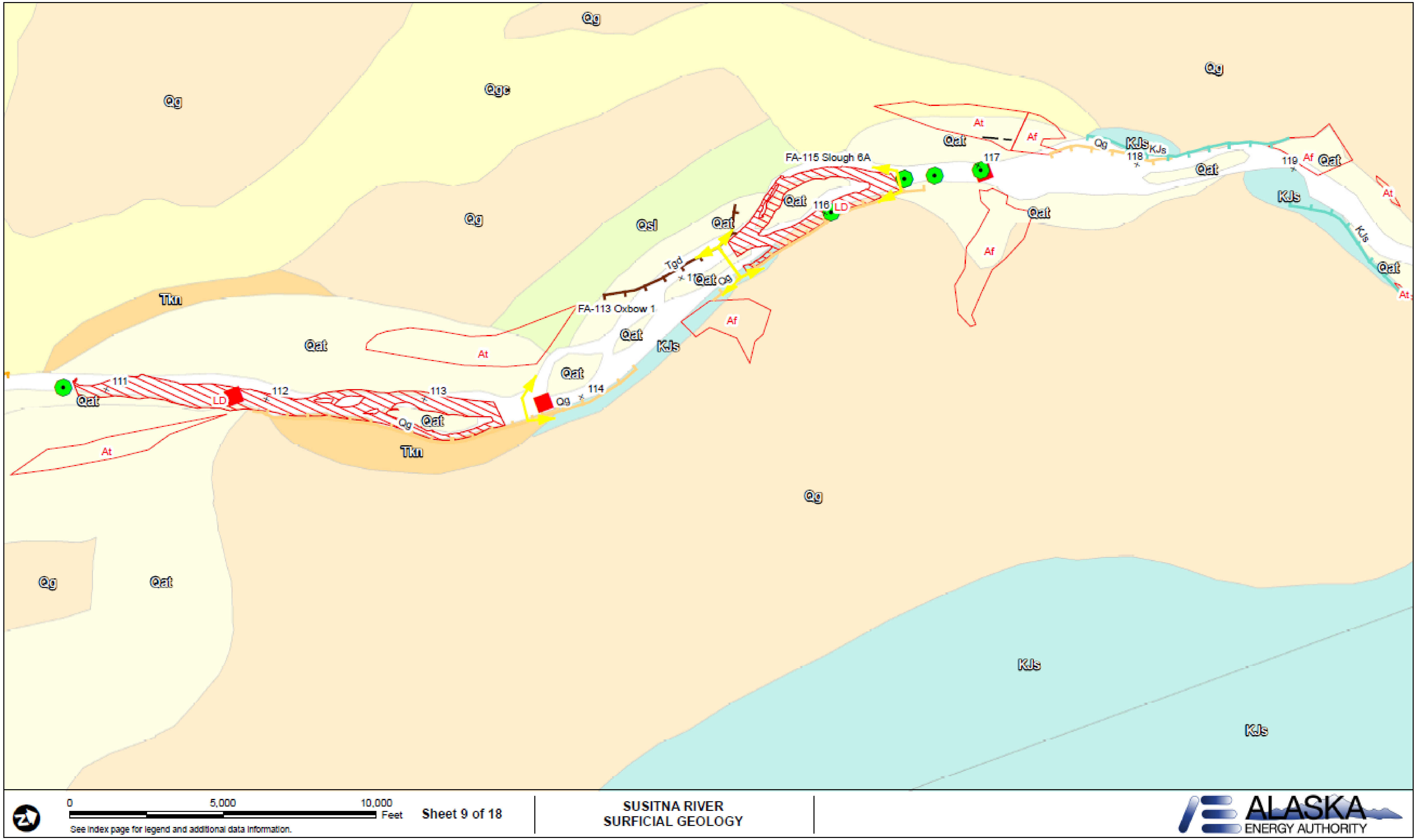

Figure A.1-10: Susitna River Surficial Geology Mapbook Sheet 9.

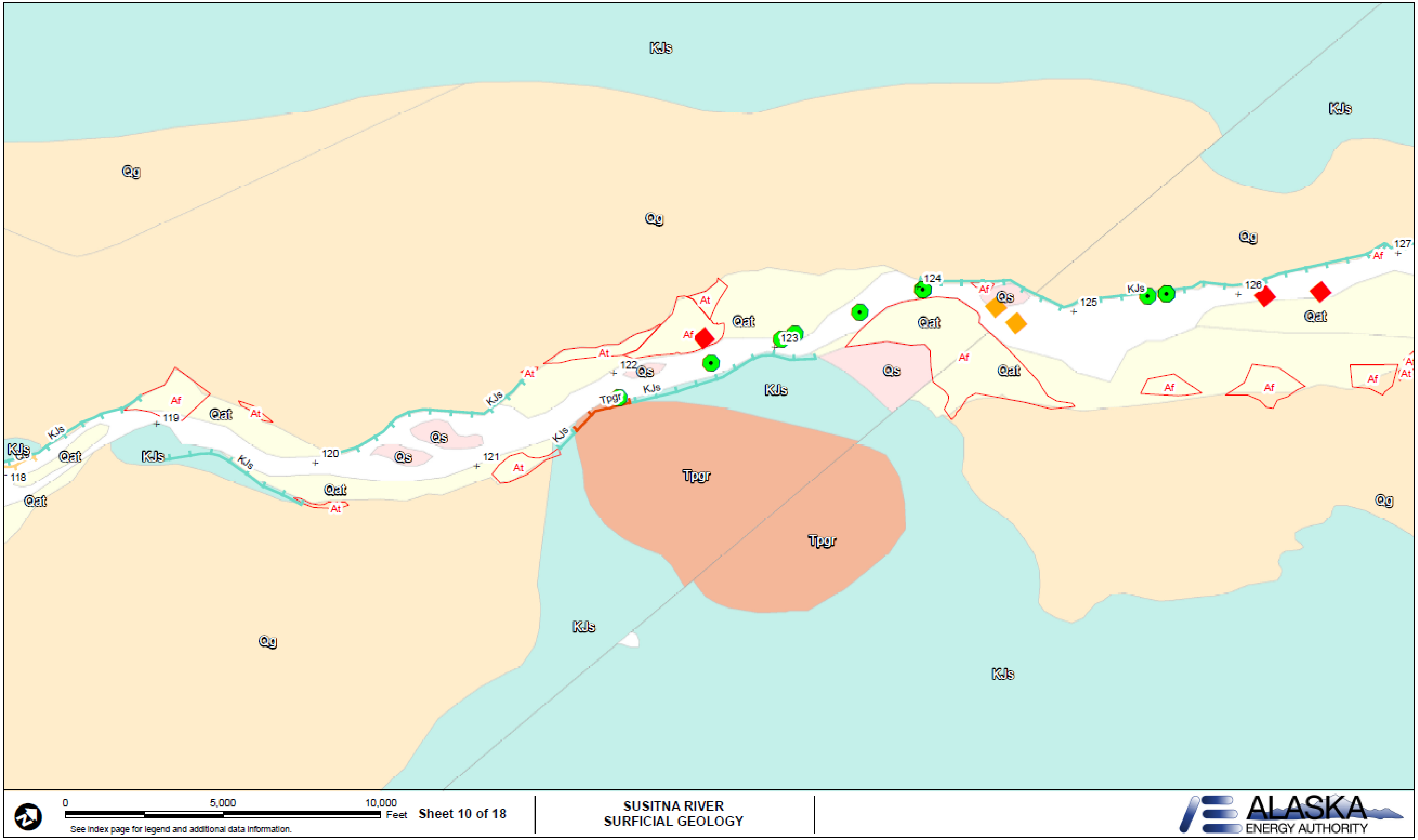

Figure A.1-11: Susitna River Surficial Geology Mapbook Sheet 10.

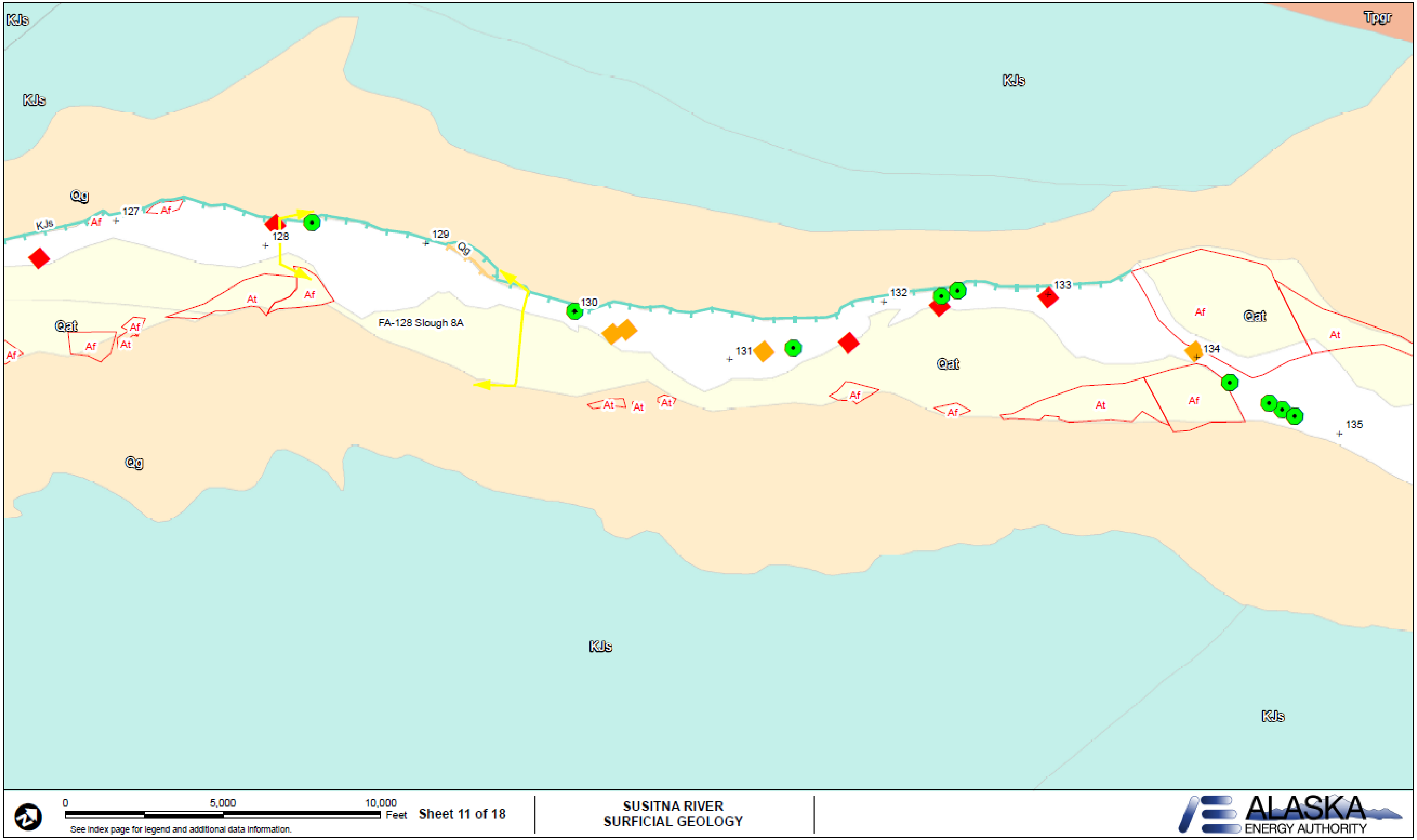

Figure A.1-12: Susitna River Surficial Geology Mapbook Sheet 11.

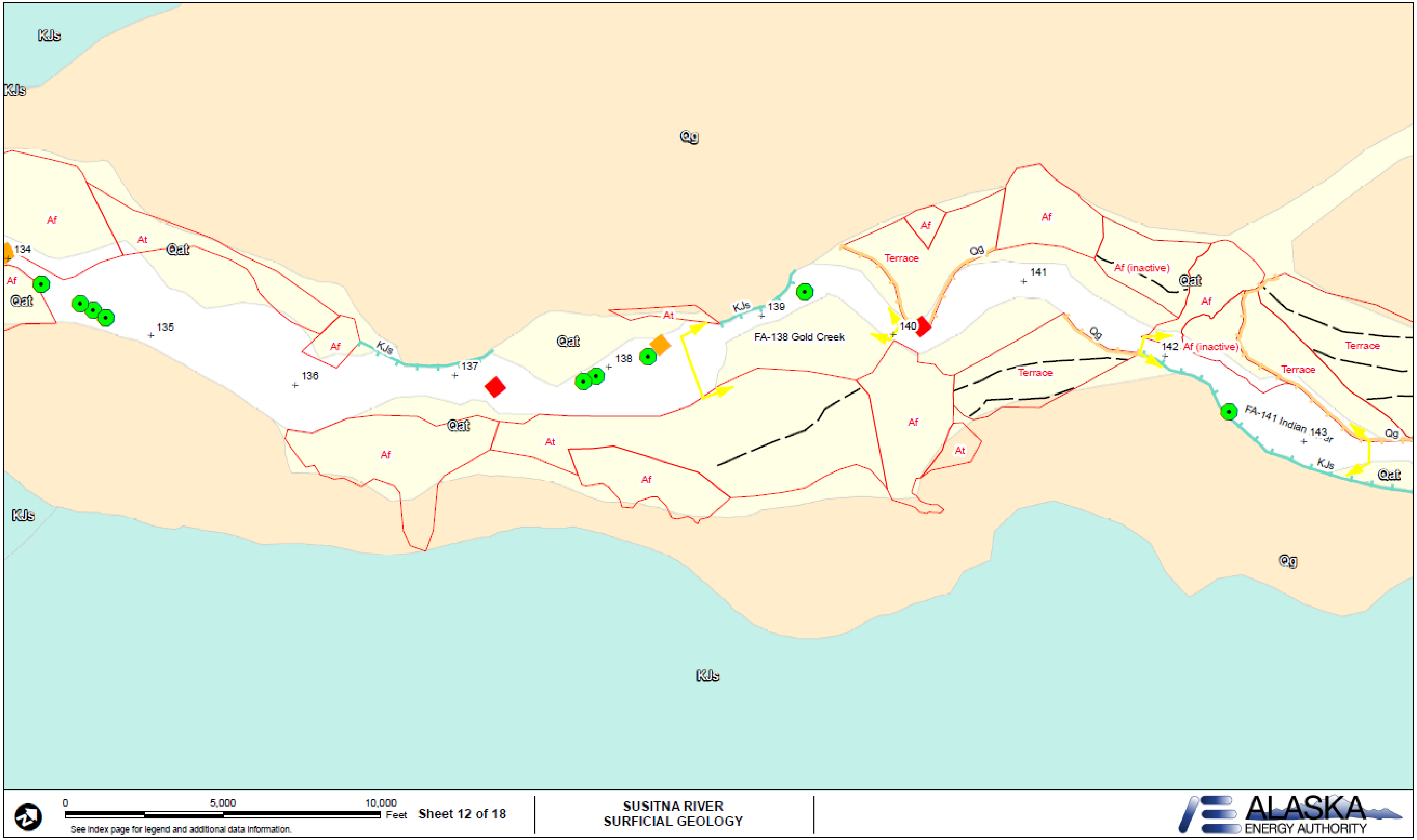

Figure A.1-13: Susitna River Surficial Geology Mapbook Sheet 12.

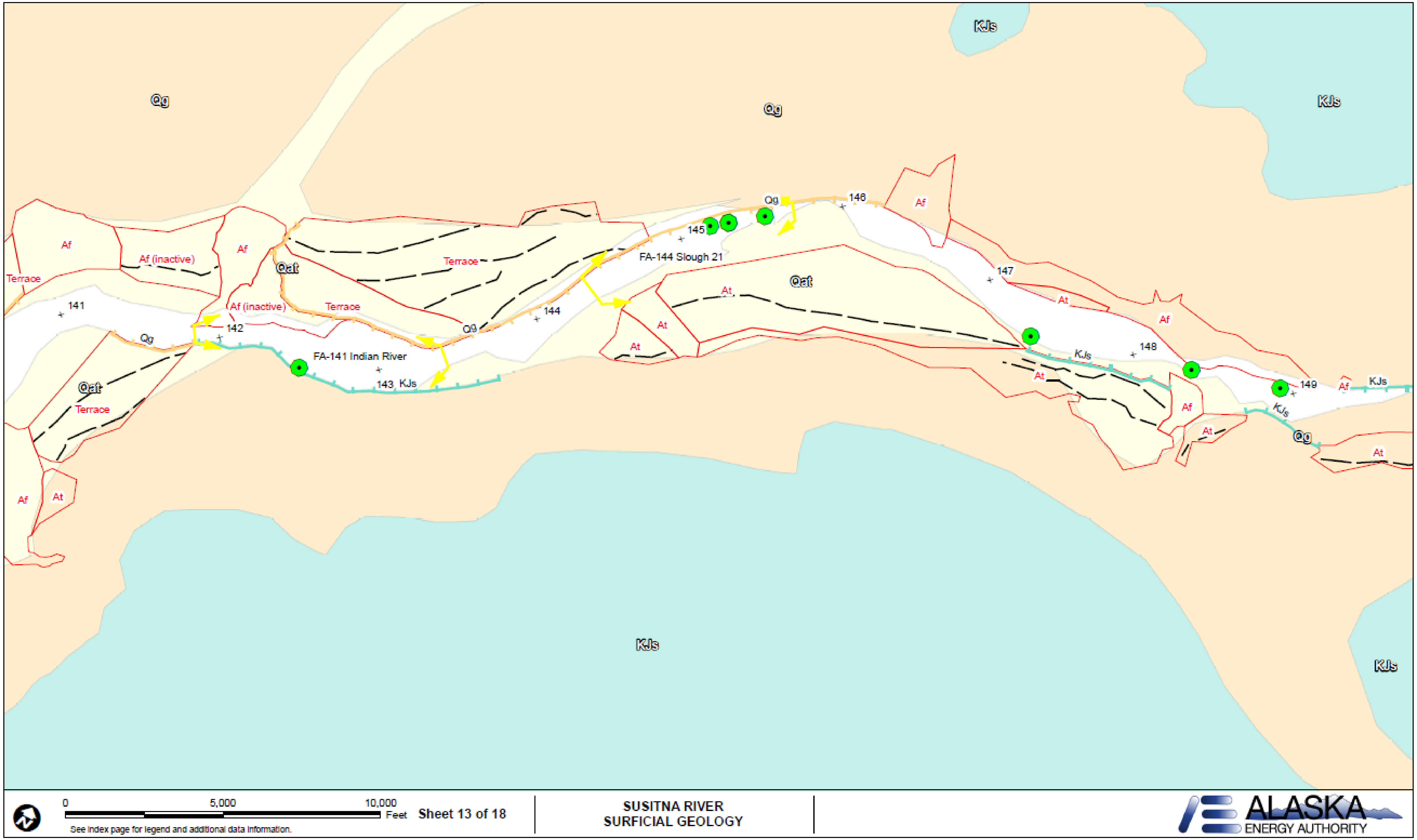

Figure A.1-14: Susitna River Surficial Geology Mapbook Sheet 13.

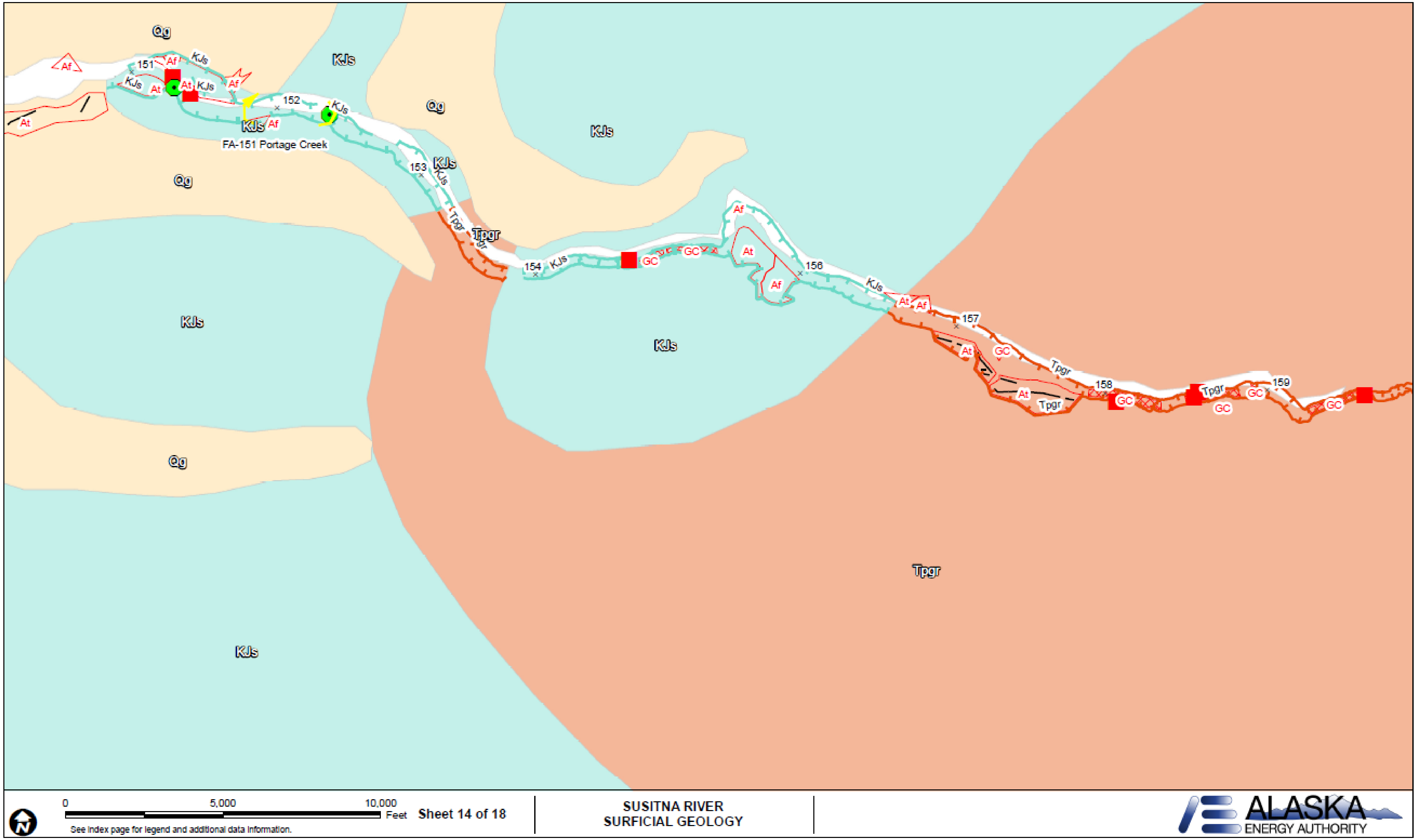

Figure A.1-15: Susitna River Surficial Geology Mapbook Sheet 14.

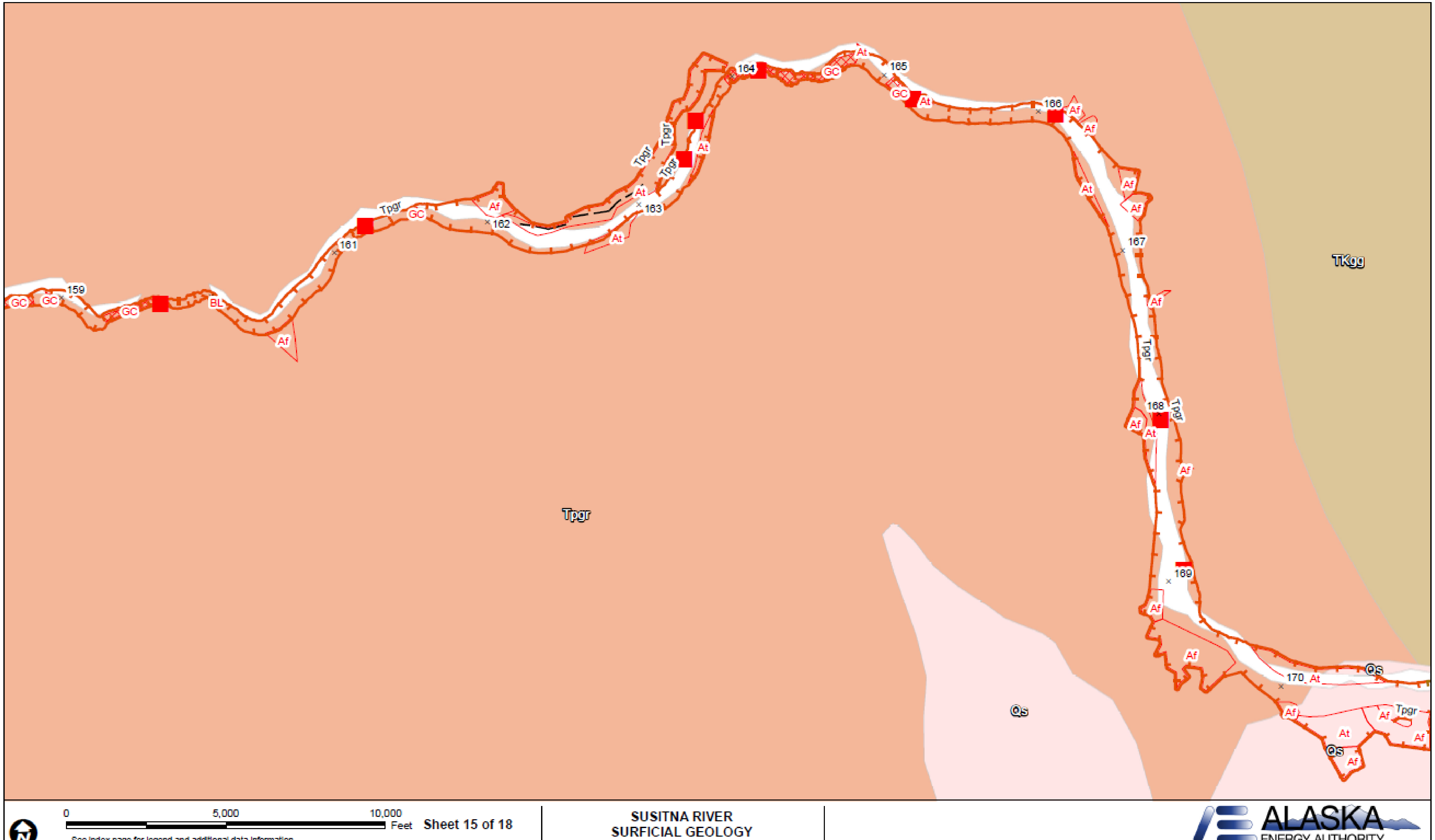

Figure A.1-16: Susitna River Surficial Geology Mapbook Sheet 15.

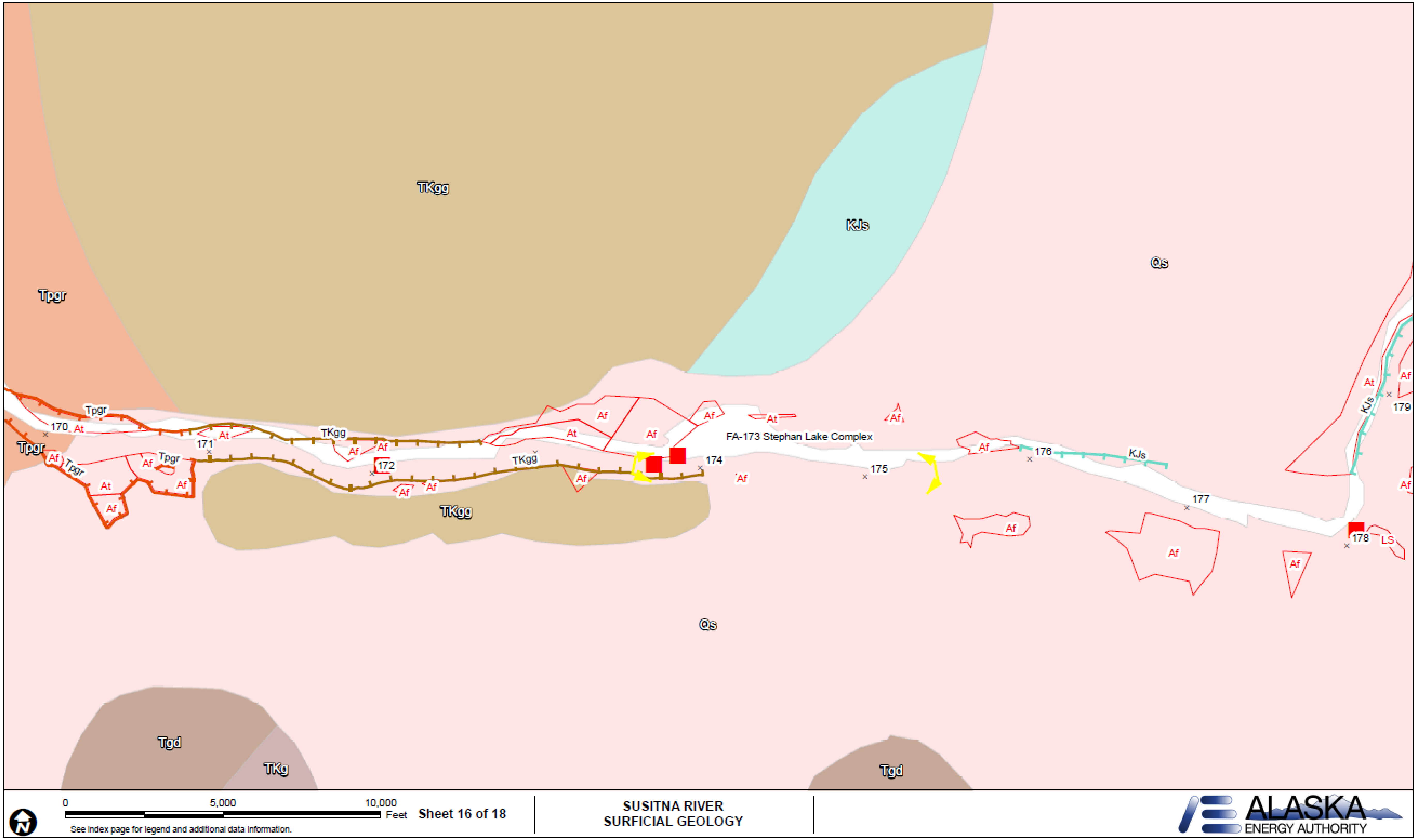

Figure A.1-17: Susitna River Surficial Geology Mapbook Sheet 16.

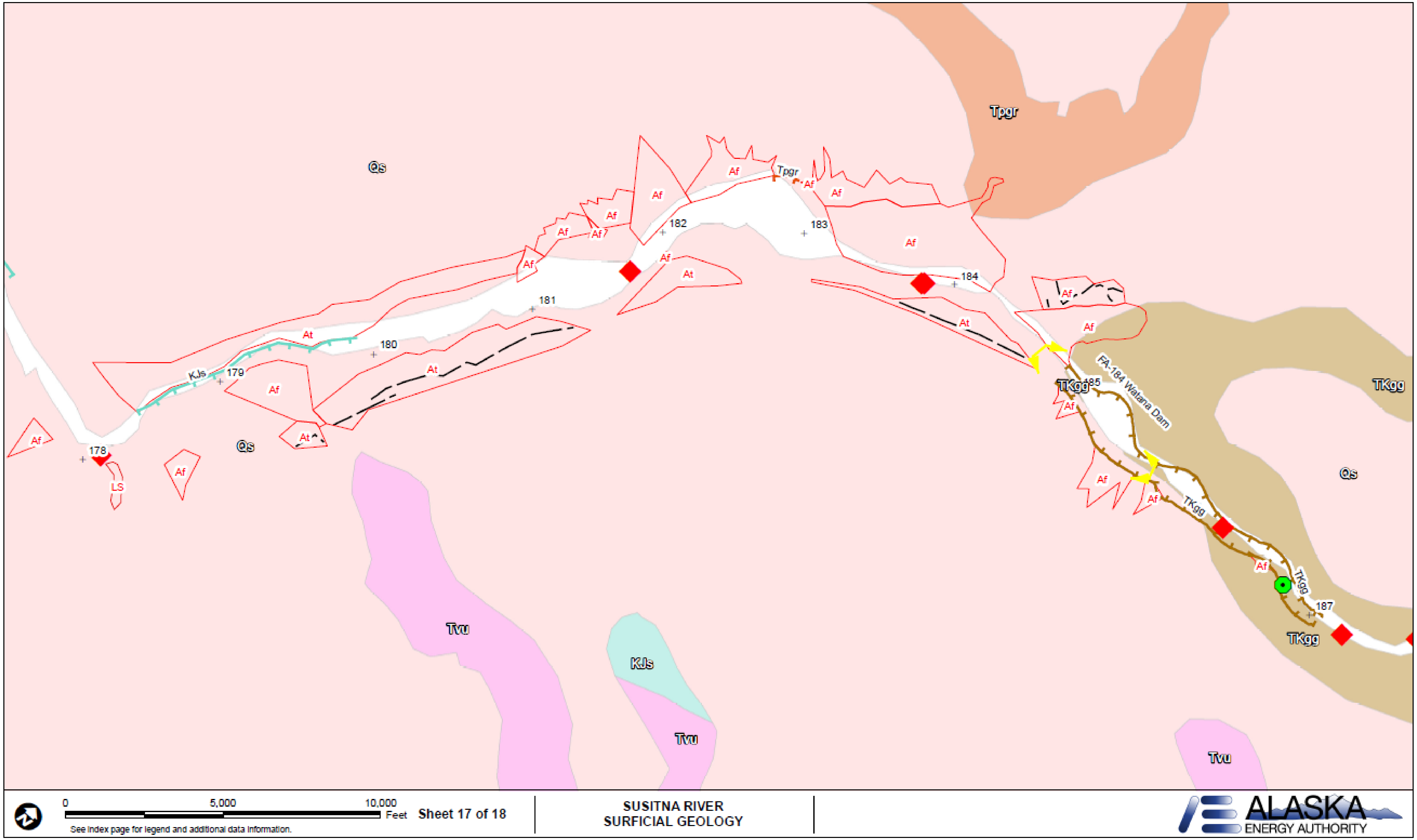

Figure A.1-18: Susitna River Surficial Geology Mapbook Sheet 17.

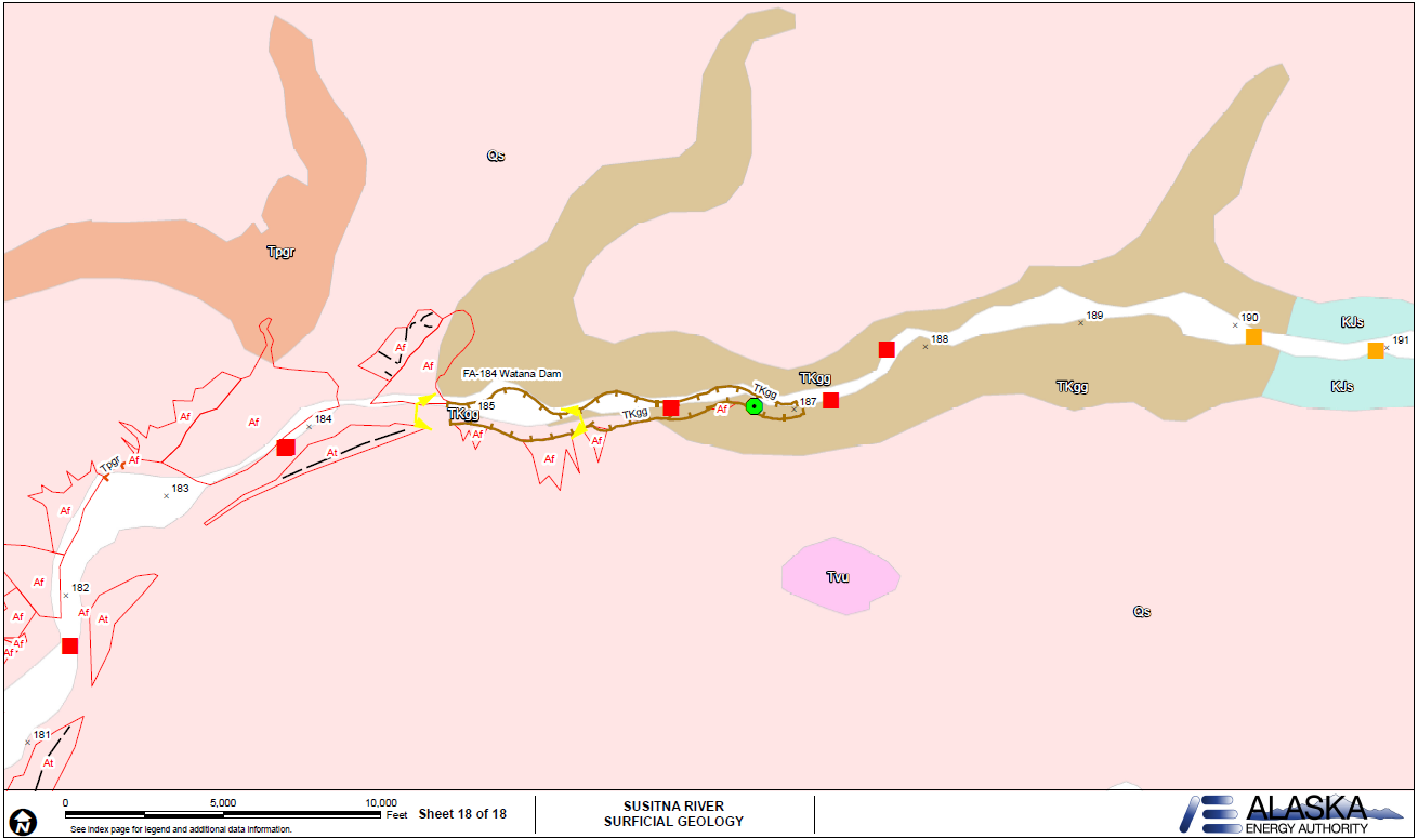

Figure A.1-19: Susitna River Surficial Geology Mapbook Sheet 18.

A.2: GEOMORPHIC SURFACE MAPPING FOR 7 FOCUS AREAS

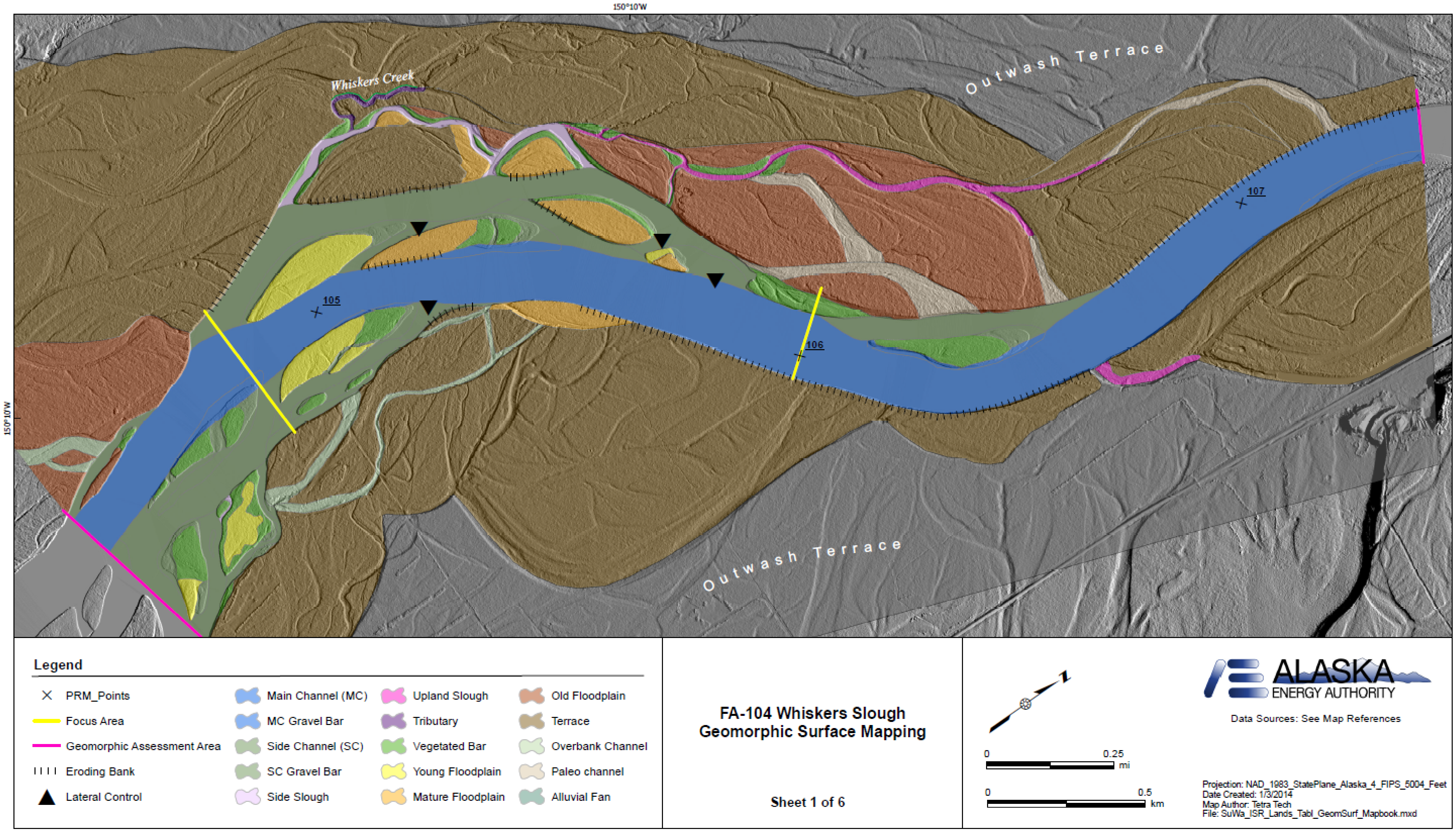

Figure A.2-1: Geomorphic Surface Mapping in FA-104 (Whiskers Slough).

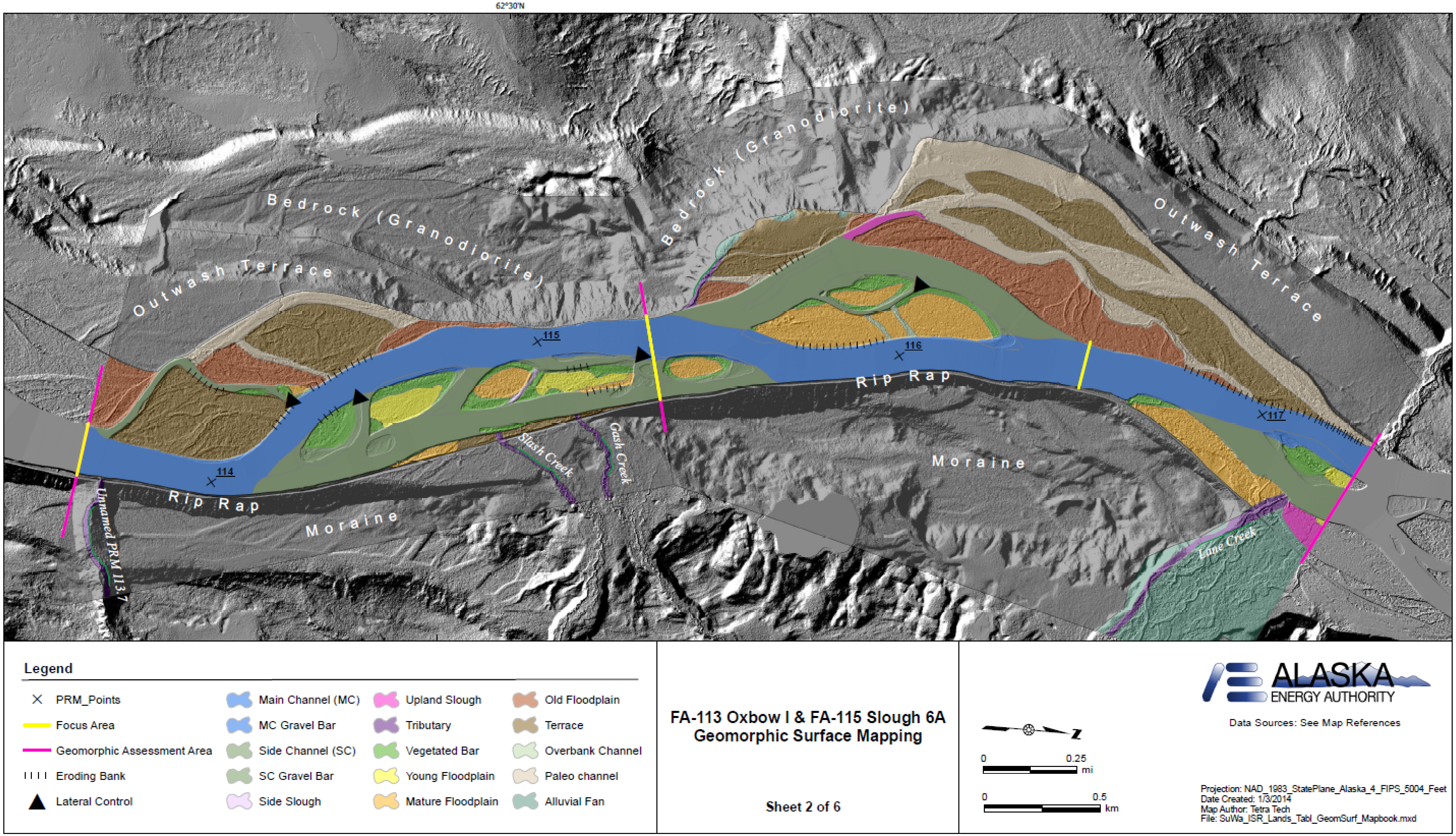

Figure A.2-2: Geomorphic Surface Mapping in FA-113 (Oxbow I) and FA-115 (Slough 6A).

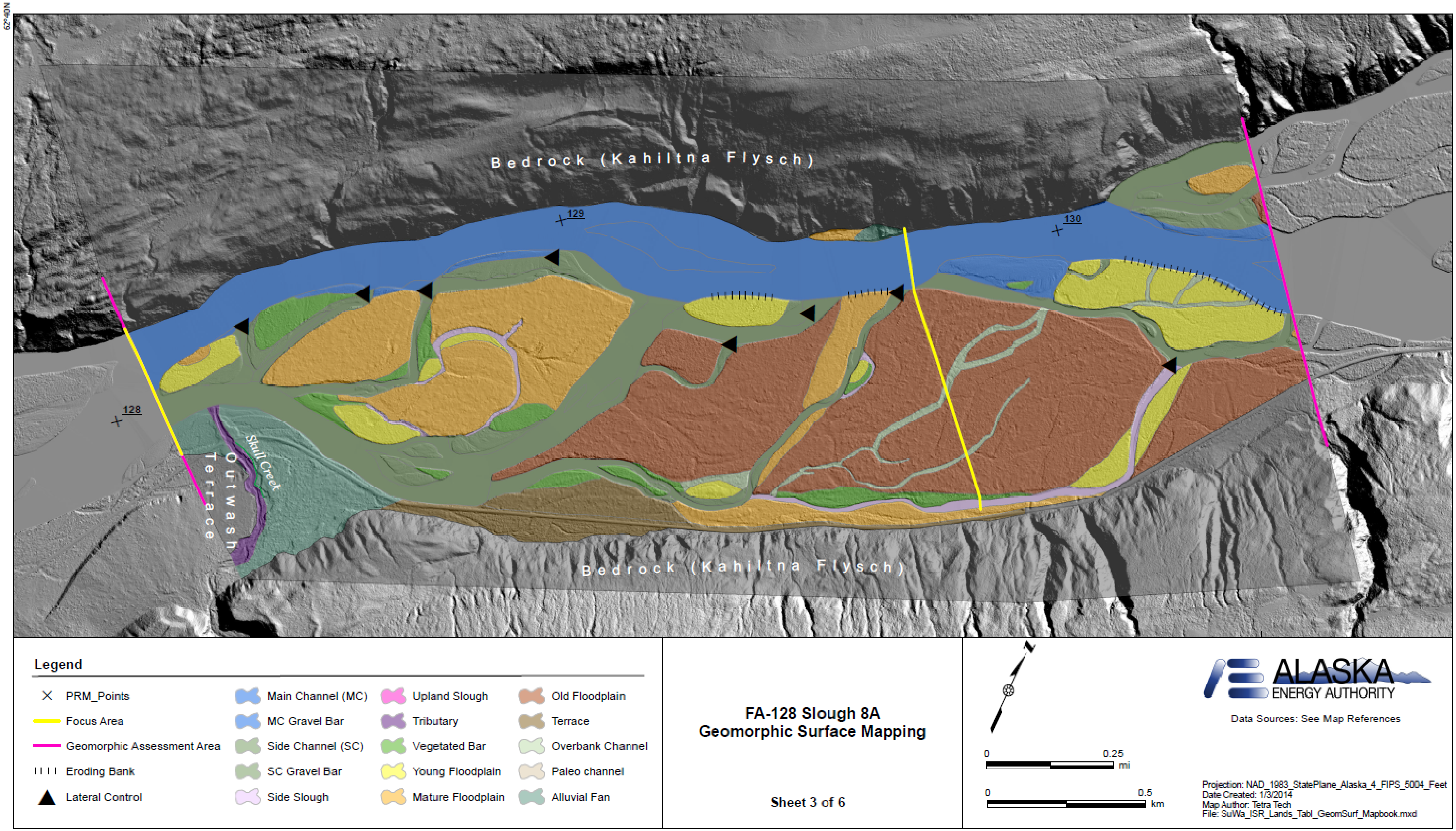

Figure A.2-3: Geomorphic Surface Mapping in FA-128 (Slough 8A).

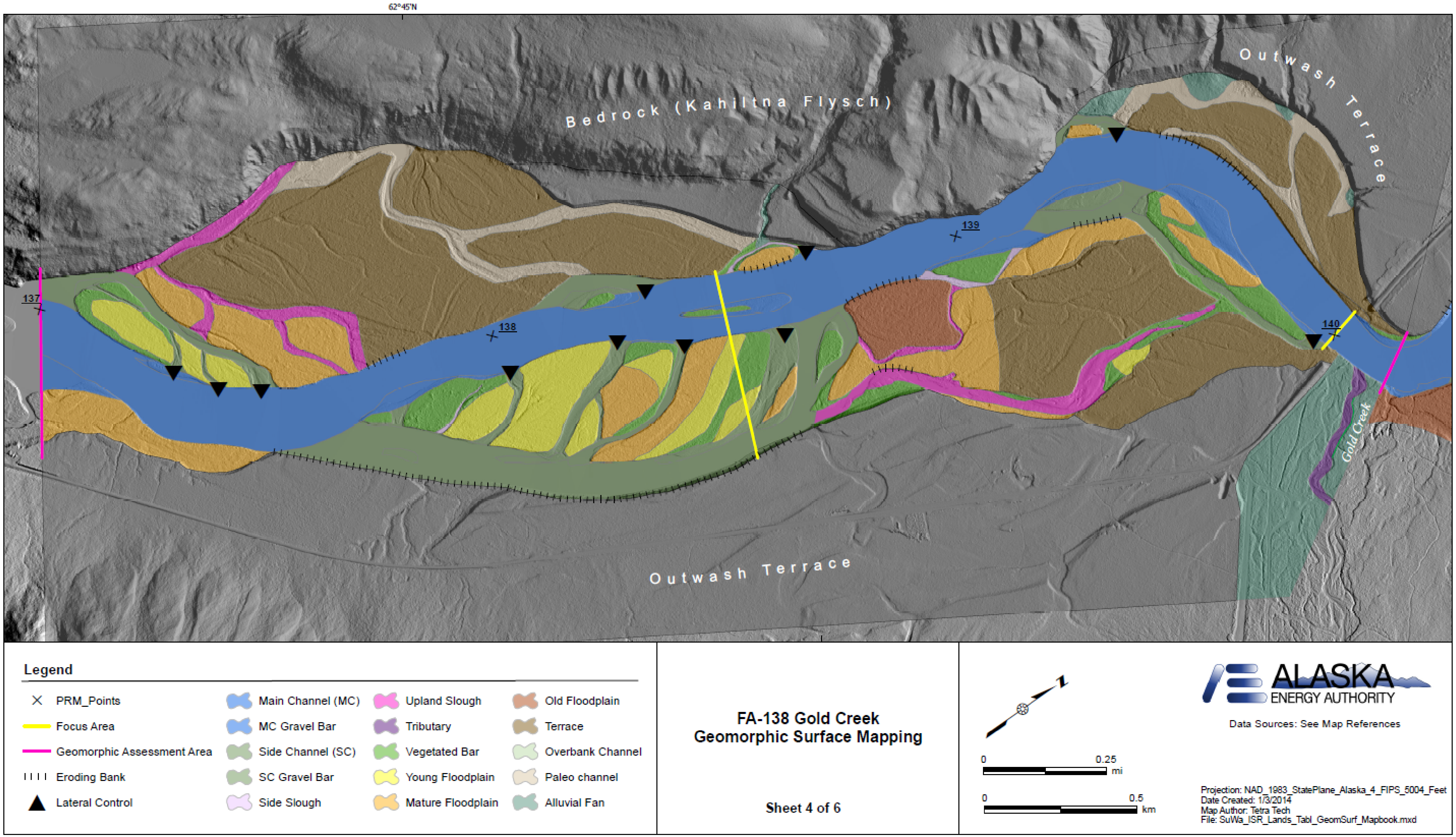

Figure A.2-4: Geomorphic Surface Mapping in FA-138 (Gold Creek).

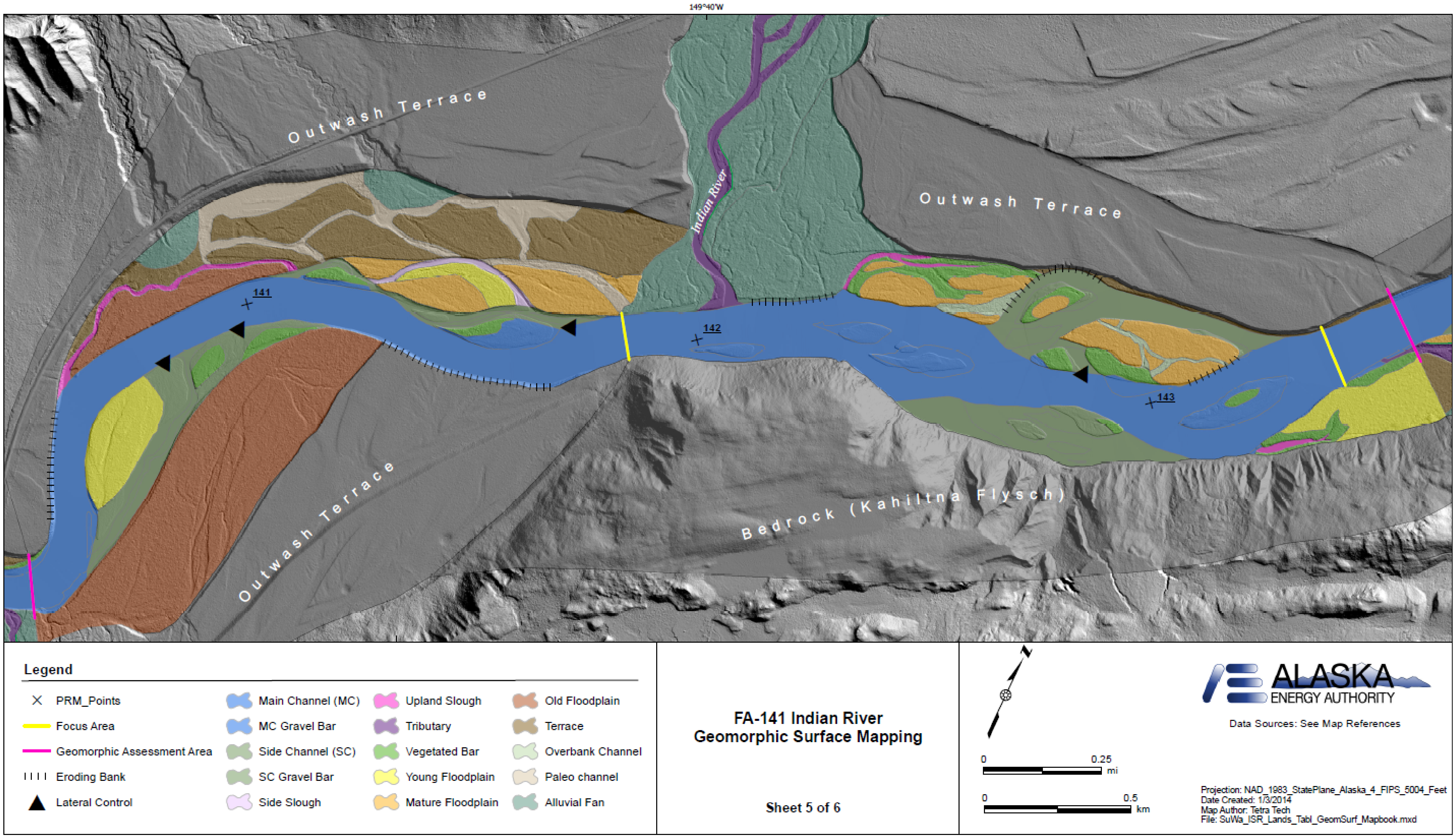

Figure A.2-5: Geomorphic Surface Mapping in FA-141 (Indian River).

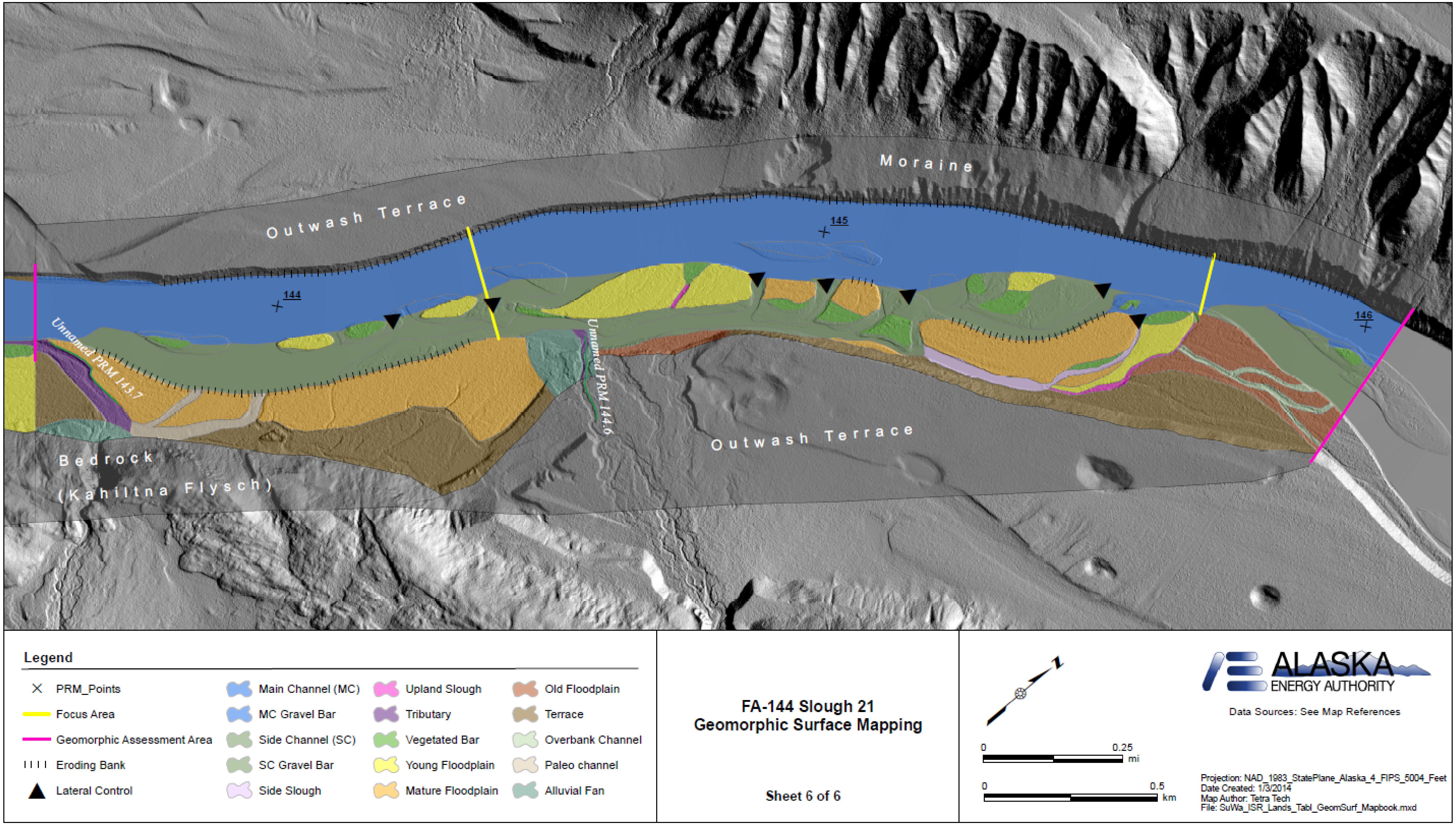

Figure A.2-6: Geomorphic Surface Mapping in FA-144 (Slough 21).

A.3: RATING CURVES FOR 7 FOCUS AREAS

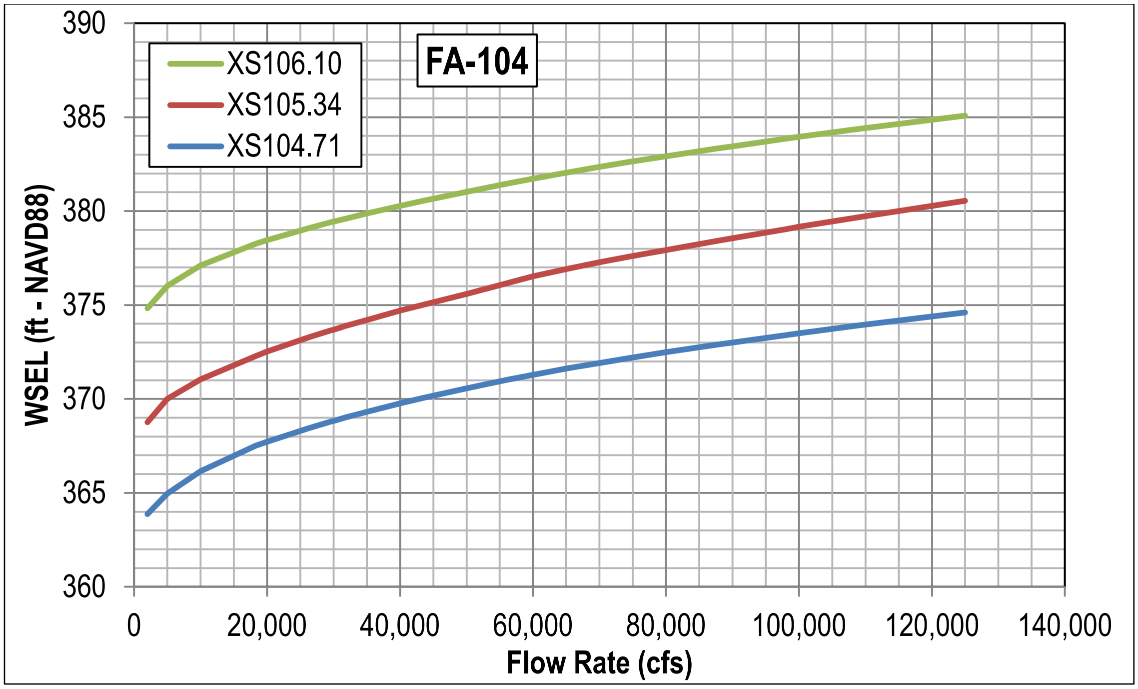

Figure A.3-1: Water surface elevation (ft) versus flow rate (cfs) developed from preliminary 1-D Flow Routing Model for FA-104 Whiskers Slough.

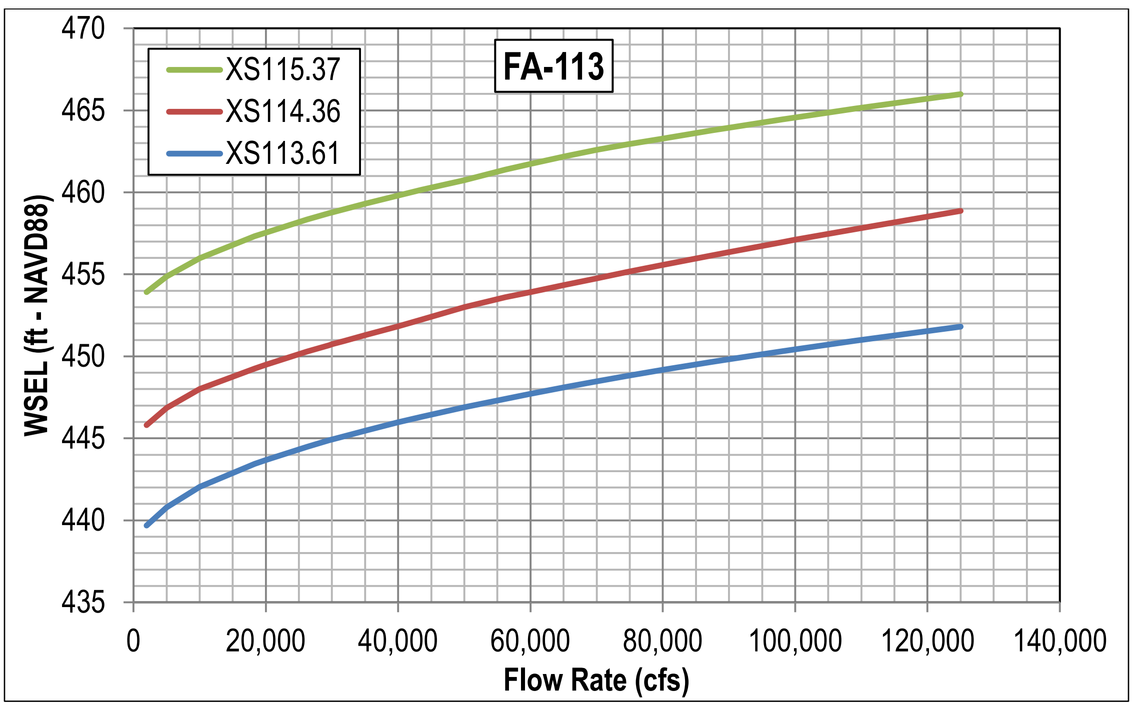

Figure A.3-2: Water surface elevation (ft) versus flow rate (cfs) developed from preliminary 1-D Flow Routing Model for FA-113 Oxbow I.

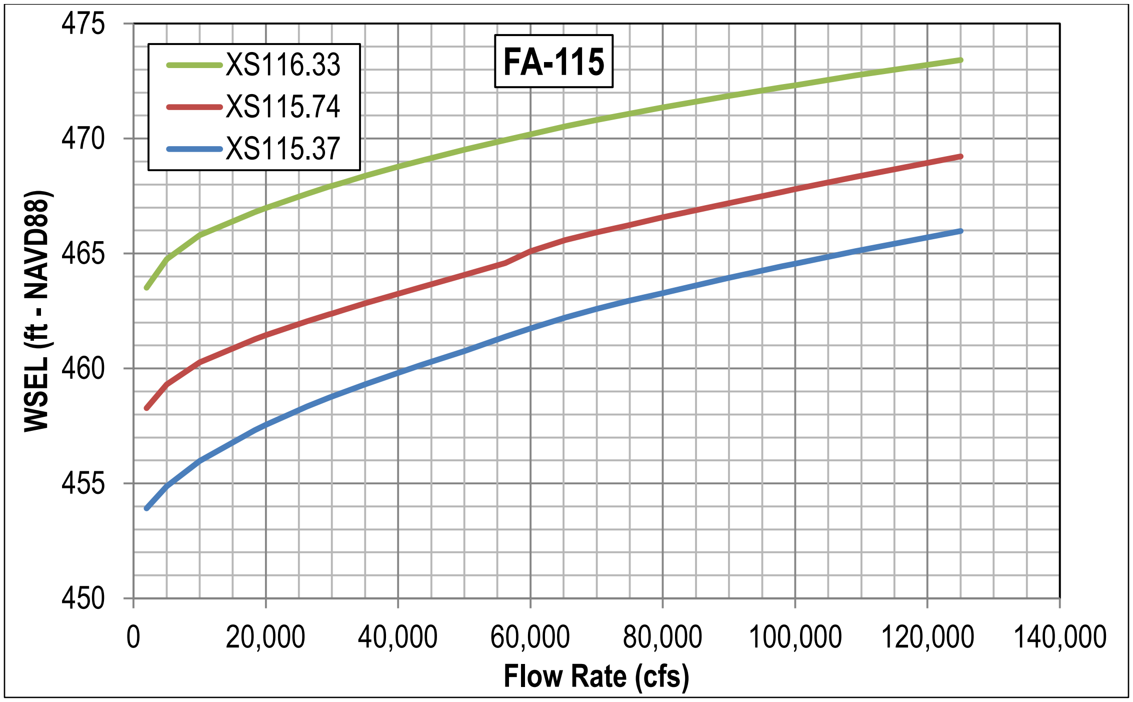

Figure A.3-3: Water surface elevation (ft) versus flow rate (cfs) developed from preliminary 1-D Flow Routing Model for FA-115 Slough 6A.

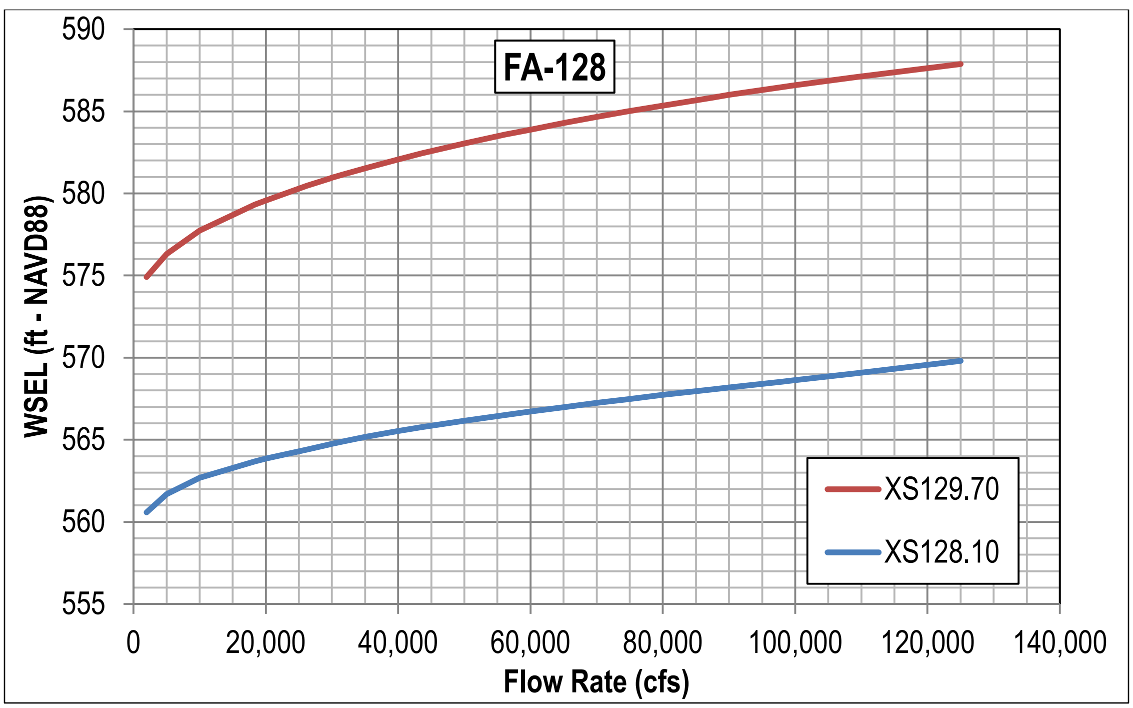

Figure A.3-4: Water surface elevation (ft) versus flow rate (cfs) developed from preliminary 1-D Flow Routing Model for FA-128 Slough 8A.

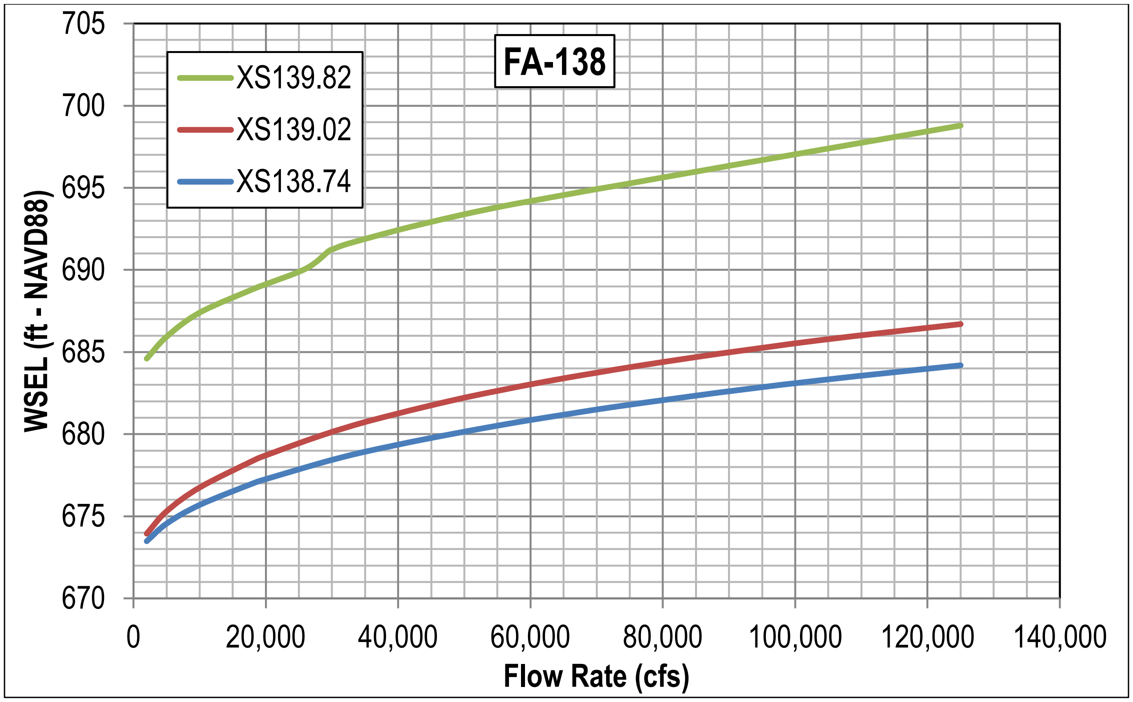

Figure A.3-5: Water surface elevation (ft) versus flow rate (cfs) developed from preliminary 1-D Flow Routing Model for FA-138 Gold Creek.

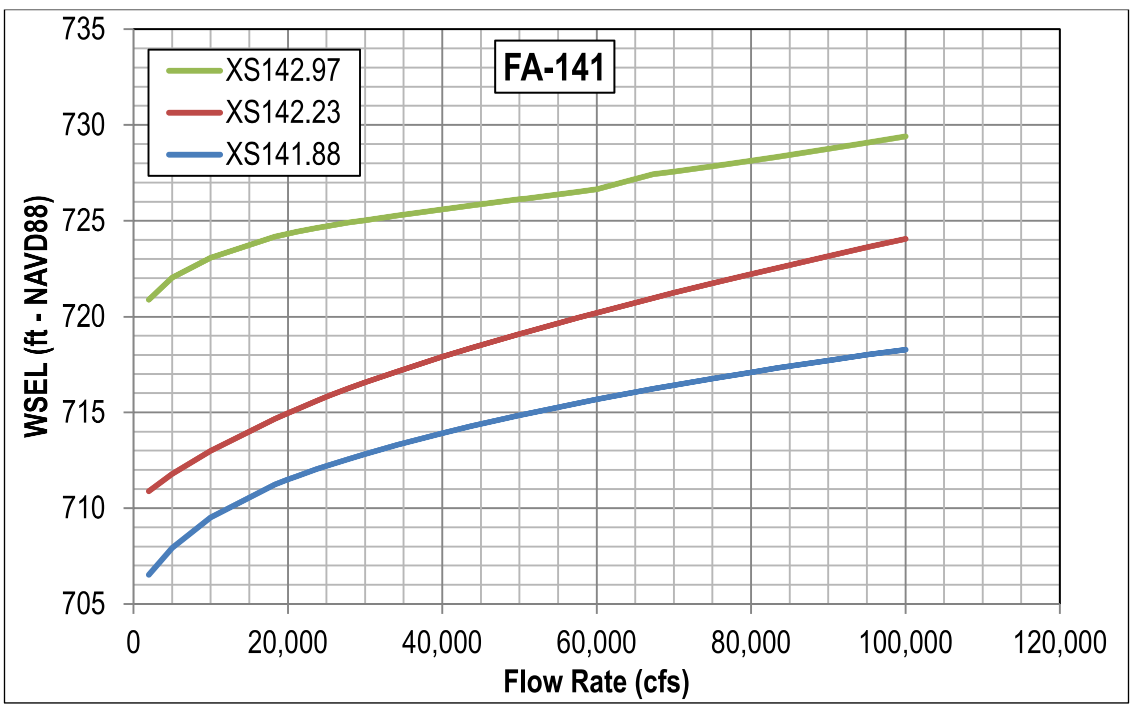

Figure A.3-6: Water surface elevation (ft) versus flow rate (cfs) developed from preliminary 1-D Flow Routing Model for FA-141 Indian River.

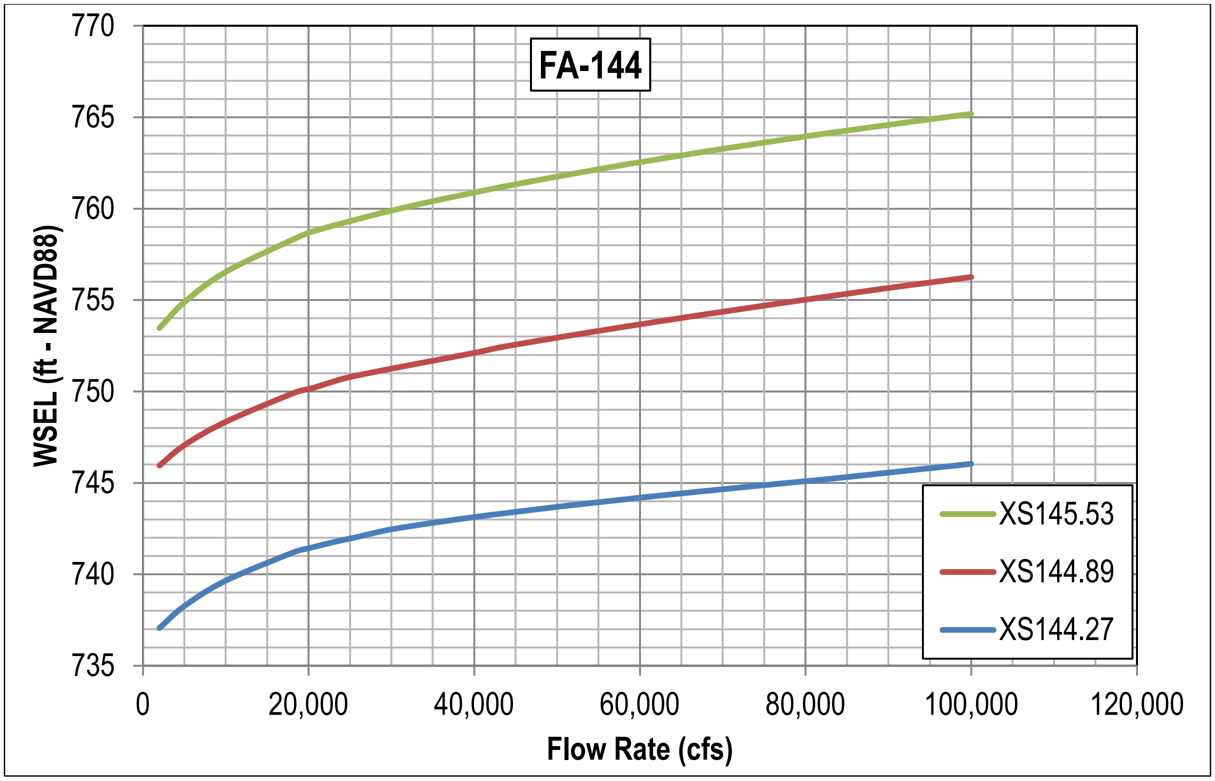

Figure A.3-7: Water surface elevation (ft) versus flow rate (cfs) developed from preliminary 1-D Flow Routing Model for FA-144 Slough 21.

A.4: RECURRENCE INTERVAL PLOTS FOR 7 FOCUS AREAS

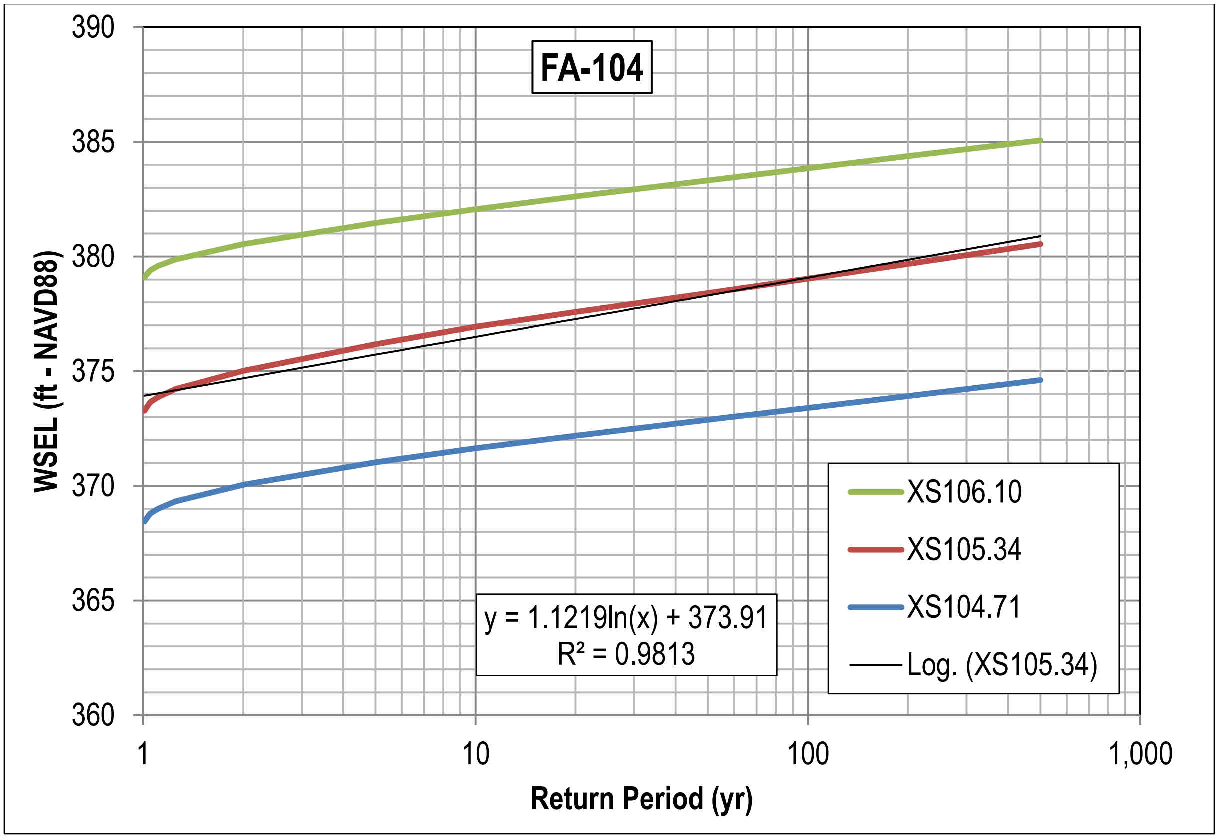

Figure A.4-1: Water surface elevation (ft) versus return period (yr) developed from preliminary 1-D Flow Routing Model for FA-104 Whiskers Slough.

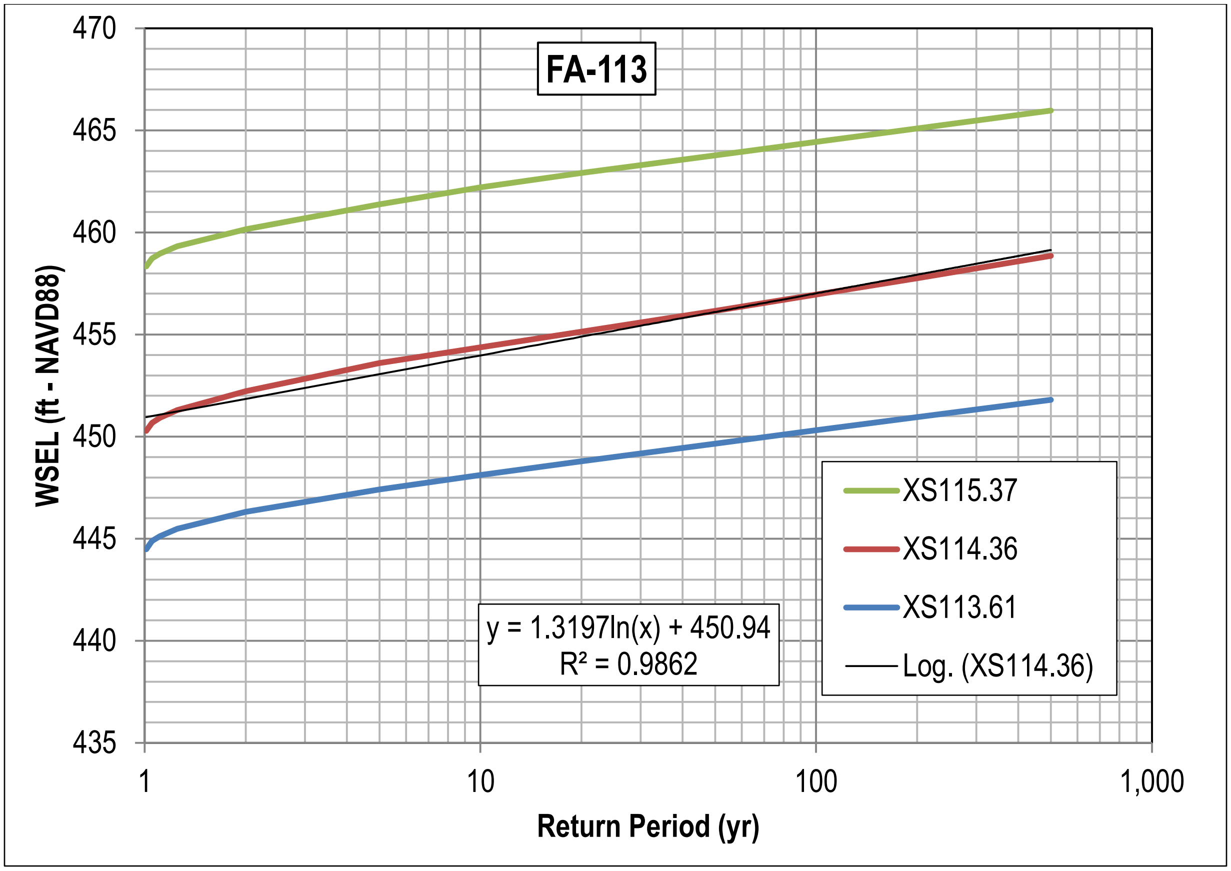

Figure A.4-2: Water surface elevation (ft) versus return period (yr) developed from preliminary 1-D Flow Routing Model for FA-113 Oxbow I.

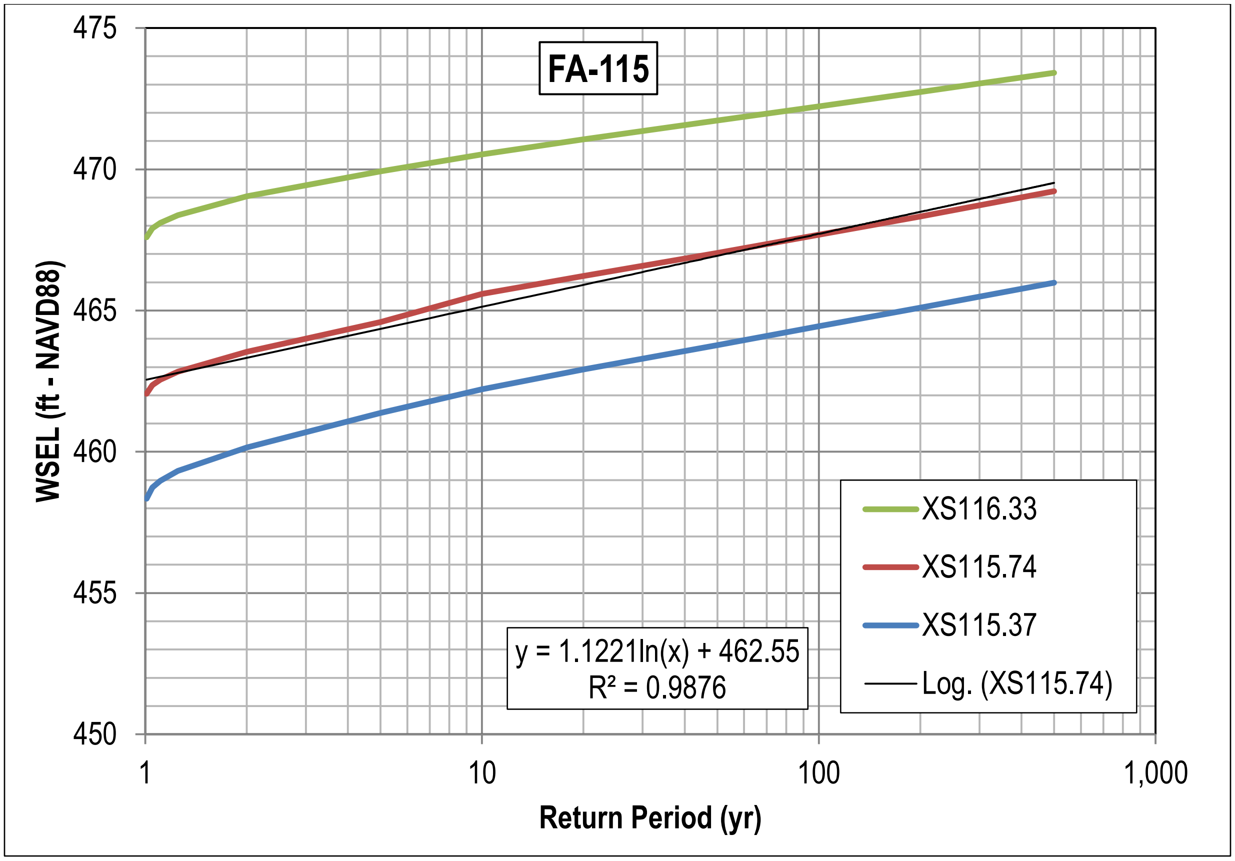

Figure A.4-3: Water surface elevation (ft) versus return period (yr) developed from preliminary 1-D Flow Routing Model for FA-115 Slough 6A.

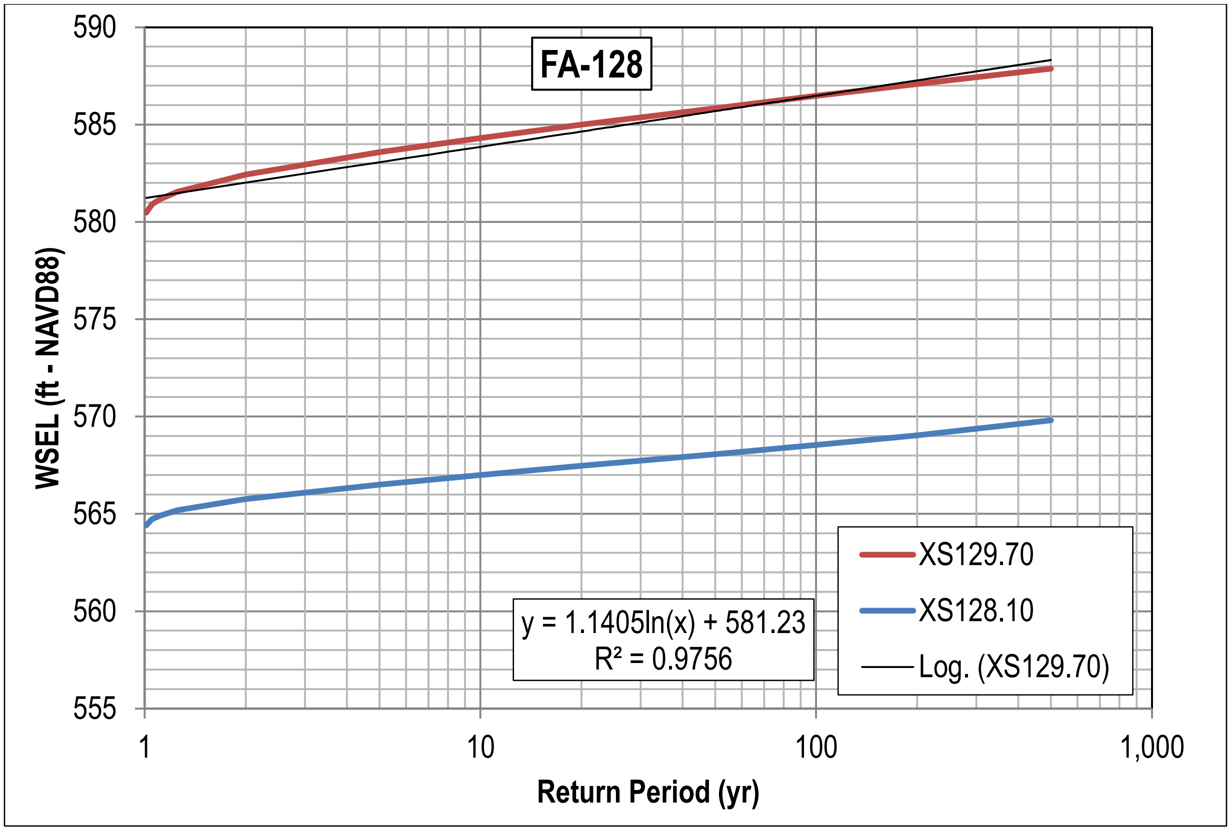

Figure A.4-4: Water surface elevation (ft) versus return period (yr) developed from preliminary 1-D Flow Routing Model for FA-128 Slough 8A.

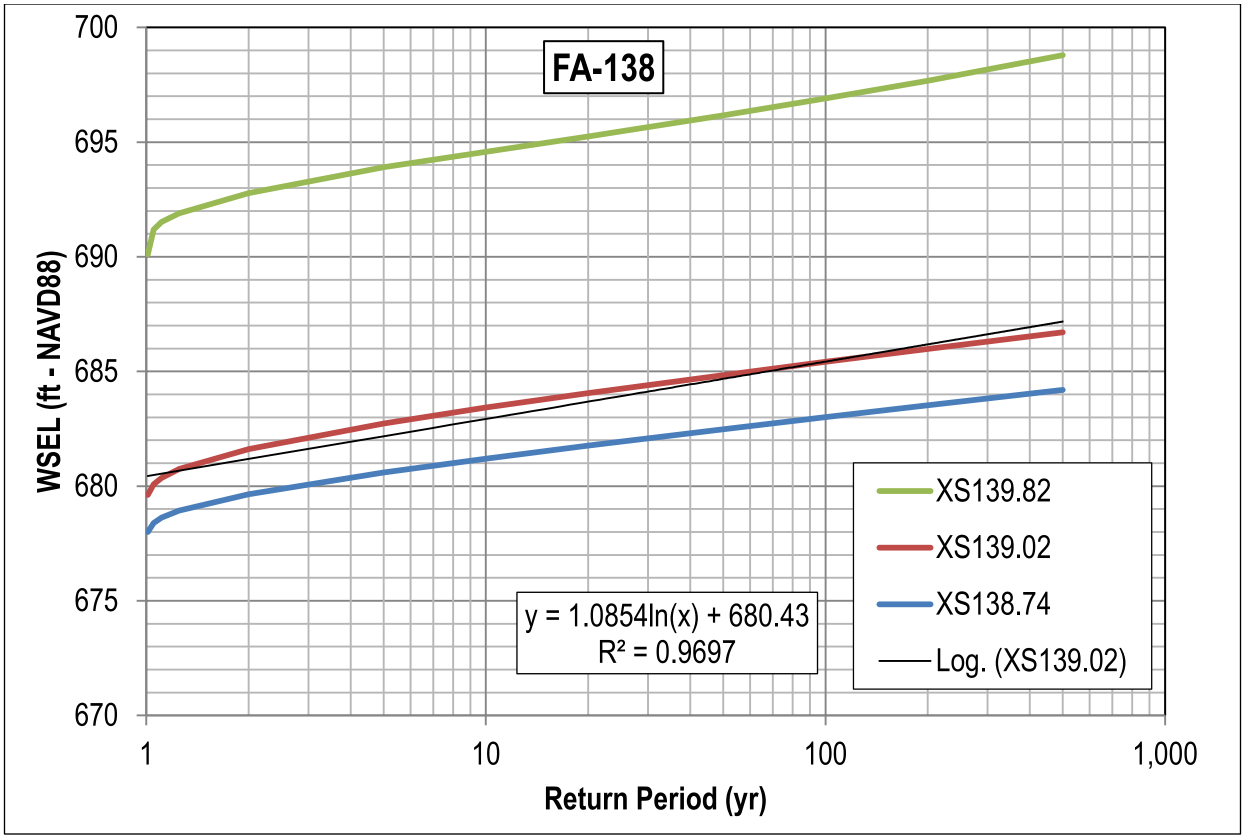

Figure A.4-5: Water surface elevation (ft) versus return period (yr) developed from preliminary 1-D Flow Routing Model for FA-138 Gold Creek.

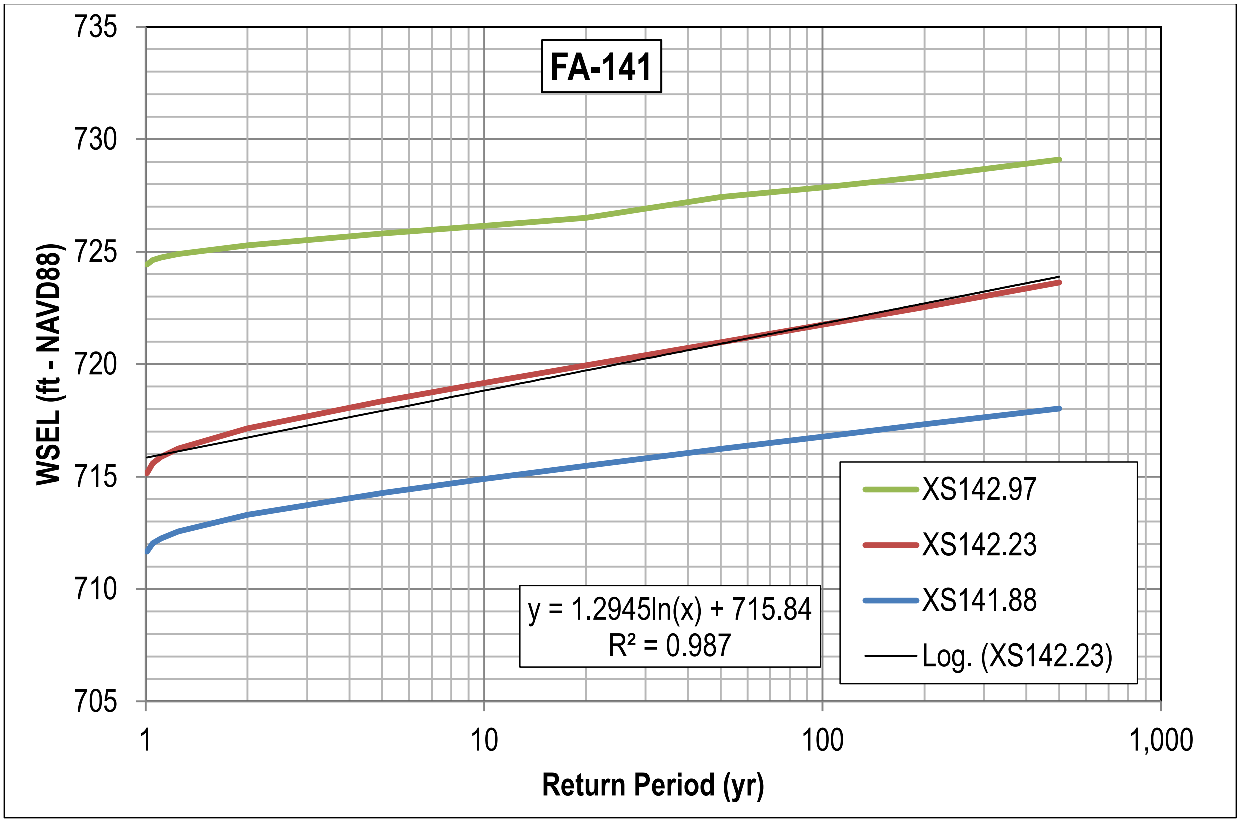

Figure A.4-6: Water surface elevation (ft) versus return period (yr) developed from preliminary 1-D Flow Routing Model for FA-141 Indian River.

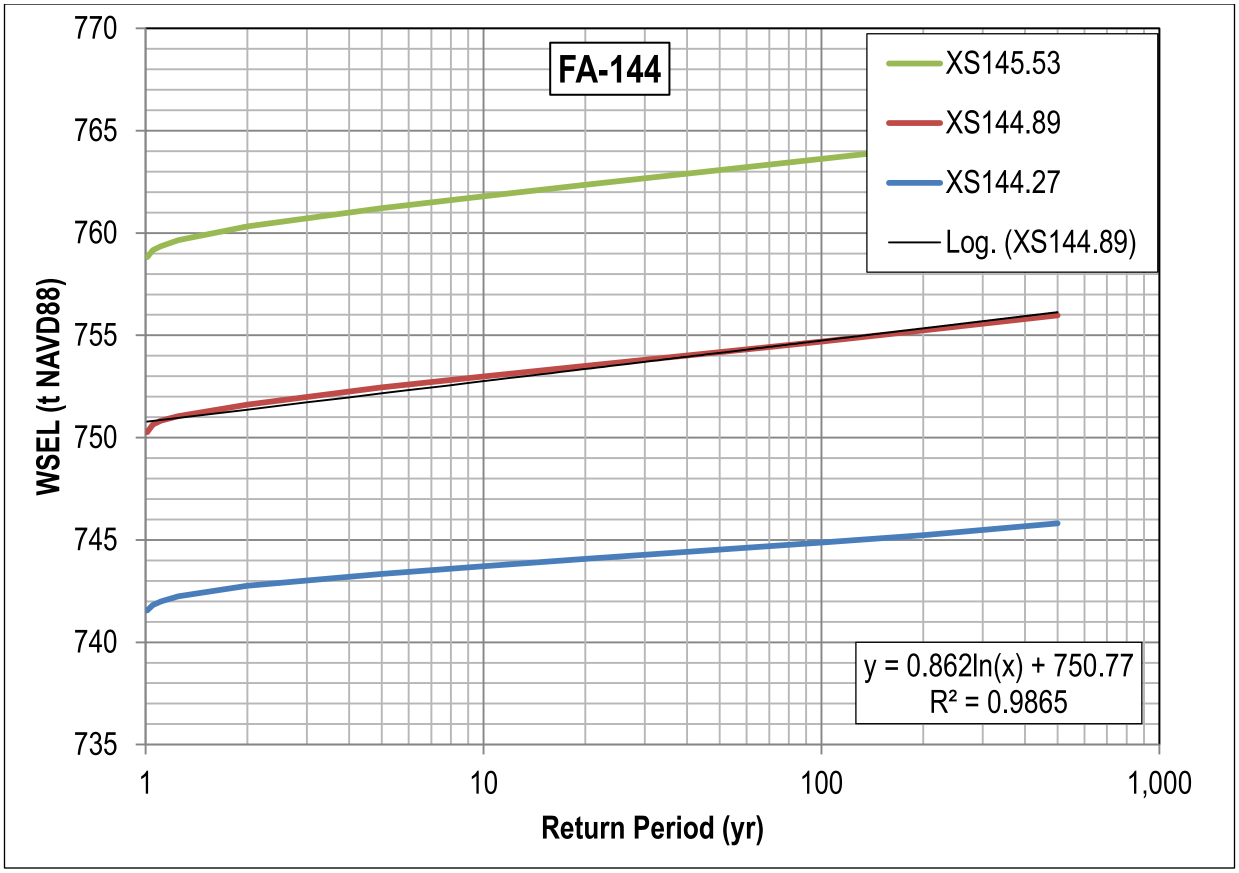

Figure A.4-7: Water surface elevation (ft) versus return period (yr) developed from preliminary 1-D Flow Routing Model for FA-144 Slough 21.

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Geomorphology Study (6.5)

Part A - Appendix B

Study Component 3 - Initial Effective Discharge Analysis for the Mainstem Susitna River and Tributaries

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

June 2014

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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

1. INTRODUCTION

The purpose of this study effort was to make initial estimates of the effective discharge at three different gaged locations along the Susitna River as well as three of its major tributaries. The effective discharge for the pre-Project condition was compared to the Max Load Following OS-1 condition at each of these locations. Estimates of the potential change in effective discharge between historical and post-Project conditions initially represented by Maximum Load Following OS-1 conditions, provides a basis for evaluating whether channel form may change due to the Project, and if so, the likely trajectory and magnitude of the changes. The nature of the change in the effective discharge, and thus, the bankfull channel capacity between the pre-Project and Max Load Following OS-1 scenarios may indicate possible changes in the river's morphology.

The concept of effective discharge, as advanced by Wolman and Miller (1960), relates the frequency and magnitude of various discharges to their ability to do geomorphic work by transporting sediment. They concluded that events of moderate magnitude and frequency transport the most sediment over the long-term, and these flows are the most effective in forming and maintaining the planform and geometry of a channel.

Sediment-transport relationships (sediment load versus discharge rating curves) were developed at three locations on the mainstem Susitna River (Gold Creek, Sunshine, and Susitna Station), and on its three largest tributaries (Chulitna, Talkeetna, and Yentna Rivers). The relationships were applied to the long-term hydrologic conditions represented by the Pre-Project and Maximum Load Following OS-1 scenarios. These sediment transport relationships were used in conjunction with the pre-Project and Maximum Load Following OS-1 hydrologic conditions to develop the effective discharge estimates.

The Reconnaissance-level Geomorphic and Aquatic Habitat Assessment of Project Effects on Lower River Channel study component of RSP Study 6.5 includes, among other objectives, a preliminary evaluation of the relative magnitude of changes in the sediment regime associated the Susitna-Watana Hydroelectric Project. This appendix builds on the technical memorandum titled Development of Sediment-Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a). The purpose of the memo is to summarize the effective discharge analysis performed as part of the Sediment Load Comparison section of the Sediment Transport Assessment. This analysis was based on the pre- 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 the six streamflow gages listed above using 61 years of extended hydrologic records developed by the USGS (2012) for the period from WY1950 through WY2010. The Maximum Load Following OS-1 hydrology used for the post-Project analysis is a simulated flow record developed with the operations and initial flow routing models (MWH 2012) for the same 61-year period as the pre-Project record.

The main components of the effective discharge analysis include the following:

- Application of selected sediment transport relationships to both the pre-Project and Maximum Load Following OS-1 flow records to estimate effective discharge of the Susitna River and its main tributaries.

- Comparison of the estimated effective discharge magnitudes between the pre-Project and Maximum Load Following OS-1 scenarios.

2. STUDY OBJECTIVES

The overall objective of this memorandum is to make initial estimates of the effective discharge for pre-Project conditions and the magnitude of the changes in effective discharge that will occur under post-Project conditions represented by Maximum Load Following OS-1 hydrologic conditions.

Alluvial rivers adjust their shape in response to flows that transport sediment. Numerous authors have attempted to relate the effective discharge to the concepts of dominant discharge, channel-forming discharge, and bankfull discharge, and it is often assumed that these discharges are roughly equivalent and correspond to approximately the mean annual flood peak (Benson and Thomas 1966; Pickup 1976; Pickup and Warner 1976; Andrews 1980, 1986; Nolan et al. 1987; Andrews and Nankervis 1995). Quantification of the range of flows that transport the most sediment provides useful information to assess the current state of adjustment of the channel and to evaluate the potential effects of altered discharge and sediment delivery on channel behavior. Andrews (1980) defined the effective discharge as *"the increment of discharge that transports the largest fraction of the annual sediment load over a period of years."* The effective discharge is an indicator of the ability of a river to transport sediment under different hydrologic conditions. This analysis will provide insight into the potential effect of the Maximum Load Following OS-1 condition on the morphology of the Susitna River in the post-Project scenario.

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) in the flow extension study (USGS 2012). 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 near Susitna Station and the Susitna River at Sunshine gages. 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 mainstem gages and three primary tributary gages located downstream of the Watana dam-site PRM 187.1 (Figure 3-1) were used to characterize the sediment-transport regime under the 61-year hydrology record for each portion of the reach, as follows:

- Mainstem Gages
  - Middle River mainstem: Susitna River at Gold Creek Gage (15292000) and Susitna River near Talkeetna Gage (15292100)[1]
  - Lower River mainstem below Three Rivers Confluence: Susitna River at Sunshine Gage (15292780)
  - Lower River mainstem below Yentna River: Susitna River at Susitna Station Gage (15294350)
- Primary Tributary Gages
  - Tributary supply to Three Rivers Confluence: Chulitna River near Talkeetna Gage (15292400) and the Chulitna River below Canyon near Talkeetna gage (15292410)[1]
  - Tributary supply to Three Rivers Confluence: 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 3-2). 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.

4. METHODS

As discussed above, 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 (Chulitna, Talkeetna, and Yentna Rivers) (Tetra Tech 2013a). These relationships were applied to the long-term hydrologic conditions represented by the pre-Project and Maximum Load Following OS-1 scenarios to estimate the sediment load for each day in the 61-

[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.

year flow record. The flows were then divided into equal interval bins, the total sediment transported during flows within each bin was summed and the bin with the greatest total amount of sediment load was identified as the effective discharge.

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 size classes of sediment; wash load, sand load, and gravel load (Tetra Tech 2013a). This effective discharge investigation analyzed the bed material load (a combination of the sand and gravel load) as well as just the gravel load by itself because of the importance of gravel to forming channel geometry. Although various investigators have used only the suspended sediment load and the total sediment load to compute the effective discharge, the bed material load should generally be used when evaluating the linkage between sediment loads and channel morphology because it is the bed material load that has the most influence on the morphology of the channel (Schumm 1963; Biedenharn et al. 2000).

This section describes the methods used to develop the effective discharge at the six USGS gaging stations for both the pre-Project and Maximum Load Following OS-1 extended flow records.

4.1. Variances from Study Plan

In addition to Gold Creek and Sunshine, the effective discharge was computed for the mainstem Susitna River at Susitna Station for both the pre-Project and Maximum Load Following OS-1 conditions. Susitna Station was not identified in the RSP as one of the locations for calculation of effective discharge. It was added as a result of the decision to extend the 1-D bed evolution model downstream to PRM 29.9. The effective discharge was also computed for the three main tributaries to the Susitna River at the Chulitna, Talkeetna, and Yentna Rivers for the pre-Project hydrologic condition (since the hydrologic conditions do not change for the three tributaries, calculation of post-Project effective discharge was not necessary). Though Tsusena Creek is listed in the RSP as a location for effective discharge calculation, because a sufficient period of record was not available, the effective discharge was not calculated at Susitna River below Tsusena Creek. Also, in accordance with the relevant literature, equal arithmetic bins and not logarithmic bins were used in the effective discharge analysis (Biedenharn et al. 2000).

4.2. Sediment Load Rating Curves

A technical memorandum, entitled, Development of Sediment-Transport Relationships and an Initial Sediment Balance for the Middle and Lower Susitna River Segments (Tetra Tech 2013a) summarizes the methods used to develop the 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)

New data, collected since 1985, were added to the Knott et al. (1987) data set. Other studies have documented the potential for bias in suspended load rating curves due to scatter in the relationship between sediment concentration or load and flow (Walling 1977a). Bias is also introduced in performing linear least-squares regressions using logarithmically-transformed data and then back-transforming the predicted sediment loads to their arithmetic values (Walling 1977b; Thomas 1985; Ferguson 1986, Koch and Smillie 1986). The Minimum Variance Unbiased Estimator (MVUE) bias correction was used to remove bias in the rating curves associated with transforming the data (Tetra Tech 2013a). 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.

4.3. Effective Discharge

The analysis was performed by dividing the full range of flows at each location into equal arithmetic flow classes or bins (Biedenharn et al. 2000). A discharge increment of 2,000 cfs was used to define the bins for the Gold Creek gage on the mainstem and the Chulitna and Talkeetna Rivers gages. A bin size of 4,000 cfs was used for the Sunshine gage on the mainstem and the Yentna River, and a bin size of 8,000 cfs was used for the Susitna Station gage. Data input for this analysis included the daily sediment loads estimated from the application of the relevant rating curves (Table 4.1-1) and the USGS 61-year extended hydrologic mean daily record at each gage. The bed-material transport over the long-term was determined by summing the individual sediment-transport rates within each flow class. The effective discharge is the flow increment that transports the largest quantity of sediment. Effective discharges were determined for both the pre-Project and Maximum Load Following OS-1 conditions. Differences in the effective discharge between the two scenarios provide an indication that the morphology of the channel may change.

5. RESULTS

This section summarizes the effective discharge results developed using the methods described in Section 4.

5.1. Pre-Project

Under pre-Project conditions, the estimated effective discharge at the Gold Creek/near Talkeetna gage, the most upstream location on the mainstem of the Susitna River for which sufficient data are available, is approximately 27,000 cfs (Figure 5.1-1). This estimate is based on 43 equal arithmetic bins of 2,000 cfs. The estimate for the effective discharge at the Sunshine gage on the Susitna River (Figure 5.1-2) was approximately 66,000 cfs. The Susitna Station gage on the

Susitna River, the most downstream gage, had the largest range of flows; thus, 37 8,000 cfs bins were used for the analysis. The effective discharge estimate at the Susitna Station gage (Figure 5.1-3) was the largest at approximately 124,000 cfs. This is almost twice as large at the Sunshine gage and nearly five times as large as the result at Gold Creek.

The analysis for the Chulitna and Talkeetna River used 37 and 32 2,000-cfs bins, respectively. The effective discharge at the Chulitna River gage (Figure 5.1-4) was just over twice as large (23,000 cfs) as the effective discharge at the Talkeetna River gage (11,000 cfs) (Figure 5.1-5), though the load for the Talkeetna River at 9,000 cfs was nearly the same indicating an effective discharge between 9,000 and 11,000 cfs. Bin sizes of 4,000 cfs were used for the Yentna River, the largest downstream tributary, and for the Sunshine gage on the Susitna River. The Yentna River analysis used 36 bins based on its observed range of flows while the Sunshine gage used 41 bins with a slightly larger range of flows. The effective discharge estimate at the Yentna River (Figure 5.1-6) was approximately 50,000 cfs.

A tabulation of the effective discharge results under pre-Project conditions at each of the three mainstem gages and three tributary gages are provided in Tables 5.1-1 and 5.1-2, respectively.

5.2. Maximum Load Following Operation Scenario 1

For the Maximum Load Following OS-1 condition, the bin size for each gage was held the same to facilitate the comparison between the two hydrologic conditions. The estimated effective discharge at the Gold Creek/near Talkeetna gage is approximately 9,000 cfs (Figure 5.2-1). This estimate is based on 25 equal arithmetic bins of 2,000 cfs each. The estimate at Gold Creek may not take into account the limited supply of sediment in the Middle River after the closure of Watana Dam. The second peak shown in Figure 5.2-1, 23,000 cfs, may be a more realistic estimate. The analysis of the Sunshine gage on the Susitna River used 32 4,000-cfs bins and yielded an estimate of the effective discharge of approximately 46,000 cfs (Figure 5.2-2). The Susitna Station gage on the Susitna River again used 37 8,000-cfs bins. The effective discharge estimate at the Susitna Station gage (Figure 5.2-3) was again the largest overall at approximately 108,000 cfs. This is more than twice as large in magnitude in comparison to the gage at Sunshine and nearly twelve times as large as the result at Gold Creek. A tabulation of the effective discharge results under Maximum Load Following OS-1 conditions at each of the three mainstem gages is provided in Table 5.2-1.

6. DISCUSSION

The effective discharge analyses presented in the previous sections provide an initial comparison of the change in the range of flows that transport the most sediment between the pre-Project and Maximum Load Following OS-1 conditions. This gives insight into the potential effects of the dam on channel form in the mainstem of the Susitna River.

As discussed in Tetra Tech (2013a), the dam would likely cut off approximately 90 percent of the silt/clay supply and essentially all of the sand-and-gravel supply to the head of the Middle River. The effects on all components of the sediment load would diminish in the downstream direction due to contributions from the tributaries and entrainment of material that is currently stored in the channel. This is evident in the change in the magnitude of the effective discharge between the pre-Project and Maximum Load Following OS-1 scenarios. Gold Creek, located in the Middle River Segment, displays a greater reduction in the effective discharge on a percentage basis of its total range of flows if the lower peak is used, though this appears to be unlikely considering the available sediment supply. In contrast, Susitna Station, the most downstream gage and farthest from the dam site, shows a smaller relative change.

Gold Creek shows a decrease of approximately 18,000 cfs as the estimated effective discharge dropped from 27,000 to 9,000 cfs from the pre-Project to the Maximum Load Following OS-1 conditions (Figure 6.1-1). This equates to a roughly 67-percent decrease. However, Figure 6.1-1 indicates that this estimate of effective discharge may be low. The use of the rating curves to analyze the effective discharge assumes a sufficient supply of sediment. The dam may trap at least 90 percent of the silt/clay supply and essentially all of the sand-and-gravel supply. Tetra Tech (2013a) indicates that the supply of sand and gravel below the dam may be 213,000 tons/year and the transport capacity is 326,000 tons/year. Therefore, the greatest transport may occur for a higher discharge than is indicated by Figure 6.1-1. The second peak (23,000 cfs) in the Gold Creek effective discharge curve (Figure 6.1-1) appears to be a more representative value for the reduced effective discharge in the Maximum Load Following OS-1 scenario. This would equate to a reduction of 4,000 cfs (approximately 15 percent).

At the Sunshine gage, the effective discharge decreases from 66,000 cfs under pre-Project conditions to 46,000 cfs under the Maximum Load Following OS-1 conditions (Figure 6.1-2). This equates to a reduction in effective discharge of 20,000 cfs (30 percent). Although the sand supply to the upstream end of the Middle River will be essentially eliminated under post-Project conditions, the Chulitna River supplies a very large quantity of sand and gravel to the mainstem; thus, the effective discharge estimate at Sunshine appears to be reasonable.

At Susitna Station, the estimated effective discharge decreases from 124,000 cfs under pre-Project conditions to 108,000 cfs under Maximum Load Following OS-1 conditions (Figure 6.1-3). This equates to a reduction in effective discharge of 16,000 cfs (13 percent). Based on the available data, 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 potential Project effects on the sand load can be estimated by directly integrating the sand-load rating curves over the Project conditions flow record.

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 (Tetra Tech 2013a), the local tributaries likely supply a significant amount of gravel to the river, and the response rate of upstream changes in supply may progress downstream relatively slowly compared to the sand.

The bed-material load is the sum of the sand load (carried primarily in suspension as well as in the bed load) and the gravel load (carried primarily in the bed load). In this system, the bed-material load is predominantly sand. The results of this analysis are influenced heavily by the sand load moving through the system, and are thus, representative of the sand load. A separate analysis, using the same methods described in Section 4, was completed separating out the sediment loads by size fraction and analyzing the gravel load separately (Figures 6.2-1 through 6.2-4). Table 6.1-1 summarizes the effective discharge results for gravel conditions and compares these results with total load, which is dominated by sand. The gravel load was separated out because of the importance of gravel in forming channel bed geometry. Sand, however, is more important in forming floodplain features and channel banks.

For gravel loads the pre-Project effective discharge plot shows numerous peaks, but the flow that transports the greatest amount of gravel is 79,000 cfs. For Maximum Load Following OS-1 conditions the effective discharge is 37,000 cfs, a reduction of 53 percent. At Sunshine, downstream of the Three Rivers Confluence where the Chulitna River contributes a large supply of gravel, the effective discharge for gravel is the same as sand (66,000 cfs) and for Maximum Load Following OS-1 conditions the analysis shows two peaks (Figure 6.2-2). It should be noted that the gravel load power function rating curve ($Q_s = aQ^b$) at this location does not appear to be consistent with the critical discharge for bed movement (incipient motion), which is estimated as 16,000 cfs (Tetra Tech 2013b). Therefore, the first peak (10,000 cfs) is likely to transport only minimal gravel. The second peak (54,000 cfs) is greater than the critical discharge and a more reasonable estimate of the effective discharge for gravel under this operational scenario. At Susitna Station, the effective discharge values for gravel and for total load are the same.

Wolman and Miller (1960) concluded that hydrologic events of moderate magnitude and frequency transport the most sediment over the long-term, and these flows are most effective in forming and maintaining the planform and geometry of a channel. The overall decrease in effective discharge on the mainstem of the Susitna River suggests that the morphology of the channel may change because there is a reasonably well identified relationship between the effective discharge and the size of the channel.

Detailed 1-D bed evolution modeling of the Susitna River to be conducted in 2014 between Watana Dam and Susitna Station will be a key tool in making assessments as to how the channel morphology may change. The 1-D sediment-transport modeling will help address these questions and allow for a more refined estimate of the sediment balance and effective discharges for both the pre-Project and the range of operational scenarios in the Middle and Lower River Segments.

7. REFERENCES

Alaska Energy Authority (AEA). 2012. 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. Published on-line at 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(1980). pp 311-330.

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

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

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

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

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

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

Knott, J.M., Lipscomb, S.W. and Lewis, T.W. 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.

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.

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

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

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

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

Tetra Tech 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 2013b. Reconnaissance Level Assessment of Potential Channel Change in the Lower Susitna River Segment. Susitna-Watana Hydroelectric Project. 2012 Study Technical Memorandum. Prepared for the Alaska Energy Authority. Anchorage, Alaska.

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

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

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

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

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

Wolman, M.G. and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology. v 68(1). pp 54–74.

8. TABLES

Table 3-1. List of Streamflow Gages

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

Table 3-2. 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	$6.97E\text{-}10\ Q^{3.00}$	$1.09E\text{-}11\ Q^{3.38}$	$4.49E\text{-}9\ Q^{2.46}$	$1.89E\text{-}20\ Q^{4.84}$
			n = 51 (46/5), R^2 = 0.89	$1.02E\text{-}11\ Q^{3.10}$	
15292400	Chulitna River near Talkeetna	$1.12E\text{-}7\ Q^{2.66}$	$1.01E\text{-}5\ Q^{2.14}$	$5.1E\text{-}6\ Q^{2.09}$	$2.6E\text{-}9\ Q^{2.80}$
		n = 50 (48/2), R^2 = 0.91	n = 48 (46/2), R^2 = 0.86	$3.51E\text{-}12\ Q^{3.63}$	$1.23E\text{-}14\ Q^{4.22}$
15292700	Talkeetna River near Talkeetna	$2.33E\text{-}8\ Q^{2.81}$	$2.58E\text{-}6\ Q^{2.32}$	$2.17E\text{-}5\ Q^{1.82}$	Parker Equation
		n = 76 (53/23), R^2 = 0.76	n = 78 (56/22), R^2 = 0.86	$1.43E\text{-}12\ Q^{3.99}$	
15292780	Susitna River at Sunshine	$2.29E\text{-}8\ Q^{2.61}$	$3.28E\text{-}6\ Q^{2.12}$	$8.16E\text{-}4\ Q^{1.29}$	$3.11E\text{-}17\ Q^{4.07}$
		n = 54 (52/2), R^2 = 0.82	n = 55 (53/2), R^2 = 0.83		$3.68E\text{-}2\ Q^{0.820}$
15294345	Yentna River near Susitna Station	$1.27E\text{-}7\ Q^{2.48}$	$4.10E\text{-}6\ Q^{2.14}$	$1.93E\text{-}4\ Q^{1.63}$	$1.99E\text{-}9\ Q^{2.49}$
		n = 25 (24/1), R^2 = 0.94	n = 25 (24/1), R^2 = 0.84		
15294350	Susitna River at Susitna Station	$4.49E\text{-}8\ Q^{2.46}$	$3.31E\text{-}3\ Q^{1.46}$	$4.45E\text{-}7\ Q^{2.04}$	$4.85E\text{-}10\ Q^{2.47}$
		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 5.1-1. Effective Discharge for the Mainstem of the Susitna River under Pre-Project Conditions

Bins	Gold Creek (pre-Project)	Sunshine (pre-Project)	Susitna Station (pre-Project)
	43	41	37
Bin Size (cfs)	2,000	4,000	8,000
Max Bin □ (to	7,185,000	37,287,000	113,434,000
$Q_{Effective}$ (cfs)	27,000	66,000	124,000

Table 5.1-2. Effective Discharge for the Major Tributaries of Susitna River

Bins	**Chulitna**	**Talkeetna**	**Yentna**
	37	32	36
Bin Size (cfs)	2,000	2,000	4,000
Max Bin Δ (tons)	46,350,000	9,868,000	65,255,000
$Q_{Effective}$ (cfs)	23,000	11,000	50,000

Table 5.2-1. Effective Discharge for the Mainstem of the Susitna River under Maximum Load Following OS-1 Conditions

Bins	Gold Creek (MAX LF OS-1)	Sunshine (MAX LF OS-1)	Susitna Station (MAX LF OS-1)
	25	32	37
Bin Size (cfs)	2,000	4,000	8,000
Max Bin Δ (tons)	3,212,000	31,564,000	118,845,000
$Q_{Effective}$ (cfs)	23,000[1]	46,000	108,000

Table 6.1-1. Comparison of Effective Discharge for the Mainstem of the Susitna River under Pre-Project and Maximum Load Following OS-1 Conditions

	Gold Creek		Sunshine		Susitna Station	
	pre-Project	MAX LF OS-1	pre-Project	MAX LF OS-1	pre-Project	MAX LF OS-1
$Q_{Effective}$ (cfs)	27,000	9,000	66,000	46,000	124,000	108,000

[1] This estimate for effective discharge corresponds to the second peak shown in Figure 5.2-1.

9. FIGURES

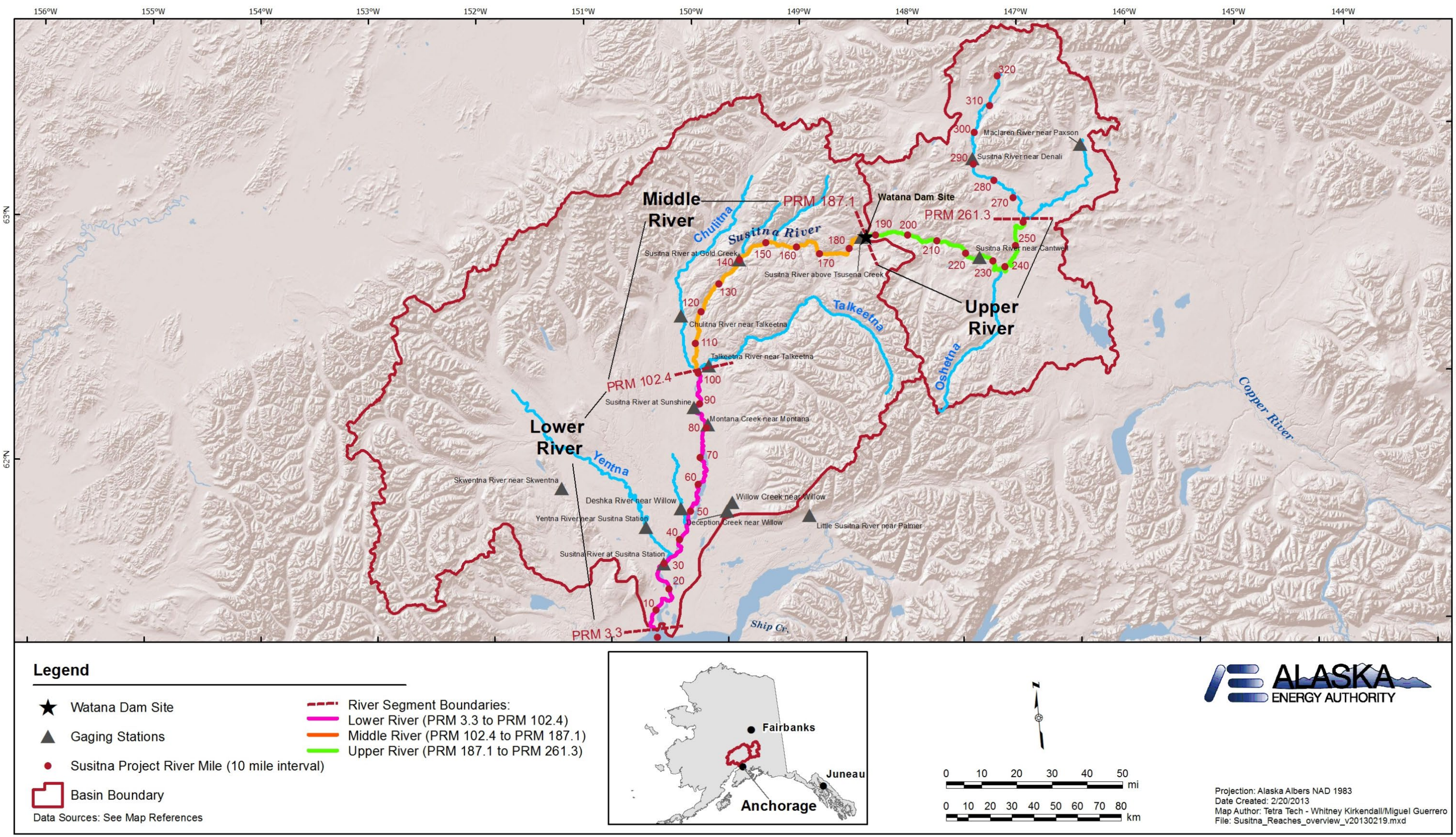

Figure 3-1. Susitna River study area and large-scale river segments.

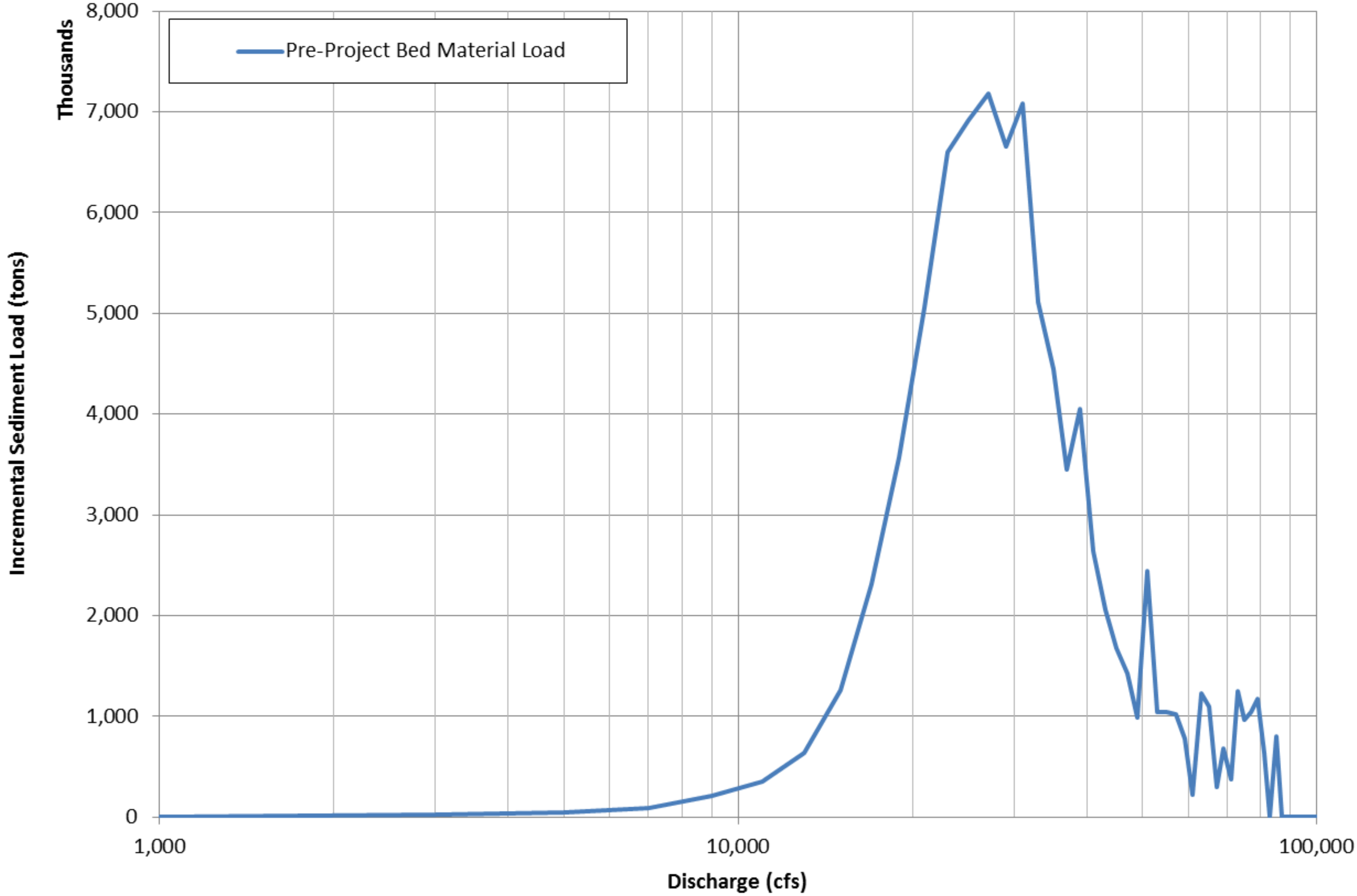

Figure 5.1-1. Effective discharge at the Gold Creek (Gage No. 15292000)/Susitna River near Talkeetna (Gage No. 15292100) gage over the 61-year period of flows under pre-Project conditions.

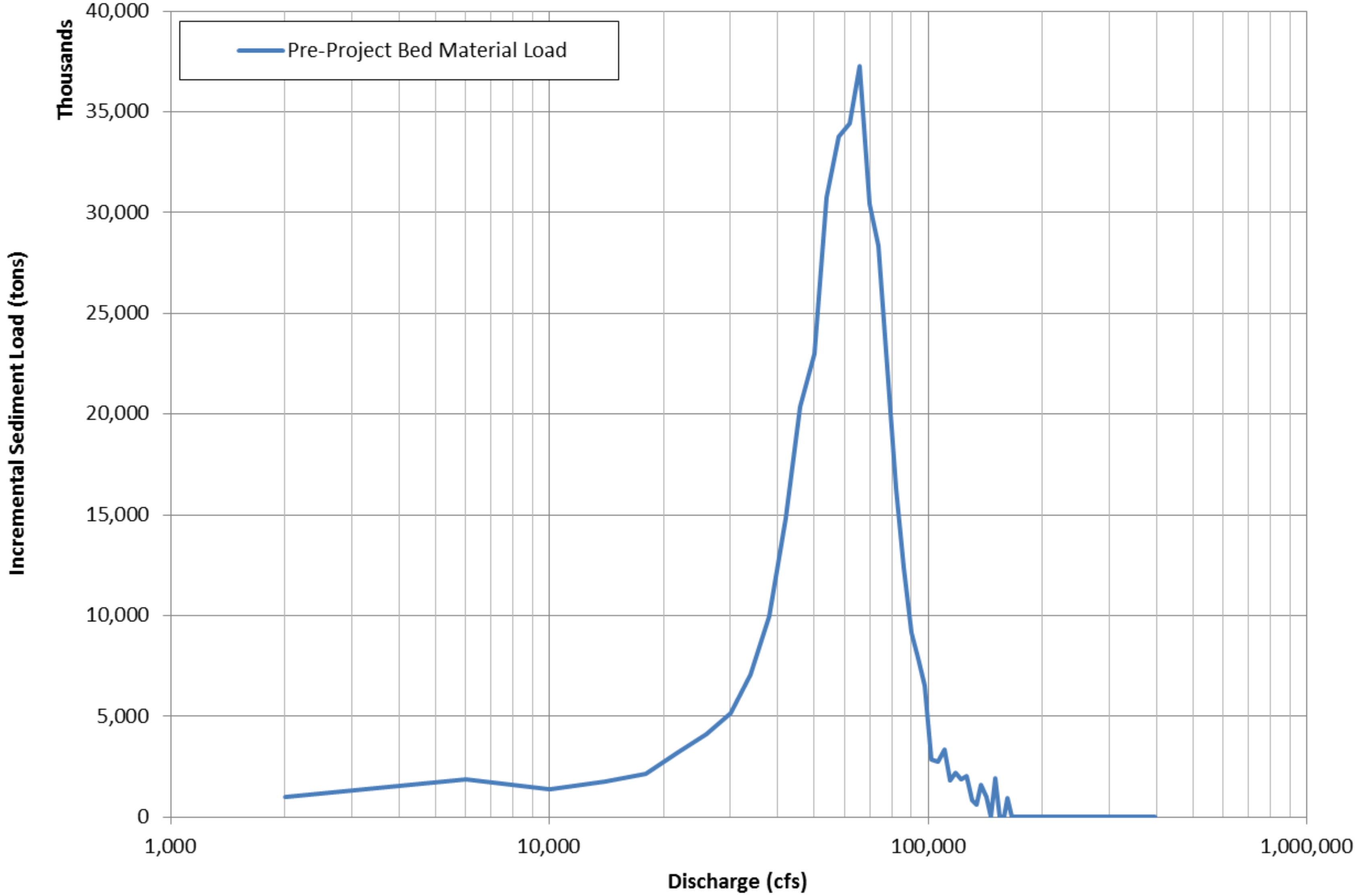

Figure 5.1-2. Effective discharge at the Susitna River at Sunshine (Gage No. 15292780) gage over the 61-year period of flows under pre-Project conditions.

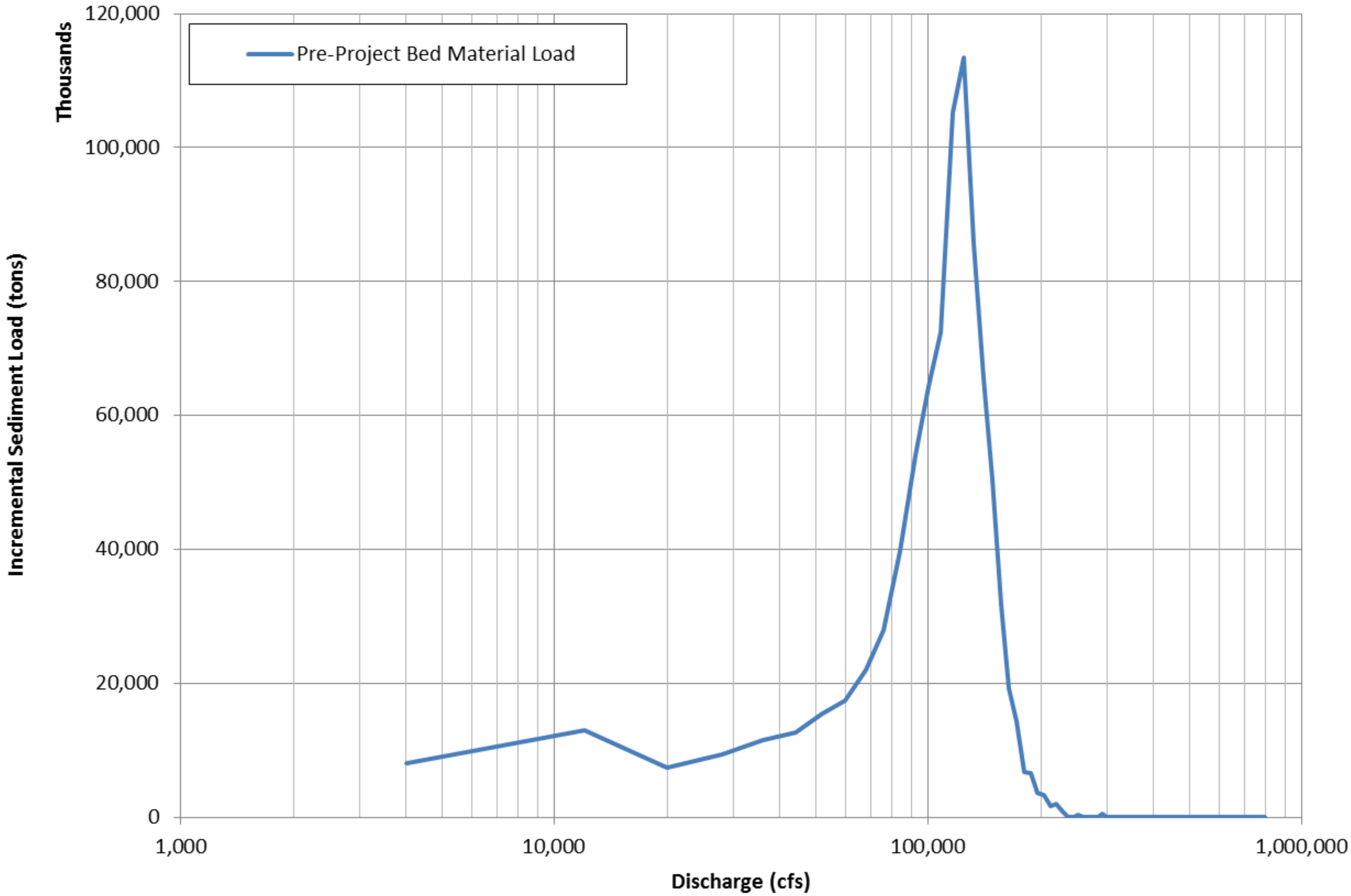

Figure 5.1-3. Effective discharge at the Susitna River at Susitna Station (Gage No. 15294350) gage over the 61-year period of flows under pre-Project conditions.

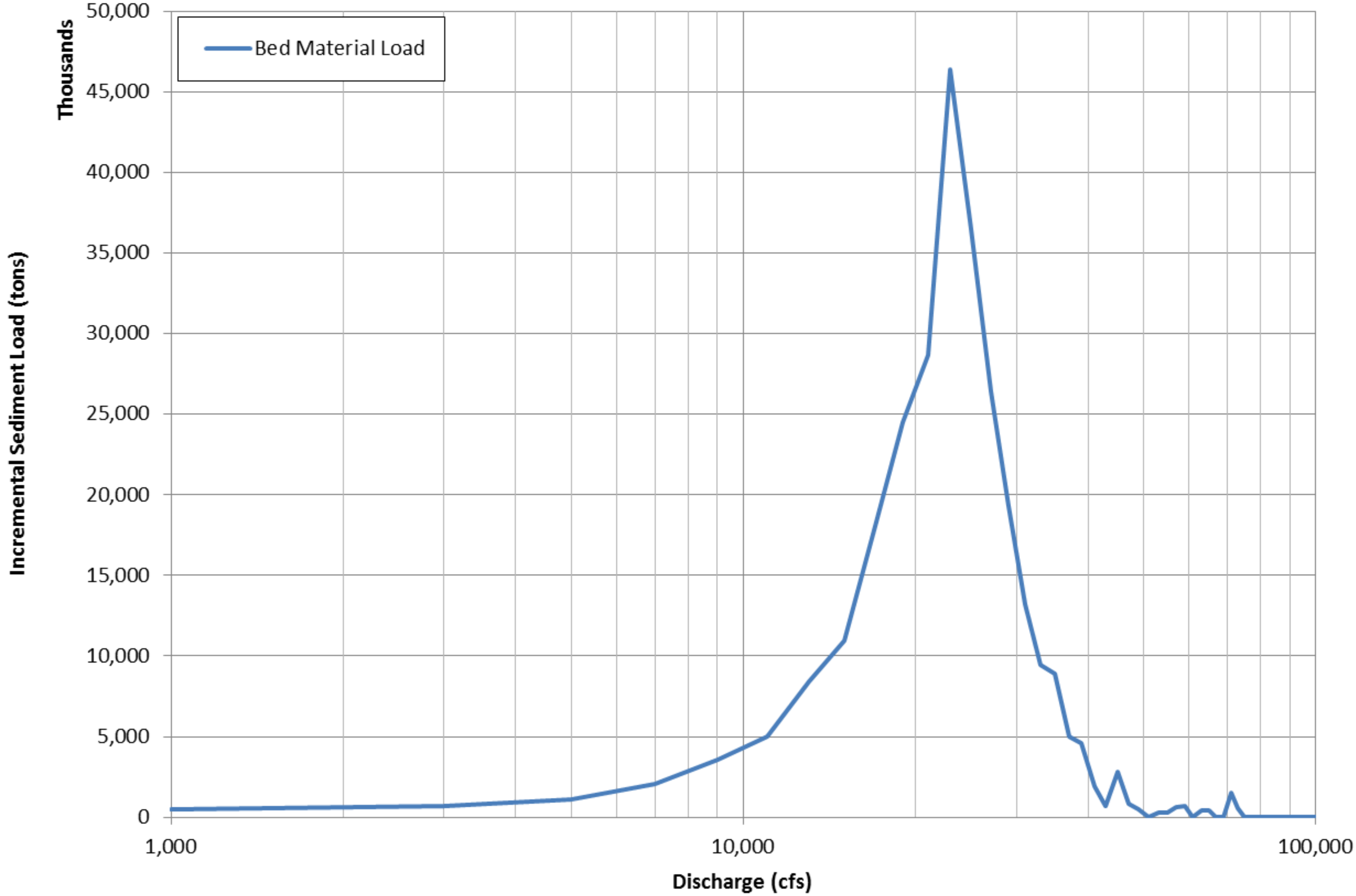

Figure 5.1-4. Effective discharge at the Chulitna River near Talkeetna (Gage No. 15292400), Chulitna River below Canyon near Talkeetna (Gage No. 15292410) gage over the 61-year period of flows.

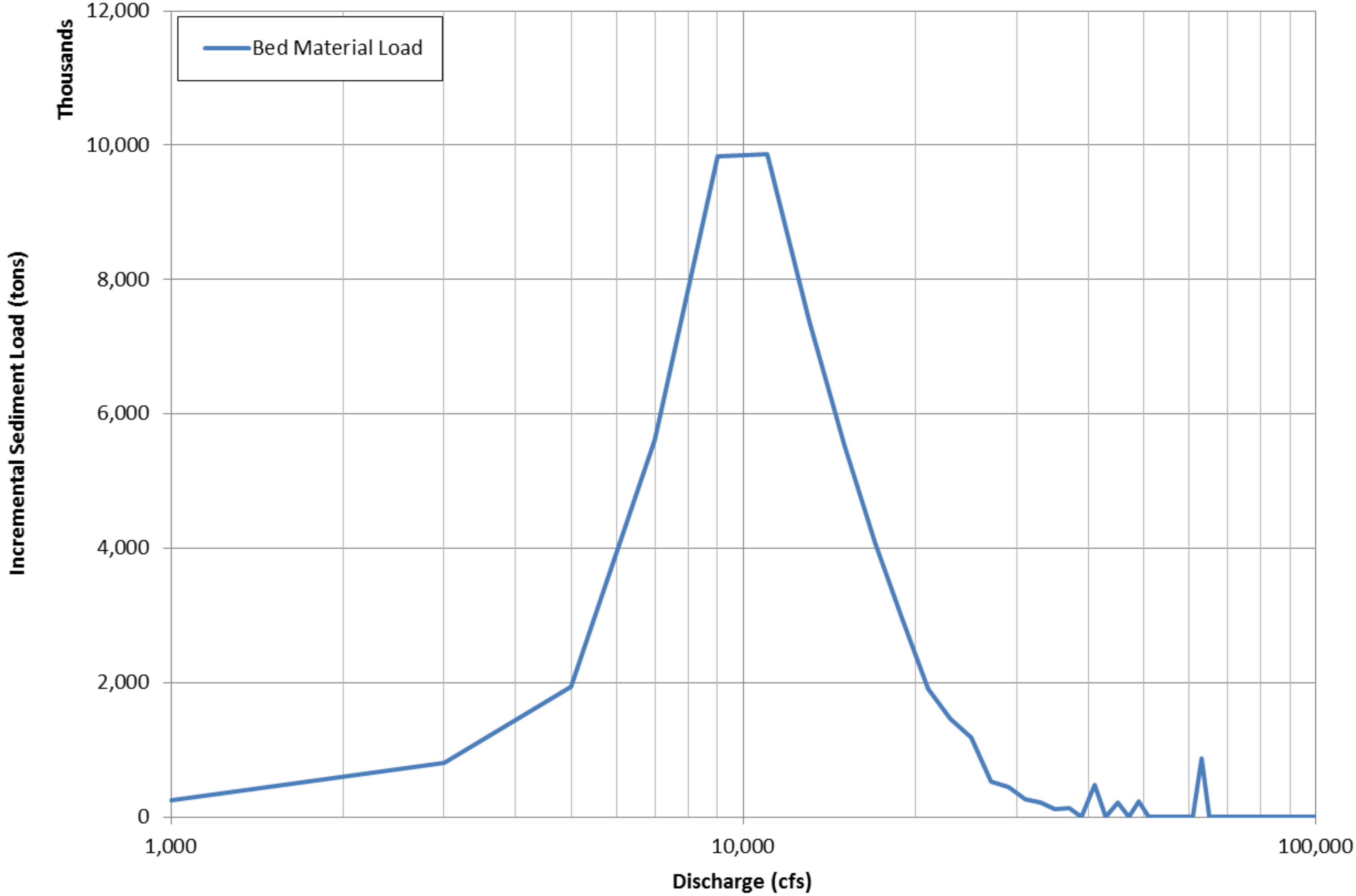

Figure 5.1-5. Effective discharge at the Talkeetna River near Talkeetna (Gage No. 15292700) gage over the 61-year period of flows.

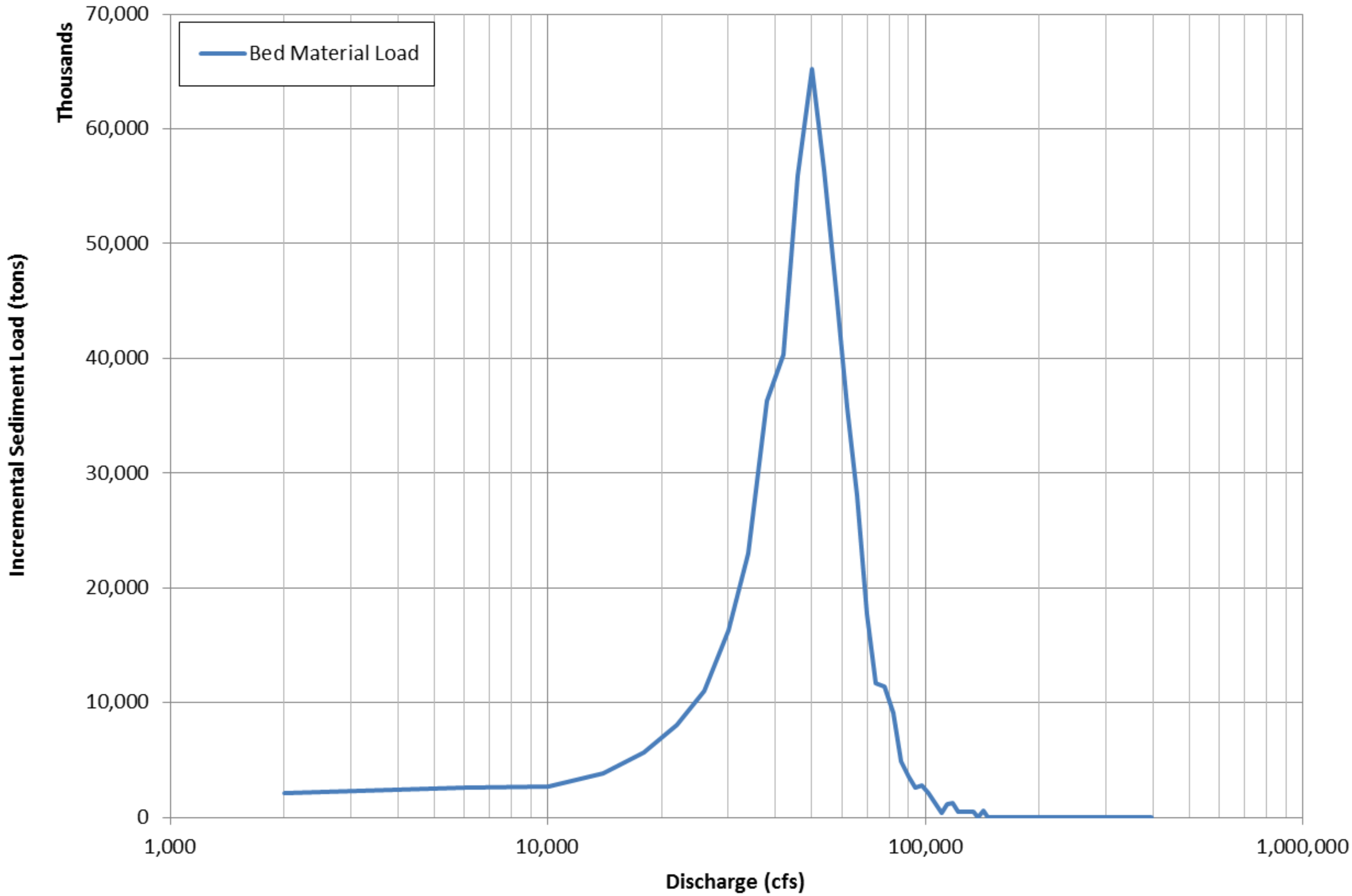

Figure 5.1-6. Effective discharge at the Yentna River near Susitna Station (Gage No. 15294345) gage over the 61-year period of flows.

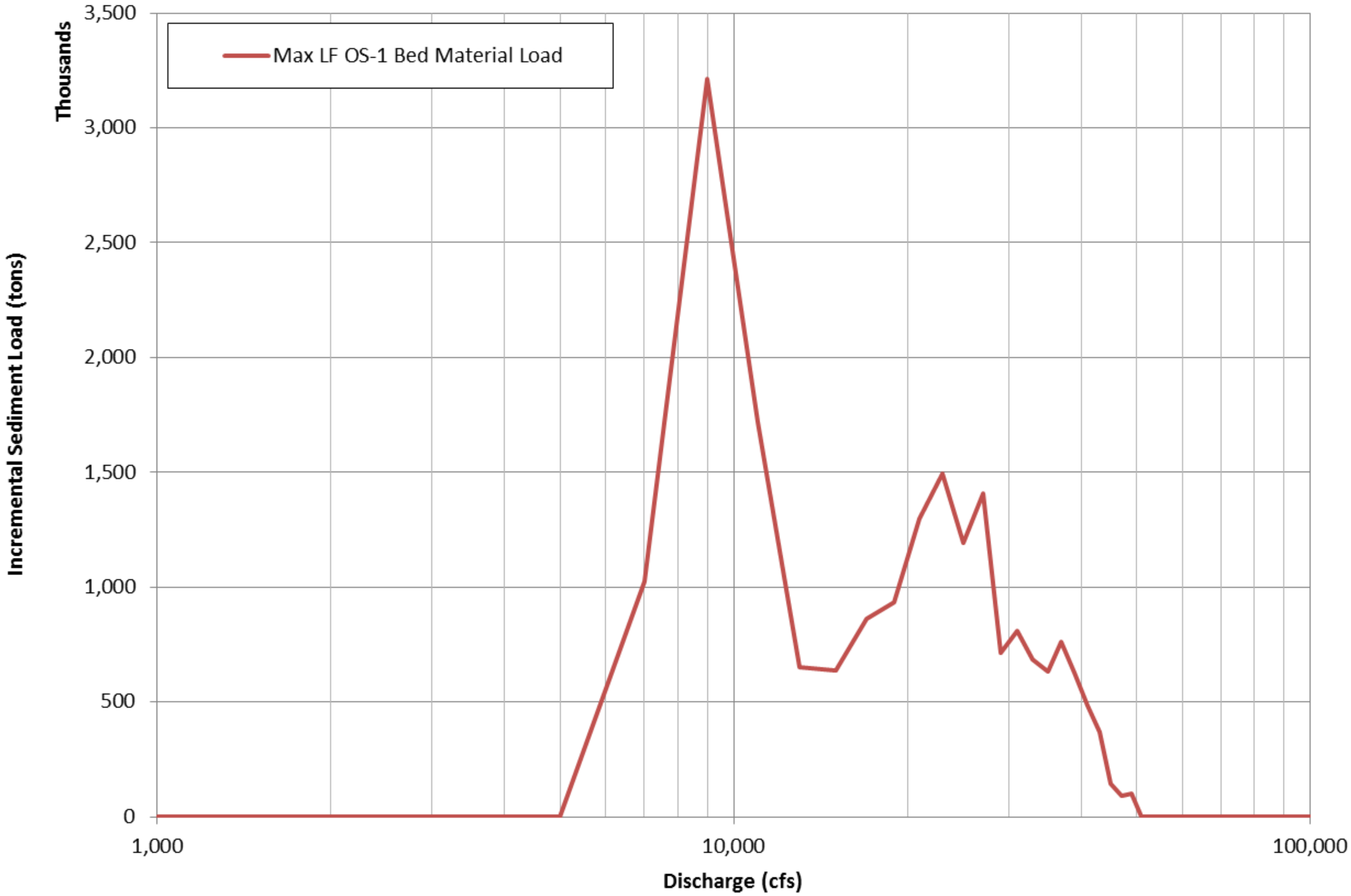

Figure 5.2-1. Effective discharge at the Gold Creek (Gage No. 15292000)/Susitna River near Talkeetna (Gage No. 15292100) gage over the 61-year period of flows under Maximum Load Following OS-1 conditions.

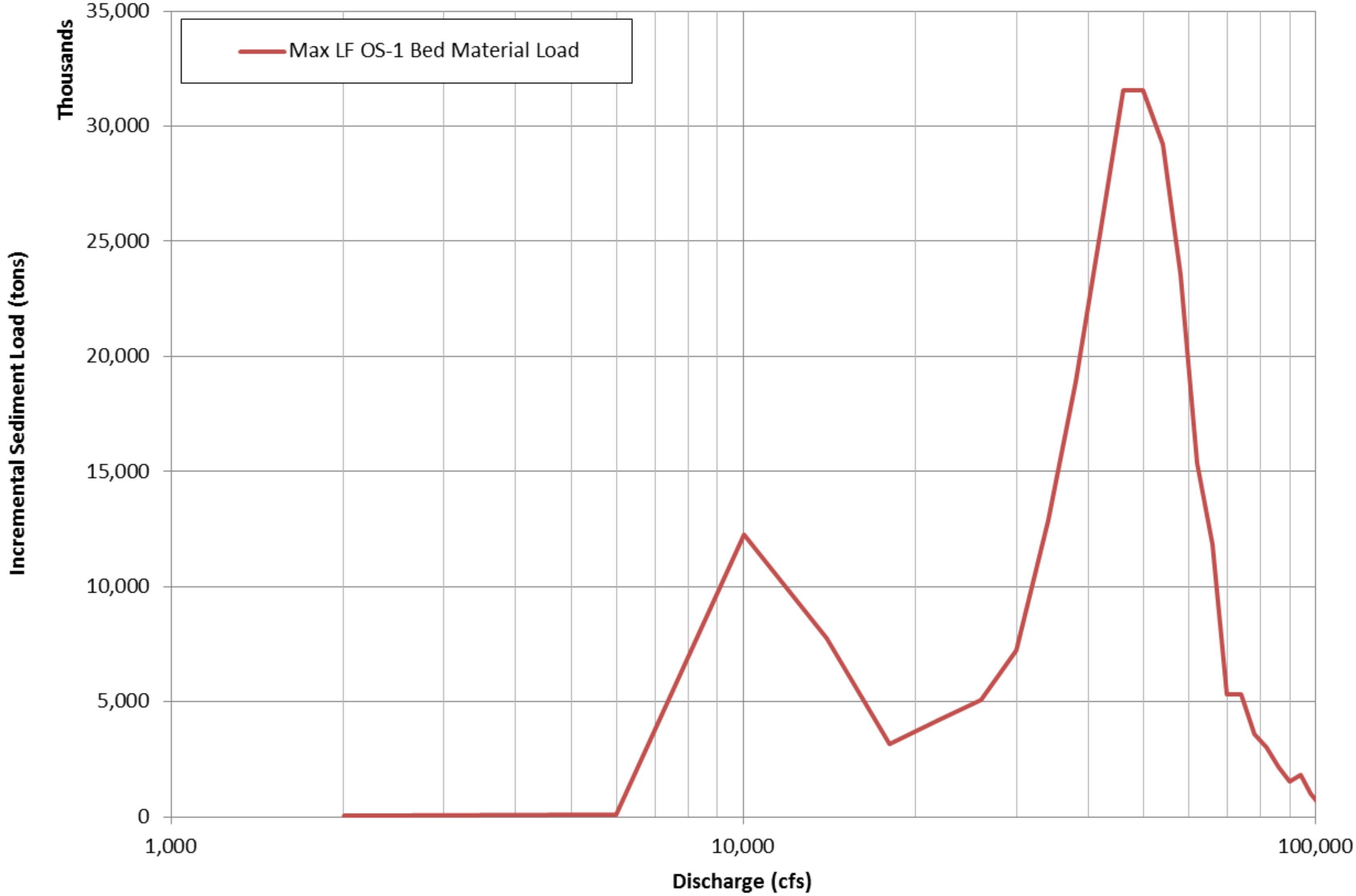

Figure 5.2-2. Effective discharge at the Susitna River at Sunshine (Gage No. 15292780) gage over the 61-year period of flows under Maximum Load Following OS-1 conditions.

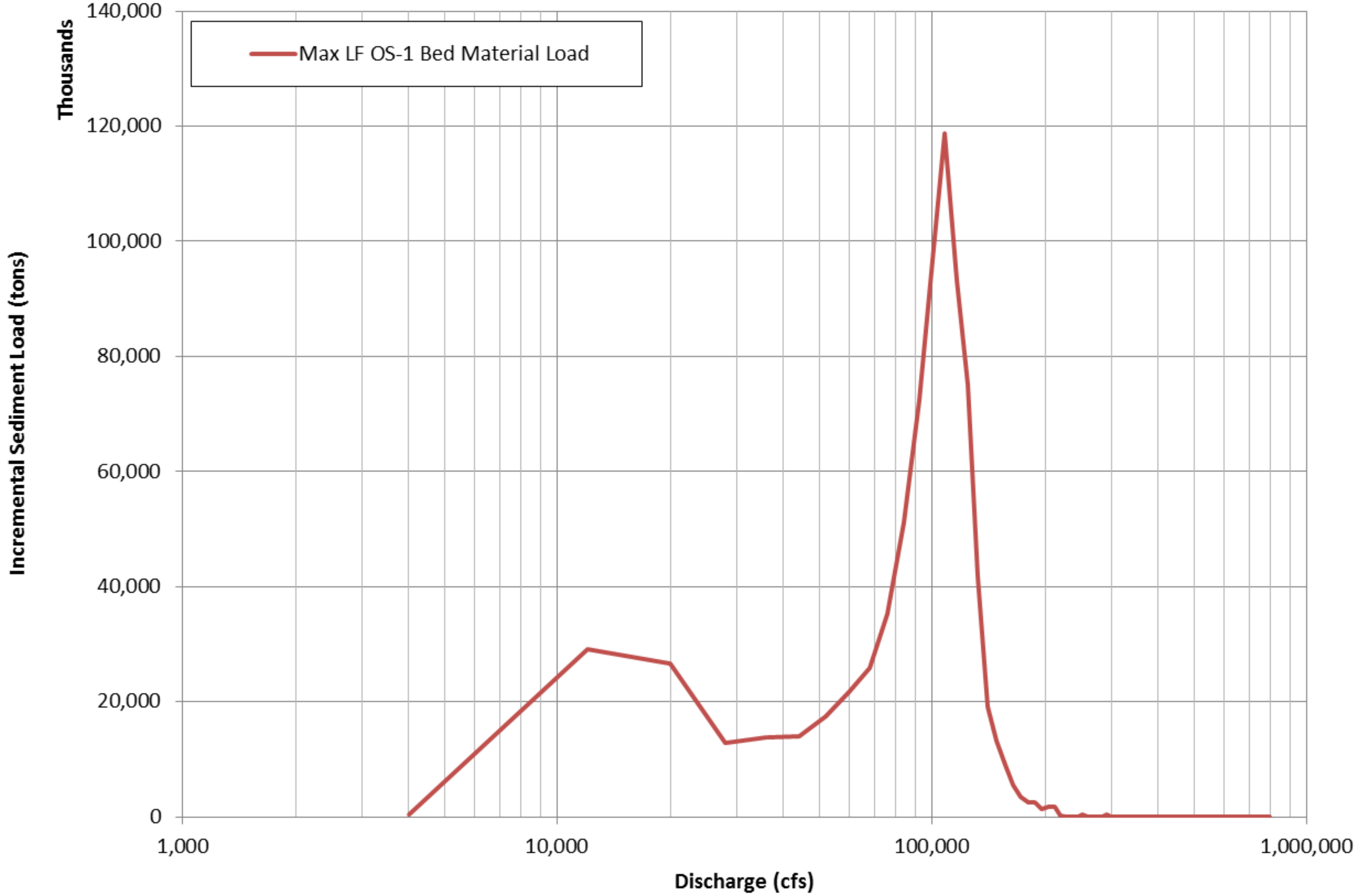

Figure 5.2-3. Effective discharge at the Susitna River at Susitna Station (Gage No. 15294350) gage over the 61-year period of flows under Maximum Load Following OS-1 conditions.

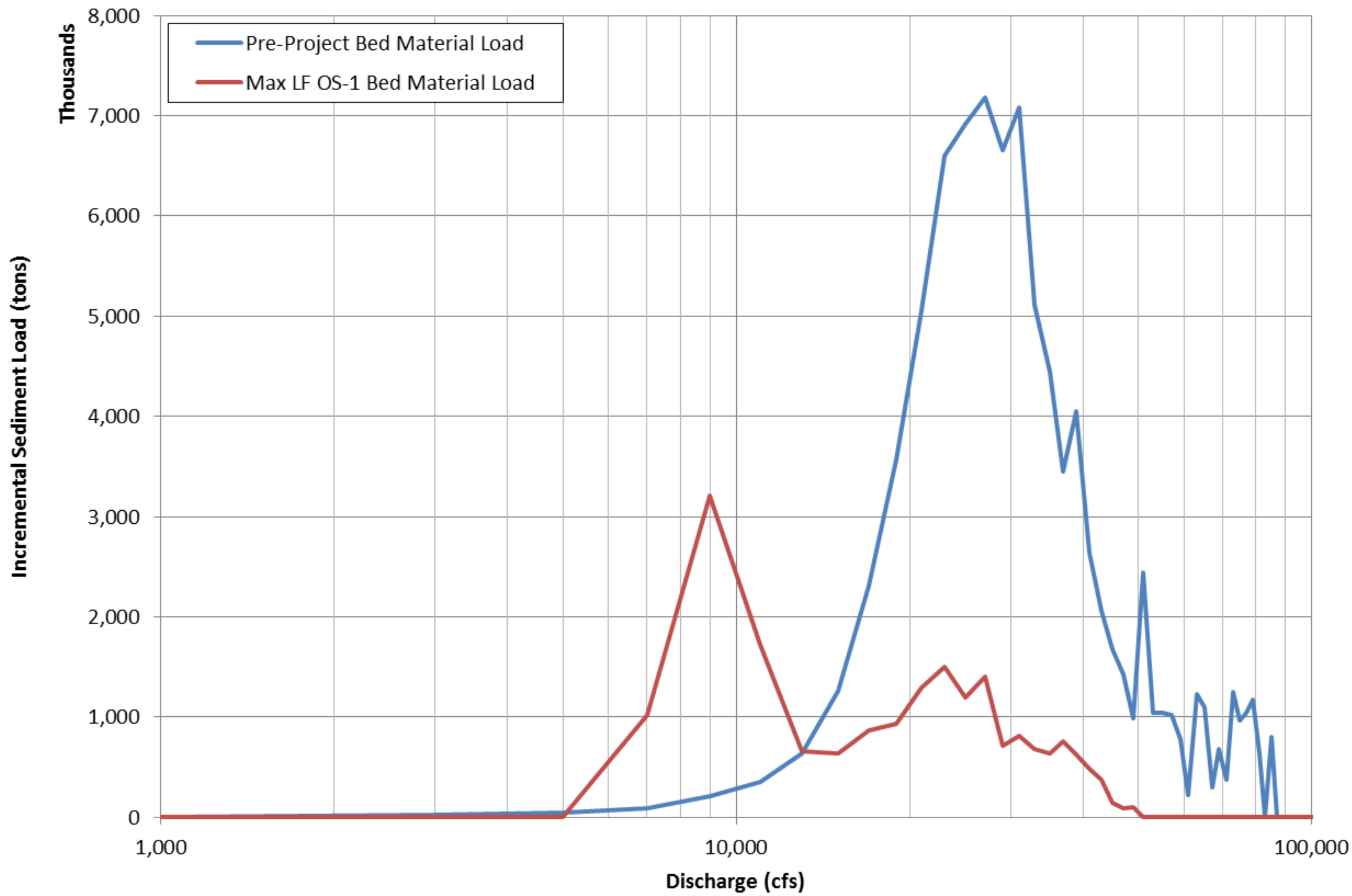

Figure 6.1-1. Effective discharge at the Gold Creek (Gage No. 15292000)/, Susitna River near Talkeetna (Gage No. 15292100) gage over the 61-year period of flows under pre-Project and Maximum Load Following OS-1 conditions.

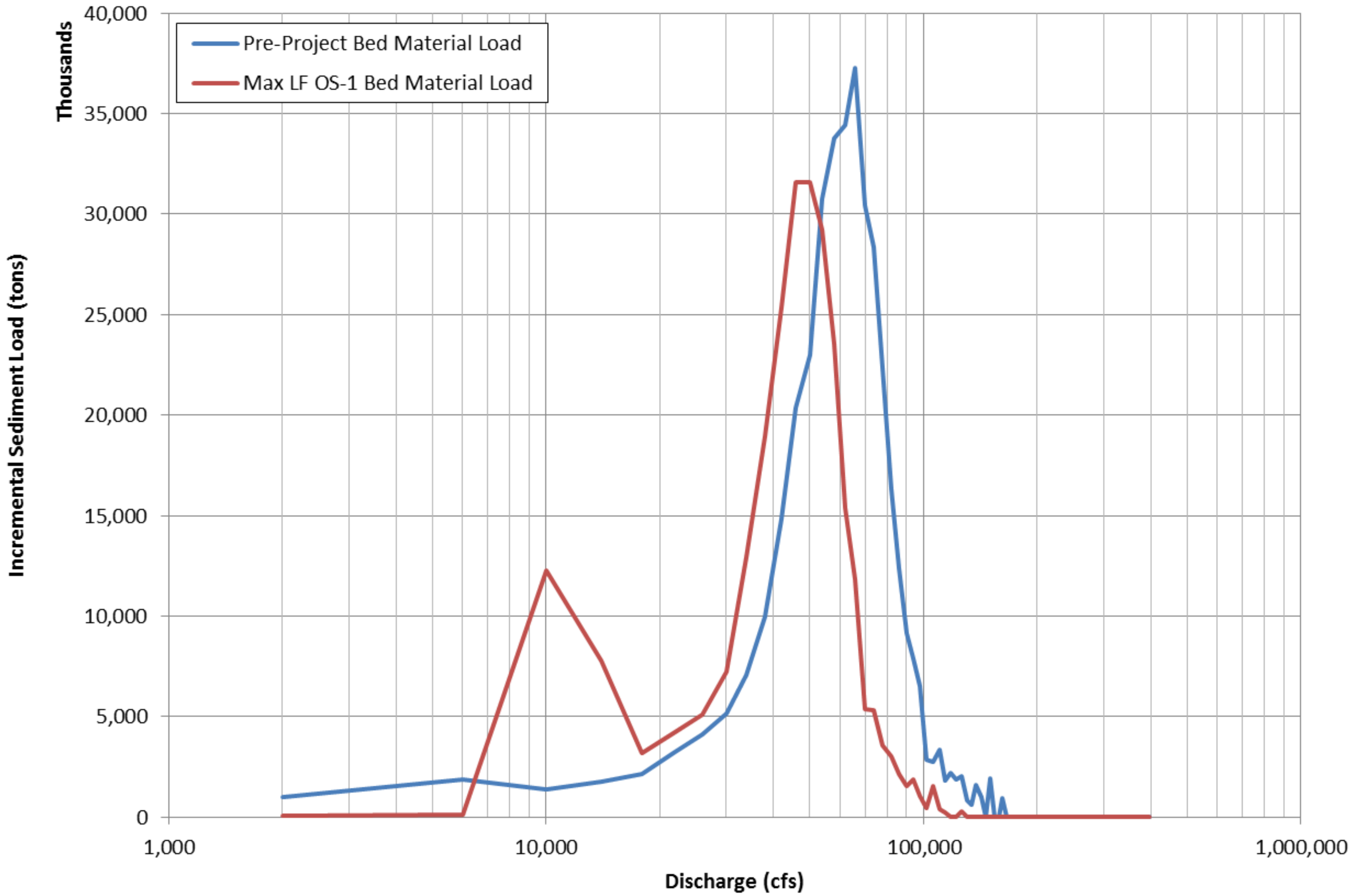

Figure 6.1-2. Effective discharge at the Susitna River at Sunshine (Gage No. 15292780) gage over the 61-year period of flows under pre-Project and Maximum Load Following OS-1 conditions.

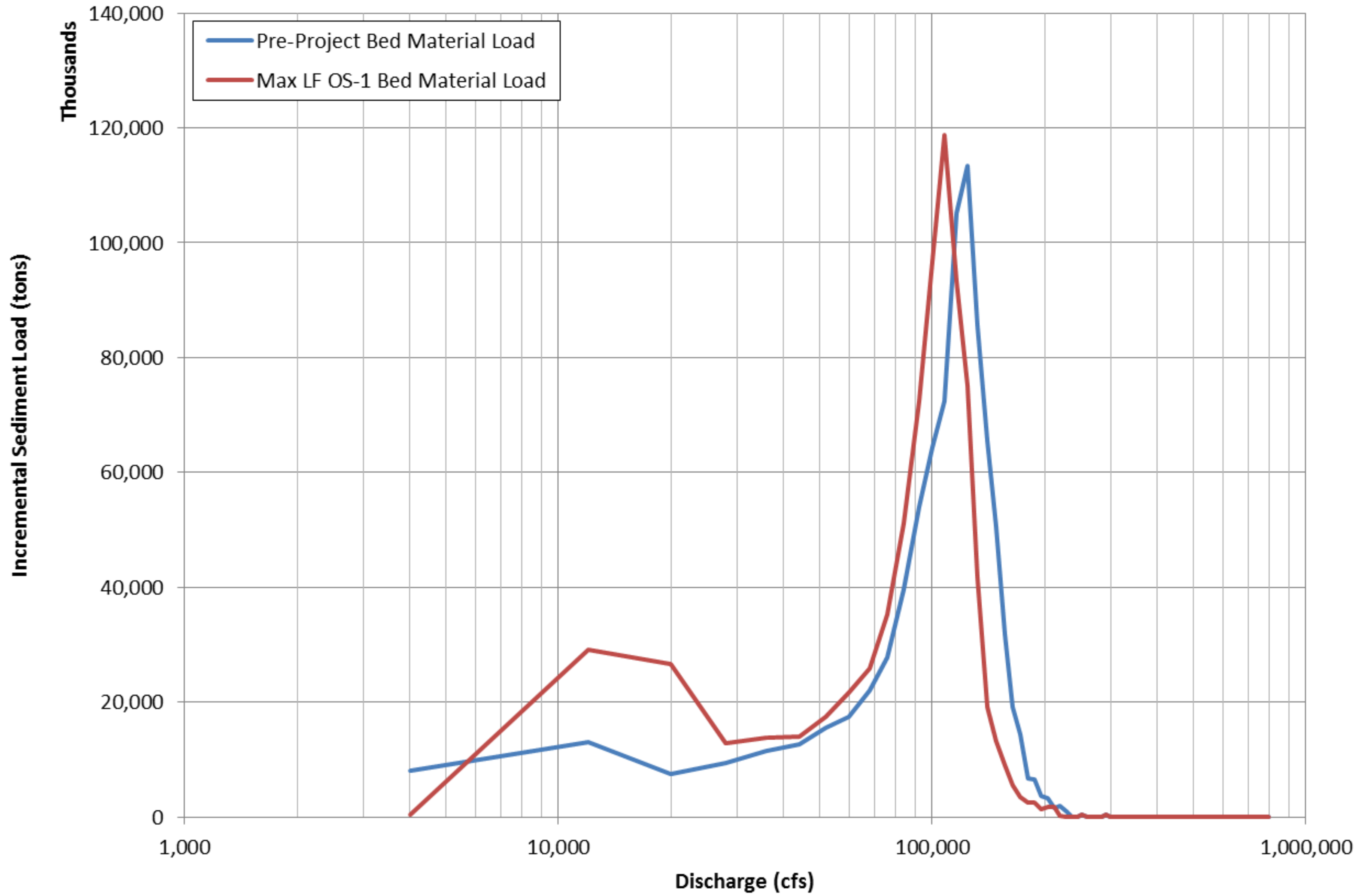

Figure 6.1-3. Effective discharge at the Susitna River at Susitna Station (Gage No. 15294350) gage over the 61-year period of flows under pre-Project and Maximum Load Following OS-1 conditions.

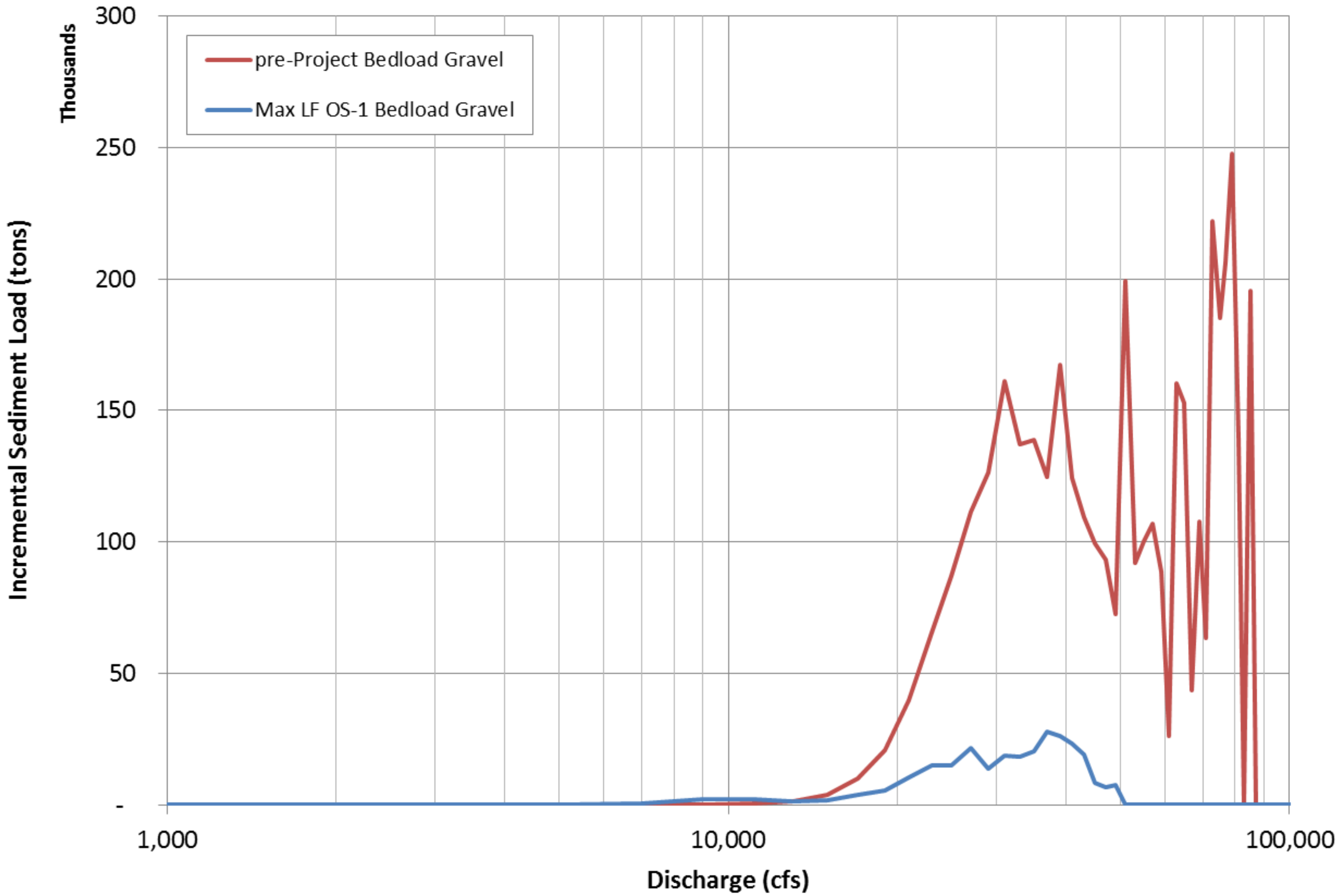

Figure 6.2-1. Effective discharge (Bed-load Gravel only) at the Gold Creek (Gage No. 15292000), Susitna River near Talkeetna (Gage No. 15292100) gage over the 61-year period of flows under pre-Project and Maximum Load Following OS-1 conditions.

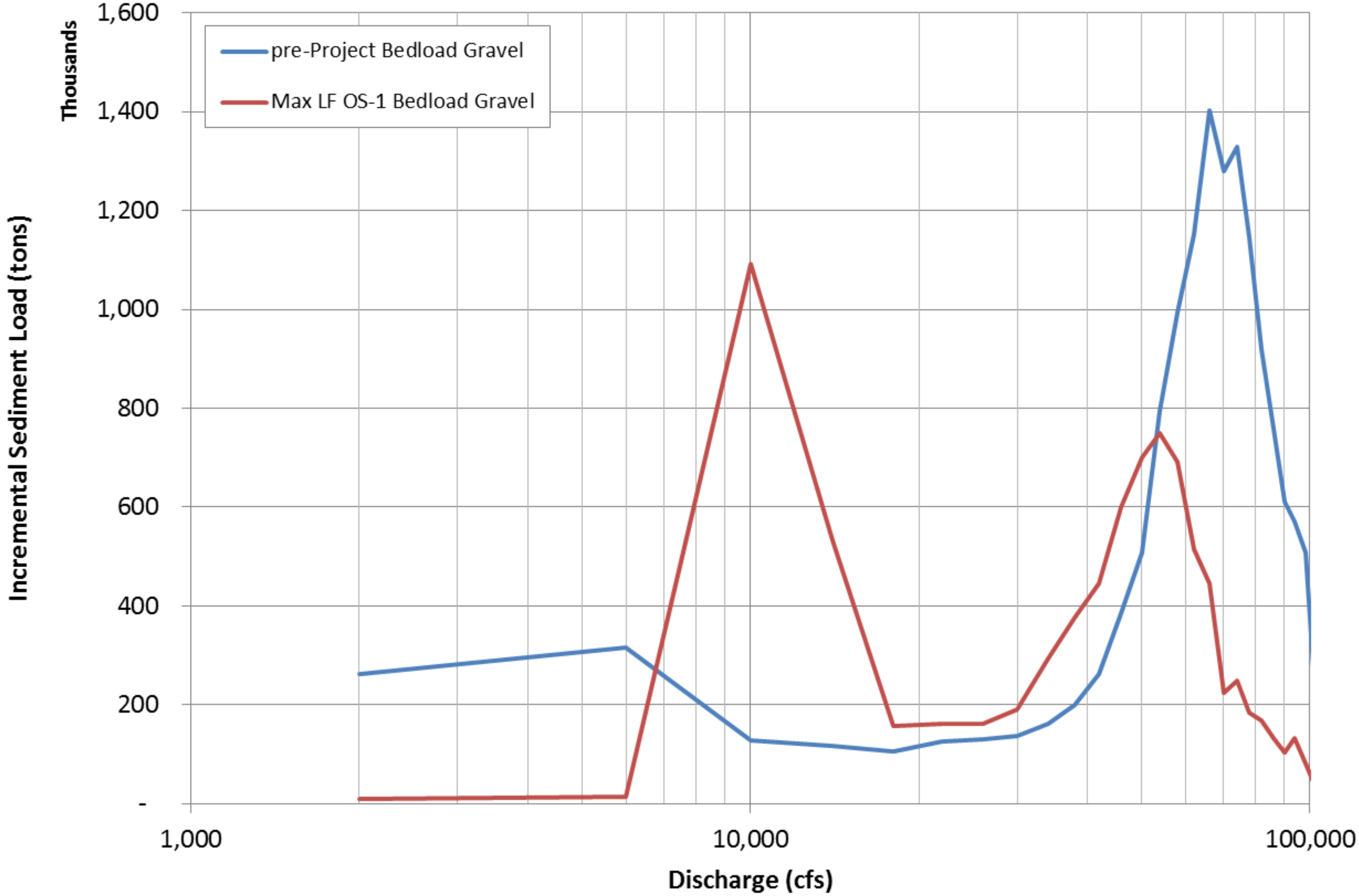

Figure 6.2-2. Effective discharge (Bed-load Gravel only) at the Susitna River at Sunshine (Gage No. 15292780) gage over the 61-year period of flows under pre-Project and Maximum Load Following OS-1 conditions.

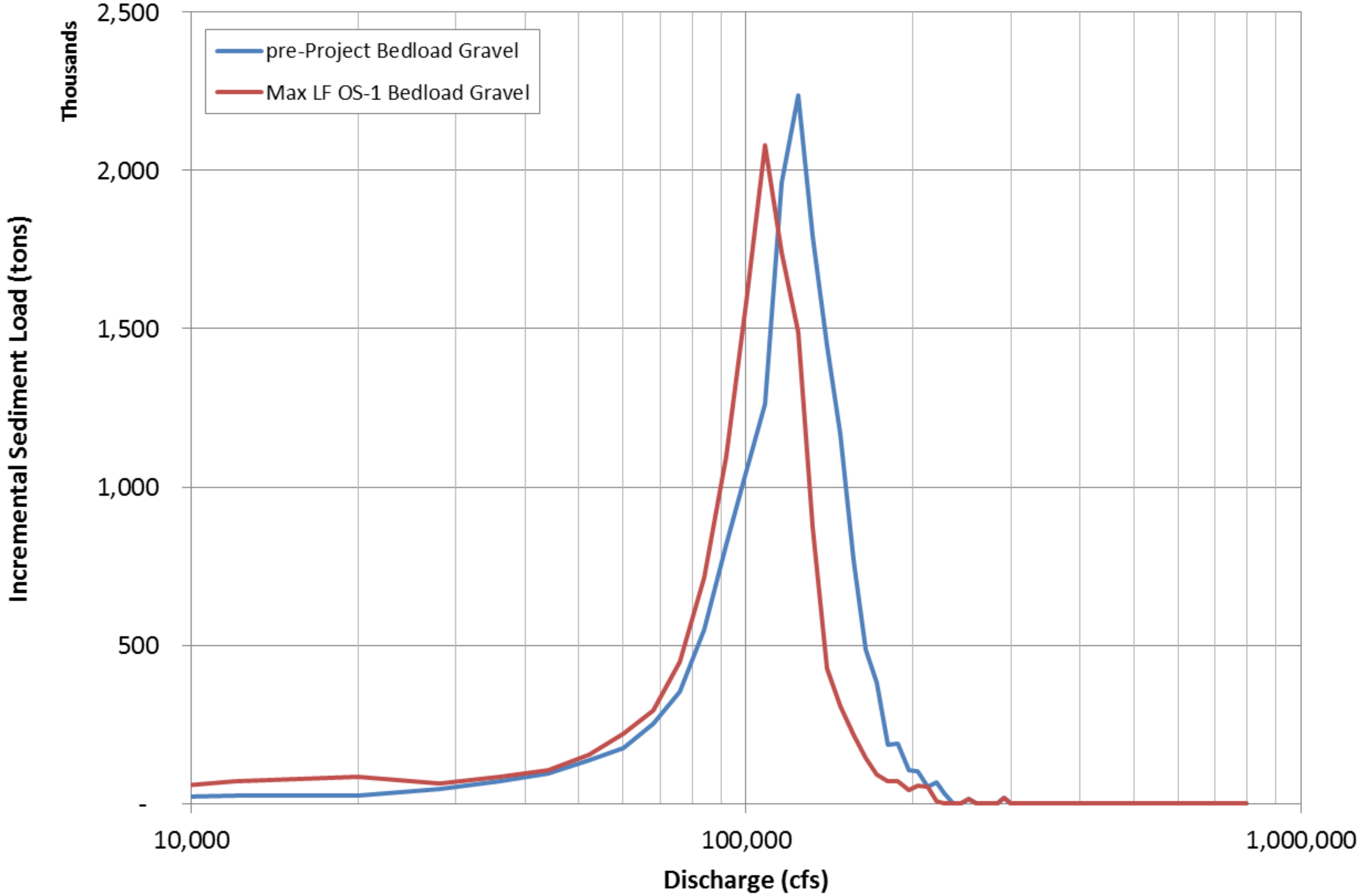

Figure 6.2-3. Effective discharge (Bedload Gravel only) at the Susitna River at Susitna Station (Gage No. 15294350) gage over the 61-year period of flows under pre-Project and Maximum Load Following OS-1 conditions.

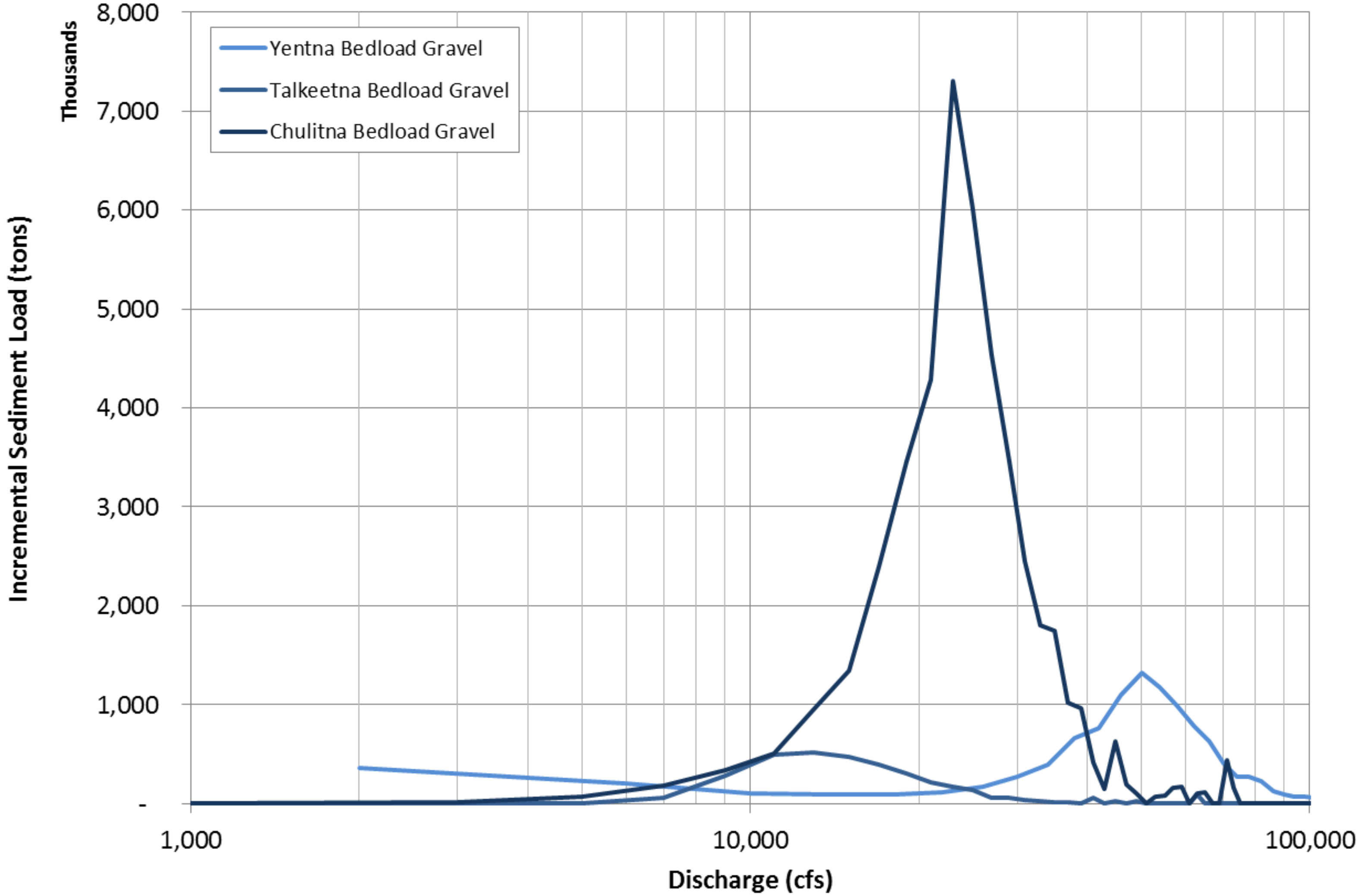

Figure 6.2-4. Effective discharge (Bed-load Gravel only) at the Chulitna River near Talkeetna (Gage No. 15292400)/Chulitna River below Canyon near Talkeetna (Gage No. 15292410) gage, the Talkeetna River near Talkeetna (Gage No. 15292700) gage, and the Yentna River near Susitna Station (Gage No. 15294345) gage over the 61-year period of flows.

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Geomorphology Study (6.5)

Part A - Appendix C
Study Component 6 – Compilation of References from Literature Search on the Downstream Effects of Dams

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

June 2014

Angradi, Ted R, E William Schweiger, David W Bolgrien, Peter Ismert, and Tony Selle. 2004. Bank stabilization, riparian land use and the distribution of large woody debris in a regulated reach of the upper Missouri River, North Dakota, USA. *River Research and Applications* 20, no. 7: 829-846. http://doi.wiley.com/10.1002/rra.797.

Andersson, Elasabet, Christer Nilsson, and Mats E. Johansson. 2000. *Regulated Rivers: Research & Management* 16: 83-89.

Anselmetti, Flavio S, Raphael Bühler, David Finger, Stéphanie Girardclos, Andy Lancini, Christian Rellstab, and Mike Sturm. 2007. Effects of Alpine hydropower dams on particle transport and lacustrine sedimentation. *Aquatic Sciences* 69, no. 2: 179-198.

Assani, Ali a, Raphaëlle Landry, Jonathan Daigle, Alain Chalifour. 2011. *Water Resources Management* 25, no. 25: 3661-3675

Ayles, C.P., and Michael Church. Downstream Channel Gradation in the Regulated Peace River. In *The regulation of Peace River.* ms. Edited by Michael Church. In preparation.

Ayles, C.P., and Michael Church. Tributary Gradation due to Regulation of Peace River. In *The regulation of Peace River.* ms. Edited by Michael Church. In preparation

Bang, A, C Nilsson, and S Holm. 2007. The potential role of tributaries as seed sources to an impoundment in Northern Sweden: a field experiment with seed mimics. *River Research and Applications* 23, no. 10: 1049-1057.

Baozhong, Liua, Daqing Yang, Baisheng Ye, and Svetlana Berezovskaya.2005. Long-term open-water season stream temperature variations and changes over Lena River Basin in Siberia. *Global and Planetary Change* 48: 96-111.

Bejarano, Maria Dolores, Christer Nilsson, Marta González del Tánago, and Miguel Marchamalo. 2011. Responses of riparian trees and shrubs to flow regulation along a boreal stream in northern Sweden. *Freshwater Biology* 53: 853-866.

Bejarano, M. Dolores, and Á. Sordo-Ward. 2011. Riparian woodland encroachment following flow regulation: a comparative study of Mediterranean and Boreal streams. *Knowledge and Management of Aquatic Ecosystems* 402, no. 20: 1-15.

Beltaos, Spyros, and Brian C. Burrell. 2002. Extreme ice jam floods along the Saint John River , New Brunswick , Canada. *The extremes of the Extremes: Extraordinary Floods* (Proceedings of a symposium held at Reykjavik, Iceland, July 2000), no. 271.

Bergeron, Normand E., André G. Roy, Diane Chaumont, Yves Mailhot, and Éric Guay. 1998. Winter geomorphological processes in the Sainte-Anne River (Québec) and their impact on the migratory behaviour of Atlantic tomcod (Microgadus tomcod). *Regulated rivers: Research & Management* 14: 95-105.

Blackburn, J., F. Hicks. 2003. Suitability of Dynamic Modeling for Flood Forecasting during Ice Jam Release Surge Events. *Journal of Cold Regions Engineering* 17, no. 1: 18-36.

Boucher, Étienne, Yves Bégin, and Dominique Arseneault. 2009. Impacts of recurring ice jams on channel geometry and geomorphology in a small high-boreal watershed. *Geomorphology* 108, no. 3-4: 273-281.

Burke, Michael, Klaus Jorde, and John M. Buffington. 2008. Application of a hierarchical framework for assessing environmental impacts of dam operation: changes in streamflow, bed mobility and recruitment of riparian trees in a western North American river. *Journal of environmental management* 90: S224-36.

Calay, R.K., V.K. Sarda, R. Dhiman. 2008. An empirical approach to river bed degradation. *International Journal of Multiphysics* 2, no. 4: 407-419.

Charron, Isabelle, Olivier Lalonde, André G. Roy, Claudine Boyer, and Samuel Turgeon. 2008. Changes in riparian habitats along five major tributaries of the Saint Lawrence River, Québec, Canada: 1964–1997. *River Research and Applications* 24: 617-631.

Church, Michael. 1995. Geomorphic Response to River Flow Regulation: Case Studies and Time-Scales. *Regulated Rivers: Research & Management* 11: 3-22.

Church, Michael. The hydraulic geometry of Peace River. In *The regulation of Peace River.* ms. Edited by Michael Church. In preparation.

Church, Michael and Jiongxin Xu. Post-regulation Morphological Change on Peace River. In *The regulation of Peace River.* ms. Edited by Michael Church. In preparation.

Curran, Janet H., and Monica L. McTeague. 2011. Geomorphology and Bank Erosion of the Matanuska River, Southcentral Alaska. U.S. Geological Survey Scientific Investigations Report 2011 – 5214, 52 p.

Delaney, Allan J., Steven A. Arcone, and Edward F. Chaocho, Jr. 1990. Winter Short-Pulse Radar Studies on the Tanana River, Alaska. *Arctic* 43, no. 3: 244-250.

Elliott, John G., Lauren A. Hammack. 2000. Entrainment of riparian gravel and cobbles in an alluvial reach of a regulated canyon river. *Regulated Rivers: Research & Management* 16: 37-50.

Ettema, Robert, and Steven F. Daly. 2004. Sediment Transport Under U.S Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, ERDC/CRREL TR-04-20.

Ettema, Robert, and Leonard Zabilansky. 2004. Ice Influences on Channel Stability: Insights from Missouri's Fort Peck Reach. *Journal of Hydraulic Engineering* 130, no. 4, 279-292.

Ettema, Robert. 2002. Review of Alluvial-channel Responses to River Ice. *Journal of cold Regions Engineering* 16, no. 4: 191-217.

Ettema, Robert, Marian Muste, and Anton Kruger. 1999. Ice Jams in River Confluences. US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, CRREL Report 99-6.

Faustini, John M. and Julia A. Jones. 2003. Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. *Geomorphology* 51: 187-205.

Fergus, Tharan. 1997. Geomorphological Response of a River Regulated for Hydropower: River Fortun, Norway. *Regulated Rivers: Research & Management* 13: 449-461.

Ferrick, Michael G, Lawrence W. Gatto, and Steven A Grant. 2005. Soil Freeze-Thaw Effects on Bank Erosion and Stability: Connecticut River Field Site, Norwich, Vermont. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, ERDC/CRREL TN-05-7.

Fitzhugh, Thomas W., and Richard M. Vogel. 2010. The impact of dams on flood flows in the United States. *River Research and Applications,* DOI: 10.1002/rra.

Fortier, Catherine, Ali A. Assani1, Mhamed Mesfioui, and André G. Roy. 2011. Comparison of the interannual and interdecadal variability of heavy flood characteristics upstream and downstream from dams in inversed hydrologic regime: Case study of Matawin River (Québec, Canada). *River Research and Applications* 27: 1277-1289.

Górski, K., L.V. Van Den Bosch, K.E. Van de Wolfshaar, H. Middelkoop, L. A. J. Nagelkerke, O. V. Filippov, D. V. Zolotarev, S.V.Y. Yakovlev, A. E, Minin, H. V. Winter, J. J. De Leeuw, A. D. Buijse, J. A. J. Verreth. 2012. Post-Damming Flow Regime Development in a Large Lowland River (Volga, Russian Federation): Implications for Floodplain Inundation and Fisheries. *River Research and Applications* 28, 1121-1134.

Healy, Dan, and F.E. Hicks. 2007. Experimental Study of Ice Jam Thickening under Dynamic Flow Conditions. *Journal of Cold Regions Engineering* 21, no. 3: 72-91.

Helm, D.J., and William B. Collins. 1997. Vegetation Succession and Disturbance on a Boreal Forest Floodplain, Susitna River, Alaska. *The Canadian Field-Naturalist* 111: 553-574.

Hjort, Jan, and Miska Luoto. 2009. Interaction of geomorphic and ecologic features across altitudinal zones in a subarctic landscape. *Geomorphology* 112: 324-333.

Jansson, Roland, Christer Nilsson, Mats Dynesius and Elisabet Andersson. 2000. Effects of River Regulation on River-Margin Vegetation: A Comparison of Eight Boreal Rivers. *Ecological Applications* 10, no. 1: 203-224.

Jeffries, Richard, Stephen E. Darby, and David A. Sear. 2003. The influence of vegetation and organic debris on flood-plain sediment dynamics: case study of a low-order stream in the New Forest, England. *Geomorphology* 51: 61-80.

Johansson, M. E., and C. Nilsson. 2002. Responses of riparian plants to flooding in free-flowing and regulated boreal rivers: an experimental study. *Journal of Applied Ecology* 39: 971-986.

Johnson, W. Carter, Mark D. Dixon, Michael L. Scott, Lisa Rabbe, Gary Larson, Malia Volke and Brett Werner. 2012. Forty Years of Vegetation Change on the Missouri River Floodplain. *BioScience* 62, no. 2: 123-135.

Johnson, W. Carter, Mark D. Dixon, Robert Simons, Susan Jenson, and Kevin Larson. 1995. Mapping the response of riparian vegetation to possible flow reductions in the Snake River, Idaho. *Geomorphology* 13: 159-173.

Kellerhals, Rolf, and Don Gill. 1973. Observed and Potential Downstream Effects of Large Storage Projects in Northern Canada. *International Commission of Large Dams*: 731-754.

Kraft, Clifford E., Rebecca L. Schneider, and Dana R. Warren. 2002. Ice storm impacts on woody debris and debris dam formation in northeastern U.S. streams. *Canadian Journal of Fish Aquatic Sciences* 59: 1677-1684.

Kreutzweiser, David P., Kevin P. Good, and Trent M. Sutton. 2005. Large woody debris characteristics and contributions to pool formation in forest streams of the Boreal Shield. *Canadian Journal of Forest Restoration* 35: 1213-1223.

Landry, R., A.A. Assani, and S. Biron. 2013. *River Research and Applications,* DOI: 10.1002/rra.2644.

Langedal, Marianne. 1997. The influence of a large anthropogenic sediment source on the fluvial geomorphology of the Knabeåna—Kvina rivers, Norway. *Geomorphology* 19: 117-132.

Loizeau, Jean-Luc and Janusz Dominik. 2000. Evolution of the Upper Rhone River discharge and suspended sediment load during the last 80 years and some implications for Lake Geneva. *Aquatic Sciences* 62: 54-67.

Moore, J.N., and E.M. Landrigan. 1999. Mobilization of metal-contaminated sediment by ice-jam floods. *Environmental Geology* 37: 96-101.

North, Margaret E A, and Michael Church. Studies of Riparian Vegetation along Peace River, British Columbia. In *The regulation of Peace River.* ms. Edited by Michael Church. In preparation.

Papa, F. C. Prigent, W. B. Rossow. 2007. Ob' River flood inundations from satellite observations: A relationship with winter snow parameters and river runoff. *Journal of Geophysical Research* 112: D18103.

Peters, Daniel L., and Terry D. Prowse. 2001. Regulation effects on the lower Peace River, Canada. *Hydrological Processes* 15: 3181-3194.

Prowse, Terry, Knut Alfredsen, Spyros Beltaos, Barrie R. Bonsal, William B. Bowden, Claude R. Duguay, Atte Korhola, Jim McNamara, Warwick F. Vincent, Valery Vuglinsky, Katey M. Walter Anthony, Gesa A. Weyhenmeyer. 2011. Effects of Changes in Arctic Lake and River Ice. *Ambio* 40:63-74.

Prowse, T D, S. Beltaos, J. T. Gardner, J.J. Gibson, R.J. Granger, R. Leconte, D.L. Peters, A. Pietroniro, L. Romolo, B. Toth. 2006. Climate change, flow regulation and land-use effects on the hydrology of the Peace-Athabasca-Slave System; findings from the Northern Rivers Ecosystem Initiative. *Environmental Monitoring and Assessment* 113: 167-197.

Prowse, T. D., F.M. Conly, M. Church, M.C. English. 2002. A review of hydroecological results of the Northern River Basins Study, Canada. Part 1. Peace and Slave rivers. *River Research and Applications* 18: 429-446.

Prowse, T. D., and F.M. Conly. 2002. A review of hydroecological results of the Northern River Basins Study, Canada. Part 2. Peace-Athabasca Delta. *River Research and Applications* 18: 447-460.

Renöfält, Birgitta Malm, David M. Merritt, and Christer Nilsson. 2007. Connecting variation in vegetation and stream flow: the role of geomorphic context in vegetation response to large floods along boreal rivers. *Journal of Applied Ecology* 44: 147-157.

Scott, Kevin M. 1982. Erosion and Sedimentation in the Kenai River, Alaska. Geological Survey Professional Paper 1235. United States Department of the Interior. Washington, D.C.

She, Yuntong, Faye Hicks, Robyn Andrishak. 2012. The role of hydro-peaking in freeze-up consolidation events on regulated rivers. *Cold Regions Science and Technology* 73: 41-49.

Smith, Derald G. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. *Geological Society of America Bulletin* 87: 857-860.

Smith, Derald G., and Cheryl M. Pearce. 2002. Ice jam-caused fluvial gullies and scour holes on northern river flood plains. *Geomorphology* 42: 85-95.

Stickler, Morten, Knut T. Alfredsen, Tommi Linnansaari, and Hans-Petter Fjeldstad. 2010. The influence of dynamic ice formation on hydraulic heterogeneity in steep streams. *River Research and Applications* 26: 1187-1197.

Svendsen Kristen M., Carl E. Renshaw, Francis J. Magilligan, Keith H. Nislow, and James M. Kaste. 2009. Flow and sediment regimes at tributary junctions on a regulated river: impact on sediment residence time and benthic macroinvertebrate communities. *Hydrological Processes* 23: 284-296.

Syvitski, James P.M. 2002. Sediment discharge variability in Arctic rivers: implications for a warmer future. *Polar Research* 21, no. 2: 323-330.

Takashi Gomi, Roy C. Sidle, Mason D. Bryant, and Richard D. Woodsmith. 2001. The characteristics of woody debris and sediment distribution in headwater streams, southeastern Alaska. *Canadian Journal of Forest Research* 31: 1386-1399.

Takashi Gomi, Roy C. Sidle, Richard D. Woodsmith, and Mason D. Bryant. 2003. Characteristics of channel steps and reach morphology in headwater streams, southeast Alaska. *Geomorphology* 51: 225-242.

Tuthill, A.M., K.D. White, C.M. Vuyovich, and L.A. Daniels. 2009. Effects of proposed dam removal on ice jamming and bridge scour on the Clark Fork River, Montana. *Cold Regions Science and Technology* 55: 186-194.

Uunila, Lars S. 1997. Effects of river ice on bank morphology and riparian vegetation along Peace River, Clayhurst to Fort Vermilion. *The 9th Workshop on River Ice*: 315-334.

Uunila, Lars, and Michael Church. Ice on Peace River: Effects on Bank Morphology and Riparian Vegetation. In *The regulation of Peace River.* ms. Edited by Michael Church. In preparation.

Vadnais, Marie-Ève, Ali A. Assani, Raphaëlle Landry, Denis Leroux, and Denis Gratton. 2012. Analysis of the effects of human activities on the hydromorphological evolution channel of the Saint-Maurice River downstream from La Gabelle dam (Québec, Canada). *Geomorphology* 175-176: 199-208.

White, Kathleen D, and Johnnie N Moore. 2002. Impacts of Dam Removal on Riverine Ice Regime. *Journal of Cold Regions Engineering*: 2-16.

Wuebben, James L., Steven F. Daly, Kathleen D. White, John J. Gagnon, Jean-Claude Tatinclaux, and Jon E. Zufelt. 1995. Ice Impacts on Flow Along the Missouri River. U.S. Army Corps of Engineers, Cold Regiosn Research & Engineering Laboratory, Special Report 95-13.

Yang, Daqing, Baisheng Ye, and Alexander I Shiklomanov. 2004. Discharge Characteristics and Changes over the Ob River Watershed in Siberia. *Journal of Hydrometeorology* 5, no. 4: 595.

Yang, Daqing, Douglas L. Kane, Larry D. Hinzman, Xuebin Zhang, Tingjun Zhang, and Hengchun Ye. 2002. Siberian Lena River hydrologic regime and recent change. *Journal of Geophysical Research* 107, No. D23, 4694.

Yarie, J., Viereck, L., Van Cleve, K., & Adams, P. 1998. Flooding and Ecosystem Dynamics along the Tanana River. *BioScience*, 48(9): 690–695.

Ye, Baisheng, Daqing Yang, and Douglas L. Kane. 2003. Changes in Lena River streamflow hydrology: Human impacts versus natural variations. *Water Resources Research* 39, no. 7, 1200.

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Geomorphology Study (6.5)

Part A - Appendix D
Study Component 9

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

Watershed GeoDynamics

June 2014

TABLE OF CONTENTS

D.1: LARGE WOODY DEBRIS AERIAL PHOTOGRAPH DIGITIZING

1. METHODS

The 2012 or 2013 aerial photographs (1 foot pixel resolution) were (2012 aerials) or will be (2013 aerials) used as a base to digitize large woody debris (LWD) within the Susitna River Geomorphic Feature (GeomFeat) classifications as listed in Table 1.1. Pieces of LWD that are contained wholly or partially within the GeomFeat polygons as noted in Table 1.1 were digitized (e.g., LWD that is contained wholly within vegetated islands (VI), additional open water (AOW) or background (BG) were not digitized, but wood that extends from, for example, VI into main channel (MC) were digitized[1]).

All wood in the middle and upper Susitna River (PRM 102.4 to PRM 261.3) was digitized. In the lower river (PRM 3.3 to PRM 102.4), a sub-sample of wood in the Bar Island Complex and Side Channel Complex features were digitized to obtain representative wood densities on these mobile features.

Table 1.1. Large Woody Debris (LWD) Digitizing within Geomorphic Features

Geomorphic Feature Code	Description	Lower River?	Middle River?	LWD Digitized?
MC/EXP MC	Main Channel	X	X	Yes
SC/EXP SC	Side Channel	X	X	Yes
SCC	Side Channel Complex	X		Sub-sample*
BIC	Bar Island Complex	X		Sub-sample*
BAB	Bar/Attached Bar	X		Sub-sample*
SS/EXP SS	Side Slough	X	X	Yes
US/EXP US	Upland Slough	X	X	Yes
TR/EXP TR	Tributary	X	X	Yes
TD	Tributary Delta	X		Yes
TM, MCTM, SCTM, TRTM	Tributary Mouth (Main Channel TM, Side Channel TM, Tributary TM)		X	Yes
VI	Vegetated Island	X	X	No
AOW	Additional Open Water	X	X	No
BG	Background	X	X	No

* Due to the high number of pieces of large wood on the Side Channel Complex, Bar Island Complex, and Bar/Attached Bar features in the lower river, the large area of complexes, and the likely transient nature of the wood here, these areas were sub-sampled to obtain a density of large wood and log jams. The density of wood features will be apportioned over the total area of Side Channel Complex or Bar Island Complex to estimate total wood loading.

1.1. Individual pieces of LWD

Logs that are within or extend into the designated geomorphic features were digitized as single segment line features from the root wad or thickest end (start of line) to the thinnest end of the LWD (end of line). Digitizing took place at a 1:1,000 scale within ArcMap. Individual pieces of wood with a minimum length of 20 feet were digitized. In log jams (see below), individual pieces that were over 20 feet in length and were discernible were digitized.

[1] Note that the LWD mapping is taking place at the 1:1,000 scale and the geomorphic mapping took place at 1:3000 scale, so some wood along the channel margins may be clearly within the wetted channel based on the aerial photographs at the 1:1000 scale, but may fall within the VI map unit. This wood will be digitized because it is important from a habitat standpoint.

The following attributes were assigned to each individual LWD feature:

- RootWad (Y or N)—is there a visible root wad, defined as visible thickened end, on the piece of LWD? (this is a judgment call, resolution of photos not always good enough to be definitive).
- Jam (Y or N)—is the LWD contained within a log jam, defined as three or more touching pieces of visible/digitized LWD?
- Local_Scr—is the LWD definitively from a local (adjacent bank) source—generally determined to be a local source if the LWD extends perpendicular or at an oblique angle from the vegetated bank into the flow (e.g., not parallel to the bank) or if the piece of large wood has the majority of the branches intact (indicating it was not transported very far).
- Channel Position – the channel position of the wood was identified in the following categories:
    - BJ—Bank Adjacent—adjacent to vegetated bank at the side of a channel
    - AB—Apex of Bar—at the apex of a bar feature
    - DB—Downstream end of Bar—at the downstream end of an unvegetated bar feature
    - SB—Side of a bar—along the side or in the middle of an unvegetated bar feature
    - MDC—Middle of the Channel—within the wetted channel
    - HSC—Head of a Side Channel—spanning the head of a side channel feature
    - SPC—Span Channel—spanning a small channel at a location other than the head of the channel
    - BG—Biogeomorphic, e.g., contained in beaver dam or lodge
- Image Date—the date of the aerial photograph image that was used for digitizing.
- Length (ft)—length of the piece of LWD as calculated within ArcMap from length of the line feature.

1.2. Log Jams

Log jams were digitized as polygon features. Single, distinguishable pieces of LWD within these polygons were also digitized as line features as described above. The following attributes were recorded for log jam features:

- PRM_ID – Project River Mile Identifier coded as PRM-XXX with XXX being sequential number in an upstream direction.
- Channel Position – same as used for individual pieces of wood, described above.
- Image Date – the date of the aerial photograph image that was used for digitizing.
- Area (in square-feet) of the polygon that will be calculated with ArcMap.

1.3. Limitations

- Some pieces of LWD are either partially buried within bar sediments, hidden under the water, obscured by bank vegetation or shadows (on the western shorelines or in small sloughs), or partially obscured within log jams.

- There are also objects within the flow that are obviously large obstructions, but it is not clear due to turbid water conditions if these are root wads, logs, boulders, or other features.
- Scale and resolution of aerial photographs makes it difficult to definitively determine whether or not some pieces have root wads.

The planned field verification will help to determine the magnitude of these limitations.

2. HISTORICAL AERIAL PHOTOGRAPHS

Wood within LWD sample areas will be digitized from the 1980s and 1950s aerial photographs if feasible using methods described above.

D.2: LARGE WOODY DEBRIS INVENTORY FIELD PROTOCOL

1. PURPOSE

- To field-check aerial photograph mapping of large woody debris.
- To collect information on large woody debris that cannot be collected remotely (for example diameter, species, and decay class).
- To provide large woody debris and log jam information and dimensions for 2-D hydraulic/sediment modeling and fisheries habitat modeling.

2. METHODS

Data were (2013 field season) or will be (in the next field season) collected on each piece of large wood in the LWD sample areas described in Section 2.3. Wood over 20 feet in length and 12 inches dbh (diameter breast height) was inventoried within the geomorphic feature codes listed in Table 2.1.

Table 2.1. Large Woody Debris (LWD) Field Data Collection within Geomorphic Feature

Geomorphic Feature Code	Description	Lower River?	Middle River?	LWD Field Data Collection?
MC/EXP MC	Main Channel	X	X	Yes
SC/EXP SC	Side Channel	X	X	Yes
SCC	Side Channel Complex	X		Sub-sample*
BIC	Bar Island Complex	X		Sub-sample*
BAB	Bar/Attached Bar	X		Sub-sample*
SS/EXP SS	Side Slough	X	X	Yes
US/EXP US	Upland Slough	X	X	Yes
TR/EXP TR	Tributary	X	X	Yes
TD	Tributary Delta	X		Yes
TM, MCTM, SCTM, TRTM	Tributary Mouth (Main Channel TM, Side Channel TM, Tributary TM)		X	Yes
VI	Vegetated Island	X	X	No
AOW	Additional Open Water	X	X	No
BG	Background	X	X	No
UPPER RIVER: no geomorphic mapping has been completed in Upper River (upstream of PRM 184.3). Wood will be located using a GPS within similar geomorphic areas as in the middle and lower river (e.g., main channel, side channel, unvegetated bars)				

* Due to the high number of pieces of large wood on the Side Channel Complex, Bar Island Complex, and Bar/Attached Bar features in the lower river, the large area of complexes, and the likely transient nature of the wood here, these areas were sub-sampled to obtain a density of large wood and log jams. The density of wood features will be apportioned over the total area of Side Channel Complex, Bar/Attached Bar or Bar Island Complex to estimate total wood loading.

2.1. Single Pieces

For single pieces of large woody debris not included in a jam (defined as three or more pieces of touching, countable wood), a GPS point was taken at the thickest end and the following information was entered into a Trimble GeoExplorer 6000 GeoXH GPS unit (minimum 20 location counts/point). If it was not possible to take the point at the thick end due to safety or access considerations, an alternate location point along the log was recorded, or an offset point was entered.

- GPS (point) location
  - Thick/root end
  - Thin end
  - Middle
  - Other (note in comments)
- Orientation (degrees) taken from GPS point location toward other end of log using 360 degree compass with declination set to 19° E
- Wood length
  - Length in feet
- Wood diameter category (measured at dbh location or approximately 3 feet from thickest end if no root wad)
  - Less than 6 inches
  - 6-12 inches
  - 12-24 inches
  - 24-36 inches
  - Over 36 inches
- Root wad (Y/N)—defined as root wad if over 3 feet in diameter
- Leaves/branches present (assumes each lower category present if checked)
  - Leaves
  - Twigs (1/2 inch diameter)
  - Branches
  - None
- Bark
  - Intact
  - Some bark transport scoured/abraded
  - Loose
  - Absent
- Surface Texture
  - Intact/firm
  - Abraded/slightly rotted
  - Extensively rotted (some holes/openings)
  - Completely rotted (many holes/openings)
- Species
  - Balsam poplar
  - White spruce
  - Paper birch
  - Alder
  - Other

  - Unknown
- Input mechanism
  - Windthrow
  - Bank erosion
  - Mass wasting
  - Ice processes
  - Unknown
- Channel position
  - BJ – Bank Adjacent—adjacent to vegetated bank at the side of a channel
  - AB – Apex of Bar—at the apex of a bar feature
  - DB – Downstream end of Bar—at the downstream end of an unvegetated bar feature
  - SB – Side of a bar—along the side or in the middle of an unvegetated bar feature
  - MDC – Middle of the Channel—within the wetted channel
  - HSC – Head of a Side Channel—spanning the head of a side channel feature
  - SPC – Span Channel—spanning a small channel at a location other than the head of the channel
  - BG – Biogeomorphic, e.g., contained in beaver dam or lodge
- Wetted/bankfull (classified as wetted if any part within wetted channel at time of survey)
  - Wetted
  - Bankfull channel
- Stability
  - Buried in sediment >50 percent of diameter at any point
  - Anchored on bank (in vegetation)
  - Pinned on boulder/stable vegetation/in jam
  - Unstable
- Function
  - Scour pool
  - Bar forming
  - Island forming
  - Side channel inlet protection
  - Bank protection
  - Aquatic cover
  - Unclear
- Date/Time stamp
- Surveyors
- Comments

2.2. Log Jams

A GPS point was taken at each log jam (defined as three or more touching pieces of wood over 20 feet long) and the following information was entered into a Trimble GeoExplorer 6000 GeoXH GPS unit (minimum 20 location counts/point). Individual pieces of wood within the jams were not entered separately (e.g., not entered as separate points under the "Single Pieces" description in the previous section).

- GPS (point) location
    - Upstream center
    - Middle
    - Left side
    - Right side
    - Downstream center
- Average Jam Length (ft)
- Average Jam Width (ft)
- Average Jam Height (ft)
- Key Member 1
    - Wood Length class
        - 20-35 feet
        - 35-50 feet
        - Greater than 50 feet
    - Wood diameter class (measured at dbh location or approximately 3 feet from thickest end if no root wad)
        - 6-12 inches
        - 12-24 inches
        - 24-36 inches
        - Over 36 inches
    - Root wad (Y/N) – defined as root wad if over 3 feet in diameter
- Key Member 2
    - Wood Length class
        - 20-35 feet
        - 35-50 feet
        - Greater than 50 feet
    - Wood diameter class (measured at dbh location or approximately 3 feet from thickest end if no root wad)
        - 6-12 inches
        - 12-24 inches
        - 24-36 inches
        - Over 36 inches
    - Root wad (Y/N) – defined as root wad if over 3 feet in diameter
- Key Member 3
    - Wood Length class
        - 20-35 feet
        - 35-50 feet
        - Greater than 50 feet
    - Wood diameter class (measured at dbh location or approximately 3 feet from thickest end if no root wad)
        - 6-12 inches
        - 12-24 inches
        - 24-36 inches
        - Over 36 inches
    - Root wad (Y/N) – defined as root wad if over 3 feet in diameter
- Other wood in jam (pieces in each size class – see Table 2.2 for classes)

- Size class 1
- Size class 2
- Size class 3
- Size class 4
- Size class 5
- Size class 6
- Size class 7
- Size class 8
- Size class 9
- Size class 10
- Size class 11
- Size class 12
- Number of pieces with root wads (not including key pieces)

- Jam Channel position
  - BJ – Bank Adjacent—adjacent to vegetated bank at the side of a channel
  - AB – Apex of Bar—at the apex of a bar feature
  - DB – Downstream end of Bar—at the downstream end of an unvegetated bar feature
  - SB – Side of a bar—along the side or in the middle of an unvegetated bar feature
  - MDC – Middle of the Channel—within the wetted channel
  - HSC – Head of a Side Channel—spanning the head of a side channel feature
  - SPC – Span Channel—spanning a small channel at a location other than the head of the channel
  - BG—Biogeomorphic, e.g., beaver dam or lodge
- Wetted/bankfull (classified as wetted if any part within wetted channel at time of survey)
  - Wetted
  - Bankfull channel
- Stability
  - Buried in sediment >50 % of diameter at any point
  - Pinned on boulder/stable vegetation
  - Unstable
- Jam Function
  - Scour pool
  - Bar forming
  - Island forming
  - Side channel inlet protection
  - Bank protection
  - Aquatic cover
  - Unclear
- Date/Time stamp
- Surveyors
- Comments

Table 2.2. Log Jam Individual Piece Size Classes

Length (ft)	Diameter (inches)			
	6-12	12-24	24-36	>36
20-35	1	4	7	10
35-50	2	5	8	11
>50	3	6	9	12

2.3. Large Woody Debris Sample Areas

Table 2.3 shows the proposed distribution of LWD sample areas. Large woody debris was or will be sampled in the following locations assuming safe access is possible:

- All Focus Areas (10).
- 20 (±) sites distributed throughout the Susitna River between the mouth (PRM 3.3) and the Maclaren River (PRM 261.3).

Table 2.3. Large Woody Debris Sample Areas - Proposed Distribution

Geomorph Reach	Reach Breaks (PRM)		Reach Classifi-cation	Slope (ft/mi)	Reach Length (mi)	Focus Area Sample	*Add'l LWD Sample*	Additional LWD Sample Site (PRM) *Red italics- Planned in the next field season*
	Up stream	Down-stream						
Upper Susitna River Segment (UR)						-	*8*	
UR-1	261.3	248.6	SC2	NA	13	-	*1*	*250-251 or 259-260*
UR-2	248.6	234.5	SC1	NA	14	-	*1*	*240-241*
UR-3	234.5	224.9	SC1	NA	10	-	*1*	*231-233*
UR-4	224.9	208.1	SC2	NA	17	-	*2*	*222-224, 211-214 or 208-210*
UR-5	208.1	203.4	SC1	NA	5	-	*1*	*206-207*
UR-6	203.4	187.1	SC2	NA	16	-	*2*	*196-197, 199-201*
Middle Susitna River Segment (MR)						10	5	
MR-1	187.1	184.6	SC2	9	2	*1*		
MR-2	184.6	169.6	SC2	10	15	*1*	*1*	*181*
MR-3	169.6	166.1	SC2	17	4	-	-	
MR-4	166.1	153.9	SC1	30	12	-	*-*	
MR-5	153.9	148.4	SC2	12	6	*1*	-	
MR-6	148.4	122.7	SC3	10	25	4	2	126 135-136
MR-7	122.7	107.8	SC2	8	16	2	2	109-110 121-122
MR-8	107.8	102.4	MC1/SC2	8	6	1	-	
Lower Susitna River Segment (LR)						-	6	
LR-1	102.4	87.9	MC1	5	14	-	1	92-93
LR-2	87.9	65.6	MC2/MC3	5	22	-	1	78-82
LR-3	65.6	44.6	MC3	4	21	-	1	47-51
LR-4	44.6	32.3	MC2	2	13	-	1	40-43
LR-5	32.3	23.5	SC2	2	9	-	1	26-28
LR-6	23.5	3.3	MC4	1.4	20	-	*1*	*9-12*

D.3: LARGE WOODY DEBRIS STUDY AREA MAPS

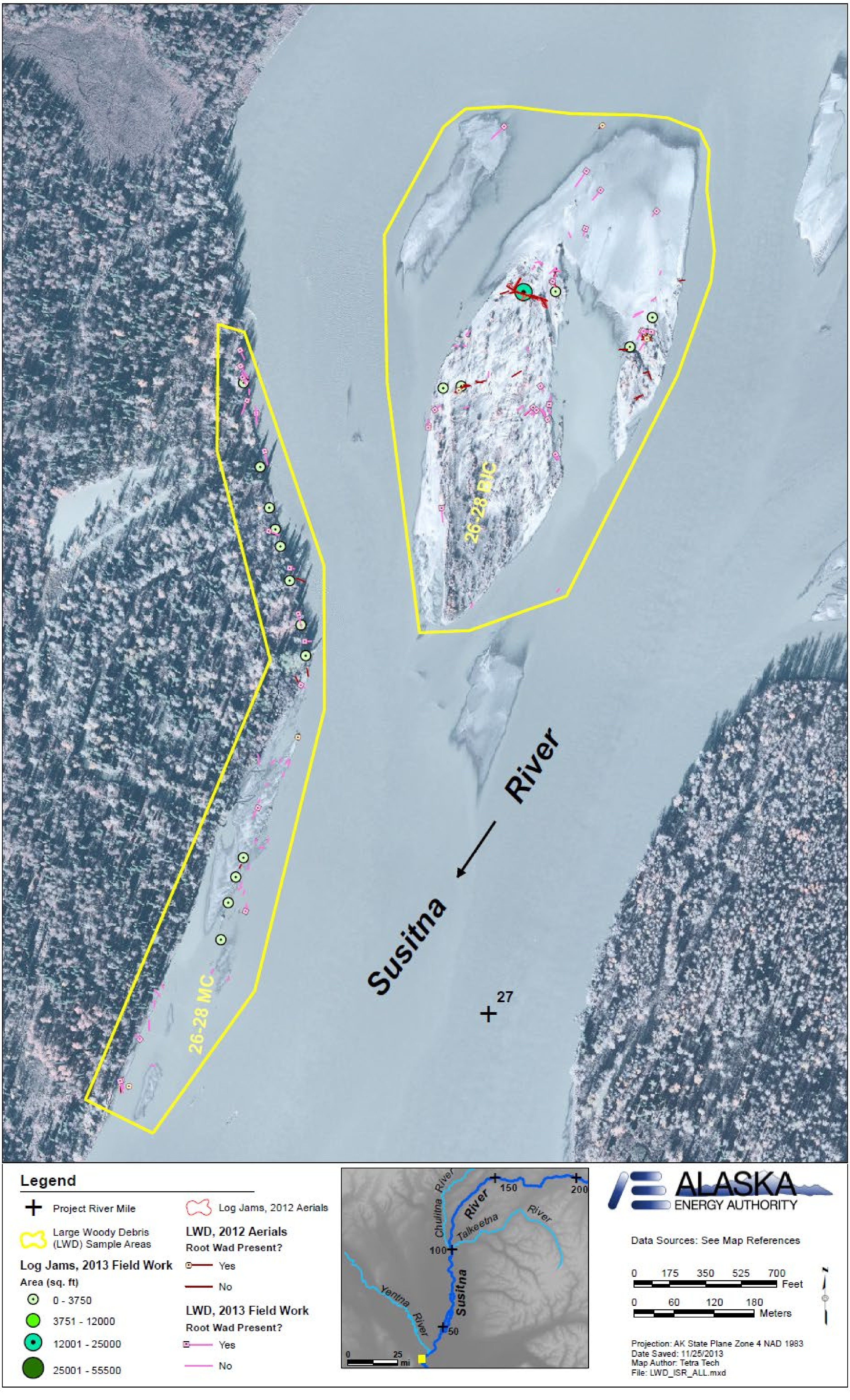

Figure D.3-1: LWD Sample Area PRM 26-28.

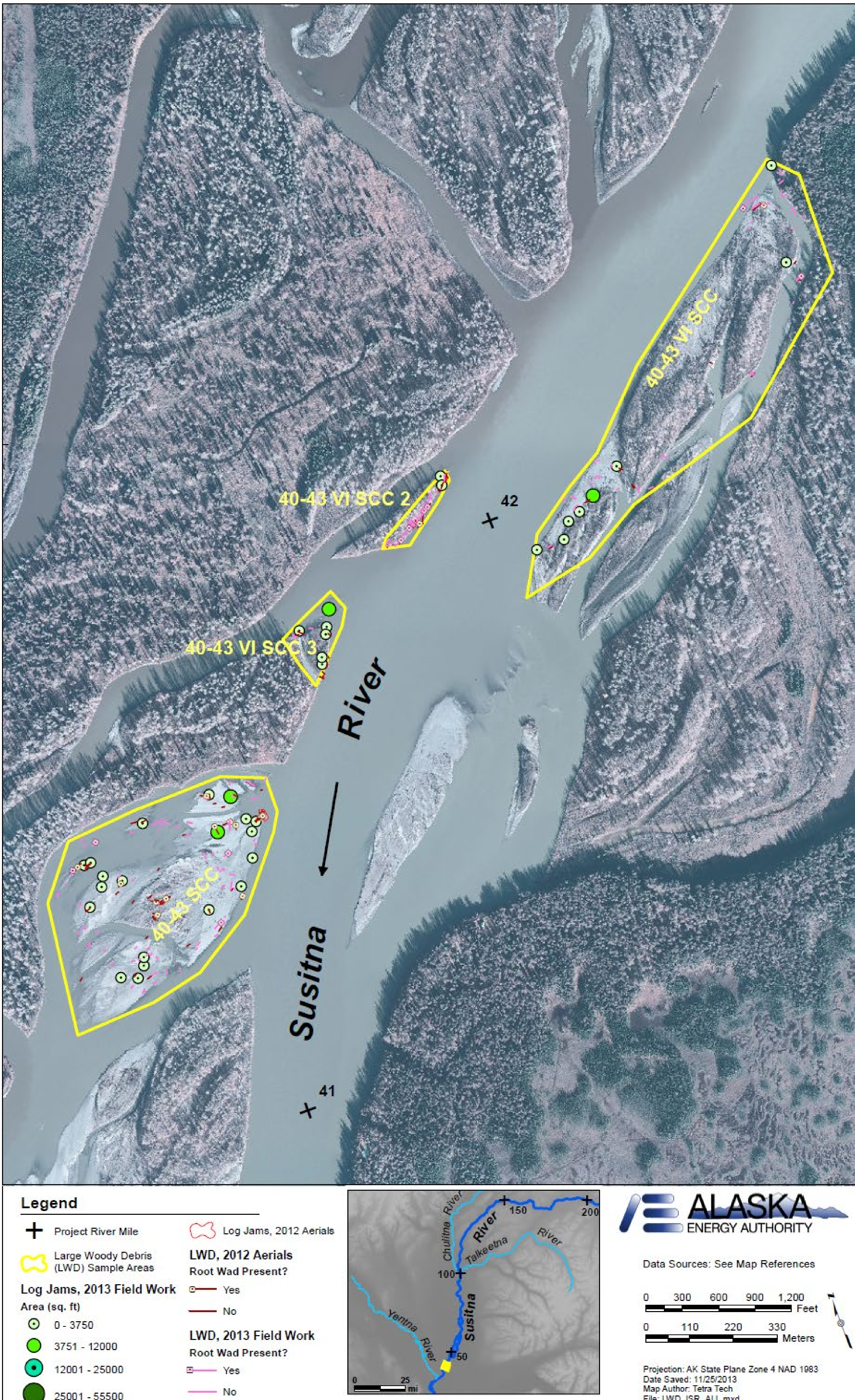

Figure D.3-2: LWD Sample Area PRM 40-43.

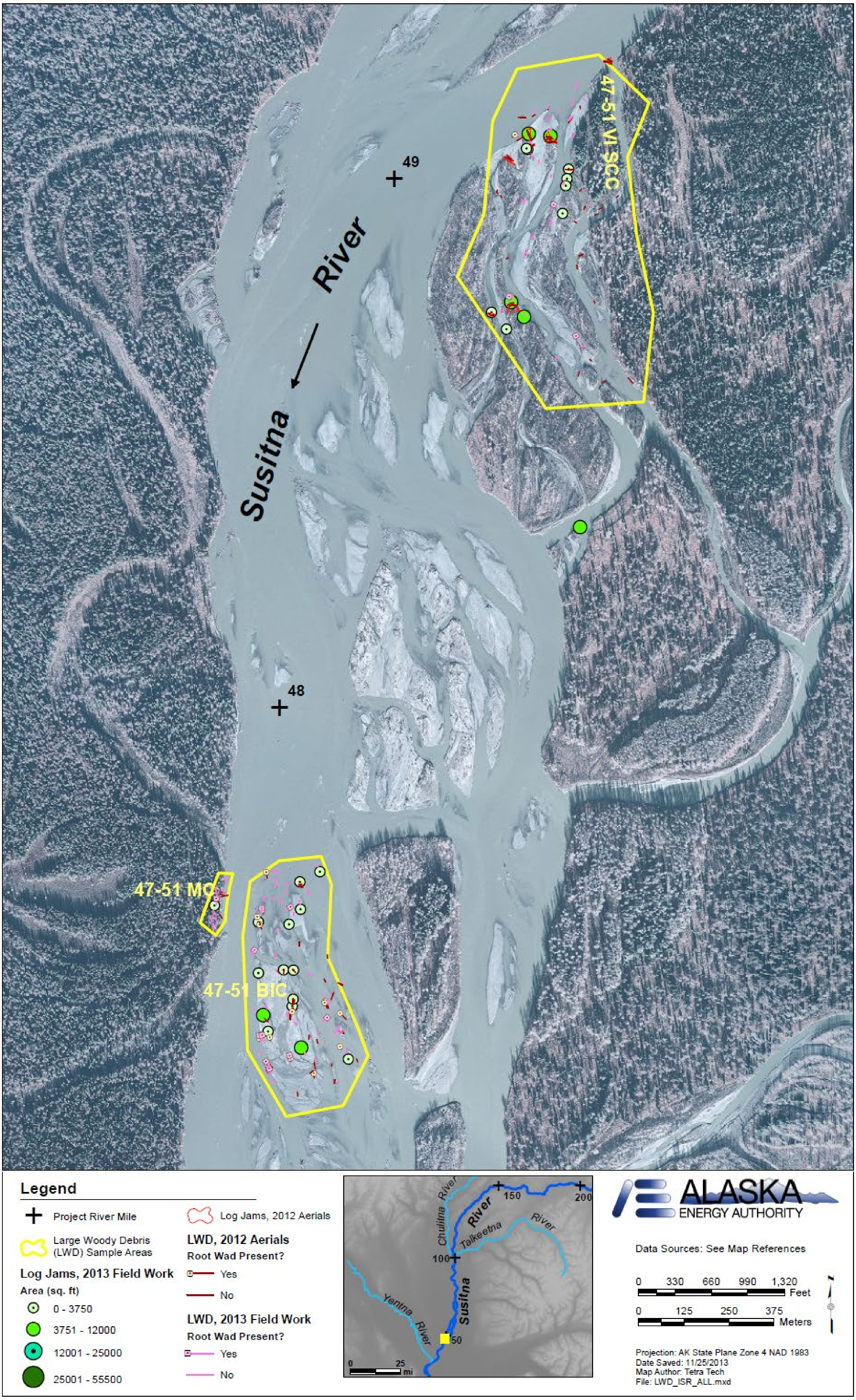

Figure D.3-3: LWD Sample Area PRM 47-51.

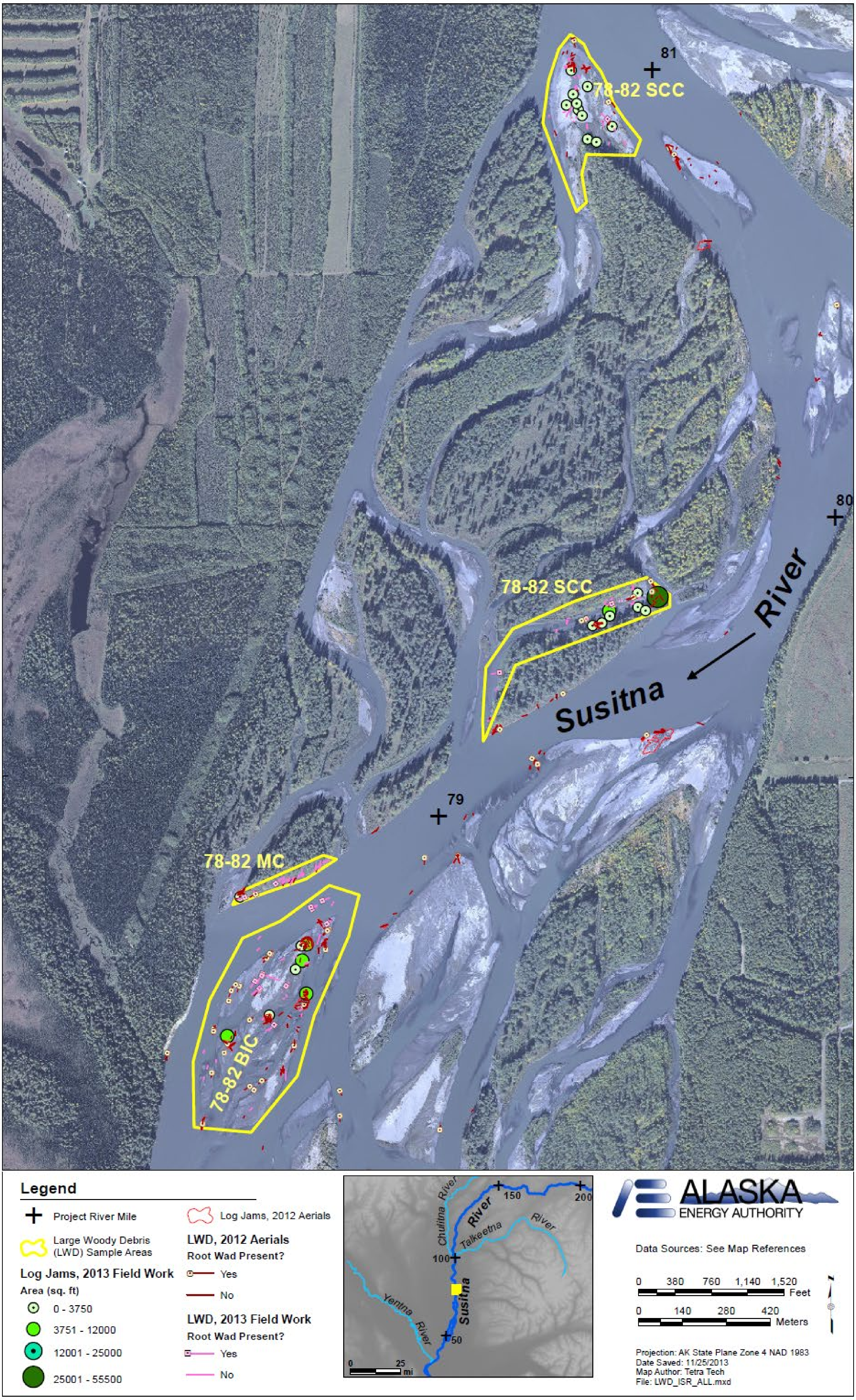

Figure D.3-4: LWD Sample Area PRM 78-82.

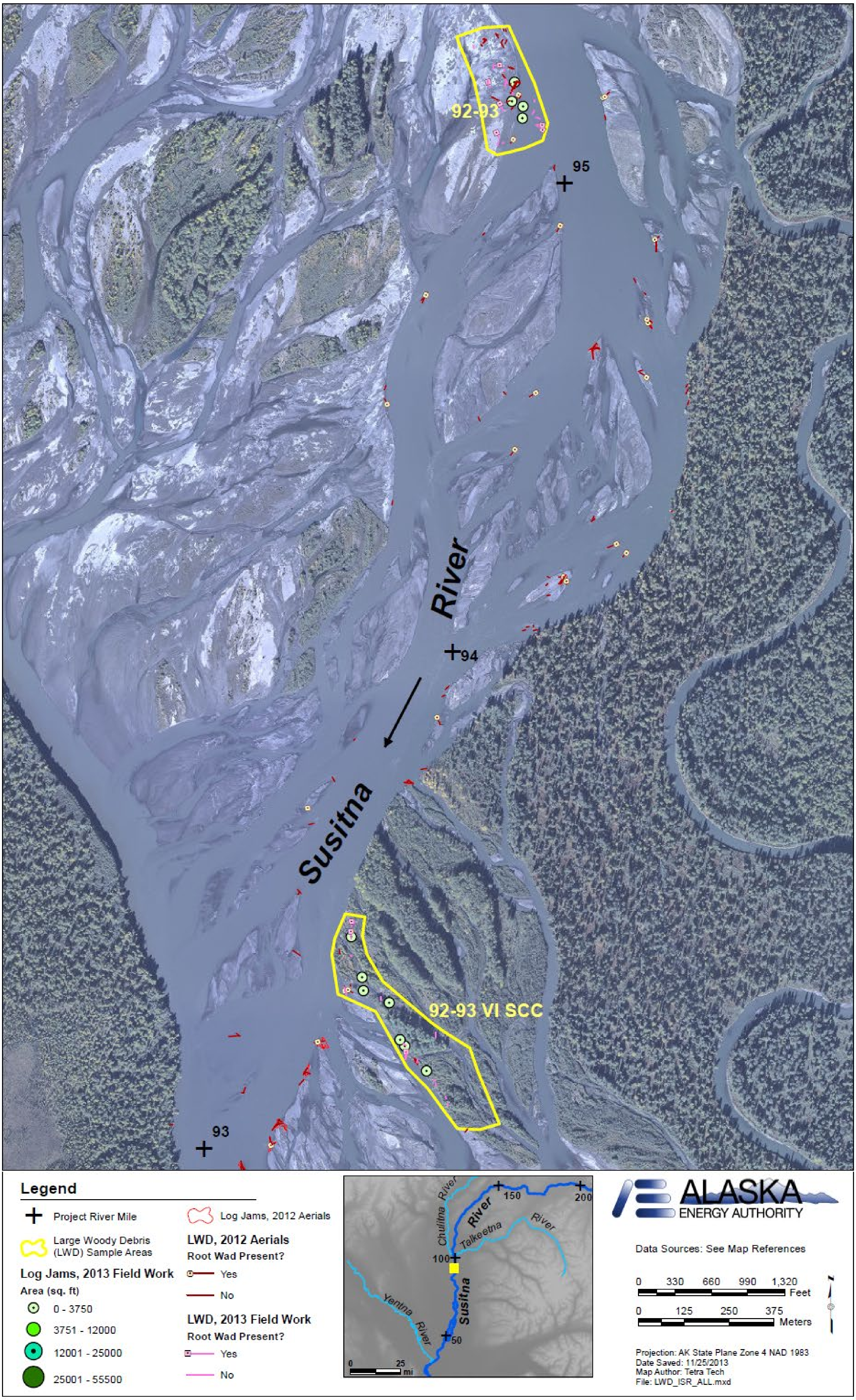

Figure D.3-5: LWD Sample Area PRM 92-93.

Figure D.3-6: LWD Sample Area FA-104 (Whiskers Slough).

Figure D.3-7: LWD Sample Area PRM 109-110.

Figure D.3-8: LWD Sample Area FA-113 (Oxbow I).

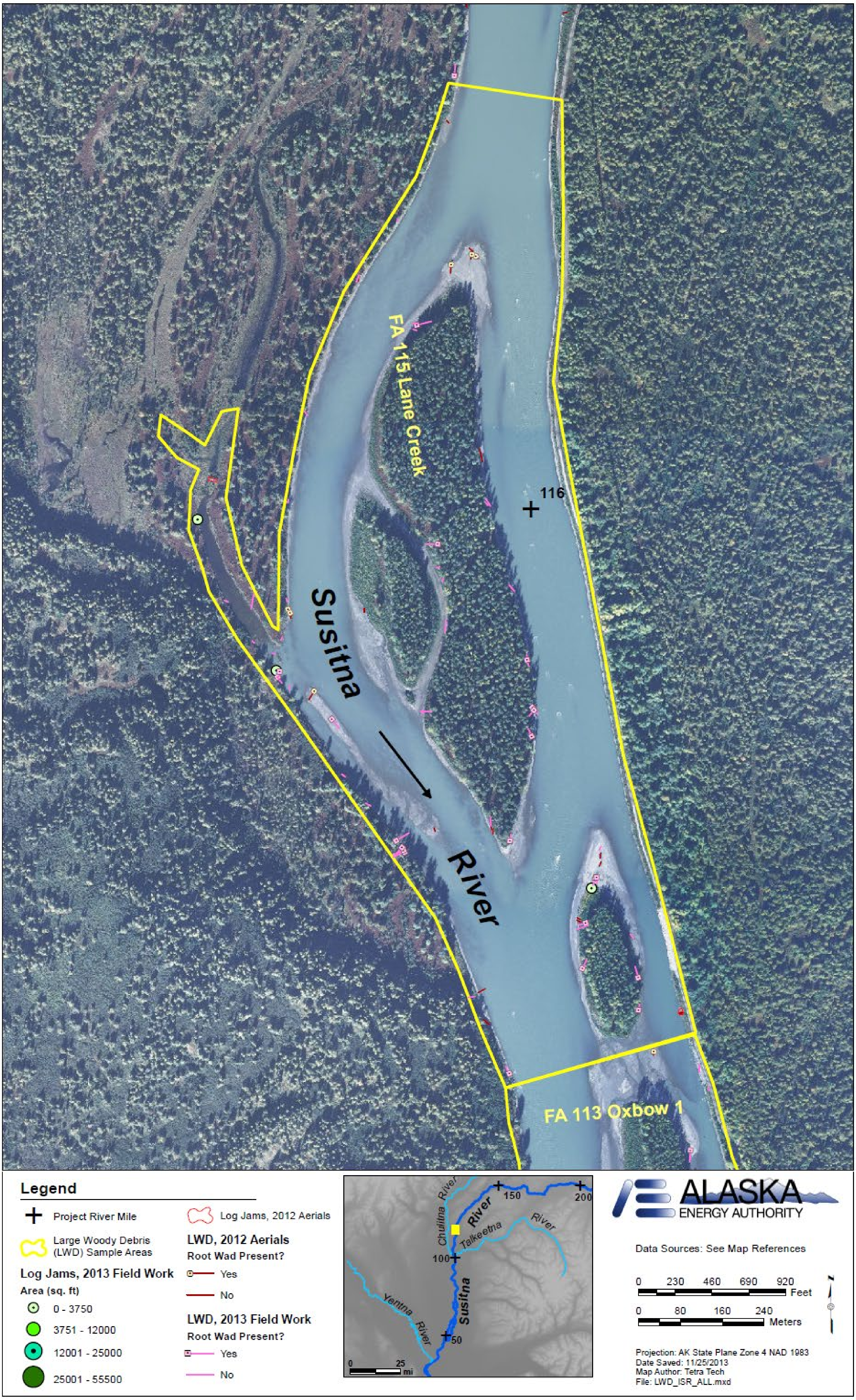

Figure D.3-9: LWD Sample Area FA-115 (Slough 6A).

Figure D.3-10: LWD Sample Area PRM 121-122.

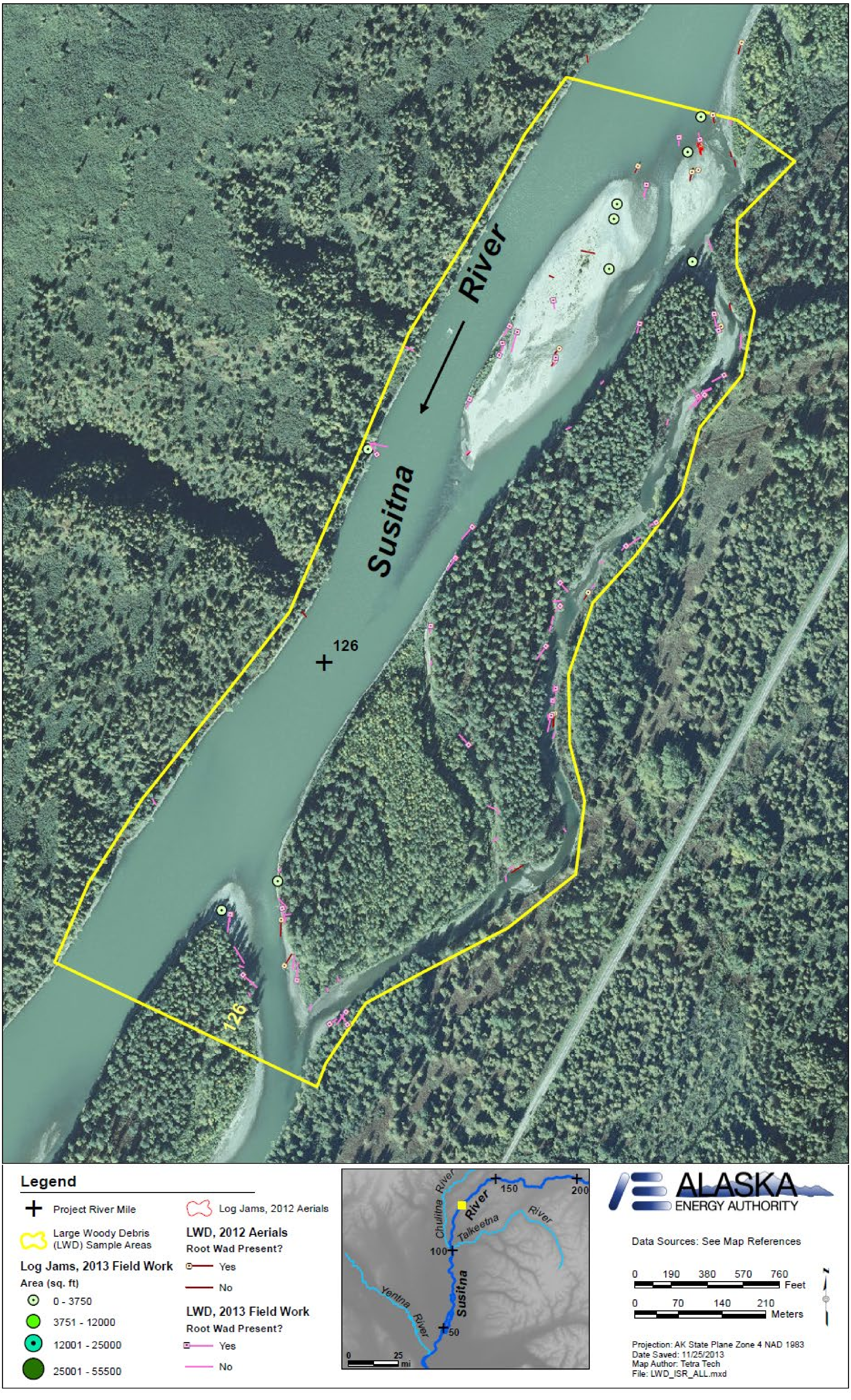

Figure D.3-11: LWD Sample Area PRM 126.

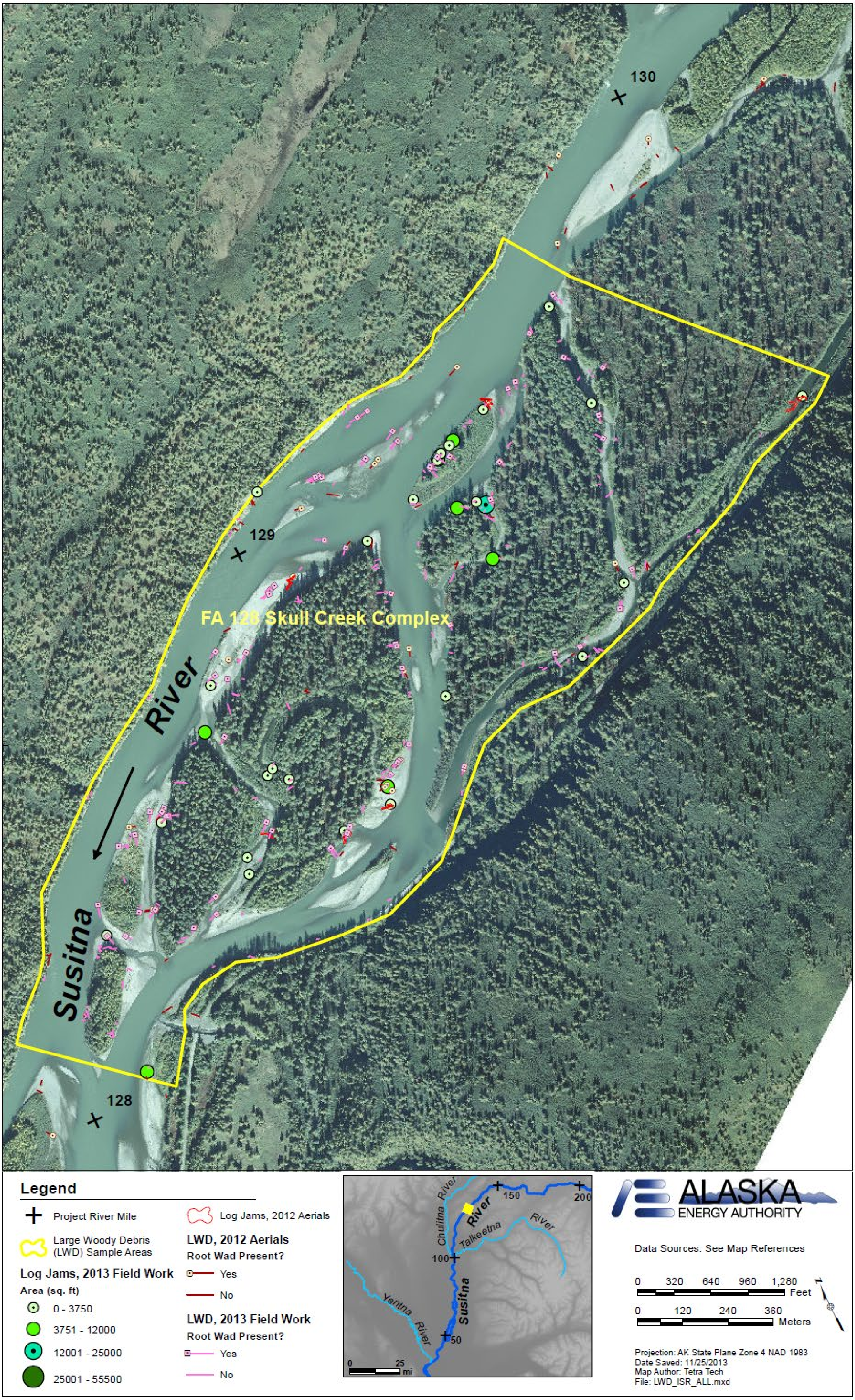

Figure D.3-12: LWD Sample Area FA-128 (Slough 8A).

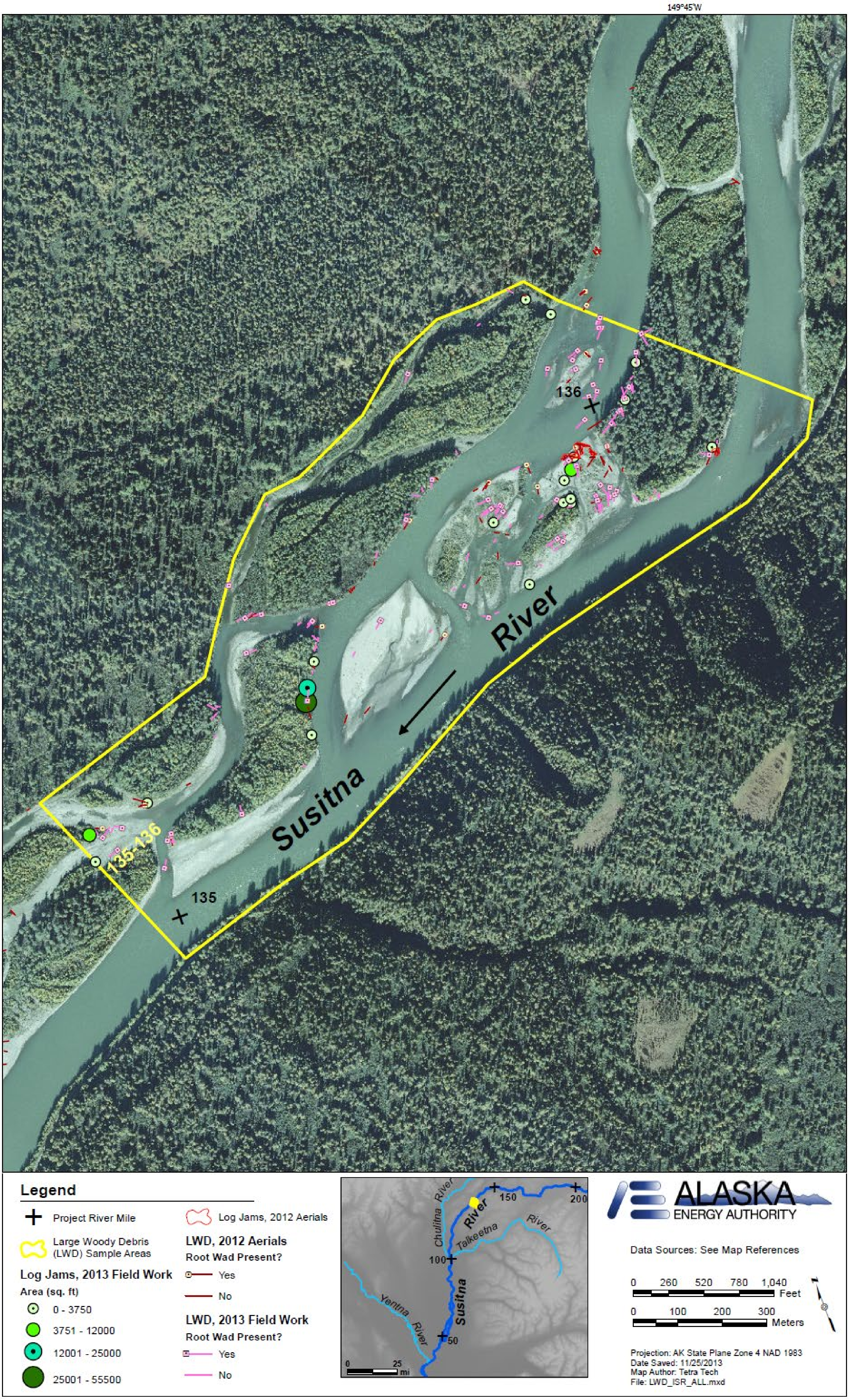

Figure D.3-13: LWD Sample Area PRM 135-136.

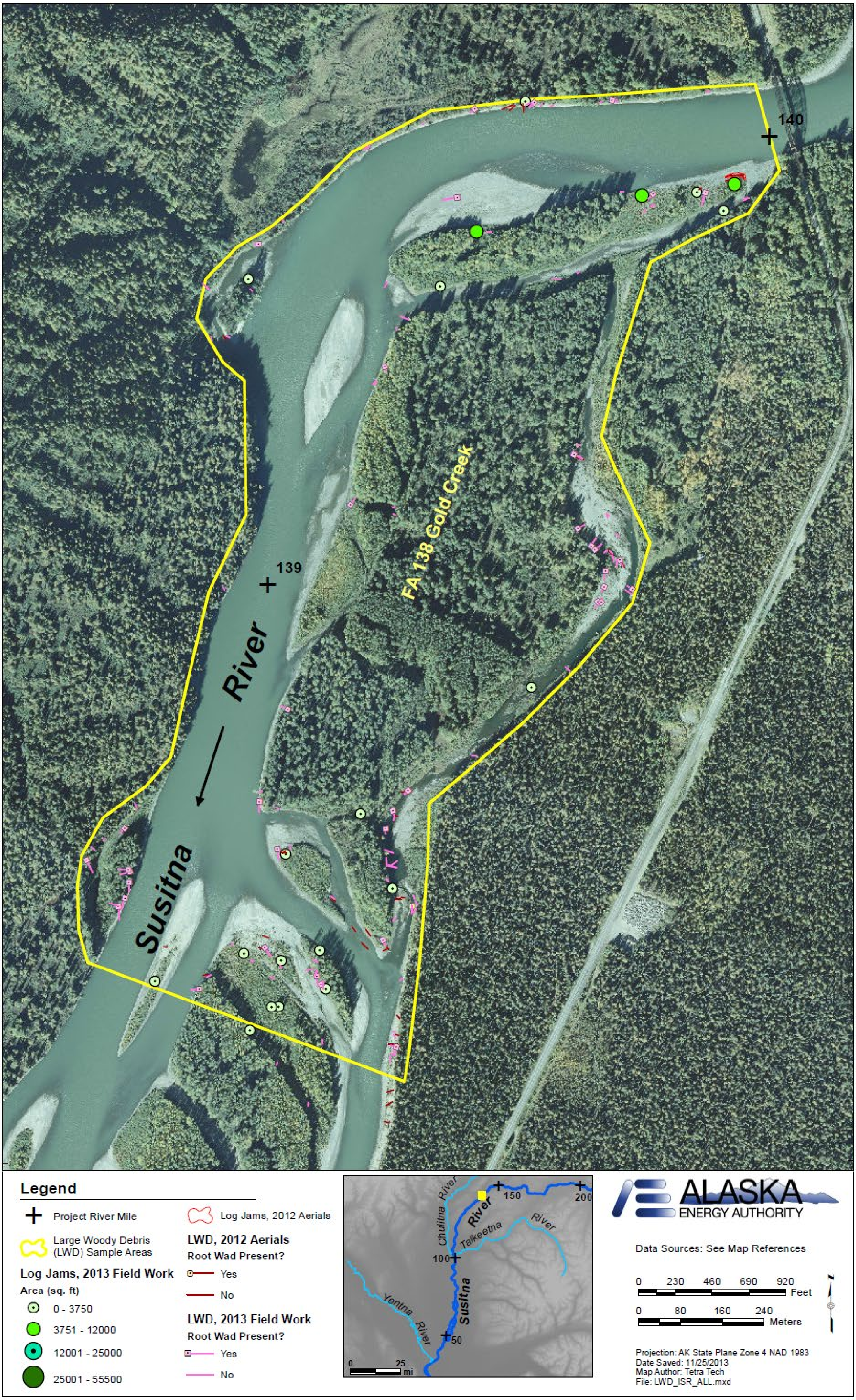

Figure D.3-14: LWD Sample Area FA-138 (Gold Creek).

Figure D.3-15: LWD Sample Area FA-141 (Indian River).

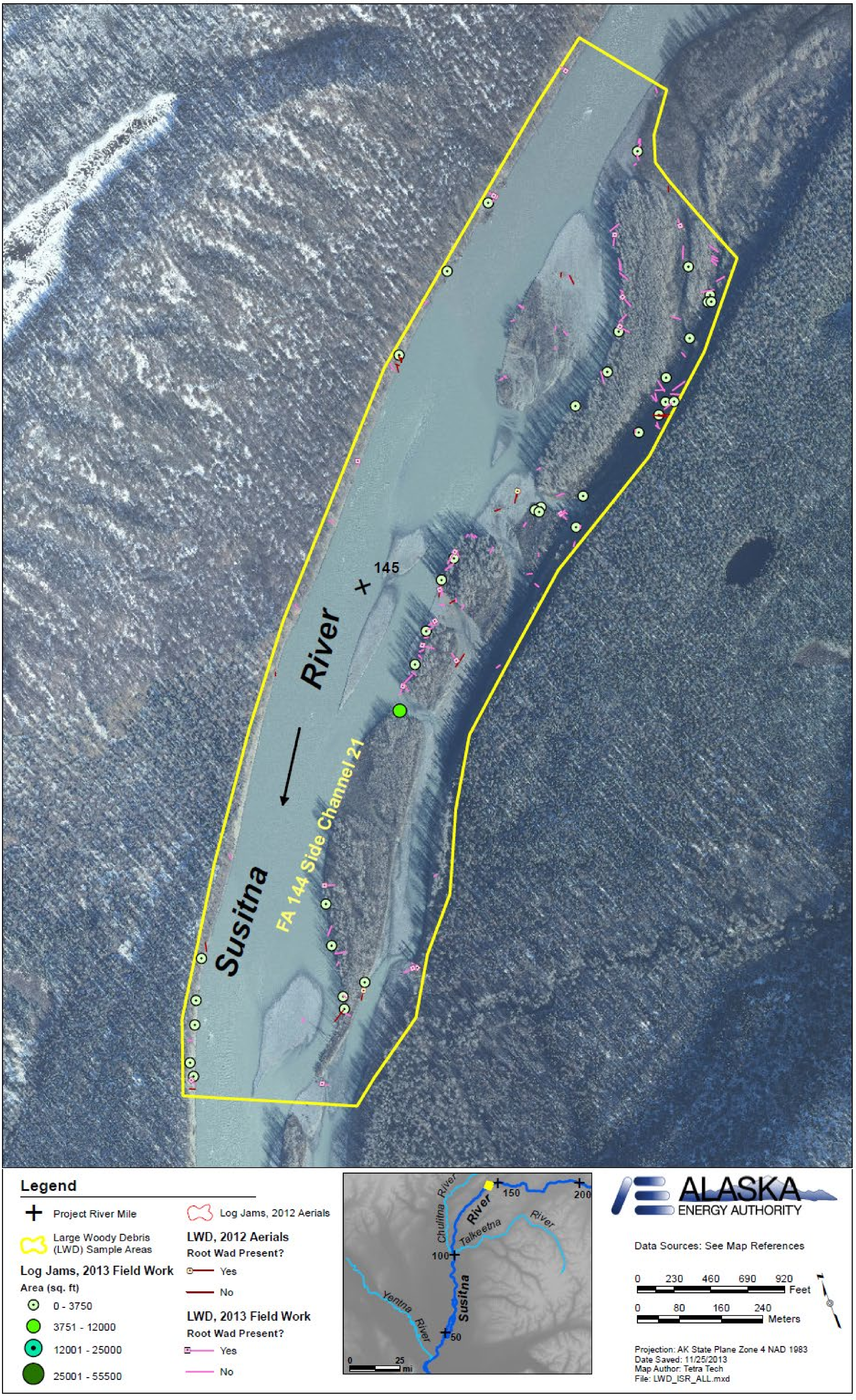

Figure D.3-16: LWD Sample Area FA-144 (Slough 21).

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Geomorphology Study (6.5)

Part A - Attachment A
Susitna River Flow Aerotriangulation Summary

Initial Study Report

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Aero-Metric, Inc.

Tetra Tech

June 2014

PART A - ATTACHMENT A

Sub-Part A: Susitna River Flow Aerotriangulation Summary - September 2013

Sub-Part B: Susitna River Flow Aerotriangulation Summary - November 2013

SUB-PART A: SUSITNA RIVER FLOW AEROTRIANGULATION SUMMARY - SEPTEMBER 2013

Susitna River Flow Aerotriangulation (AT) Summary Part A

Company: Aero-Metric, INC., 2014 Merrill Field Drive, Anchorage, AK 99501
Project Name: **6130605 Susitna River Flow**
Date: **September 2013**

Overview:

• Location: This project is located in south-central Alaska, centered approximately 62.2° North and 149.0° West

• Product: 4-band DMC Imagery, AT results

• Control: · NAD83, Alaska State Plane Zone 4, U.S. Survey Feet, NAVD88 (Geoid09-Alaska)
· Airborne GPS/IMU data collected using an Applanix System during photo acquisition.
· Ground Surveyed Control from Project 6110401 Mat Su DMC

• Imagery: 4-band digital imagery
Images are named with a kernel, underscore, three digits for flightline, tilde, three digits for exposure, underscore, rgbn.
The identifiers in the aerotriangulation have the "_rgbn" truncated from the names.
Example: SRF0001AMI040_001~001 is flight 1, exposure 1, image file SRF0001AMI040_001~001_rgbn.tif

· Nominal Scale: 1:24000 (1"=2000') (flights 24 through 29 not flown as of 2013-10-18)
909 Images

Date:	Mission:	Kernel:		
9-16-2013	G091613A	SRF0001AMI121	DMC121	Flights 30,31,36-38
9-20-2013	G092013A	SRF0002AMI121	DMC121	Flights 31A-35
9-20-2013	H092013A	SRF0001AMI040	DMC040	Flights 1-19
9-24-2013	G092413A	SRF0003AMI121	DMC121	Flights 20-23

Procedure:

• The AT was performed with INPHO MATCH-AT, version 5.5.0
INPHO Project Name: ***6130605_Su_Flow.prj***

Tie points were created using autocorrelation routines and manually measuring points. Control points were manually measured. The project was split into two sub-blocks for processing because of the absent flights. Sub-block "south" contains flights 1 through 23. Sub-block "east" contains flights 30 through 38. The final run is a simultaneous bundle solution for each sub-block.

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

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

The check points in the AT block are photo identifiable points which were measured in a previous project which had the same horizontal and vertical datums. They are relative to the previous project and do not reflect absolute accuracies.

• Residual Summary:

· **Sub-block *south***

RMS control points with default standard deviation set (number: 3)

x	0.913 [feet]
y	1.047 [feet]

RMS control points with default standard deviation set (number: 6)

z	0.202 [feet]

RMS IMU observations (number: 715)

omega	0.008 [deg]
phi	0.007 [deg]
kappa	0.011 [deg]

RMS GNSS observations (number: 715)

x	0.211 [feet]
y	0.210 [feet]
z	0.188 [feet]

mean standard deviations of rotations

omega	0.8 [deg/1000]
phi	0.9 [deg/1000]
kappa	0.8 [deg/1000]

mean standard deviations of translations

x	0.102 [feet]
y	0.114 [feet]
z	0.240 [feet]

mean standard deviations of terrain points

x	0.143 [feet]
y	0.115 [feet]
z	0.447 [feet]

Sigma naught : 1.7 [micron] = 0.1 [pixel in level 0]

· **Sub-block *east***

RMS control points with default standard deviation set (number: 0)

x	0.000 [feet]
y	0.000 [feet]

RMS control points with default standard deviation set (number: 2)

z	0.188 [feet]

RMS IMU observations (number: 190)

omega	0.005 [deg]
phi	0.004 [deg]
kappa	0.010 [deg]

RMS GNSS observations (number: 190)

x	0.203 [feet]
y	0.182 [feet]
z	0.233 [feet]

mean standard deviations of rotations

omega	0.9 [deg/1000]
phi	0.9 [deg/1000]
kappa	0.9 [deg/1000]

mean standard deviations of translations

x	0.112 [feet]
y	0.110 [feet]
z	0.447 [feet]

mean standard deviations of terrain points

x	0.141 [feet]
y	0.158 [feet]

z 0.603 [feet]

Sigma naught : 1.7 [micron] = 0.1 [pixel in level 0]

• Included AT text files:

6130605_Su_Flow_EO.txt
· Adjusted exterior orientation parameters for all exposure stations

6130605_Su_Flow_aat.log
· AT output with residuals and standard deviations for each exposure and control point in the AT adjustment

• other files

6130605_Su_Flow_Layout.pdf
· PDF file with photo center Layout

camera_INPHO_AME121_2013.txt
camera_INPHO_DMC040_2012.txt
· Text file with INPHO formatted camera definition

camera_SummitEV_AME121_2013.txt
camera_SummitEV_DMC040_2012.txt
· Text file with SummitEV formatted camera definition

SUB-PART B: SUSITNA RIVER FLOW AEROTRIANGULATION SUMMARY - NOVEMBER 2013

Susitna River Flow Aerotriangulation (AT) Summary Part B

Company: Aero-Metric, INC., 2014 Merrill Field Drive, Anchorage, AK 99501
Project Name: **6130605 Susitna River Flow**
Date: **November 2013**

Overview:

• Location: This project is located in south-central Alaska, centered approximately 62.2° North and 149.0° West

• Product: 4-band DMC Imagery, AT results

• Control: · NAD83, Alaska State Plane Zone 4, U.S. Survey Feet, NAVD88 (Geoid09-Alaska)
· Airborne GPS/IMU data collected using an Applanix System during photo acquisition.
· Ground Surveyed Control from Project 6110401 Mat Su DMC

• Imagery: 4-band digital imagery
Images are named with a kernel, underscore, three digits for flightline, tilde, three digits for exposure, underscore, rgbn.
The identifiers in the aerotriangulation have the "_rgbn" truncated from the names.
Example: SRF0004AMI040_024~001 is flight 24, exposure 1, image file SRF0004AMI040_024~001_rgbn.tif

· Nominal Scale: 1:24000 (1"=2000')
(909 Images are in Part 1)
101 Images are in Part 2

Date:	Mission:	Kernel:		
11-06-2013	G110613A	SRF0004AMI121	DMC121	Flights 24-29

Procedure:

• The AT was performed with INPHO MATCH-AT, version 5.5.0
INPHO Project Name: ***6130605_SU_Flow_2.prj***
(Reference ***6130605Su_Flow.prj*** from Part 1)

Tie points were created using autocorrelation routines and manually measuring points. Control points were manually measured. The final run is a simultaneous bundle solution.

Only one surveyed control point from the Mat Su DMC project falls on the imagery for this area, point 2014 which was used vertically only (constrained to default standard deviations). To ensure continuity with Part 1, 19 photo identifiable points were passed from Part 1 and measured as control in Part 2, with relaxed constraints on those points (held to Class 1 standard deviations).

The check points in the AT block are photo identifiable points which were measured in a previous project which had the same horizontal and vertical datums. They are relative to the previous project and do not reflect absolute accuracies.

• Residual Summary:

· **Complete Block**

RMS control points with default standard deviation set (number: 1)

z	0.094 [feet]

RMS control points with standard deviation set 1 (number: 19)

x	0.671 [feet]
y	1.238 [feet]

RMS control points with standard deviation set 1 (number: 19)

z	0.326 [feet]

RMS IMU observations (number: 101)

omega	0.004 [deg]
phi	0.004 [deg]
kappa	0.018 [deg]

RMS GNSS observations (number: 101)

x	0.229 [feet]
y	0.237 [feet]
z	0.169 [feet]

mean standard deviations of rotations

omega	0.7 [deg/1000]
phi	0.7 [deg/1000]
kappa	0.6 [deg/1000]

mean standard deviations of translations

x	0.103 [feet]
y	0.096 [feet]
z	0.194 [feet]

mean standard deviations of terrain points

x	0.128
y	0.164
z	0.425

Sigma naught : 1.8 [micron] = 0.1 [pixel in level 0]

• Included AT text files:

6130605_SU_Flow_2_EO.txt

· Adjusted exterior orientation parameters for all exposure stations

6130605_SU_Flow_2_aat.log

· AT output with residuals and standard deviations for each exposure and control point in the AT adjustment

• other files

6130605_Su_Flow_2_Layout.pdf

· PDF file with photo center Layout

camera_INPHO_AME121_2013.txt

· Text file with INPHO formatted camera definition

camera_SummitEV_AME121_2013.txt

· Text file with SummitEV formatted camera definition