Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fluvial Geomorphology Modeling below Watana Dam
Study Plan Section 6.6

2014-2015 Study Implementation Report

Attachment 1

2014 Fluvial Geomorphology Model Development Technical Memorandum

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

Tetra Tech

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	**Definition**
1-D	One-dimensional
2-D	Two-dimensional
AEA	Alaska Energy Authority
BEI	Bank Energy Index
cfs	cubic feet per second
D/S	Downstream
FA(s)	Focus Area(s)
FERC	Federal Energy Regulatory Commission
HEC-RAS	Hydrologic Engineering Centers River Analysis System
LiDAR	Light detecting and ranging
LWD	Large woody debris
m	Meter
OS	Operational Scenario
PDO	Pacific Decadal Oscillation
POC	Proof of Concept
PRM	Project River Mile
RSP	Revised Study Plan
SPD	Study Plan Determination
SRH-1D (2D)	Sedimentation and River Hydraulics-One Dimension (Two Dimensions)
U/S	Upstream
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

1. INTRODUCTION

The Alaska Energy Authority (AEA) is preparing a license application that will be submitted to the Federal Energy Regulatory Commission (FERC) for the Susitna-Watana Hydroelectric Project (Project) using the Integrated Licensing Process (ILP). The Project is located on the Susitna River, an approximately 300-mile-long river in the south-central region of Alaska. The Project's dam site will be located at Project River Mile (PRM) 187.1. The results of this study will provide information needed to support the FERC's National Environmental Policy Act (NEPA) analysis for the Project license.

The Project will alter flow rates and sediment supply downstream of the dam, and the channel form is expected to respond to the changes. To evaluate the changes, Fluvial Geomorphology Modeling (FGM) studies were developed to assess the potential effects of the Project on the dynamic behavior of the river downstream of the proposed dam, with particular focus on potential changes in instream and riparian habitats.

The three study components for the Fluvial Geomorphology Modeling study are:

1. Bed Evolution Model Development, Coordination, and Calibration
2. Model Existing and with-Project Conditions
3. Coordination and Interpretation of Model Results

In May 2014, AEA submitted an Updated Fluvial Geomorphology Modeling (FGM) Approach Technical Memorandum (Tetra Tech 2014a) to Federal Energy Regulatory Commission (FERC) that described the purpose and methodology of the 1- and 2-dimensional sediment transport modeling. The memorandum addressed items including:

- Selection of 1- and 2-D hydraulic and sediment transport models, including the rationale, criteria and descriptions of the available models.
- Location and extent of 1- and 2-D models.
- Overview of the model development procedure.
- Approaches for using the 1- and 2-D models to evaluate potential changes in channel characteristics over time and provide information to other studies including the aquatic habitat modeling.

Attachment A of the Updated FGM Approach TM (Tetra Tech 2014a) is the hydraulic modeling Proof of Concept (POC) for FA-128 (Slough 8A). The POC exercise was intended primarily as a demonstration that the results of the detailed 2-D hydraulic model could be used for aquatic habitat analysis, but it incorporated aspects of each of the three FGM study components. For study component 1, the POC demonstrated:

- the use of land survey, bathymetric, and LiDAR data to develop the model network
- the use of aerial imagery and field observations to delineate cover properties for the network
- coordination with the Fish and Aquatics Instream Flow Study (IFS) (Study 8.5) to make sure the model results included the required variables (velocity, depth, bed scour, shear

stress) at the desired model resolution (down to 2m for some areas) for the appropriate range of flows.
- calibration results of the hydraulic model including comparisons with measured water surface elevations, velocities, and flow distribution (discharges measured in the main channel and lateral features).

For study component 2, the POC demonstrated that results of the 2-D hydraulic model can be used to evaluate habitat conditions for existing and with-Project conditions for year zero conditions. For this initial condition the channel and riparian vegetation properties would be the same for both existing and any with-Project operational scenario. The differences at year zero are only the changes in flow and sediment from the proposed dam. Because the Project is anticipated for an initial 50-year license period, additional analyses are required to estimate channel, vegetation, and habitat characteristics into the future.

For study component 3, the POC demonstrated:

- setup of file structure to transfer the required variables to be used in the aquatic habitat models
- coordination with IFS on the inclusion of groundwater sources into the 2-D hydraulic model results to better represent lateral habitats that are not always connected to main channel at the upstream end of the lateral feature
- interpretation of model results to use bed shear stress and substrate material size to evaluate whether spawning areas are likely to scour.

The ISR (Study 6.6 Section 7.2.1.1.5) states that “Model development, calibration and validation efforts will be documented as the work progresses” during 1-D and 2-D model calibration and validation. This technical memo is a demonstration of using 1-D reach-scale and 2-D local-scale bed morphology models to more fully address study component 2. The main body of this TM includes the methods, results and discussion related to the reach- and local-scale models. There are two appendices to this TM, which provide detail on the model geometric and variable inputs, and model calibration and validation for the 1-D (Appendix A) and 2-D (Appendix B) bed evolution models.

The reach-scale model is used to analyze 50-years of existing and with-project conditions for the majority of the Susitna River below the proposed dam. The local-scale models are used to analyze conditions at the focus areas at years 0, 25, and 50. This technical memo includes the development, calibration, and validation of the models, as well as the application of these models for existing conditions and a with-Project operational scenario. In the future, it is planned to run the reach- and local-scale models for existing conditions and several operational scenarios as needed. At this point in this study, only the Maximum Load Following OS-1b (Max LF OS-1b) hydrologic conditions have been considered; in this document, this condition is referred to as the with-Project conditions.

The models included in this technical memorandum are initial models that will be finalized as the project advances. They are considered initial models because coordination with other studies is ongoing and data collection efforts were ongoing during model development, calibration, and implementation. The additional coordination includes additional tributary hydrologic information provided by IFS (Study 8.5) and additional operational scenarios that will be considered. The additional data that were collected in 2014 and need to be incorporated are:

- channel cross section surveys conducted in the Middle and Lower Susitna River Segments
- cross section discharge and water surface elevation measurements conducted at surveyed cross sections
- high-density LiDAR collected in the Middle Susitna River
- detailed bathymetry collected at several focus areas
- stage hydrographs collected using pressure transducers at locations within focus areas
- discharge measurements collected in lateral features at focus areas to provide groundwater sources for 2-D hydraulic modeling
- Susitna River bed and bank material samples that were collected for areas upstream of PRM 146 that were not accessible prior to the 2014 summer field season
- tributary surveys and bed material samples, especially for tributaries upstream of PRM 146

One other future addition to the initial 1-D model will be the inclusion of the Chulitna and Talkeetna Rivers as tributary reaches. The effects of these major tributaries are currently included as flow and sediment inputs rather than as reaches. This change will more fully address the potential for interaction between the Susitna River and these tributaries.

2. STUDY OBJECTIVES

The purpose of this technical memorandum is to document the development, calibration, validation, and application of the initial 1- and 2-D sediment transport models. The objectives of the effort covered by this technical memorandum were to:

- Develop and calibrate/validate the initial 1-D sediment transport model of the Susitna River and tributaries
- Demonstrate the application of the initial 1-D model to evaluate the existing conditions along the Susitna River
- Develop initial tributary sediment inflows
- Develop and validate an initial 2-D sediment transport model of FA-128 (Slough 8A)
- Demonstrate the approach within the Geomorphology Modeling below Watana Dam Study (Study 6.6) to determine the likely changes to physical conditions that help describe habitats through time and space for existing and with-Project conditions

2.1. Background

A full description of the 1- and 2-D modeling approaches is provided in Tetra Tech (2014a). Much of the following modeling approach discussion is summarized from that document.

The proposed modeling approach considers the need to address both reach-scale and local-scale conditions and the practicality of developing and applying various models based on data collection needs, computational time, analysis effort, and model limitations. Based on these considerations, an approach that uses 1-D models to address reach-scale issues and 2-D models to address local-scale issues was developed.

The 1-D models are being used to evaluate the general hydraulic and sediment-transport characteristics from the proposed Watana Dam site (PRM 187.1) to Susitna Station (PRM 29.9).

Susitna Station is identified as the downstream FGM study limit based on the initial 1-D bed morphology modeling that indicated that Project-related effects on flow and sediment conditions below this point are small compared to the range of natural variability (Tetra Tech 2014b).

The 2-D models are being used to evaluate the detailed hydraulic and sediment-transport characteristics at locations where it is necessary to consider the more complex flow patterns to understand and quantify flow distribution, habitat, lateral feature breaching, and erosion and deposition issues related to changing hydrology, sediment supply, ice, and LWD conditions. Two types of 2-D models are required for open water flow conditions. High-resolution models are required to provide detailed hydraulic information for habitat analyses. These high-resolution models are over a range of flows to provide hydraulic information at specific discharges. Less spatially refined models are required for bed evolution simulations because of the added computation demands of sediment transport and long run times required by unsteady flow conditions. These models are of sufficient detail for sediment transport analyses and are run for a range of representative annual open-water flow hydrographs.

The 2-D models are being applied to Focus Areas that are representative of important habitat conditions and the various geomorphic reaches. These sites were chosen in coordination with the Fish and Aquatics Instream Flow, Riparian Instream Flow, Ice Processes, and Fish and Aquatic Resources studies to facilitate integration of available information between the studies (see Sections 6.6.4.1.2.4, 8.5.4.2.1.2, and 8.6.3.2 of the Revised Study Plan (RSP), AEA 2012; R2 Resource Consultants 2013a, 2013b).

In addition to the reach-scale 1-D models for existing and with-project conditions, 1-D models are being developed for a selected subset of tributaries to provide sediment inputs to both the reach-scale model and the 2-D Focus Area models. These tributaries are being evaluated using models developed with cross section and bed material data collected near the mouth and using tributary flows developed from the other studies. The reach-scale model is used to develop boundary conditions for the 2-D models that include water-surface elevation versus discharge rating curves for the downstream boundary, and the sediment supply at the upstream boundary.

The integration of the 1-D reach-scale modeling with the local-scale 2-D Focus Area modeling provides the following advantages:

- The 1-D model allows for efficient assessment of the hydraulic conditions and sediment-transport balance over the length of the study reach between Watana Dam and Susitna Station.
- The 1-D model reaches will extend up the Chulitna and Talkeetna Rivers to more fully represent these sediment sink/sources and to evaluate potential Project effects on the morphology and flooding potential of these tributary channels.
- The 1-D model uses cross-sectional data that were obtained as part of the Open-Water Flow Routing portion of the Instream Flow studies plus additional cross sections to represent stream-wise variation in planform and profile.
- The 1-D model provides the boundary conditions for the 2-D model in the Focus Areas, including starting water-surface elevations and upstream sediment supply.
- The 1-D model will provide reach-scale evaluation of potential sediment-transport effects due to changes in LWD amounts.
- The 2-D model applied at the Focus Areas, which are also being evaluated for the ice processes and riparian instream flow studies, allows for the fullest level of integration of

these efforts, particularly as they relate to assessments of potential changes in channel width and pattern.

- The 2-D model can provide additional information on erosion and sedimentation processes related to ice jam surge, channel and lateral features blockage by ice, and flows diverted onto floodplain areas by ice jams.
- The 2-D model at the Focus Areas will provide an understanding of the hydraulic conditions and sediment-transport processes that contribute to formation of individual habitat types.
- The 2-D model at the Focus Areas will be used to evaluate flow conditions and bed mobilization around LWD obstructions.
- The 2-D model provides a much more detailed and accurate representation of the complex hydraulic interaction between the main channel and the lateral habitats than possible with a 1-D model.

2.2. Comprehensive Modeling Approach

As described above, 1-D modeling is being used to evaluate reach-scale channel morphology and 2-D modeling is being used at the focus areas for channel morphology and habitat analyses.

These models require input (boundary conditions) of inflowing water and sediment, and downstream water surface (stage-discharge relationships). Sediment sampling provided bed material gradations for the 1- and 2-D morphology modeling and field observations and calibration were used to establish roughness values for all the morphology and hydraulic models. Therefore, the various types of models will need to be conducted in a sequence where certain models or analyses provide input to other models. For example, the dam operations model is being used to provide flow hydrographs to the 1- and 2-D morphology models and the 2-D hydraulic models are being used to provide hydraulic results for the habitat analysis models.

Table 2.2-1 illustrates the series of four types of models that comprise the majority of the fluvial geomorphology modeling component of the study. For each of these model types the hydrology, sediment, hydraulic, and geometric (channel and floodplain) input and results are summarized. The source of the input information is identified when it is provided by another study component. The type of information that will be used by other study components is identified for the fluvial geomorphic modeling results.

A prerequisite for the 1-D reach-scale morphology models is to determine the sediment supplied by each of the tributaries. This modeling will be conducted for a range of flows to develop sediment rating curves at all tributaries located at Focus Areas, selected tributaries in the Lower Susitna River Segment for sediment supply and limited habitat analyses, and other selected tributaries in the Middle Susitna River Segment for sediment supply only. The range of tributaries will be used to develop sediment inflow for other tributaries throughout the model domain. Some of these tributaries will also be analyzed to provide information for the aquatic habitat and barrier studies.

Boundary conditions for the 1-D model include water and sediment inflow and downstream water surface elevations. The 1-D reach-scale morphology modeling is being run for a 50-year continuous flow record for Existing conditions and with-Project operational scenarios. The inflows to the model are the outflows from the dam for the existing conditions plus tributary inflows. No sediment is included at the upstream limit of the model for the with-Project model runs. Tributary sediment inflow are also included. It was originally intended that the entire river from Watana Dam (PRM 187.1) to Susitna Station (PRM 29.9) would be included in a single model. Then the only hydraulic boundary condition would have been the stage-discharge relationship at the Susitna Station gage. Because bed material characteristics and sediment transport conditions change dramatically below the Chulitna River confluence, the model was divided at this point; allowing the two models to have different sediment transport functions. The flow and sediment from the Middle River model is the upstream boundary condition for the Lower River model and normal depth was set as the downstream hydraulic boundary condition for the Middle River model. The two models have significant overlap from PRMs 96 to 107 so the boundary condition inputs from one model would not overly influence the results of the other model. The existing channel and floodplain geometry is the starting condition and the model simulates potential channel change throughout the 50-year license period.

The reach-scale modeling provides information to the 2-D local-scale morphology modeling efforts and to other study components. Local-scale models are being developed at the Focus Areas representing conditions at years-0, -25, and -50. If bed elevations or channel widths change over the 50 year period, the reach-scale model results will not only be used to alter the future (years-25 and -50) geometry, but will also provide year-0 and future downstream stage-discharge and upstream sediment supply rating curves to the local-scale models.

The 1-D reach-scale models are providing information to other studies. For example, aquatic and riparian habitat studies use stage-discharge information from the reach scale model at specific locations over the 50-year license period. There may also be the need to incorporate future channel change into the River1D ice model or flow routing models. This would only be necessary if the magnitude of geometric change would significantly affect the results of these studies.

The 2-D local-scale morphology models of the focus areas will not be run for the full 50-year period, but will be run for year 0 (initial conditions), year 25 and year 50. These short duration runs (~6 months) will be performed for a range of hydrologic conditions represented by the wet, average, and dry years. It was determined that flows during the open water period are not significantly affected by Pacific Decadal Oscillation (PDO) (ISR Study 6.6, Appendix E) so separate warm and cool PDO conditions are not included as additional sets of representative wet, average, and dry annual hydrographs. The model results from the three hydrologic conditions will be used to interpret changes in the local-scale morphology and compare Existing and with-Project conditions in the main channel, secondary channels, other lateral features, islands, and floodplain areas. Just as the channel changes in the reach-scale models are used to develop the future geometry of the local-scale morphology models, the local-scale morphology model results will be used to modify lateral feature geometry in the 2-D local-scale hydraulic models and to provide other studies with information on changes to substrate and deposition patterns.

The local-scale hydraulic models are necessary because they have much greater mesh refinement than can be achieved in the morphology models and they are steady-state models run for a range of flows rather than dynamic models run for seasonal hydrographs. The habitat analyses require a sequence of steady flows that can be applied to the range of flow magnitudes, durations, and timings of the analysis scenarios. The 2-D hydraulic modeling provides depth, velocity, water-surface elevation and other parameters for the range of flows throughout the local-scale model domains. These data will be used by the aquatic habitat, riparian habitat, and barrier studies to evaluate potential Project effects.

Table 2.2-1 also includes 2-D morphology modeling to be conducted for a range of ice blockage and breakup conditions to evaluate erosion and deposition potential. The table includes 2-D hydraulic modeling related to changes in LWD accumulations to evaluate potential habitat change. The specific conditions for these simulations will be coordinated with input from agencies and other study components.

3. STUDY AREA

The Susitna River, located in south-central 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 Cook Inlet (U.S. Geological Survey [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 elevation in the basin is at Mt. McKinley at 20,320 feet while its lowest elevation is 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, which 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°F.

3.1. 1-Dimensional Model

The 1-D model extends from the Watana Dam site (PRM 187.1) to Susitna Station (PRM 29.9). Figures 4-1 through 4-8 of the updated FGM model approach TM (Tetra Tech 2014a) show the cross sections and channel network for the Susitna River 1-D model. The cross section locations for the Chulitna and Talkeetna Rivers are also shown and these tributary reaches are being added to future versions of the 1-D model (including updates for inclusion of 2014 data such as additional cross section and bed material samples). The modeled section of the Talkeetna River extends from the confluence with the Susitna River to the USGS Talkeetna River Near Talkeetna gage (USGS no. 15292700) located 4.8 miles upstream. The modeled reach of the Chulitna River extends approximately 18.4 miles upstream of the confluence to the USGS Chulitna River Near Talkeetna gage (USGS no. 15292400).

3.2. 2-Dimensional Model

Of the 10 Focus Areas identified, this Technical Memorandum addresses FA-128 (Slough 8A). The 2-D sediment transport model of FA-128 (Slough 8A) extends slightly up- and downstream of the FA limits (Appendix B, Figure 1.1) to improve the location of boundary conditions and to include the upstream end of Slough 8A. The FA boundary extends from PRM 128.13 to PRM 129.72, whereas the model mesh extends from PRM 128.05 to PRM 130.10, which is consistent with the 2-D hydraulic model. Skull Creek is a tributary to the Susitna River within FA-128 (Slough 8A); the confluence is located on the left (west) bank approximately 800 feet upstream of the downstream boundary of the mesh.

The habitat analysis limits for all 10 Focus Areas are shown in Figures 4-9 through 4-18 of the updated FGM approach TM (Tetra Tech 2014a). The limits for modeling purposes may extend further up- or downstream to better locate boundary conditions for hydraulic and sediment transport models.

4. METHODS

The 1- and 2-D models will be used to address hydraulics, sediment transport and morphology at reach and local scales. As described in Tetra Tech (2014a), HEC-RAS version 5.0 (beta version) was selected as the 1-D bed evolution model and SHR2D version 3 was selected for 2-D hydraulic and bed evolution modeling.

4.1. 1-D Modeling

An overview of calibration and validation is included below. Review and quality control procedures for model inputs included: checking cross section data, alignment and roughness values, other geometric input, program computational warnings, hydrologic input and routed flows, computed water surface elevations, sediment inputs and routed sediment loads and gradations, and bed material gradations.

The 1-D sediment-transport model was developed using the following steps, which are discussed in more detail in Tetra Tech (2014a):

1. Determine the overall model layout.
2. Develop cross-sectional data.
3. Develop flow resistance (roughness) data for cross sections.
4. Develop bed and bank material gradation and layer information.
5. Develop inflow hydrographs and sediment inflows for existing and with-project conditions.
6. Incorporate other considerations including ineffective flow areas.
7. Test the hydraulic model over a range of flow conditions.
8. Calibrate and validate the hydraulic model.
9. Test the sediment-transport model.
10. Calibrate and validate the sediment-transport model.
11. Run and evaluate the results of the sediment-transport simulations.

4.1.1. 1-D Bed Evolution Modeling

This section provides a summary of the 1-D Bed Evolution Model Development, which is described in detail in Appendix A. The 1-D Bed Evolution Model was developed using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) version 5.0.0 Beta August 2014 computational engines (USACE – in process). This software was made available by U.S. Army Corps of Engineers Hydraulic Engineering Center (HEC) because of the new unsteady-flow sediment routing routines, which are ideally suited to the Susitna River and tributaries. The initial 1-D Bed Evolution Model is comprised of two main reaches: (1) Middle Susitna River (PRM 187.1 to PRM 107.1); (2) Lower Susitna River (PRM 107.1 to PRM 29.9). The final model will incorporate survey and LiDAR data collected in 2014 and will include two addition reaches for two major tributaries; (1) the lower extent of the Chulitna River (PRM 18.1 to PRM 0.0); and, (2) the lower extent of the Talkeetna River (PRM 4.7 to PRM

0.0). Each reach is defined by cross-sections perpendicular to the primary flow path and located to capture key hydraulic controls of each system. Three secondary flow paths (flow splits) are included in four locations in the Middle River and two in the Lower River. Five additional splits are anticipated for the Middle River model. The Middle River model is defined by 166 surveyed cross-sections with an average spacing of about 3,000 feet. The Lower River model is defined by 93 surveyed cross-sections with an average spacing of about 4,000 feet. The Talkeetna River model is defined by 14 cross-sections (10 that were surveyed and 4 that were developed from LiDAR) with an average spacing of about 1,800 feet. The Chulitna River model is defined by 34 cross-sections (2 that were surveyed and 32 that were developed from LiDAR) with an average spacing of about 2,800 feet. The models also include interpolated cross sections and will be updated to include cross sections surveyed in 2014. In many cases the surveyed cross sections will replace interpolated sections.

Overbank topography for the Middle and Lower River was available from LiDAR mapping collected between May 2011 and October 2011 (ISR Study 6.6, Part A, Section 5.1.9.5). LiDAR for the Talkeetna and Chulitna overbank topography was collected in September 2013 (ISR Study 6.6, Part A, Section 5.1.9.5). Bathymetric data for each reach were surveyed at each cross-section by Geovera (ISR Study 8.5, Part A, Section 5.3.1). Survey efforts for the Talkeetna and Chulitna reaches were conducted in August 2013. The Middle and Lower River reaches were surveyed between June 2012 and August 2013. Between PRM 165.9 and PRM 154.6 (Devils Canyon), the Middle River is inaccessible to surveyors so a simplified trapezoidal geometry developed as part of ISR Study 7.6 Ice Processes in the Susitna River was used for bathymetry in this area. Throughout all of the model reaches, at each cross-section the bathymetric surveys were merged with the LiDAR topography to create continuous geometry. Additional cross sections were surveyed in the Middle and Lower River reaches in 2014. These cross sections will be incorporated into the next versions of the 1-D models along with LiDAR flown in 2014 in the Middle River.

Following guidance provided by staff at HEC for using the mobile-bed capabilities within HEC-RAS, the number of points that define each cross-section was filtered to reduce the potential for bed adjustment issues while still preserving the essential geometry. In areas with dramatic topographic changes between cross-sections, additional sections were included to keep conveyance ratios within reasonable limits. Geometry for these new cross-sections was estimated using a feature within HEC-RAS to linearly interpolate geometry between bounding surveys. Ineffective flow areas were used in the Middle River along the tops of islands to simulate the high roughness and low conveyance over these features. A simplified scheme of overbank and channel roughness values was initially based on field observations and refined during the calibration of each model.

The 1-D bed evolution modeling used the pre-Project and Max LF OS-1b hydrology for the mainstem Susitna River and tributaries was prepared within the Fish and Aquatics Instream Flow Study (Study 8.5) as described in ISR Study 8.5 Part C, Appendix K.

The hydraulic model is the foundation of the sediment routing model; additional functionality and associated inputs were specified to develop the sediment routing model. Sediment supplies at model boundaries, bed material gradations and layering, the bed sorting method, the sediment transport function, and the fall velocity method are the main components of the sediment routing model that need to be specified. The bias-corrected sediment rating curves developed as part of the 2014 Update of Sediment-Transport Relationship and a Revised Sediment Balance for the

Middle and Lower Susitna River Segments Technical Memorandum (Tetra Tech 2014c) were specified as the sediment load rating curves at major inflows (i.e., the dam site, the Chulitna River, the Talkeetna River, and the Yentna River). Bed material gradations for surface and subsurface materials were based on field measurements documented in both ISR Study 6.6 Part A and the Winter Sampling of Main Channel Bed Material Technical Memorandum (Tetra Tech 2014d). Due to the armored channel bed throughout the Middle River the Exner 5 bed sorting method was selected and coupled with a user-defined sediment transport function based on the Ackers-White function. Given the sand- and gravel-dominated bed material in the Lower River Segment, the Exner 7 bed sorting method was selected and it was coupled with the Ackers-White transport function (Ackers and White 1973; Ackers 1993).

4.1.2. Tributary Sediment Supply Modeling

Tributary modeling was carried out to quantify required sediment loads input to (1) the bed evolution models, both the 1-D and the 2-D (Section 4.1.1), and (2) the tributary delta formation models (Section 4.1.6). The tributary sediment loads were based on combining calculated sediment rating curves with long-term flow hydrographs. The hydrologic flow series for all tributaries to the Middle River and Lower River were provided as presented in Section 5.4.1.2.4 of Appendix K to the Study 8.5 ISR. Tetra Tech (2014c) developed bed material sediment rating curves for major tributaries where measurements of sediment transport were available (i.e., Chulitna River, Talkeetna River, and Yentna River). Except for Skull Creek, sediment rating curves were not developed for ungaged tributaries as part of the initial model development, but will be for subsequent modeling. This decision was made because of (1) Tetra Tech’s (2014c) finding from analysis of USGS sediment transport measurements on Portage Creek and Indian River (Knott et al. 1986) that ungaged tributaries along the Middle Susitna River may produce negligible amounts of silt and sand, but may transport greater amounts of gravel and coarser sized material than is transported by the main river, (2) field observations indicating that ungaged tributaries tend to be clear-water, supplying virtually no wash load and little sand to the Susitna River (3) Knott et. al (1987) finding no discernable difference between bed load and suspended load measurements between Susitna River at Gold Creek (station number 15292000) and Susitna River near Talkeetna (station number 15292100), and (4) the need to prioritize efforts for the initial modeling. While Tetra Tech (2014c) identified the potential significance of the gravel loading from the ungaged tributaries to the Middle River, their sediment balance indicated the high probability that gravel is either being stored in fans at the tributary mouths, or is being stored along the Middle River channel. Therefore, Skull Creek was the only ungaged tributary where sediment modeling was performed for the initial model development. Sediment supplied from Skull Creek and other ungaged tributaries along the Middle Susitna River will be evaluated for future model development including tributary delta formation models.; but, this modeling initiated the refinements described below to the modeling methods described in Section 4.1.2.6 of the Study 6.6 ISR

Section 5.1.6 of the Study 6.6 ISR describes the development of the HEC-RAS model for ungaged tributaries, including the surveys of cross section geometry, collection of bed material samples, and preliminary hydraulic calibration. Specifics related to the Skull Creek model are provided in Section 3.1.2 of Appendix B. The Skull Creek model was used to simulate hydraulics (hydraulic depth, top width, channel velocity, and slope) over a range of flows encompassing the hourly minimum and maximum over the 61-year extended flow series developed by Study 8.5. Reach averaged hydraulics were calculated from the HEC-RAS results. The reach-averaged hydraulics were coupled with measured bed-material gradations to develop representative discharge versus bed material transport relationships using Parker's (1990) surface-based bedload function and Einstein's (1950) function for suspended load. The primary refinement was that the sampled surface gradation was adjusted to include material finer than 4 mm not adequately represented in the sampled gradation (due to bias associated with pebble counts) so that the gradation of the simulated transport aligned with the gradation of the subsurface sediment sample collected from the Skull Creek delta. This approach will be used for the remaining tributaries and other bedload functions may be evaluated for applicability.

4.1.3. Evaluate long-term change in channel width

Under the with-Project conditions, it is anticipated that long-term width change (narrowing) will occur along the Susitna River based on reductions in ~2-year recurrence interval flows for the with-Project scenarios (Tetra Tech 2014a and 2014b).

An analysis of the change in width was conducted to determine, if any, the amount of width change to apply to the 1-D model. The analysis was conducted using typical downstream hydraulic geometry relationships. For example, Leopold and Maddock (1953) reported the bankfull channel width is proportional to bankfull discharge to the 0.5 power. Other researchers have proposed other values for the exponent. For example Parker (2010) indicates a power of 0.461 for gravel-bed rivers. A consistent flow frequency (Q_2) or effective discharge is used to predict the eventual equilibrium width for the new hydrologic regime.

For the Lower Susitna River Segment, potential width change was evaluated as in the decision whether to extended fluvial geomorphology modeling below Susitna Station (Tetra Tech 2014b). The results of the 1-D Bed Evolution model will be compared based on the 50-year record for both the pre-Project and Max LF OS-1b scenario to develop annual peak flows. The change in peak flows will be used to estimate the potential for change in width based on the assumption that the change in width is proportional to the square root of the ratio of channel forming discharges. Discharges in the range of the 1.5- to 5-year peaks are often representative of the channel forming or effective discharge to which the bankfull channel capacity adjusts in streams such as the Lower Susitna River Segment that have mobile bed material and a substantial sediment supply.

The feedback between riparian vegetation and channel geomorphic processes is part of the coordination between Studies 6.6 and 8.6. Specifically, the coordination includes the use of geomorphic threshold relationships to understand the potential for removal of vegetation by the flows and the potential for channel narrowing effectively due to changes in the vegetation patterns (ISR Study 6.6 Section 4.3.2.2).

For the Middle Susitna River Segment, where there would not be a substantial sediment supply under with-Project conditions, an alternative approach was developed. Without appreciable sediment to build channel banks (including the boundaries of islands that act as banks in multiple channel areas) the primary aspect of channel narrowing would be through vegetation encroachment. The amount of vegetation encroachment depends on the ability of vegetation to colonize areas with varying degrees of inundation through time. Just as channel peak discharge in the range of 1.5 to 5 years is used to represent geometric change, it can also be used as an initial indicator for vegetation limits that can be refined based on coordination with Study 8.6.

The 1-D bed morphology modeling of the Middle and Lower Susitna River Segments is intended to evaluate potential reach-scale bed changes, but does not directly incorporate lateral adjustment. When channels are subjected to a changed condition, they are expected to have adjustments in each of their degrees of freedom unless some type of control limits a particular type of adjustment(s). Not only can depth and width adjust, but also slope, bed material size, and planform. Of these potential adjustments, width and planform adjustment are not fully addressed in a standard 1-D model application. Because channel narrowing, which is expected to occur on the Susitna River, could have a feedback on future sediment transport characteristics, Study 6.6 included 1-D model runs that incorporates width change. Specifically, it was decided to perform a demonstration 50-year 1-D Bed Evolution Model run with potential width adjustment at two selected intermediate points in the 50 year period (ISR Study 6.6 Section 7.2.1.2.2). A rapid rate of narrowing was imposed to provide an upper bound on the potential effects of channel narrowing.

The primary method for depicting vegetation in hydraulic models is by increased roughness. This approach was used throughout the Middle and Lower Susitna River Segments outside the active channel limits. This approach could also be used when the overall channel limits include vegetated islands within multiple channel areas. However, for high flows, this approach generates a composite channel roughness and hydraulic radius that are dramatically affected and the calculated conveyance of both water and sediment are significantly diminished. The reduced transport occurs for flows that should have the greatest sediment transport potential. Alternatively, ineffective flow areas can be designated for vegetated islands within active multiple channels. As illustrated in Figure 4.1-1 for the cross section at PRM 122.1, vegetated islands were designated as ineffective flow areas in the 1-D models. Ineffective flow is a 1-D model feature that eliminates flow from an area when the area is blocked or conveys little or no water downstream. Using this approach maintains a high conveyance of water and sediment for the active channel areas. Figure 4.1-1 shows a channel split around an island at station 600 and a submerged, active bar at station 900. The island area conveys no flow because of the ineffective flow designation.

The ISR (Study 6.6 Section 7.2.1.2.2) states that Study 6.6 will "Perform a demonstration 50-year 1-D Bed Evolution Model run with potential width adjustment at two selected intermediate points in the 50 year period." This demonstration used two different methods in the Middle versus Lower Susitna River 1-D models. In the Middle River, hydrology and sediment supply will be significantly affected. Without a supply of sand and finer sizes, width adjustment would primarily occur through vegetation encroachment along the channel margins and by vegetation colonizing gravel bars that are less frequently submerged under with-Project conditions. For demonstration purposes, the 2-year with-Project flow level was used to establish the modified vegetation limits. Also, as a conservative approach and assuming that vegetation would become established quite quickly, the new vegetation limits were set only once at the beginning of the 50-year simulation.

In the Lower Susitna River 1-D model, flow frequency is affected much less than the Middle River, and sediment supply remains high due primarily to contributions from the Chulitna River. Therefore, for this demonstration, the 1-D model bank stations and margins of the islands were adjusted twice to narrow the active channel. The first adjustment was made at the beginning of the 50-year run but represents width adjustment over the first 25-years and the second adjustment made at year 25 to represent the remaining simulation period. For both the Middle and Lower Susitna River 1-D models, the amount and timing of width adjustment will be coordinated with the Riparian Instream Flow Study (8.6) in the final models.

Figure 4.1-1 also shows the initial condition for simulating width adjustment in the Middle River using the approximate 2-year water surface elevation, which does not inundate the island. The approximate 2-year flows are also shown for existing and Max LF OS-1b conditions in Figure 4.1-2, which shows how the ineffective flow areas were adjusted for the with-Project condition. The first adjustment expands any existing ineffective flow areas down to the with-Project 2-year water surface. The second adjustment creates additional ineffective flow areas for areas that would be exposed under the reduced 2-year flow. If the bank stations at a cross section are above the with-Project 2-year flow elevation, then they are moved down to that elevation to represent the potential for vegetation encroachment along the channel banks. For the Middle Susitna River Segment, this model was run for the entire 50-year open water flow period without further adjustment.

The Lower Susitna River Segment includes significant flow and sediment inputs from the Chulitna and Talkeetna Rivers. The 1.5- to 5-year peak flows are reduced by 19 to 17 percent indicating a 10 to 9 percent potential narrowing due to long-term hydrologic effects of the Project (Tetra Tech 2014b). The Lower Susitna River Segment is a very active alluvial channel that would respond to long-term hydrologic change and would likely have significant response to short-term flows including individual events. For example between the 1950s and present conditions, the Lower Susitna River geomorphic reaches show width changes from approximately -20 percent to +12 percent (Tetra Tech 2014b). Therefore, channel narrowing of 10 percent over a 50 year period is reasonable.

Figures 4.1-3 through 4.1-7 illustrate the application of 10 percent channel narrowing to the 1-D bed morphology model of the Lower River. Because the sediment transport simulation is uncoupled from the narrowing, the model was run by imposing width adjustments over two periods. Figure 4.1-3 shows the cross section at PRM 78.0 with an ineffective flow area for the vegetated island. Areas between the bank stations and ineffective flow areas are active channel and active (non-vegetated) bars. Because there is considerable sediment to build features, the geometry was adjusted to simulate the narrowing process. Figure 4.1-4 shows that the active channels were compressed laterally between the ineffective flow areas and the channel banks without changing bed elevations.

The model was run for 25 years to simulate changes in sediment transport and bed morphology. Figure 4.1-5 shows the channel geometry at the end of 25 years compared to the initial, un-narrowed cross section. Note that point elevations in the channel are slightly higher, indicating minor aggradation. This geometry was then narrowed an additional 5 percent to achieve the estimated value of 10-perecnt total narrowing by again compressing the channels between bank stations and ineffective flow areas (Figure 4.1-6). This geometry was used to simulate bed evolution for years 25 through 50. The final geometry is compared to the initial (year 0 un-narrowed) cross section in Figure 4.1-7. As before, bed elevations are higher than the initial condition due to minor amounts of aggradation. For reference, the water surfaces shown in Figures 4.1-3 through 4.1-7 are for a discharge of 100,000 cfs. Width change would occur continuously (and sporadically) over time. The initial imposition of 5 percent is meant to represent the first 25 year period and the additional 5 percent represents the second 25 year period. These amounts and the timing may be adjusted in the final model simulations.

4.1.4. Large Woody Debris Effects

One of the objectives of the geomorphology study (AEA 2012, Section 6.5.1.1) is to “Assess Large Woody Debris Transport and recruitment, their influence on geomorphic forms and, in conjunction with the Fluvial Geomorphology Modeling Study, effects related to the Project." The geomorphology study is evaluating large woody debris sources, loading, and transport in the Susitna River. Loading from upstream and major tributaries will be evaluated for pre- and with-Project scenarios. The fluvial geomorphology modeling study will evaluate the potential Project effects from changes in large woody debris input. The anticipated methods are described in this section but have not been implemented with the initial models developed at this point in the study.

Bank erosion rates under the existing and with-Project scenarios will be evaluated using the Bank Energy Index (BEI) (Mussetter et al. 1995; Mussetter and Harvey 1996), a semi-quantitative index of the total energy applied to the channel banks. One- and 2-D modeling results will be used to compute the BEI values. BEI was applied to 2-D model results at FA-128 (Slough 8A) to evaluate the applicability of this approach to open water flow conditions. The BEI values will be correlated to existing bank erosion rates at specific locations based on the turnover analysis (Tetra Tech 2014e). With-Project bank erosion rates will be estimated using this correlation to estimate LWD recruitment.

At the reach-scale, large woody debris increases overall flow resistance, reduces velocity, and reduces sediment transport (Smith et al. 1993, Shields and Grippel 1995; Assani and Petit 1995; Buffington and Montgomery 1999). The cumulative drag force of debris in a particular reach will be distributed over the reach by equating area-distributed drag force to the equivalent shear stress to compute an incremental increase in flow resistance associated with the LWD (Hygelund and Manga 2003). For existing conditions, the amount of debris, type of obstruction, size, and other attributes will be used to evaluate the contribution of debris to total flow resistance. The input flow resistance coefficients will then be modified in the Project-conditions models to reflect changes in LWD due to the Project by proportioning the amounts of debris and the resulting total flow resistance based on the altered LWD supply. Depending on the relative LWD supply, effects on reach-average hydraulics may be negligible in some areas, but could be significant in others. LWD supply from upstream of the dam will be eliminated by the Project, but LWD supplied from tributaries downstream from the dam will be unchanged. If bank erosion rates decrease based on the BEI analysis, then this supply will also be reduced.

4.1.5. 1-D Ice Effects

As part of the ice processes study (Study 7.6) for the Susitna River, "predictive ice, hydrodynamic and thermal modeling using River1D is planned for the Middle River between the proposed dam and the Three River Confluence near Talkeetna" (RSP Section 7.6.3.2, AEA 2012). Additional ice-related, reach-scale modeling will be performed as part of the fluvial geomorphology modeling study but has not been conducted with the initial models developed at this point in the study. It is tentatively assumed that the existing bed material is generally stable (i.e., below incipient motion conditions) under ice conditions, due to reduced velocities and shear stresses associated with low river flows and the ice cover. The validity of this assumption under both existing and with-Project conditions will be tested by performing an incipient motion analysis using shear stress results from the River1D modeling. Should the results indicate that substantial sediment transport should occur at the reach scale, the 1-D model will be adjusted to incorporate appropriate rates of sediment transport for ice covered conditions. AEA anticipates this could be accomplished by extending the simulation period, and adjusting flow magnitudes and durations of the 1-D modeling to account for sediment transported under these conditions.

One-dimensional dynamic modeling will also be performed of ice jam breakup surges to develop inflow hydrographs for 2-D dynamic models. The 1-D modeling will be performed using HEC-RAS and will be similar to dam break simulations of the rapidly released water stored above the ice jam.

4.1.6. Tributary Delta Formation

Section 4.8.2.2 of the Study 6.5 ISR and Section 4.1.2.6 of the Study 6.6 ISR describe methods for modeling geomorphic change of tributary deltas. The methods in ISR Study 6.5 focus on Upper River tributaries entering the proposed Watana Reservoir whereas the methods in ISR Study 6.6 focus on Middle River and Lower River tributaries; the methods are being closely coordinated between studies. Section 7.1.1.8 and Table 7.1-1 of the Study 6.5 ISR present the selection (as coordinated with Studies 9.5 and 9.12) of the six Upper River tributaries for modeling potential delta formation. Section 7.1.1.1.1 and Table 7.1-1 of the Study 6.6 ISR describe the selection of 19 Middle River tributaries and five Lower River tributaries for delta modeling in coordination with Studies 9.6 and 9.12.

As a precursor to modeling geomorphic change of the tributary deltas, the sediment supply to the deltas has to be characterized (Section 4.1.2). The sediment supply from the tributaries is important not only as needed input to the bed evolution modeling of the Susitna River, but also to assess potential Project effects on the ability of fish to access the tributaries and the extent of clear-water habitat associated with some tributary confluences. The 2-D bed evolution model simulates formation of tributary deltas when the deltas are located within Focus Areas (FA) (Section 4.1.1); a simplified modeling approach is used to simulate formation of tributary deltas for selected tributaries outside of FAs. For this POC effort, the simplified approach was applied to Skull Creek so the results could be directly compared to the delta formation simulated using the 2-D bed evolution model of FA-128 (Slough 8A) (Section 4.2.3).

The processes governing tributary delta formation along the Susitna River can be conceptually simplified using incipient motion. The basis of incipient motion is that sediment particles will be mobilized when the hydrodynamic lift force (mobilizing force) applied on the particle exceeds the submerged particle weight (resisting force). The foreset slope of a delta (Figure 4.1-8) can progress into the Susitna River until the reduction in mainstem channel flow area (caused by continued deposition of sediment) increases mainstem shear stress during a frequent flow so that sediment deposited on the foreset is mobilized and further riverward progression of the foreset is checked. This balance was explicitly simulated by the 2-D bed evolution model. Outside of FAs, the mobilizing force was calculated using 1-D numerical models to simulate mainstem hydraulic conditions; the resisting force was evaluated using delta sediment samples (D_{84}) and the foreset slope of the delta.

The hydraulic conditions at the Skull Creek delta were simulated using the U.S. Army Corps of Engineers HEC-RAS software (Version 5.0.0). The model was developed using inputs to and results from the 2-D bed evolution model of FA-128 (Skull Creek); the HEC-RAS model was calibrated to water-surface elevations simulated by the 2-D bed evolution model. Nine cross sections were delineated across the Skull Creek delta and the adjacent mainstem channel (Figure 4.1-9). Cross section geometry was derived from topographic models input to (initial conditions) or calculated by the 2-D bed evolution model (future conditions under existing conditions hydrology or Max LF OS-1b hydrology, Section 5.2.1.1). Manning's n-values were adjusted to simulate water-surface elevations at each cross sections that were ±0.5 feet of the water-surface elevations simulated by the 2-D bed evolution model at 10,000 cfs intervals between 10,000 cfs and 100,000 cfs.

The Shields (1936) parameter was calculated to quantify incipient motion using Equation 4.1.6-1 (which is the ratio of the mobilizing force to the resisting force):

$$\tau_* = \frac{\gamma R_h S_f}{(\gamma_s - \gamma) D_s} \qquad \text{(Equation 4.1.6-1)}$$

Where:

τ_* = Shields parameter (dimensionless)
γ = unit weight of water (pounds per cubic foot [lbs/ft^3])
R_h = hydraulic radius (ft)
S_f = local friction slope (ft/ft)
γ_s = unit weight of sediment (lbs/ft^3)
D_s = median dimension of a sediment particle for which *s* percent of a gradation is finer (ft)

In Equation 4.1.6-1, the numerator is the total bed shear stress. The total bed shear stress was partitioned to isolate the component that acts on the sediment particles (grain shear). The equation for the semi-logarithmic velocity profile (Equation 4.1.6-2) was used to partition the shear, using the roughness height (k_s) of 3.5*D_{84} proposed by Hey (1979). Consequently, the grain hydraulic radius (R_h') was calculated and used in Equation 4.1.6-1.

$$\frac{V}{u_*} = 6.25 + 5.75\, Log_{10}\left(\frac{R_h'}{k_s}\right) \qquad \text{(Equation 4.1.6-2)}$$

Where:

V = channel velocity (ft/s)
u_* = shear velocity (ft/s), equals $\sqrt[2]{g R_h' S_f}$
g = gravitational constant (32.2 ft/s^2)
R_h' = grain hydraulic radius (ft)
k_s = roughness height (ft), set equal to 3.5*D_{84} (Hey 1979)

The critical value of the Shields parameter, corresponding to incipient motion, is not as straightforward as balancing mobilizing and resisting forces. For unconsolidated, mixed-size sediments (such as sediment deposited on the foreset of a delta), the critical value of the Shields parameter (corresponding to the beginning of motion) is typically set to 0.02 to 0.03 (Andrews 1983; Neill 1968). Neill (1968) indicated that consistent movement and bed deformation is observed at values 2 to 3 times the values corresponding to initiation of motion, which is consistent with Vanoni (1967) attributing small but measureable transport to a value of 0.06. Buffington and Montgomery (1997) conclude that for gravel bed rivers, visually-based incipient motion correlates with Shields parameters ranging from 0.03 to 0.073 with 0.045 as a typical value; reference-based incipient motion (extrapolating to zero transport) correlates with greater Shields parameters ranging from 0.052 to 0.086. The appropriate value of the Shields parameter was selected by applying incipient motion to a dynamically stable delta morphology with the shear produced during a flow with an average annual recurrence interval of approximately 2 years. This recurrence interval was selected so that over the long term, the number of years in which the delta foreset would prograde into the mainstem would be balanced by the number of years in which the delta foreset would be eroded by the mainstem, resulting in a dynamically stable foreset location. The Shields parameter was selected so that a condition of incipient motion would be achieved for the D_{84} of the sediment deposited on the delta. Carter (1953) developed the simplified relationship (Equation 4.1.6-3) between foreset slope and angle of repose that reduces the critical Shields parameter to account for the decrease in the force holding a particle in place on a slope:

$$\tau_{\theta c} = \tau_* \sqrt{1 - \left(\frac{\sin^2\theta}{\sin^2\varphi}\right)} \qquad \text{(Equation 4.1.6-3)}$$

Where:

$\tau_{\theta c}$ = Shields parameter for an embankment slope (dimensionless)
τ_* = Shields parameter (dimensionless)
θ = embankment slope (degrees)
φ = angle of repose (degrees), set to 40 degrees

The calibrated HEC-RAS model was used to calculate channel velocity and local friction slope for input to Equation 4.1.6-2. A subsurface sediment sample from the Skull Creek delta (Section 5.1.9.3 Study 6.6 ISR) was used to calculate the sediment gradation and the D_{84} of 89.7 mm. Since the surface of the foreset slope could not be sampled, it was assumed because of natural sorting and coarsening that the D_{84} of the subsurface sample is representative of foreset surface sediment. The calculated D_{84} was input to Equation 4.1.6-2 and used as D_s for input to Equation 4.1.6-1. The topographic surfaces input to (initial conditions) or simulated using the 2-D bed evolution model (future conditions) (Section 4.2.2) were used to initially calculate the foreset slope. Under the initial conditions, future conditions under existing hydrology, and future conditions under Max LF OS-1b hydrology, the foreset slopes were calculated as 2.3, 5.8, and 5.7 degrees, respectively. These values were judged unreasonably low (resulting from 2-D modeling limitations presented in Section 4.2.3), so a 25 degree slope was assumed (approximately 2.1H:1V) and input to Equation 4.1.6-3. The grain shear (τ') at the 2-year peak discharge for the future delta morphology under existing hydrology (i.e., dynamically stable foreset location) was input to Equation 4.1.6-1 to back calculate a Shields parameter of 0.025 (which is reduced to 0.019 after applying Equation 4.1.6-3) corresponding to incipient motion. If the grain shear at the 5-year peak discharge is used, the resulting Shields parameter is 0.034, which is reduced to 0.026 after applying Equation 4.1.6-3. If the grain shear for a particular flow exceeded the critical grain shear (τ'_c) associated with incipient motion, that flow was capable of mobilizing sediment from the delta foreset; otherwise, the sediment on the foreset was immobile for that flow. In this manner, the stability of the foreset was calculated over a range of flows, and the critical flow and associated recurrence interval were determined from flow frequency analyses. The flow frequency analyses were based on hourly flows over the 50 years of open-water flow periods routed using the validated 1-D BEM to the USGS gaging station at Gold Creek (PRM 140.1). The flow frequency analyses followed the methods presented in Tetra Tech (2013).

4.2. 2-D Modeling

The initial Proof of Concept (Attachment A of Tetra Tech, 2014a) was developed to demonstrate integration between the IFS and the 2-D hydraulic modeling. The hydraulic modeling was conducted for the Year 0 conditions at FA-128 (Slough 8A) and did not incorporate changes in bed geometry or other effects for future conditions (Tetra Tech, 2014a). At Year 0 all of the scenarios have the same bathymetry, topography, substrate, and vegetation characteristics. Therefore, at Year 0 the range of steady flows simulated with the hydraulic model are representative of all operational conditions. The 2-D hydraulic model for FA-128 (Slough 8A) contains over 200,000 elements and was run for a range of flows from 2,000 to 50,000 cfs. The model output was provided to the IFS team to evaluate instream habitat.

The local scale 2-D sediment transport modeling will be performed at the Focus Areas to primarily support evaluation of future habitat conditions. The 2-D sediment transport modeling includes an analyses of the existing channel geometry with existing hydrology as a baseline for comparison. A 2-D sediment transport model of FA-128 (Slough 8A) was performed to demonstrate the development of the channel geometry for future conditions under Existing and Max LF OS-1b hydrology conditions. The model results are used to evaluate potential Project effects on sediment transport and bed morphology, including changes in bed composition and flow distribution to lateral channels, vegetation, and tributary fan development at Skull Creek which in turn can be used to evaluate potential changes in habitat at the Focus Area.

Due to the intensive computational requirements of 2-D sediment-transport modeling and the potentially long execution times, it not practical to apply the fine resolution 2-D hydraulic model for the sediment transport analyses. Therefore, 2-D sediment transport models with a coarser grid are being developed to simulate the bed evolution changes. For FA-128 (Slough 8A) the 2-D sediment transport models consist of fewer than 20,000 elements. Furthermore, it is not practical to run the 2-D sediment-transport models over 25 or 50-year periods; therefore, a method of predicting the bed geometry at 25- and 50-year was developed by simulating representative annual runoff hydrographs selected to represent the wet (1981), average (1985) and dry (1976) (ISR Study 8.5 Appendix J) conditions. The representative runoff hydrographs were developed from the results from the open-water model (ISR Study 8.5).

The 2-D sediment transport model for FA-128 (Slough 8A) was run over the representative (Wet, Average and Dry) annual hydrographs for the existing and with-Project conditions with each model starting with the same initial condition. These model outputs were used to compare the changes in channel geometry, bed material characteristics and hydraulic conditions (depth, velocity and flow distribution) under existing and with-Project conditions. To gain more insight into future conditions, a sequence of flows were also developed to represent an 8 year period. The model output from the 8-year long simulation was used to develop the future channel geometry (years 25 and 50) for the existing and with-Project conditions. The future channel geometry also includes main channel bed elevation changes from the 1-D model. Width change caused by vegetation that was incorporated in the 1-D modeling was also included in the 2-D models.

The Year 25 channel geometry for the existing and with-Project conditions was incorporated into the hydraulic model. In addition, channel width change due to vegetation encroachment was also incorporated in the hydraulic model. The existing conditions and with-Project conditions hydraulic models were run for steady-state discharges of 12,000 cfs and 30,000 cfs. The hydraulic model outputs for the existing and with-Project conditions were compared to demonstrate the ability to identify change in habitat in terms of depth and velocity. These outputs had previously been demonstrated as suitable for habitat analyses during the POC exercise (Attachment A of Tetra Tech 2014a).

A Bank Energy Index (BEI) analyses was performed to evaluate the potential changes in bank erosion (lateral migration) between existing and with-Project conditions. To perform the BEI analysis, the turnover mapping for the period from the 1980's to 2012 (Tetra Tech, 2014d) was evaluated and 16 representative bank erosion sites were selected. At each location, the erosion between the 1980's and 2012 was measured and the BEI was calculated using output from the 2-D sediment transport model and existing and with-Project hydrology. For the existing conditions, a regression equation was developed between the amount of bank erosion and the BEI. The regression equation was used to estimate the amount of bank erosion under the with-Project conditions.

A Sediment Delivery Index (SDI) analyses was performed to evaluate the relative change in sedimentation (vertical accretion) on vegetated islands and overbank surfaces and to provide a means of quantifying the relative sedimentation potential between the existing and With-Project conditions. Sediment concentration is used as a predictor of sediment deposition, with higher sediment concentrations creating higher sedimentation potential, and conversely, lower sediment concentrations creating lower sedimentation potential.

To perform the SDI analysis, overtopping discharges were assigned to each geomorphic surface. Sediment concentrations for the sand and silt sized materials were computed based on the hourly discharges for the existing and with-Project (Max LF OS-1b) conditions for the 50-year open water flow period using 1-D model results at PRM 129. The cumulative sediment load for each geomorphic surface was calculated by integrating the sediment concentration over the 50-year flow period. The SDI values were computed on an average annual basis by dividing the cumulative sediment load by the period of record (50 years). The SDI values were compared to evaluate the change in sedimentation potential on the geomorphic surfaces under existing and With-Project conditions.

The SDI values address the potential for sedimentation on the vegetated island and overbank surfaces and may be refined in coordination with Riparian Instream Flow Study (Study 8.6) and Ice Processes Study (Study 7.6). Further coordination with these studies will address correlating SDI values to measured sedimentation rates.

4.2.1. Model Development and Validation

A full description of the 2-D model development and calibration is provided in Appendix B. Tetra Tech (2014a) provides an overview of the earlier combined development of the FA-128 (Slough 8A) 2-D hydraulic and sediment transport models for the initial POC. The following is a summary of the steps taken to develop the 2-D sediment-transport model of FA-128 (Slough 8A). The steps include the development of the following information and approaches:

1. Overall model layout
2. Geometric base data
3. Model network
4. Flow resistance and turbulence inputs
5. Bed and bank material gradations and layers
6. Flow hydrographs and sediment input
7. Other considerations (Ice processes and LWD to be added later)
8. Test model hydraulically
9. Calibrate hydraulic model
10. Test sediment model
11. Calibrate sediment model (adjust sediment gradations and bed layers as necessary)

12. Run and evaluate results.

4.2.2. 2-D Sediment Transport Modeling Procedure

It was originally intended that the changes in bed elevation predicted by the 1-D model would be used to develop the 2-D model channel geometry for the 25-year and 50-year conditions. Evaluation of the 1-D model results over the 50-year simulation indicated little or no change in bed elevation along the majority of the Middle River, including at FA-128 (Slough 8A). The 1-D model predicted small amounts of localized aggradation and degradation at cross-sections in the middle river; on average, the model predicted no change in bed elevations in the vicinity of FA-128 (Slough 8A). Therefore, the 2-D model did not need to reflect changes in the main channel..

The initial 2-D model results for the Existing and Max LF OS-1b conditions supported the 1-D model results by predicting relatively small amounts of aggradation/degradation in the main channel; however, the 2-D model did predict significant amounts of deposition at the Skull Creek confluence. It was concluded that the majority of change in FA-128 (Slough 8A) would occur in the vicinity of the Skull Creek confluence.

The following methodology was developed to estimate the future channel geometry under existing and with-Project conditions.

Representative bed material gradations were assigned to the main channel, side channels, gravel bars, and other channel features. Vegetated areas were assigned as non-erodible due to the stabilizing effects of the vegetation. All the areas could accumulate sediment but only channels can erode and the sediment gradation of each element can change during the simulation.

Three annual hydrographs were selected to represent the Wet (1981), Average (1985) and Dry (1976) (ISR Study 8.5 Appendix J). The models were initially run for each of the Wet, Average and Dry year hydrographs for the Existing and Max LF OS-1b hydrology. The channel geometry at the end of the hydrograph is referred to as Year-1 conditions. The simulations were then continued over a series of 8 hydrographs developed to represent a long-term simulation. The hydrographs for the 8 year simulations were developed using various combinations of the representative Wet, Average and Dry years. The development of the hydrograph sequence is detailed in Appendix B. The channel geometry at the end of the series of hydrographs is referred to as Year 8 conditions. The changes in channel geometry over the 8 year simulation were evaluated and used to develop the Year 25 channel geometry for the Existing and Max LF OS-1b conditions. The models with the Year 25 geometry were then re-run for the Wet, Average and Dry year hydrographs, and the geometry at the end of the simulation was used with the previous model results to develop the channel geometry for the Year-50 conditions.

To estimate the geometry in the vicinity of Skull Creek, a representative area was selected that extends up- and downstream of Skull Creek (Figure 4.2-1). The change in volume over the duration of the simulation was calculated and a volume versus duration plot was developed which followed the “rate law” (Wu et al., 2012). A best-fit line was fitted to the points and the curve was extrapolated to estimate the volume at Year 25. To develop the Year 25 geometry (Existing and Max LF OS-1b), the geometry of the Year 8 mesh was adjusted so that the mesh area matched the predicted volume for the Year 25 conditions. The geometry for the remaining portions of the mesh where set to the conditions at the end of Year 8. A restart file from the end of the Year 8 conditions was used to set the bed material gradations for the entire mesh.

The Existing and Max LF OS-1b models with the Year 25 geometry were run over their respective Wet, Average and Dry year hydrographs. The change in volume was calculated for each simulation and the results were used to calculate a total change in volume for a four year period by adding the volume changes for the Wet, Dry and two times the Average. The results were used to update the volume versus duration curve. A new best-fit line was developed and was extrapolated to estimate the volume at Year 50.

The Existing and Max LF OS-1b models with the Year 50 geometry were run over their respective Wet, Average and Dry year hydrographs and the volumes at the end of the simulation were calculated using the same method applied to the Year 25 conditions.

4.2.3. Tributary Fan Modeling

Tributary delta modeling is an intrinsic part of the 2-D bed evolution modeling at the FAs. The methods for 2-D tributary fan modeling are fundamentally different from the methods described in Section 4.1.6 for 1-D modeling. The 2-D analyses are based on sediment transport equations where delta growth and erosion are based on comparisons of sediment supply versus transport capacity over time for each element. Although the fan topset is well-represented in the 2-D model, the foreset is unlikely to be as steep because of element resolution limitations (e.g. foreset slopes may be only a few feet in length and elements are tens of feet in across), and because the angle of repose (as represented in Equation 4.1.6-3) is not accounted for in the 2-D model sediment mobility. The 2-D model does however, provide a more complete comparison of fan evolution for Existing and with-Project conditions including the potential for side channel blockage. Some important questions to be addressed by the tributary modeling are:

- Will the tributary fan continue to develop under Existing and Max LF OS-1b conditions?
- Could progressive tributary fan formation eventually cut off the side channel?
- Would the tributary fan form a new quasi-equilibrium geometry? (A quasi-equilibrium condition is reached when the short-term fan geometry varies with little change occurring over longer periods.)
- How will future tributary bar geometry affect habitat or fish access to habitat?

As discussed in the hydrology (Appendix B) and Bed Evolution Modeling section (4.2.2), flow hydrographs for Skull Creek were developed for the Wet, Average and Dry years using results from the open flow routing model (ISR Study 8.5). The discharge versus sediment load rating curve was developed for Skull Creek to input sediment to the model. The same hydrographs and sediment rating curves for Skull Creek were applied to the Existing and with-Project conditions.

The material type on the island located opposite the mouth of Skull Creek was set as non-erodible in order to prevent erosion of the island. This was done to evaluate the geometry of the bar over time. The results of the tributary delta modeling were compared to the 1-D tributary delta modeling and the 2-D model results are used to validate the methodology used to predict the geometry using the 1-D model output.

4.2.4. Bank Energy Index Analysis

An analysis of the relative effects of changes in flow regime on lateral erosion potential within FA-128 (Slough 8A) was conducted using the Bank Energy Index (BEI) concept. The BEI analysis quantifies energy expenditure against a bank and provides a basis for evaluating the relative change in the bank erosion (lateral migration) potential between the existing and with-dam hydrologic regimes.

The BEI method is site calibrated by relating observed historical bank movement to the energy expended on the banks over the same period. To perform the BEI analysis for sites on the Susitna River, the turnover mapping for the period from the 1980’s to 2012 (Tetra Tech, 2014b) was evaluated to identify representative bank erosion locations. At each location, the amount of erosion between the 1980’s and 2012 was measured and the BEI was calculated using output from the 2-D sediment transport model for the existing and with-Project conditions.

For the existing conditions, a regression equation was developed between the amount of bank erosion and the BEI. The resulting regression equation provides insight to the bank erosion processes. The regression equation along with determination of the index with the 2-D model (hydrodynamic portion of the sediment transport model) were used to estimate the amount of bank erosion under the Max LF OS-1b conditions.

4.2.4.1. Site Selection

Sixteen locations in the area of FA-128 (Slough 8A) were selected to compare the BEI values and to develop a relationship between the amount of bank erosion and the BEI values (Figure 4.2-2). The turnover mapping for the period from the 1980’s to 2012 was evaluated to identify representative locations where the bank had clearly eroded and the bank materials were considered to have similar erodibility. At each site, the amount of erosion was measured for the period from the 1980’s to 2012.

Many factors including bank material characteristics, vegetation and man-made bank protection, affect the actual erosion potential. Some areas of observed bank erosion were not considered because the bank materials were significantly different and likely limited the amount of erosion. These areas include: (1) along the right bank of the Susitna River which is the valley wall and contains areas of bed rock outcrop, and (2) along the left bank upstream of Skull Creek which has riprap to protect the railroad.

The turnover mapping for the period from the 1950’s to the 1980’s was not used in the analysis because river alignment was sufficiently different from the 2-D model geometry, that the 2-D model output is less representative of the bank erosion over this period.

Some of the selected sites are located on the inside of the bends (e.g. Sites 15 and 16). Typically, bank erosion due to fluvial processes occurs on the outside of bends due to larger velocities and the presence of helical flow. The presence of eroding bank on the insides of the bends suggests the erosion is not entirely due to open water conditions but is also influenced by ice processes.

4.2.4.2. Description of BEI Method

The Bank Energy Index (BEI) concept, in conjunction with qualitative information about the bank materials and other site characteristics, provides a means of quantifying the relative effects of changes in the flow regime between the existing and with-dam hydrologic regime. The BEI is an index of the total energy applied to the banks at specific locations, and is computed based on the hydraulic characteristics of the channel, the channel planform and the magnitude and duration of flows (Mussetter and Harvey 1995). The BEI, thus, accounts for both the magnitude and duration of stresses imposed on the channel boundary by the flows. It is important to note that the BEI is only an index of erosion potential; other physical factors such as the relative erodibility of the bank materials have a significant effect on the actual erosion that occurs at any specific location (Mussetter, Harvey and Sing 1995). Furthermore, the BEI analysis does not consider ice erosion or ice breakup effects.

The BEI is developed from basic physical principles as follows. Energy is defined as the product of the stream power expended on the banks and the incremental time over which it is applied. Bank stream power is the product of the flow velocity (V_{ch}) and the shear stress acting on the bank (τ_b). The BEI analysis method was originally developed using the main channel velocities (Vch) predicted by a 1-dimensional hydraulic model, then applying a factor (K_b) to account for the effects of channel curvature on the shear stress acting on the outside of a bend [K_b depends on the ratio of the radius of curvature to the channel top width (R_c/W)]). Since, the 2-D model intrinsically accounts for the channel curvature, a value of K_b=1 was used for all the BEI calculations and the velocities and shear stresses were obtained from the 2-D model output. Shear stress was not used as a point value from a single element, but was averaged over several elements along the areas of interest.

For a given flow period the total energy expended on the banks at a given location can be determined by integrating the bank stream power over the flow period:

$$BEI = \int (V_{ch} \tau_b) dt \qquad \text{(Equation 4.2.4.2-1)}$$

where BEI = total energy expended at a specific bank location, and dt = the incremental time associated with each range of discharge in the flow record.

In a 1-D model, the bank shear stress is computed from:

$$\tau_b = K_b \gamma d_h S_f \qquad \text{(Equation 4.2.4.2-2)}$$

where γ = unit weight of water (62.4 lb/ft^3),
d_h = hydraulic depth,
S_f = energy slope, and
K_b = factor that accounts for the effect of channel curvature on the shear stress acting on the outside of a bend.

For the 2-D model, the value of shear stress is calculated from hydraulic conditions at the location and, as previously discussed, a K_b value of 1 was used for the analyses.

4.2.4.3. Method for FA-128 (Slough 8A)

The mean daily flow (MDF) values for the existing and with-dam (Max LF OS-1b) conditions detailed in the hydrologic analysis (Tetra Tech 2013b) were used in the BEI analysis. Because high flows are reduced for with-Project conditions the energy expenditure is likely to be significantly lower. For the BEI analysis, the mean-daily flow values for the period from WY1983 to WY2010 (28 years of record) were used in order to be consistent with the turnover mapping period.

The Gold Creek gage is located approximately 12 miles upstream of FA-128 (Slough 8A). Since there are no significant tributaries and the accretion flows are relatively small between the gage and the focus area, the Gold Creek MDF values were deemed appropriate for the analysis and no adjustments were made.

The hydrodynamic portion of the 2-D sediment transport model was run for a range of steady-state discharges from 10,000 to 100,000 cfs in increments of 10,000 cfs. It was assumed that no bank erosion occurred at less than 10,000 cfs.

Representative shear and velocity values were calculated for each site and for each discharge by averaging the model output of 3 elements located closest to the site (the element closest to the site and the up- and downstream elements along the bank alignment were selected). BEI values for the existing and with-Project conditions were calculated by integrating the shear and velocity values over the 28 year mean daily flow period. Because the BEI values integrated over time tend to be large, values are normalized by dividing by the average existing conditions BEI value. Once the relationship between the bank erosion and BEI is developed it can be used to predict the amount of bank erosion that would occur under with-Project conditions.

One common mechanism of bank failure is erosion of the toe of the bank and the subsequent collapse of the upper part of the bank. The toe of the banks along the Middle Susitna River Segment are generally comprised of gravel and cobbles. The upper portions of the bank are comprised of sands and silts with root reinforcement that provides a significant amount of erosion resistance. To provide a more complete analysis of the bank erosion processes, and in particular, how much bank erosion is due to the erosion of the bank toe under open water conditions, the BEI for the existing conditions was re-calculated by applying a critical shear stress (incipient motion) criteria on the gravels forming the base of the bank. For this calculation only flows that exceed the critical shear stress were included in the integration.

The critical shear stress was calculated for the gravels assuming a median size (D_{50}) of 54 mm and a Shields parameter of 0.047. At each site, the flow required to create the critical shear stress, and therefore mobilize the median gravel size was estimated based on the discharge vs shear stress rating curves developed from the 2-D model output; this flow is referred to as the critical flow. The BEI was re-calculated at each site using the flows that exceeded the critical discharge over the 28 year period.

4.2.5. Sediment Delivery Index

The Sediment Delivery Index (SDI) was developed to evaluate the relative change in sedimentation (vertical accretion) on vegetated islands and overbank surfaces and to provide a means of quantifying the relative sedimentation potential between the existing and With-Project conditions. Sediment concentration is used as a predictor of sediment deposition, with higher sediment concentrations represent higher sedimentation potential.

As presented at the Riparian Proof of Concept Meeting (April 29-30, 2014) the SDI is computed based on the sediment concentrations for suspended load (sand, silt, and clay sized material) and the magnitude and duration of flows overtopping the geomorphic surfaces. Larger SDI values indicate higher amounts of sedimentation potential and therefore greater vertical accretion, and conversely, smaller SDI values indicate lower sedimentation potential. The SDI can be used to compare various surfaces along the river, and changes in hydrologic regime.

It is important to note that the SDI is only an index of sediment deposition; other physical factors such as the velocity, depth, and variation in sediment concentration over the surface have an effect on the actual deposition that occurs at any specific location. The SDI analysis was related to open water conditions and does not consider ice erosion, inundation, or breakup effects. It would be feasible to correlate deposition rates to SDI for a range of geomorphic surfaces and to extend the application of SDI to ice-dominated conditions, especially breakup.

The SDI is computed as follows. Overtopping discharges were assigned to each geomorphic surface based on analyses conducted by Tetra Tech and presented at the Riparian Proof of Concept Meeting (April 29-30, 2014). The overtopping discharges were calculated based on a raster ground elevation and water-surface elevations from the 2-D hydraulic model which was run at a range of steady-state flows from 2,000 to 100,000 cfs. The inundation discharges for each raster element was calculated (Figure 4.2-3) based on the 2-D hydraulic model output and the associated overtopping recurrence-interval was calculated based on the existing conditions flood-frequency curve. A box-plot was developed for each of the mapped geomorphic features which shows the median, 25- and 75-percentile values and the minimum and maximum values (Figure 4.2-4). As shown in Figure 4.2-4, the median overtopping discharges range from 48,320 cfs for the vegetated bar to approximately 87,570 cfs for the overbank floodplain (recurrence interval approximately 50 years).

Sediment concentrations for the sand and silt sized materials were computed based on the hourly discharges for the Existing and Max LF OS-1b conditions for the 50-year open water flow period using 1-D model results at PRM 129 (Appendix A). The sediment concentrations for the existing (Equations 4.2.5-1 and 4.2.5-2) conditions were computed using the sediment load regression equations that were developed from the sediment-transport analyses at Gold Creek Gage (Tetra Tech 2014c). The coefficients for the equations were adjusted to represent the sand, and silt/clay loads estimated for With-Project conditions (Equations 4.2.5-3 and 4.2.5-4), which include sediment passing the dam and tributary supply (Tetra Tech 2014c):

$$C_{Existing\_Sand} = 4.1x10^{-15}Q^{2.29} \quad \text{(Equation 4.2.5-1)}$$
$$C_{Existing\_Silt/clay} = 2.9x10^{-12}Q^{1.67} \quad \text{(Equation 4.2.5-2)}$$
$$C_{With\text{-}Dam\_Sand} = 1.71x10^{-16}Q^{2.29} \quad \text{(Equation 4.2.5-3)}$$
$$C_{With\text{-}Dam\_Silt/clay} = 8.98x10^{-13}Q^{1.67} \quad \text{(Equation 4.2.5-4)}$$

Where C = sediment concentration by volume
Q = total discharge (cfs)

The SDI for each point in a geomorphic surface was calculated by integrating the sediment concentration over the specified flow period:

$$SDI = \int C\, dt \quad \text{(Equation 4.2.5-5)}$$

where SDI = Cumulative sediment concentration, and
dt = the incremental time associated with each range of discharge in the flow record.

The SDI values were computed on an average annual basis by dividing the SDI value by the period of simulation for the open water flow period (50 years).

4.2.6. Hydraulic Modeling for Habitat Analysis and Long-Term Width Change

To illustrate the application of the 2-D model to the Instream Flow Studies, the bed elevations in the Year 25 Existing and Max LF OS-1b conditions were incorporated into the hydraulic models. In addition, as discussed for the 1-D model width change analysis in the Middle River, the max LF OS-1b model was adjusted to account for the likely changes in vegetation growth along channel and lateral feature margins.

The methodology for channel narrowing in the Focus Areas is similar to the Middle River 1-D model. Rather than using ineffective flow, which is only a 1-D model feature, the roughness is adjusted for any element where vegetation is expected. Since conveyance of water and sediment is computed for each element of a 2-D model rather than the 1-D model cross section with only three subdivisions (channel and two overbank areas), adjusting roughness does not cause unrepresentative hydraulic effects in the channels.

As with the 1-D model, the with-Project 2-year flow was used as the reference flow for evaluating the potential for vegetation colonization. This is shown in Figure 4.2-5. Areas with shading are dry for Max LF OS-1b 2-year flow (24,000 cfs) but wet for existing conditions 2-year flow (44,000 cfs). All non-shaded areas are either wet for both conditions (channels) or dry for both conditions (islands, floodplains, terraces, etc.). The shaded areas are considered as likely for vegetation colonization. Many of the areas are bars adjacent to vegetated islands and some are the high points of channel bars that currently have no vegetation.

The upper end of Slough 8A, which currently is connected at its upstream end for flows greater than 30,000 cfs, may vegetate because this flow would occur less frequently than the with-Project 2-year flow of 24,000 cfs. The areas of continued vegetation encroachment would extend the long-term trend of Slough 8A being a much wider in the 1950s and 1980s than it is currently. From the geomorphic features and turnover mapping (Tetra Tech 2014d) Slough 8A has narrowed from a 150 to 300 ft wide side slough in the 1950s, to a 50 to 150 ft wide side slough in the 1980s, to a current width ranging from 30 to 100 ft. The upper end of Slough 8A becoming fully vegetated is a reasonable expectation for with-Project conditions, but also looks like a likely occurrence without the Project, though likely over a longer time frame. If this occurs, Slough 8A will have evolved to an upland slough.

The areas around the margins of the islands and floodplains that were dry under Max LF OS-1b and wet under Existing conditions were identified. These areas were assumed to increase in riparian vegetation, and therefore increase roughness, under Max LF OS-1b conditions over the 25-year period. To account for the increase in roughness, a Manning's n value of 0.12 was applied to these areas. No adjustment was made to the existing conditions model.

The hydraulic models were re-run at steady-state discharges of 12,000 and 30,000 cfs. The predicted depth and velocity values for the Year 25 Existing and Max LF OS-1b conditions were compared to the Existing (Year 0) conditions.

As with the output from the Year 0 simulations, the output from the 2-D hydraulic models with the Year 25 geometry for the Existing and Max LF OS-1b conditions will be provided for the same steady state flows to the habitat analysis teams for each flow condition. Results for the existing channel topography will provide the baseline for comparison of potential Project effects. The output values for the required hydraulic variables that include depth, velocity, water-surface elevation, shear stress, and bed mobilization, will be provided at each node along with the associated geo-referenced horizontal coordinates and elevations.

4.2.7. Large Woody Debris Effects

The updated FGM approach TM (Tetra Tech 2014a, Section 4.3.2.1) provides information on the planned application of the 2-D sediment transport model to assess the changes in the amount and distribution of LWD on local hydraulic and sediment-transport conditions under with-Project conditions. At this stage, no analyses has been conducted to evaluate Project effects on LWD.

4.2.8. Ice Effects

The updated FGM approach TM (Tetra Tech 2014a, Section 4.3.3) provides information on the planned application of the 2-D sediment transport model to assess the influence of ice processes on channel morphology and riparian vegetation. The analyses will evaluate the ice effects on sediment mobilization, lateral features, and floodplains. At this stage, no modeling has been conducted to evaluate the ice effects on channel evolution.

5. RESULTS

This section includes the results of reach-scale (1-D) and local-scale (2-D) bed evolution modeling for Existing and the Maximum Load Following Operational Scenario 1B (Max LF OS-1b). The 1-D model results are from the initial models used to support the decision whether to extend fluvial geomorphology modeling below PRM 29.9 (Tetra Tech 2014b). The 2-D model results are from sediment transport models developed at FA-128 (Slough 8A), which was the focus area used in the initial Proof of Concept exercise demonstrating that the 2-D hydraulic modeling would provide the required information for aquatic habitat analyses (Tetra Tech 2014a).

5.1. 1-D Model Results

The development of the initial 1-D bed evolution model is described in Appendix A of this technical memorandum. The model results included in this section focus on comparisons of bed evolution and bed material transport results from the Middle and Lower Susitna River models for Existing and Max LF OS-1b conditions. These include potential Project effects on sand and gravel loads and concentrations, bed material gradations, channel bed elevations, and sediment stored, eroded, and transported through the system.

5.1.1. Sediment Loads and Concentrations

Figure 5.1-1 shows the sediment loads calculated for PRM 140.0 (Gold Creek gage) for Existing and Max LF OS-1b conditions. For Existing conditions, there is considerable variability in sediment load over the 50 years. There is virtually no sediment load (sand and coarser) for the with-Project condition because the reservoir would trap 100 percent of this material but also because sediment supply from tributaries is excluded from these initial models. Gravel makes up less than 1 percent of the total load for Existing conditions but may become the primary load under with-Project conditions when tributary loads are incorporated into the final models.

The scale of Figure 5.1-1 was selected to facilitate comparison with the sediment loads for the Lower River, which are shown in Figure 5.1-2 (PRM 88.0, Sunshine gage) and Figure 5.1-3 (PRM 29.9, Susitna Station gage). The Sunshine gage includes sediment from the Middle Susitna River, Chulitna River, and Talkeetna River. There is considerable variability in both the Existing conditions and Max LF OS-1b results over time. Since there is little sediment supplied by the Middle River for the with-Project condition, the difference reflects cutoff of the sediment supply from upstream of the dam resulting in a reduction in bed material load of approximately 30 percent for the with-Project condition.

As shown in Figure 5.1-3, sediment loads at Susitna Station are approximately double the loads at Sunshine. The Yentna River is the primary source of sediment at this location. At Susitna station, the with-Project loads are approximately 15 percent less than the Existing conditions. Gravel load at Susitna Station is less than 2 percent of the total load.

Although the 1-D bed evolution model is run with the open water flow periods for 50 years, as shown in these three figures the results can also be reviewed annually. Several analyses will be conducted using the selected representative wet (1981), average (1985), and dry (1976) years. In the Middle River (Figure 5.1-1) the sediment load for the representative wet year is exceeded twice, in 1964 and 1971. The average year sediment load (1.7 million tons) is very close to the median value (1.6 million tons) and the representative dry year exceeds other annual sediment loads 6 times. Although the selection of the representative years was made based on Gold Creek gage records, this pattern is repeated for the Lower River. At both the Sunshine and Susitna Station gages the representative wet year load is exceeded twice, but for different years (1990 and 2005 for the Lower River stations compared to 1964 and 1971 at Gold Creek), and the representative dry year exceeds other years 6 times at Sunshine and 7 times at Susitna Station. For both gages the average year plots within 5 percent of the median of the 50 years. Therefore, for both the Middle and Lower Rivers, the average year well represents the middle two quartiles (50 percent of the time) and the dry year well represents the lower quartile. The wet year appears to be slightly biased high based only on sediment transport, but is still representative of the upper quartile.

Figures 5.1-4 and 5.1-5 show computed sediment loads and sediment concentrations plotted versus discharge for the Existing and Max LF OS-1b conditions. Three Middle River locations are included in each plot; Watana Dam site (PRM 187.1), Gold Creek gage (PRM 140.0) and PRM 107.2. PRM 107.2 was selected because this is the location of most of the USGS Middle River sediment transport measurements. This is also the location selected at the upstream boundary for the Lower River model.

At Watana Dam, the upstream model boundary, the sediment loads are calculated from a rating curve and therefore include no scatter. Only the Existing conditions values are plotted at the input boundary because no sediment was included at the dam for with-Project conditions for the initial 1-D model runs. At the downstream locations, the model shows moderate scatter and a slightly flatter slope than at the dam, though the slope (in log space) is approximately 3. Downstream sediment loads are several orders of magnitude lower for with-Project conditions. In this initial model these loads only reflect the main channel bed as a sediment source (no tributary inputs). The with-Project loads are also much more variable because they gradually decrease through time as the finer materials are removed from the bed. The plot of sediment concentration is very similar to the load, except that the slope of the data are reduced by one (from 3 to 2 for existing conditions). This plot shows that sediment concentration (not including silt and clay sizes) ranges from 10 PPM to approximately 3,000 PPM for Existing conditions but is predominantly less than 10 PPM for with-Project conditions.

The very large differences in sediment load or concentrations between Existing and with-Project conditions seen in the Middle River are barely discernable in the Lower River. As shown in Figure 5.1-6 (load) and Figure 5.1-7 (concentration), the trends and the level of variability are nearly identical between the two operational conditions. This is true for both Sunshine gage (PRM 88.0) and Susitna Station (PRM 29.9). Because the trends and variability of the instantaneous loads versus discharge between scenarios (Figures 5.1-6 and 5.1-7) are similar in the Lower River, the differences in annual and long-term loads between the scenarios (Figures 5.1-2 and 5.1-3) in the Lower River appear to be driven more by hydrology with fewer high flows and extended periods of lower flow for the with-Project condition.

5.1.2. Bed Material Gradations

In the process of routing sediment through the system, the 1-D bed evolution model adjusts the channel geometry, and the gradations and thicknesses of the sediment layers. In coarse bed channels, the surface layer material controls sediment transport capacity by armoring and limiting the availability of the finer subsurface materials. At high shear stresses the armor may be disturbed and the bed mobilizes resulting in nearly full access to the subsurface materials. Figure 5.1-8 shows reach average bed surface material sizes for the Middle and Lower Rivers. Standard sizes (D_{84}, D_{50}, and D_{16}) are shown for Existing conditions and two Max LF OS-1b conditions (with and without channel narrowing).

In the Middle River the surface bed sizes show a general tendency for fining in the downstream direction. There is a significant drop in surface bed material size from the Middle River to the Lower River in response to the Chulitna River sediment supply. For existing conditions D_{84} drops by nearly a factor of 3.2, D_{50} drops by a factor of 2, and D_{16} drops by a factor of 1.4. This is expected based on the dominant sediment supply coming from the Chulitna River. For the Lower River, the sizes fine downstream through the first three geomorphic reaches (LR-1 through LR-3), then tend to coarsen from LR-3 to LR-5. This is consistent with the sediment load analyses (Tetra Tech 2014c) where coarse material is shown to be accumulating between Sunshine (PRM 88) and Susitna Station (PRM 29.9). There is a significant constriction at the boundary between LR-3 and LR-4 and the Yentna River confluence at the lower end of LR-4. Therefore, the increase in size for LR-4 and LR-5 may be reflecting locally derived coarse materials from the constricting terraces and the combined effects of a major tributary input just above another major constriction at Susitna Station. The trends in bed material gradation are similar for the with-Project simulations with fining in the downstream direction through LR-3 and coarsening in LR-4 and LR-5. The with-Project standard sediment sizes are similar for all simulations and are generally within half-phi ($\sqrt{2}$) of the existing conditions values. If there were significant coarsening under with-Project conditions, this would indicate that the bed is armoring in response to the low sediment supply from upstream. This is not the case so it is much more likely that the Middle River bed armor is rarely disturbed for either Existing or with-Project conditions. Throughout the Lower River, some reaches coarsen and other fine for the with-Project simulations. This variable response is probably due to relative upstream supply versus bed and tributary supply and altered hydrology affecting the relative transport rates of the range of bed material sizes.

5.1.3. Bed Change

The bed evolution model includes several interrelated processes in a dynamic sediment transport simulation. Sediment supply and sediment transport capacity are compared to determine the potential for deposition or entrainment of bed material. The availability of material may be limited by an armor, so even if there is excess transport capacity, without access to subsurface material the bed may not change. The gradation and thickness of the surface and subsurface layers can also change in response to entrainment or deposition. Cross section elevations are adjusted based on volumes of material that are deposited (aggradation) or entrained (degradation). Cross section velocity and depth change in response to changes in channel geometry, so there is a continuous feedback between the sediment transport, adjustments in channel geometry and bed material gradations, and hydraulic conditions.

In this section the amount of bed change for Existing conditions is compared to Max LF OS-1b for the Middle and Lower River models. For the with-Project condition, simulations using the existing geometry and a narrowed channel geometry are included to provide a range of potential outcomes. Bed change is evaluated in terms of change in bed elevation and change in bed volume. The two metrics are considered since wider channels can store or erode larger amounts of sediment with little change in bed elevation compared to similar volumetric change in a narrower channel.

5.1.3.1. Middle River

Figure 5.1-9 shows Middle River bed elevation change at each cross section over the 50-year simulation period with the channel profile for reference. Three simulations are shown, Existing condition, Max LF OS-1b and Max LF OS-1b with channel narrowing. The three simulations have very similar results. Throughout the Middle River bed elevation changes are predominantly between +/- 1 foot and rarely exceed 2 feet of change in 50 years.

The bed change figure generally shows a shorter distance between bed elevation change points below Devils Canyon compared with upstream of Devils Canyon. This is not an indication of a more dynamic response, but the result of greater cross section density below Devils Canyon than upstream. This initial model only has 2012 surveyed cross sections upstream of Devils Canyon as it does not include the cross sections surveyed in 2014 and no cross sections were surveyed above Devils Canyon in 2013 (the model will be updated with 2014 cross sections at bed material data in subsequent model versions). The figure also shows no bed elevation change in Devils Canyon (Geomorphic Reach MR-4 from PRM 154 to 166) which stands out as the steepest section of river. In Devils Canyon the model is set as a fixed bed to pass sediment without interaction with the bed to reflect the bedrock control throughout this reach. The model extends slightly into the Lower River (PRM 102 to PRM 96). Although the results are comparable to the Lower River model, since the sediment transport function was calibrated for Middle River conditions (see Appendix A) the Lower River model results apply to this area.

The greatest variability in bed response for Existing conditions occurs between PRM 120 and PRM 150, which coincides with generally with geomorphic reach MR-6 (PRM 148.4 to PRM 122.7). MR-6 stands out among the Middle River geomorphic reaches as having the greatest number of channels (averaging 2.4) with the exception of MR-8 (PRM 107.8 to PRM 102.4), which is a transitional reach to the braided Lower River planform (ISR Study 6.5). Individual cross section variability should not be given much weight in a 1-D model. Therefore, reach averaging is used to evaluate bed evolution trends. Figure 5.1-10 shows the reach average annual bed elevation changes for the three simulations and the cross section sediment stored (or eroded) through the Middle River. For the three simulations, reach average bed change is generally within +/- 0.01 ft/yr, or within +/- 0.5 ft over the 50-year simulation period. All the models shows slight degradational tendencies upstream of Devils Canyon. For Existing conditions this result may be because sediment supplied from fairly large tributaries (Tsusena, Little Tsusena, and Fog Creeks) is not included in the initial version of the model. These tributary sediment supplies would also be included in the with-Project runs so the slight degradation in these models would also be decreased.

For Existing conditions, the only Middle River geomorphic reach that approaches 0.01 ft/yr of aggradation is MR-8 (PRM 107.8 to PRM 102.4), where the Middle Susitna River is influenced by the confluence with the Chulitna River. In the with-Project simulations this reach undergoes virtually no long-term bed elevation change.

Figure 5.1-11 combines the cross section sediment storage of sand and gravel sizes into the along-channel cumulative sediment storage and plots this along with the sediment in transport. The four sets of double lines shown for Existing conditions between PRMs 105 and 130 are split flow reaches where water and sediment are routed in multiple channels around groups of islands. At each of the splits, approximately three-quarters (~1.5 million tons/yr) of the sediment is transported in the primary channel and one-quarter (0.5 million tons/yr) in the secondary channel. This figure shows that very little of the sediment (sand sizes and larger) in transport deposits within the Middle River and that the channel bed is not a significant source of material in transport. The major difference between the Existing conditions and the Max LF OS-1b conditions is the amount of material in transport through the Middle River. For Existing conditions there is nearly 2 million tons/year average annual sediment transport and for with-Project conditions the value is nearly zero in comparison (approximately 30,000 tons/yr). The load for the with-Project condition may be low due to the initial model not including tributary loads, though this is conservative in that estimated effects downstream of the dam are not mitigated by tributary inputs..

Figure 5.1-12 shows the cumulative sediment stored (or eroded where negative) in detail. As indicated above, the slight erosion (degradation) above PRM 168 for Existing conditions may reflect that the simulations did not include sediment supplied from fairly large tributaries. The gradual increase in sediment stored between PRM 150 and 120 for Existing conditions, though it equates to less than 0.5 feet in 50 years, probably reflects the numerous lateral controls in this geomorphic reach that also cause more frequent island building and multiple channels. Under with-Project conditions the slight degradation upstream of Devils Canyon is probably overstated and below Devils Canyon virtually no sediment is either stored or eroded.

5.1.3.2. Lower River

In contrast to the Middle River, the Lower Susitna River shows a consistent trend for sediment accumulation and increasing bed elevations. Figure 5.1-13 shows cross section bed elevation change and the bed profiles at the beginning and end of all three 50-year simulations (Existing conditions, Max LF OS-1b and Max LF OS-1b with channel narrowing). For all three simulations the bed elevation change ranges from 0 to 2 feet in 50 years near the Three Rivers Confluence (approximately PRM 100) and then decreases to 0 to 1 feet in 50 years below PRM 80 down to PRM 45 (upstream end of geomorphic reach of LR-4). At PRM 45 there is a significant constriction and a significant convexity in the channel profile down to the next constriction starting at PRM 31 (upstream end of geomorphic reach LR-5), which is just upstream of Susitna Station gage. The Yentna River confluence is also just upstream of the constriction and the Yenta River approximately doubles flow and sediment at this point. Bed elevation change of up to 5 feet in 50 years occur for the Existing conditions simulation, up to 4.5 feet for Max LF OS-1b conditions, and up to 7.5 feet with channel narrowing. Since the with-Project simulations include either no narrowing or extremely fast narrowing, these results are expected to bracket the range of possible Project effects and the likely effect would between these results.

Figure 5.1-14 shows the reach averaged bed elevation changes and the cross section sediment stored. On a reach basis, the bed change for existing conditions decreases from 0.024 ft/yr in LR-1 and decreases to 0.013 ft/yr in LR-2 and LR-3, then increases significantly in LR-4 and LR-5 (0.038 ft/yr and 0.07 ft/yr, respectively). These results are consistent with the braided planform of the Lower River. Very similar trends occur for the two with-Project simulations though the rates are slightly less for the no-narrowing simulation and slightly greater for the with-narrowing simulation. In either case, the dynamic character of the Lower River would be maintained under with-Project conditions.

Figure 5.1-15 shows the cross section storage, cumulative sediment stored, and sediment in transport through the Lower Susitna River for the 50-year simulations including Existing conditions and Max LF OS-1b with and without width change. The large changes in sediment transport between PRM 105 and 100 are major tributary sediment supply from the Chulitna and Talkeetna Rivers. Similarly, the large change in sediment transport at PRM 33 is the Yentna River. There are two split flow reaches (one centered on PRM 70 and the other centered on PRM 50) where approximately 75 to 80 percent of the sediment is conveyed on the primary channel and the remaining material is conveyed in the secondary channel. Although there are individual cross sections that erode slightly over the 50-year simulation period, the predominant trend is sediment storage in the lower river. The most significant storage occurs 8 miles above the Yentna River confluence, which is expected based on the highly braided planform, number of active islands, and, as shown in Figure 5.1-13, the significant convexity of the channel bed profile.

Figure 5.1-16 shows the cross section and cumulative sediment stored along the Lower River in detail. From the Three Rivers Confluence to approximately PRM 40 there are consistent rates of sediment storage and below PRM 40 there is a dramatic increase in sediment stored, which coincides with the profile convexity between PRM 45 and PRM 31. The results of the two with-Project simulations generally bracket Existing conditions results and show very similar trends.

5.1.3.3. Summary

Figures 5.1-17 and 5.1-18 show the cumulative sediment stored for the Susitna River from Watana Dam site (PRM 187.1) to Susitna Station (PRM 29.9) by combining model results from the Middle and Lower River simulations. Existing conditions and Max LF OS-1b conditions are included. Figure 5.1-18 includes the sediment transported along these river segments for reference. Very little sediment is stored or eroded from the Middle River whether or not the sediment is supplied at the proposed dam location. This indicates that sediment supplied to the Middle River (predominantly sand) is throughput load that is primarily conveyed through the Middle River and that the bed has a “static” armor that is rarely mobilized during open water periods. Therefore, the large difference in sediment supply between the existing condition and with-Project conditions caused by sediment trapped in the reservoir is not replenished by bed erosion and lowering through the Middle River.

Significant sediment inflows occur when the Chulitna and Talkeetna Rivers join the Susitna River at the upstream end of the Lower River, and then an even greater sediment input occurs when the Yentna River joins at PRM 32. These large tributary inputs are not affected by the Project. Although there is considerable sediment deposition throughout the Lower River compared to the Middle River (Figure 5.1-17), the deposition is a small percentage of the overall supply (Figure 5.1-18) at approximately 12 percent of sediment supply for Existing conditions and 10 percent of sediment supply for Max LF OS-1b conditions. For Existing and Max LF OS-1b conditions the Lower River aggrades over the 50-year simulation period, though at a slightly lower rate for the with-Project condition. The aggradation causes the geomorphically active, braided character of the Lower River, which would persist under with-Project conditions. Therefore, the Lower River is expected to have minimal Project effects related to sediment transport.

5.1.4. Tributary Sediment Supply Modeling

A discharge versus bed material transport relationship was developed for Skull Creek where the tributary flow onto the head of the delta (Figure 3.1-10 in Appendix B). This relationship was input to the 2-D bed evolution model to simulate formation of the delta and calculate the load delivered into the mainstem Susitna River. For the reasons noted in Section 4.1.2, no other sediment rating curves were developed for the POC.

5.1.5. Tributary Delta Formation

As shown by the topographic surfaces and contours in Figure 4.1-9, the 2-D bed evolution model simulated the Skull Creek delta prograding into the mainstem Susitna River for both the existing conditions hydrology and the Max LF OS-1b hydrology. As presented in Section 5.2.2 this is consistent with the results of the turnover analysis (Tetra Tech 2014e), which shows considerable growth of this fan between the 1950's and 1980's aerial photography and additional growth for current conditions. The HEC-RAS results at cross section 5 were used to evaluate the delta formation using the simplified approach. The stability of the foreset slopes is summarized in Table 5.1-1. The first column under each combination of morphology and hydrology corresponds to the Shields parameter set using the 2-year average annual recurrence interval flow; the second column corresponds to the Shields parameter set using the 5-year average annual recurrence interval flow. The results of the flow frequency analyses under existing conditions hydrology and Max LF OS-1b hydrology are provided in Table 5.1-2. The shaded areas of Table 5.1-1 indicate flows that are less than the critical flow, where the critical flow is defined as the flow corresponding to conditions of incipient motion for the D_{84} on the toe of the foreset slope. For flow less than the critical flow, if there is sufficient supply from Skull Creek, the delta will prograde. For flows greater than the critical flow ($\tau_{*c} > 1$) the foreset slope is mobile and will recede. As provided in Table 5.1-3 the results of these analyses show that when incipient motion is linked to the 2-year flow of 43,400 cfs (resulting in a Shields parameter of 0.025):

- For the initial morphology a flow of nearly 52,000 cfs (recurrence interval between 2 and 5 years, Table 5.1-2) is needed to mobilize the D_{84} from the foreset.
- For the future morphology under Max LF OS-1b hydrology, incipient motion corresponds to a flow of 27,000 cfs. As presented in Table 5.1-2 this flow has an average annual recurrence of between 1.5 and 2 years under the Max LF OS-1b hydrology.

When the results provided in Table 5.1-3 are instead linked to incipient motion at the 5-year flow of 55,700 cfs (resulting in a Shields parameter of 0.034):

- For the initial morphology a flow of nearly 76,400 cfs (recurrence interval between 20 and 50 years) is needed to mobilize the D_{84} from the foreset.

For the future morphology under Max LF OS-1b hydrology, incipient motion corresponds to a flow of 35,600 cfs. As presented in Table 5.1-2 this flow has an average annual recurrence of between 2 and 5 years under the Max LF OS-1b hydrology.

5.2. 2-D Model Results

The validated 2-D sediment transport model was run over a series of representative flood hydrographs using the model parameters detailed in Section 4.2. SRH-2D reports channel erosion (degradation) as positive values and aggradation as negative values. In the following figures that show changes in bed elevation, aggradation is shown in the blue to green color range and degradation is shown in the yellow to red color range.

5.2.1. Bed Evolution Modeling

The model for the existing and with-Project conditions is used to develop Year-25 and Year-50 conditions. The model predicted rapid changes to occur during the first year for each of the simulations (wet, average and dry years). Some of the initial changes can be attributed to the lack of a model warmup period, and therefore, the Year-1 conditions are not discussed. The representative bed material gradations specified as initial conditions in the model were based on measurements collected throughout the focus areas. However, representative bed material gradations do not capture all the variation within the focus areas, particularly in the main channel. During the initial simulation period, a redistribution of the initial bed material gradations occurs rapidly as well as changes in bed elevations. Ideally, the model would run through a warmup period to redistribute the bed material distribution, then the model would be run with the initial bed elevations.

As noted previously, two versions of the SRH-2D were used. The first version was used to run initial simulations. The second version, which was used to simulate the remaining years, has the ability to run a warmup period and restart a simulation using the initial bed elevations. In the future, the second version of SRH-2D will be used for all simulations and a warmup period will be run. The predicted bed material gradations from the warmup run will be used as the initial bed material gradations with the Year-0 bed elevations.

5.2.1.1. Year-8 Model Results

The 2-D bed evolution model was run for wet, average and dry year conditions at FA-128 (Slough 8A) with the initial bed elevations and bed material gradations. Because there is rapid change in the first year, additional years were simulated to determine whether and how long it would take the model to develop a new equilibrium condition. The goal is to evaluate change at 25 and 50 years in the future without actually running simulations of these durations. However, 1 year simulations using the three representative years did not provide sufficient information to predict future trends, especially the continued development of the Skull Creek fan. Therefore, simulations of 4 consecutive years and then an additional 4 years (for a total of 8 years) were conducted to develop a more complete understanding bed evolution at the focus area. This sequence was required to evaluate Skull Creek fan development. The need for longer simulations will be evaluated on a case-by-case basis at the remaining FAs, with tributary fan development expected to be the primary consideration.

5.2.1.1.1. ***Existing Conditions***

5.2-1 shows detailed cumulative aggradation and degradation amounts over the 8-year simulation period for Existing conditions and Figure 5.2-2 shows the same information but only distinguishes between aggradation and degradation. Minor amounts of bed change (<1’) generally occur throughout the Focus Area. An area of significant sand deposition observed in the field is in the backwater area at the lower end of side channel 8A where it joins the primary side channel at the bottom, midpoint of the focus area. This area is shown by the model to aggrade several feet. The clear-water portion of Slough 8A is shown to have almost no bed change, which is expected based on infrequent flow connection with the main channel.

Although it is difficult to use time-sequence aerial photography as a basis for identifying main channel aggradation and degradation, it is useful for identifying bar erosion, deposition, and translation. The aerial photography also shows where channels have widened or narrowed, which can be used to infer deepening (degradation) and shallowing (aggradation). When the 1983 and 2012 aerial photography is compared (see Tetra Tech 2014e) the Existing conditions model trends are consistent with the most evident trends of aggradation and degradation in the aerial photography.

The model predicts slightly degradational conditions at the head of many mid-channel and bank attached bars. In addition, most of the side channels that convey flow from the main channel are slightly degradational under existing conditions. These trends are consistent with expectations and with the turnover analysis (Tetra Tech 2014e).

The largest amounts of aggradation occur in the area of Skull Creek with up to 5 feet along Skull Creek and at the confluence with the Susitna River (Figure 5.2-3). The relatively high amount of predicted aggradation at Skull Creek is consistent with observations made following the September 2013 flooding, which deposited significant amounts of sediment from upstream of the railroad crossing to the confluence of the Susitna River. A significant amount of sediment was excavated and moved by Alaska Railroad, which resulted in a chute type channel with high berms that extend from upstream of the bridge to the confluence with the Susitna River. The continued growth of Skull Creek fan is also consistent with the aerial photography. The fan was not evident riverward of the railroad in 1951, extends nearly 300 feet from the railroad alignment in 1983 and is largely unvegetated, and in 2012 extends approximately 400 feet from the railroad alignment and much of the 1983 fan is now vegetated.

In the vicinity of Skull Creek fan, the sediment deposition volume changes rapidly over the first hydrograph (Figure 5.2-4) (the change in sediment volume is calculated for the area shown in Figure 4.2-1 broadly representing the Skull Creek fan). Sequences of Average, Wet, and Dry years (A-W-D-A and A-D-W-A) were run to evaluate fan development. Over the subsequent hydrographs, aggradation occurs during the dry and average years and degradation occurs during the wet years. This is an expected result based on varying sediment supply from the tributary and range of hydraulic conditions in the receiving channel. A best fit-line developed using the rate-law (Wu et al., 2012) fitted to the change in volume results shows that on average, the area of Skull

Creek establishes an equilibrium after approximately 3 years. From Year-3 onwards, there is both aggradation and degradation in the area of Skull creek, however, on average, the area is in approximate equilibrium.

Under Existing conditions, the model predicts up to 5 feet of degradation near the upstream boundary of the model (Figure 5.2-1). This area of degradation is outside the Focus Area and outside the area of detailed bathymetric survey, so bed elevations had been estimated for this area. In the model, the initial channel geometry in the area between the upstream end of the focus area and the upstream model boundary, a distance of approximately 2000 feet, was estimated because the hydrographic survey only extended to the focus area boundary. The assumed initial channel geometry in the area between the upstream end of the focus area and the model boundary was likely set too high, and as a result, the channel bed degraded in this area and the eroded sediment was deposited in the lower half of the channel. Future simulations will incorporate the adjusted channel geometry for the area upstream of the focus area boundary.

The median (D_{50}) bed material size at the end of the Existing conditions simulation indicates the predicted bed material sizes are similar to the measured values (Figure 5.2-5). For example, the bed material sample collected at PRM 129.0 had a median size of 51 mm compared to the predicted median size of 54 mm. In the main channel, the predicted median bed material sizes generally range from 40 to 220 mm and are consistent with the gradations measured during the winter bed material sampling, which averaged approximately 90 mm (Tetra Tech 2014d). In the side channels, the predicted median sizes generally range from 30 to 60 mm., which is consistent with surface samples collected at FA-128 (Slough 8A) ranging from 35 to 92 mm (June 2014 Study 6.6 ISR Appendix A).

5.2.1.1.2. *Max LF OS-1b Conditions*

Under max LF OS-1b conditions, the model generally predicts less change in bed elevation along both the main and side channel over the duration of the simulations compared to Existing conditions (Figure 5.2-1 and Figure 5.2-2).

Similar to Existing conditions, the model predicts slightly degradational conditions at the head of the mid-channel bar and at the head of the side-channels, but less than under Existing conditions. In comparison to Existing conditions, the model predicts relatively small bed elevation changes along the side channels (less than 0.5 foot compared to generally +/- 1 foot for Existing Conditions. The model predicts up to 4 feet of degradation near the upstream boundary of the model (Figure 5.2-1) compared to approximately 5 feet of degradation under Existing conditions.

Looking more closely at the tributary delta modeled in the focus area, the largest bed elevation changes occur in the area of Skull Creek with up to 6 feet of aggradation along Skull Creek and at the confluence with the Susitna River (Figure 5.2-3). The deposition at the confluence extends further into the side channel and has a larger depositional zone compared to Existing conditions (Figure 5.2-3). The increase in aggradation extent under Max LF OS-1b conditions occurs due to the lower peak flows in the Susitna River and associated decrease in sediment-transport capacity in the side channel to remove the sediment deposited by Skull Creek. Under Existing conditions, the higher flows and sediment transport rates in the side channel result in a smaller, higher depositional area, whereas, under Max LF OS-1b conditions, the depositional area is larger, but lower due to the reduced flows. It is important to note that under the Max LF OS-1b conditions, the tributary also establishes an equilibrium, and that the tributary fan does not cut off flow in the side channel. The current side channel width is approximately 250 feet, narrows to 200 feet for Existing conditions, and 150 feet for Max LF OS-1b.

The change in sediment volume curve in the vicinity of Skull Creek is similar to the Existing conditions (Figure 5.2-4), in that, aggradation occurs during the dry and average years and degradation occurs during wet years. The best-fit line indicates it takes longer to reach a quasi-equilibrium under Max LF OS-1b conditions compared to Existing conditions. At Year-8 under Max LF OS-1b conditions, the area of Skull Creek has not established a quasi-equilibrium. The best-fit line indicates an equilibrium establishes at approximately Year-15 under Max LF OS-1b conditions compared to Year-4 under Existing conditions.

The median (D_{50}) bed material at the end of the Max LF OS-1b simulation indicates the predicted bed material sizes vary compared to Existing conditions (Figure 5.2-5). Figure 5.2-6 shows the difference in median bed material size between the Existing and Max LF OS-1b conditions. Figure 5.2-7 shows the general shift in bed material size with areas that are coarser (red areas) and finer (blue areas) under Max LF OS-1b compared to Existing conditions. In general, the median bed material sizes over the main channel in the upper half of the Focus Area are approximately 10 mm finer under Max LF OS-1b conditions compared to Existing conditions, whereas, the lower half of the main channel is approximately 25 mm coarser under Max LF OS-1b compared to Existing conditions. The upper part of the side channels are generally slightly finer and the lower part of the side channels are slightly coarse under Max LF OS-1b compared to Existing conditions.

5.2.1.2. Year 25 and Year 50 Model Results

5.2.1.2.1. ***Existing Conditions***

The adjustments to the year-25 model include only the final bed elevation and gradation conditions for the 8 year simulations because Skull Creek fan appears to have reached a quasi-equilibrium condition by the end of eight years. A comparison of the geometry of the Skull Creek fan between Year-25 and Year-0 shows the development of the fan into the side channel, the associated narrowing of the channel (Figure 5.2-8). Over the 25 year period, the Skull Creek fan encroaches approximately half-way across the side channel, which in turn, forces more flow along the bank located opposite the tributary mouth. Under these conditions, the increase in shear against the outside of the bank would likely cause some bank erosion. As mentioned previously, the bank was set as non-erodible in the model to evaluate if the Skull Creek fan would cut off flows in the side channel or if the channel reaches a new quasi-equilibrium. Based on the model output, it is apparent the side channel establishes a new quasi equilibrium.

The Year-25 existing conditions model was run over the dry, average and wet year hydrographs. The change in volume in the vicinity of the Skull Creek is shown in Figure 5.2-9. Summing over a four year period of a dry, wet and two average years, there is no change in volume of the fan, indicating the tributary fan has reached a quasi-equilibrium. Since the model was in an equilibrium condition at year-25, the channel geometry at Year-50 was kept the same as Year-25. Therefore, the model output over the duration of the dry, average and wet year hydrographs is the same as Year-25, in that on average, there is no change in volume in the vicinity of the Skull Creek fan.

5.2.1.2.2. ***Max LF OS-1b Conditions***

The model condition for Year 25 includes the changes in bed elevation and gradation at Year 8, plus additional fan deposition based on the curve from Figure 5.2-4 for Max LF OS-1b conditions. The tributary fan extends farther into the channel compared to Existing conditions (Figure 5.2-8).

The Year-25 model was run over the dry, average and wet year hydrographs. The change in volume in the vicinity of the Skull Creek is shown in Figure 5.2-10. Over a four year period of a dry, wet and two average years, the channel is still slightly aggradational. Based on this result, the best fit line was re-computed and used to predict the Year-50 geometry. The best fit-line shows minimal aggradation occurs between Year-25 and Year-50. Based on the shape of the re-computed best-fit line, it appears that the majority of the channel adjustment under Max LF OS-1b conditions occurs over the first 15 years of the simulation.

The geometry model in the vicinity of Skull Creek was adjusted to represent the predicted volume at Year-50. The model was run over the dry, wet and average hydrographs. Over the four year period, there was virtually no change in volume of the fan, indicating the tributary fan has reached a quasi-equilibrium.

5.2.2. Tributary Delta Modeling

The tributary delta modeling was inherently part of the 2-D bed evolution modeling. The changes in geometry at the Skull Creek are discussed as part of the 2-D model results (Section 5.2.1). Based on the model results, it appears that the Skull Creek fan may not currently be in a state of quasi-equilibrium, though based on the estimated sediment loads it is quite close. This is consistent with the results of the turnover analysis (Tetra Tech 2014e), which show considerable growth of this fan between the 1950's and 1980's aerial photography and additional growth for current conditions. For with-Project conditions, the fan extends further into the side channel and takes longer to reach a quasi-equilibrium condition. The area of fan growth is also at a lower elevation, which is expected because the main channel flows are lower for with-Project conditions.

5.2.3. Evaluate Long-Term Change in Channel Width

The long-term changes in channel width are discussed in the 1-D model results (Section 4.1.3). Because there is so little sediment transport in the Middle Susitna River under with-Project conditions the primary expression of width change would be through vegetation growth along channel and island banks, and on more frequently exposed bars. No specific analyses were conducted using the 2-D sediment transport model. The predicted changes in active channel width due only to vegetation encroachment (Figure 4.2-5) were incorporated into 2-D hydraulic model developed to represent the Year-25 Max LF OS-1b conditions. This model was used to evaluate the changes in habitat under Max LF OS-1b conditions, as discussed in Section 5.2.5.

5.2.4. Bank Energy Index Analysis

A comparison of the computed BEI values provides an indication of the relative amount of erosive energy that is available to drive the bank erosion process. The normalized BEI values for the 28 year period from 1983 to 2012 under the existing conditions vary from 0.02 at Site 11 to 2.73 at Site 9 (Table 5.2-1). The analysis sites are shown in Figure 4.2-2. The actual average annual bank erosion measured from aerial photographs ranged from 0.7 feet to 3.2 feet with an average of 1.7 feet for the same 28 year period.

There is no discernable pattern to the distribution of the BEI along the reach. For example, a comparison of the BEI values on the inside and outside of the bends showed no pattern, nor was there any obvious pattern between BEI values in the main channel and side channels.

A comparison between the existing conditions BEI values and bank erosion showed a weak relationship (R^2=0.50) (Figure 5.2-11). It is expected that low BEI values result in low bank erosion potential and similarly, larger BEI values have greater bank erosion potential. Although this was somewhat the case, areas of near zero BEI still had moderate bank erosion. Typically, the intercept of the best fit line would be through 0 or that no bank erosion would occur for relatively small amounts of BEI. However, Figure 5.2-11 shows the best-fit line has a non-zero intercept, suggesting that other factors, such as ice erosion, are the cause of the bank erosion.

Bank erosion is often initiated by erosion of the bank toe. The coarse bank toes of the Middle Susitna River resist erosion until the critical shear stress is exceeded. The application of the critical shear stress criteria on the toe of the bank results in very low BEI values under existing conditions because bank energy expenditure is only summed when the shear stress exceeds the critical value for the coarse bank toe materials. All the sites had a normalized BEI value of 0, except for Site 5 which had a value of 0.38 (Table 5.2-1), indicating that the forces to erode the bank were not present during the open water flow season for all but one site. The absence of time when shear stress exceeds the critical value indicates that bank toe erosion is very unlikely to be the result of open water conditions. Figure 5.2-12 shows that for all but one location (Site 5) the zero BEI is associated with observed bank erosion ranging from 20 to more than 90 feet in 28 years. Since the upper bank is heavily root reinforced and highly erosion resistant, this is further evidence that bank erosion in the Middle Susitna River is likely caused by ice processes.

Bank Energy index was not computed for the Max LF OS-1b open water conditions because the reduced flows would produce zero BEI for the threshold shear application. Alternatives to BEI application under open water conditions to characterize Project effects on bank erosion will be evaluated in coordination with the Ice Processes Study (Study 7.6).

5.2.5. Sediment Delivery Index

A comparison of the computed SDI values provides an indication of the relative amount of sediment available for deposition, and hence, vertical accretion on the various geomorphic surfaces. In addition, comparison of the SDI values between the existing and With-Project conditions provides a means of quantifying the relative effects of changes in the vertical accretion between the existing and With-Project hydrologic regime.

Under existing conditions, the computed SDI values generally decrease in value with increasing elevation of the geomorphic surface (Table 5.2-2, Figure 5.2-13); the exception to this is the overbank channel (OC). The overbank channel surfaces have a wide range of elevations and the overtopping discharges vary depending on whether the source flow originates from groundwater, backwater from the main channel or by flow over higher elevation surfaces upstream of the overbank channel.

Figure 5.2-13 shows a box-plot of the SDI values for each geomorphic surface. The upper- and lower bounds of the box represent the 10th and 90th percentile, the line within and the associated value is the median value. The median values are also reported in Table 5.2-2. The box-plots (Figure 5.2-13) show significant variability within each geomorphic surface due to the elevation differences across the surface. The box-plots show the vegetated bars (VB), young-floodplains

(YFP) and overbank channels (OCH) have the highest SDI values, whereas the mature floodplains and old floodplains have the low SDI values. These trends are similar for both the sand and silt sized materials.

The predicted SDI is 1 for the Old Floodplain surfaces indicate very low sedimentation potential. Field measurements in 2014 at FA-128 (Slough 8A) of deposition depth over the prior year's organic layer on the old floodplain surfaces indicated recent deposition of up to 0.5 feet. Young floodplain and mature floodplain showed average deposition amounts of 0.5 feet and 0.25 feet, respectively. Peak flows over the last few years have not been sufficiently high to overtop the Old Floodplain surface, and therefore, it is highly likely the sand was deposited due to ice related effects.

In general, the SDI values for the sand-sized material are on average 50-percent higher than the silt-sized material, indicating that sand likely contributes more to the vertical accretion than the silt-sized material. Silt sizes typically represent 20 to 25 percent of overbank deposits in the Middle Susitna River (June 2014 ISR Appendix C). Therefore, if a combined SDI is developed then the silt should be factored by one-half.

For Existing conditions, more frequently inundated surfaces (vegetated bar and young floodplain) have SDI values ranging from 22 to 44 (Table 5.2-2). Under Max LF OS-1b conditions, these geomorphic surfaces are less frequently inundated and the sediment concentrations are significantly lower compared to existing conditions, which results in very-low SDI values of zero for sand and 1 to 3 for silt. Infrequently inundated surfaces (mature and old floodplains) for both Existing and Max LF OS-1b conditions have low SDI, ranging from 0 to 6 for Existing conditions and zero for Max LF OS-1b. For all surfaces under Max LF OS-1b conditions the SDI values indicate very-low potential for vertical accretion and island growth under open-water periods. A box-plot for the Max LF OS-1b conditions is not shown since the SDI values are all near zero.

5.2.6. Hydraulic Modeling for Habitat Analysis

The predicted channel geometry for the Existing and Max LF OS-1b conditions at Year 25 were incorporated into the larger +200,000 element hydraulic model at Focus Area 128 (Slough 8A). As discussed previously, the effects of active channel narrowing due to vegetation encroachment were incorporated in the Max LF OS-1b model. The hydraulic models were then run at steady state flows of 12,000 and 30,000 cfs. Table 5.2-3 shows compares the initial (Year 0) flow distribution among the channel ranging from main channel, side channel and other lateral features to Year 25 conditions for both Existing and Max LF OS-1b conditions. The locations coincide with the ADCP measurement transects show in Appendix B, Figure 1.1. The differences in depth and velocity were mapped to illustrate the changes in habitat at the two flow levels. The hydraulic model output from the required range of flows would be provided to the IFS team to evaluate the changes in instream habitat characteristic under Max LF OS-1b conditions.

Figures 5.2-14 and 5.2-15 show the difference in depth and velocity (Max LF OS-1b minus Existing) for the Year-25 geometry at 12,000 cfs, respectively. Under the 25-Year conditions, the discharge, velocity and depth in the side channel [measured at T1A and T3B, (Appendix B, Figure 1.1)] are all slightly higher under Max LF OS-1b conditions compared to Existing conditions (Figures 5.2-14 and 5.2-15, Table 5.2-3). In contrast to the higher flows in the side channel, there is a decrease in velocity and flow [measured at T1B and T2D) in the main channel downstream from side channel.

The model predicts similar trends at 30,000 cfs, with an increase in discharge in the side channels (Table 5.2-3) and an associated decrease in discharge in the downstream portion of the main channel. Figure 5.2-16 show the difference (Max LF OS-1b minus Existing) in depth and Figure 5.2-17 show the difference in velocity at 30,000 cfs.

5.2.7. Large Woody Debris Effects

At this stage, no analyses have been conducted to incorporate Project effects on large woody debris (LWD) in the 2-D modeling within the Focus Areas.

5.2.8. Ice Effects

At this stage, no 2-D modeling analyses have been conducted to incorporate Project effect of ice processes on geomorphology within the Focus Areas.

6. DISCUSSION AND RECOMMENDATIONS

The 1-D initial bed evolution model (BEM) was developed from data collected in 2012 and 2013 and was used to support the decision whether to extend bed evolution modeling below PRM 29.9 (Tetra Tech 2014b). Based on the performance of the model compared to available information (comparison cross sections (Tetra Tech 2014f), measured (Tetra Tech 2014c) versus model sediment loads, and calibrated hydrographs and water surface elevations), the model performed well in the Middle and Lower Susitna Rivers. This performance indicates that there is sufficient data (bathymetric, topographic, bed material sampling, sediment transport measurements, and land cover observations) to evaluate geomorphic change in the study area and facilitate the interpretation of results in coordination with other studies. The additional data collected in 2014 is expected to enhance AEA’s ability to evaluate potential Project effects. Therefore, no additional data collection is recommended regarding the 1-D bed evolution modeling. More detailed discussion of the 1-D bed evolution modeling is provided in Section 6.1.

The initial 2-D hydraulic modeling of FA-128 (Slough 8A) was the focus of the Proof of Concept for providing hydraulic results for habitat analysis (Tetra Tech 2014a) and concluded that the 2-D hydraulic model provides the required information. The focus of this Technical Memorandum was on 2-D bed evolution modeling. Although there is less information to specifically test the reliability of the 2-D BEM, the results are consistent with the 1-D BEM showing little change in the main channel, the hydraulic results are very similar to the detailed 2-D hydraulic model, and the trends in erosion and deposition are consistent with those observed in the turnover analysis (Tetra Tech 2014e) at this Focus Area. Therefore, no additional data collection is recommended regarding the 2-D bed evolution modeling, except for completing bathymetric surveys of the three most upstream Focus Areas. More detailed discussion of the 2-D bed evolution modeling is provided in Section 6.2.

6.1. 1-D Modeling

6.1.1. Bed Evolution Modeling

The selected HEC-RAS Version 5.0 (beta) proved to be an excellent platform for unsteady flow and sediment routing on the Middle and Lower Susitna River Segments. The two segments have significantly different characteristics that control their response to the varying flow and sediment input from the proposed Watana Hydroelectric Project. Based on the very successful hydraulic and sediment calibration for existing conditions and the results of Max LF OS-1b simulations, the 1-D bed evolution modeling not only provides useful information on the processes that control geomorphic change on the Susitna River, but it is clear that the 1-D model is well-suited for providing input data to the 2-D bed evolution models as they are developed for the remaining Focus Areas. The 1-D BEM is reasonably quick to run (generally less than 12 hours depending on the simulation period and other model parameters), so it is a useful tool for evaluating potential Project effects for the various operational scenarios.

Although sediment supply of sand and coarser sizes would be eliminated at the dam site, the channel does not appreciably degrade over the 50 year license period. This is due to the very coarse bed acting as a “static” armor. The existing sand supply is conveyed through the Middle River without interacting with the main channel bed. The initial models included no tributary sediment inflows to the Middle River, though flow hydrographs were included for the tributaries. The initial model results were conservative in terms of possibly overestimating potential Project effects and indicated that tributary sediment supply appears to have little effect on existing conditions geomorphology. Therefore, as tributary sediment inflows are included in future model updates, the slight degradation (approximately 0.5 ft in 50 years for the geomorphic reach immediately downstream of the dam) for with-Project conditions will likely be reduced.

Geomorphically, the Lower River is significantly different from the Middle River. This is due primarily to the high sediment loading from the Chulitna River along with contributions from the Talkeetna River. The Lower Susitna River adopts the highly dynamic braided planform of the Chulitna River below their confluence. The Existing conditions model indicates that the Middle River is gradually aggrading at reach-average rates of between 0.5 and 1.2 ft in 50 years for nearly 60 miles below the Three Rivers Confluence, and then at rates between 2 and 4 ft down to the confluence with the Yentna River. This result is consistent with the braided planform of the Lower River. These rates of aggradation are slightly reduced under with-Project conditions indicating that the characteristics of the Lower River will not be appreciably affected by the Project.

6.1.2. Tributary Sediment Supply Modeling

Since the sediment deposited in a delta represents some of the load transported by the tributary that flows onto the delta, the gradation of subsurface sediment stored in the delta is an ideal prototype for calibrating simulated sediment loads transported by the tributary. Such an approach was successfully applied to Skull Creek. Increasing the percentages in the finer tail of the sampled surface gradation (to offset bias associated from pebble counts as described in Section 4.1.2) and inputting the adjusted gradation to the Parker (1990) function allowed the gradation of the simulated load to nearly match the subsurface gradation. This adjustment is appropriate only when the bed surface is fully mobile such that subsurface sediment is exposed, a condition assumed to correspond to dimensionless grain shear of at least 1.5 (i.e., the ratio of the applied grain shear stress to the critical shear stress required to mobilize the D_{50} of the bed surface). The Parker (1990) function simulates lesser loads in transport with finer gradation when the dimensionless grain shear is less than 1.5. Given these reasonable results, it is expected that this gradation adjustment will be applied to the development and calibration of discharge versus sediment load relationships to be calculated for the ungaged tributaries selected for modeling (Table 5.1-8 in the Study 6.6 ISR).

As the Skull Creek tributary was being modeled, consideration was given to the methods for using the modeled results to estimate sediment loads from ungaged and non-modeled tributaries. Preliminary methods were proposed in Section 4.1.2.6 of the Study 6.6 ISR, but the work on Skull Creek spurred potential refinements. For instance, the preliminarily proposed methods focused on GIS analyses of watershed characteristics in the modeled tributary drainage areas to regress against the modeled loads. The plan was to apply the identified regression relationships to the watersheds of the ungaged and non-modeled tributaries to estimate the sediment loads. The watershed characteristics considered were drainage area, slope, and underlying geology. The work on Skull Creek indicated that other characteristics, such as (1) drainage density (focused on active channel, not paleo-channels that do not convey appreciable runoff or sediment), (2) slope and geology within a buffer of the drainage network, (3) the presence of glacial deposits within the drainage area, (4) hydrothermal alteration of underlying geology, and (5) ratios of delta/fan area to watershed area, perhaps segregated by predominant geology within the watershed, may better relate to the processes that generate and convey sediment to the mouth of a tributary. Additionally, the 2-D bed evolution modeling results presented in Section 5.2.2 show that sediment delivered to the delta will not all be delivered into the mainstem Susitna River until the delta morphology becomes dynamically stable such that the mainstem channel is constricted enough that the mainstem flows can erode sediment from the foreset of the delta. Further analysis is required to identify whether a temporal relationship can be developed to govern how the delivery of sediment from tributaries changes over time in response to tributary delta reaching dynamically stable morphologies; such a relationship would be valuable when considering operational scenarios.

6.1.3. Tributary Delta Formation

The objective of the POC effort related to modeling the formation of the Skull Creek delta was to confirm that the simplified 1-D delta modeling approach could reasonably approximate the 2-D modeling approach. The results of the 1-D approach presented in Section 5.1.5 show agreement with the 2-D results presented in Section 5.2.2. This agreement indicates that the 1-D approach can reliably be applied to tributary deltas located outside of Focus Areas (i.e., outside of the domains of the 2-D models).

The 1-D tributary delta formation modeling results from the Skull Creek delta provide reassurance in the robustness of this simplified modeling approach. For example, the selected Shields parameters corresponding to the 2-year and 5-year recurrence interval flows are 0.025 and 0.034, respectively. While these values are at the low end of the range typically used for mobilization of bed material sediment from the surface of a river (Section 4.1.6), the sediment deposited on the foreset of a delta is unconsolidated, making the deposit easier to erode. Additionally, the selected values of the Shields parameters are not so low as to indicate flows with recurrence intervals of 2 to 5 years are too small to check the riverward growth of a delta. Another reassurance comes from the similarity in the recurrence interval under the existing conditions and Max LF OS-1b hydrology corresponding to conditions of incipient motion. Such similarity is expected, but it is dependent on approximately 50 feet of additional riverward progression of the Skull Creek delta foreset under the Max LF OS-1b hydrology compared to the position simulated under the existing conditions hydrology. The additional riverward growth occurs because of the regulated flows under the Max LF OS-1b operations scenario, and the need for additional constriction of the mainstem flows to generate the shear required to mobilize sediment from the foreset. Based on these results, the simplified 1-D tributary delta formation modeling approach is expected to provide a solid basis (consistent with the 2-D modeling within Focus Areas) for assessing potential Project effects on delta morphology and the ability of fish to access the tributaries.

6.2. 2-D Modeling

6.2.1. Bed Evolution Modeling

A 2-D sediment transport model of FA-128 (Slough 8A) was developed to demonstrate the development of the channel geometry for future conditions under Existing and Max LF OS-1b hydrology conditions. The results of the sediment transport modeling indicated that the models can be applied to evaluate potential Project effects on sediment transport and bed morphology, including changes in bed composition and flow distribution to lateral channels, vegetation, and tributary fan development at Skull Creek to evaluate potential changes in habitat at the Focus Area.

The following general observations were made regarding execution of the 2-D sediment transport modeling.

- The 3,100 hour long (129.2 days) hydrographs for single open water flow periods took approximately 100 hours (4 days) to run a Dell Workstation with Intel Zeon 3.60 Ghz processors. In other words, the program simulates 1.3 days of the hydrograph for every real-time hour. Extrapolating this simulation rate, modeling a 25-year hydrograph (assuming each year was 3,100 hours) would take approximately 3.5 months. Therefore, simulating long periods (25 or 50 years) is impractical.
- SRH-2D is a very stable model. The model was run with 5 second time steps based on previous experience. The model did not produced any numerical instabilities in either the hydrodynamic or sediment transport simulations. Therefore, from a model application standpoint, SRH-2D was suitable.
- The model output is consistent with anticipated results. The predicted changes in bed elevation and bed material gradations, both in terms of location and magnitude, are realistic and consistent with anticipated results. Based on the 1-D model results and comparison cross section in the Middle River (Tetra Tech 2014f), minimal bed change was expected in the main channel. Based on comparisons with 1950s and 1980s aerial photography the model predicts the continued trends of deposition and erosion throughout FA-128 (Slough 8A) and further deposition was expected at Skull Creek fan.
- SRH-2D is an appropriate model for performing the sediment transport analyses to evaluate the changes in bed elevation and bed material gradation under existing and with-project conditions. Although simulating a full 25 year period is impractical, the model results were sufficient to develop future conditions (Year-25 and Year-50) models.

Based on model results and reasons presented in Section 5.2.1 for future model simulations, the latest version of SRH-2D will be used to run a warmup simulation to provide a sorted bed material distribution that will be applied as the initial condition for subsequent model runs. Saving an end-of-simulation bed gradation as a subsequent input file was not available in the SRH-2D version used for the initial modeling.

Although running separate Wet, Average and Dry year conditions will continue as the planned approach for the remaining FAs, there may be locations similar to the Skull Creek fan where running a sequence of years will be used to better evaluate the potential for long-term change. This approach would most likely be needed at very active tributary fans.

Similar to the FA-128 (Slough 8A) simulations, the channel geometry of the other FA models may reach an equilibrium in less than 25 years. In these cases, the Year-25 geometry could also be used to represent the Year-50 geometry. In addition, the frequency of adjusting the with-Project model to account for the vegetation effects will be coordinated with Study 8.6. For the FA-128 (Slough 8A) modeling, the vegetation effects were applied to the Max LF OS-1b model at Year-25.

6.2.2. Tributary Delta Modeling

The tributary delta modeling was inherently part of the 2-D bed evolution modeling. A discussion of the tributary delta modeling is in Section 6.1.3. The 2-D bed evolution model simulated the growth of the Skull Creek delta over 8 years of open-water flow periods under both existing conditions hydrology and Max LF OS-1b hydrology. The results were sufficient to project fan conditions at years 25 and 50.

6.2.3. Evaluate Long-Term Change in Channel Width

Because there appears to be insufficient sediment supply to cause significant deposition along the channel banks, it was assumed that any narrowing of the channel would be primarily the result of vegetation encroachment of the less-frequently submerged bars and channel margins. The Manning n values were increased to reflect the increased roughness of the vegetation. These adjustments were made to the 2-D hydraulic model used for aquatic habitat analysis.

6.2.4. Bank Energy Index Analysis

The Bank Energy Index (BEI) analysis was conducted using two methods. The first method applied the 2-D model results to all open-water flows to determine if a relationship was evident between the BEI values and the bank migration over the period from WY1983 to WY2010 (28 years of record). The second method was similar to the first, except that bank energy expenditure was only summed when the shear stresses exceed the critical value for the coarse bank toe materials.

Both methods predicted low BEI values and that even where there was zero BEI a significant bank erosion had occurred. This suggests that the vast majority of bank and/or bank toes erosion is very unlikely to be the result of open water conditions. Since the upper bank is heavily root reinforced and highly erosion resistant, this is further evidence that bank erosion in the Middle Susitna River is likely caused by ice erosion.

Since, the bank erosion appears to be primarily caused by ice erosion, it is recommended that additional analyses be developed for ice breakup conditions in coordination with the Ice Processes Study (Study 7.6). Similar concepts to the BEI but adapted to evaluate bank erosion during ice breakup, may be better represent bank erosion processes and potential effects.

6.2.5. Sediment Delivery Index

The Sediment Delivery Index (SDI) analysis was conducted to evaluate the potential for relative change in sedimentation (vertical accretion) on the islands and overbanks between the Existing conditions and With-Project open water flow regimes. The SDI analysis represents the initial development of the procedure for open water conditions that may be refined in coordination with the Riparian Instream Flow Study (Study 8.6) and Ice Processes Study (Study 7.6). There are significant differences between SDI values for different geomorphic surfaces under Existing conditions that in turn indicated substantially different potentials for sediment accretion on these surfaces. There is also a much lower SDI for the Max LF OS-1b condition indicating that with-Project floodplain accretion could be much slower.

Under existing conditions, the SDI values were highest on the lower elevation surfaces, which include the Vegetated Bars, Young Floodplain and Overbank Channel surfaces. The next highest surface, the Old Floodplain, had SDI values that were approximately 80-percent less than the lower elevation surfaces. The SDI value was 1 on the Old Floodplain, which is the highest geomorphic surface, indicating very low sedimentation potential. Field observations indicated recent sand deposition on the Old Floodplain surface, which likely results from ice related sedimentation effects and not from open water conditions.

Under With-Project conditions, the predicted SDI values were approximately 95-percent lower on the Vegetated Bars, Young Floodplain and Overbank Channel Surfaces, thus indicating very little sedimentation potential. The SDI values for the mature Floodplain and Old Floodplain were 0, indicating no sedimentation potential. With-Project conditions also include areas that are likely to become vegetated in the future, such as existing gravel bars that become less frequently submerged. The SDI for these areas may indicate that even with the much lower sediment supply for with-Project flows, some minimal accretion may occur.

For With-Project conditions in the Middle River segment, the substantial reduction in sand supply will likely have a moderate impact on floodplain and island formation for open water flows. Erosion rates are likely to be reduced due to the reduction in peak flows and the frequency and duration of inundation of floodplain/island surfaces will be reduced during the open-water season. However, depending on the ice regime, especially during break up, inundation of geomorphic surfaces could either be increased or decreased, and, depending on the availability of sand and finer sized sediments, generate additional floodplain accretion.

6.2.6. Hydraulic Modeling for Habitat Analysis

The predicted channel geometry for the Existing and Max LF OS-1b conditions at Year 25 were incorporated into the larger +200,000 element hydraulic model. The model was run at 12,000 and 30,000 cfs using the same model parameters applied to the Year-0 conditions. The Year-0 and Year-25 model output were used show the changes in depth and velocity. The model output will be provided to the Fish and Aquatics Instream Flow Study (Study 8.5) team to evaluate the changes in habitat over time and under the various hydrology scenarios.

The modeling procedure of incorporating the predicted bed elevation changes from the sediment transport model into the +200,000 element hydraulic model worked well, in that it provides model output at coincident nodes that can be used by the IFS team to evaluate the changes in habitat. The IFS team successfully used the Year-0 hydraulic output to evaluate habitat in FA-128 (Slough 8A)

(Tetra Tech 2014a) and it is anticipated that this approach will be successful for Year 25 and Year 50 conditions.

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8. TABLES

Table 2.2-1. Model input and results for various study aspects.

Modeling Task	Input and Results	Hydrology	Sediment	Hydraulics	Channel and Floodplain Geometry
1-D Tributary Sediment Modeling	Input→	Range of steady flows	Bed material from site samples	Bite specific D/S stage-discharge	Existing at T = 0 (yr-0)[3]
	Results for:	Results for range of steady flows to develop sediment rating curves at mouth of each tributary			
	1-/2-D Morph.		trib. sediment rating curves		
	Aquatic Habitat			V, D, WSEL some trib. mouths	barrier/delta change for some tribs.
	Other studies				
1-D Reach-Scale Morphology Modeling	Input→	50-yrs Existing & 3 OS[1]	Existing & 3 OS[2]	rating curve at Susitna Sta.	Existing at T = 0 (yr-0)[3]
	Results for:	Results for continuous 50-year simulations throughout 1-D modeling domain			
	2-D Morphology	Dam Outflow Hydrographs	U/S sed. rating curves at FAs	D/S stage-discharge at FAs	main channel change
	1-D Ice			rating curve at 3-Rivers	main channel change[4]
	Flow Routing				main channel change[4]
	Aquatic Habitat		substrate change[4]	stage-discharge relationships	main channel change[4]
	Riparian Habitat		sediment supply to overbanks	stage-discharge relationships	bar/island/floodplain change
2-D Local-Scale Morphology Modeling	Input→	<1-yr wet, avg., dry for Existing & OS[1]	U/S sed. rating curves at FAs for yrs-0,25,50 for Existing & OS[5]	D/S stage-discharge at FAs for yrs-0,25,50 for Existing & OS[5]	Existing (yr-0)[3], yrs-25,50[5] in main channel
	Results for:	Results for range of <1-yr simulations throughout FA modeling domain			
	2-D Hydraulic		bed material gradation change[4]		lateral feature trends
	2-D Ice				lateral feature trends[4]
	Flow Routing				lateral feature trends[4]
	Aquatic Habitat		substrate change[4]		barrier/delta change
	Riparian Habitat		sediment supply to overbanks		bar/island/floodplain change
2-D Local-Scale Hydraulic Modeling	Input→	Range of steady flows[6]	Bed material gradation change[7]	D/S stage-discharge at FAs for yrs-0,25,50 for Existing & OS[5]	Existing (yr-0)[3], yrs-25,50 in main channel[5] and lateral features[7]
	Results for:	Results for range of steady flows throughout FA modeling domain			
	Ice, Flow Routing				
	Aquatic Habitat		substrate change[4]	V, D, WSE, etc. throughout FAs	
	Riparian Habitat			V, D, WSE, etc. throughout FAs	
2-D Local-Scale Morphology Modeling related to Ice Conditions	Input→	Representative ice dam and breakup hydrographs	Upstream sediment rating curves consistent with hydrology	D/S stage-discharge at FAs consistent with hydrology	Existing (yr-0)[3]
	Results for:	Results for representative short-term (<1 wk) simulations throughout FA modeling domain			
	Ice, Flow Routing				
	Aquatic Habitat		substrate change[4]		lateral feature trends[4]
	Riparian Habitat		sediment supply to overbanks		lateral feature trends[4]
2-D Local-Scale Hydraulic Modeling related LWD	Input→	Range of steady flows		D/S yr-0 stage-discharge at FAs	Existing (yr-0)[3]
	Results for:	Results for range of steady flows throughout FA modeling domain			
	Ice, Flow Routing				
	Aquatic Habitat		substrate change[4]	V, D, WSE, etc. in area of interest	
	Riparian Habitat				

Notes:

1. From flow routing study.
2. From gage data, sediment transport study, and reservoir sedimentation study.
3. From hydrographic survey, land-based survey, and LIDAR. (Survey by Tetra Tech for tributaries.)
4. Only if magnitude of change is sufficiently large to warrant inclusion in other study aspects.
5. From 1-D Reach-Scale morphology models.
6. From habitat study requirements.
7. From 2-D Local-Scale morphology modeling trends.
8. Dsfagsfdagds ‘ sdfafaj jlkfasd

Table 5.1-1. Results of Skull Creek delta foreset stability analyses.

Total Susitna Flow (cfs)	Ratio of Grain Shear (τ') to Critical Grain Shear (τ'_c)					
	Initial Skull Creek Delta Morphology		Future Skull Creek Delta Morphology, Existing Conditions Hydrology		Future Skull Creek Delta Morphology, Max LF OS-1b Hydrology	
	$\tau^*_c =$ 0.025[1]	$\tau^*_c =$ 0.034[2]	$\tau^*_c =$ 0.025[1]	$\tau^*_c =$ 0.034[2]	$\tau^*_c =$ 0.025[1]	$\tau^*_c =$ 0.034[2]
10,000	0.02	0.01	0.03	0.02	0.13	0.10
20,000	0.13	0.10	0.22	0.16	0.61	0.44
30,000	0.34	0.25	0.54	0.39	1.17	0.85
40,000	0.63	0.46	0.88	0.64	1.54	1.12
43,400	0.75	0.54	1.00	0.73	1.66	1.21
50,000	0.98	0.71	1.22	0.89	1.88	1.36
55,700	1.05	0.76	1.37	1.00	2.05	1.49
60,000	1.09	0.79	1.48	1.08	2.18	1.58
70,000	1.25	0.91	1.74	1.26	2.50	1.82
80,000	1.45	1.05	2.00	1.45	2.82	2.05
90,000	1.63	1.18	2.25	1.64	3.15	2.29
100,000	1.81	1.31	2.50	1.81	3.47	2.52

Note:

Gray shading indicates the flow is not capable of mobilizing sediment from the foreset of the delta.

[1] The critical Shields parameter corresponds to incipient motion of the D_{84} on the dynamically-stable foreset location during the peak discharge of the existing conditions 2-year recurrence interval flood. When adjusted to account for the foreset slope, this value is reduced to 0.019.

[2] The critical Shields parameter corresponds to incipient motion of the D_{84} on the dynamically-stable foreset location during the peak discharge of the existing conditions 5-year recurrence interval flood. When adjusted to account for the foreset slope, this value is reduced to 0.026.

Table 5.1-2. Flow frequency analysis for the USGS gaging station at Gold Creek (PRM 140.1) using 1-D BEM hourly routed flows.

Average Annual Recurrence Interval (years)	Flow (cfs), Existing Conditions	Flow (cfs), Max LF OS-1b
100	94,400	75,700
50	84,900	66,900
20	73,000	55,900
10	64,300	47,900
5	55,700	39,900
2	43,400	28,700
1.5	38,800	24,400
1.11	31,800	18,100
1.01	26,000	12,900

Table 5.1-3. Critical flows and corresponding average annual recurrence interval of Susitna River flows capable of mobilizing sediment from the foreset of the Skull Creek delta.

	Initial Skull Creek Delta Morphology		**Future Skull Creek Delta Morphology, Existing Conditions Hydrology**		**Future Skull Creek Delta Morphology, Max LF OS-1b Hydrology**	
	$\tau_{*c} = 0.025$[1]	$\tau_{*c} = 0.034$[2]	$\tau_{*c} = 0.025$[1]	$\tau_{*c} = 0.034$[2]	$\tau_{*c} = 0.025$[1]	$\tau_{*c} = 0.034$[2]
Critical Flow (cfs)	51,800	76,400	43,400	55,900	27,000	35,600
Approximate Average Annual Recurrence Interval	2 – 5	20 – 50	2	5	1.5 – 2	2 – 5

Note:

[1] The critical Shields parameter corresponds to incipient motion of the D_{84} on the dynamically-stable foreset location during the peak discharge of the existing conditions 2-year recurrence interval flood. When adjusted to account for the foreset slope, this value is reduced to 0.019.

[2] The critical Shields parameter corresponds to incipient motion of the D_{84} on the dynamically-stable foreset location during the peak discharge of the existing conditions 5-year recurrence interval flood. When adjusted to account for the foreset slope, this value is reduced to 0.026.

Table 5.2-1. Summary of the normalized Bank Energy Index (BEI) values for the Existing conditions with- and without consideration of the critical shear criteria.

	No Critical Shear Criteria				With Critical Shear Criteria			
Site	28-Year BEI	28-Year Migration (ft)	Avg. Annual BEI	Avg. Annual Migration (ft/year)	28-Year BEI	28-Year Migration (ft)	Avg. Annual BEI	Avg. Annual. Migration (ft/year)
1	0.12	26	0.00	0.9	0.00	26	0.00	0.9
2	1.01	40	0.04	1.4	0.00	40	0.00	1.4
3	0.85	55	0.03	2.0	0.00	55	0.00	2.0
4	1.28	70	0.05	2.5	0.00	70	0.00	2.5
5	2.72	85	0.10	3.0	0.38	85	0.01	3.0
6	0.98	35	0.03	1.3	0.00	35	0.00	1.3
7	1.25	35	0.04	1.3	0.00	35	0.00	1.3
8	1.02	60	0.04	2.1	0.00	60	0.00	2.1
9	2.73	93	0.10	3.3	0.00	93	0.00	3.3
10	0.79	20	0.03	0.7	0.00	20	0.00	0.7
11	0.02	40	0.00	1.4	0.00	40	0.00	1.4
12	0.04	35	0.00	1.3	0.00	35	0.00	1.3
13	1.07	95	0.04	3.4	0.00	95	0.00	3.4
14	0.83	60	0.03	2.1	0.00	60	0.00	2.1
15	0.76	35	0.03	1.3	0.00	35	0.00	1.3
16	0.54	50	0.02	1.8	0.00	50	0.00	1.8

Table 5.2-2. Comparison of the Average Annual Sediment Delivery Index under Existing and Max LF OS-1b conditions; median values shown for each geomorphic surface.

Geomorphic Surface	Overtopping Discharge (cfs)	Existing Conditions		With-Project Conditions (Max LF OS-1b)	
		Sand	Silt/clay	Sand	Silt/clay
Vegetated Bar (VB)	48,320	44	33	0	3
Young Floodplain (YFP)	54,840	31	22	0	1
Overbank Channel (OC)	56,080	28	20	0	1
Mature Floodplain (MFP)	77,870	6	4	0	0
Old Floodplain (OFP)	87,570	1	0	0	0

Table 5.2-3. Comparison of predicted discharge at the transect lines for the Year-0 and Year-25 Existing conditions and the Year-25 Max LF OS-1b conditions at 12,000 cfs and 30,000 cfs.

Transect	All Conditions - Year 0 - 12,000 cfs.					All Conditions - Year 0 - 30,000 cfs.				
	Far left	Left	Middle	Right	Far Right	Far left	Left	Middle	Right	Far Right
T1		1,412		10,588			10,872		19,128	
T2	1,346		2	10,652		8,295	503	1,255	19,947	
T3		15	1,331	10,655		0	963	7,360	21,677	
T4	4	11	520	7,072	4,393	23	940	4,119	14,485	10,432
T5			12,000					30,000		
T6								474		
T7								100		
Transect	Existing Conditions - Year 25 - 12,000 cfs					Existing Conditions - Year 25 - 30,000 cfs.				
	Far left	Left	Middle	Right	Far Right	Far left	Left	Middle	Right	Far Right
T1		1,673		10,327			11,404		18,596	
T2	1,290		362	10,348		8,766	610	1,990	18,634	
T3		4	1,287	10,709			828	7,944	21,227	
T4	4		690	7,231	4,075	23	805	4,528	14,825	9,819
T5			12,000					30,000		
T6								604		
T7								187		
Transect	Max LF OS-1b Conditions - Year 25 - 12,000 cfs.					Max LF OS-1b Conditions - Year 25 - 30,000 cfs.				
	Far left	Left	Middle	Right	Far Right	Far left	Left	Middle	Right	Far Right
T1		1,855		10,145			11,454		18,546	
T2	1,802		8	10,190		9,063	508	1,198	19,231	
T3		10	1,792	10,198			1,117	7,965	20,918	
T4	4	6	919	6,931	4,141	23	1,094	4,663	14,492	9,728
T5			12,000					30,000		
T6								488		
T7								131		

9. FIGURES

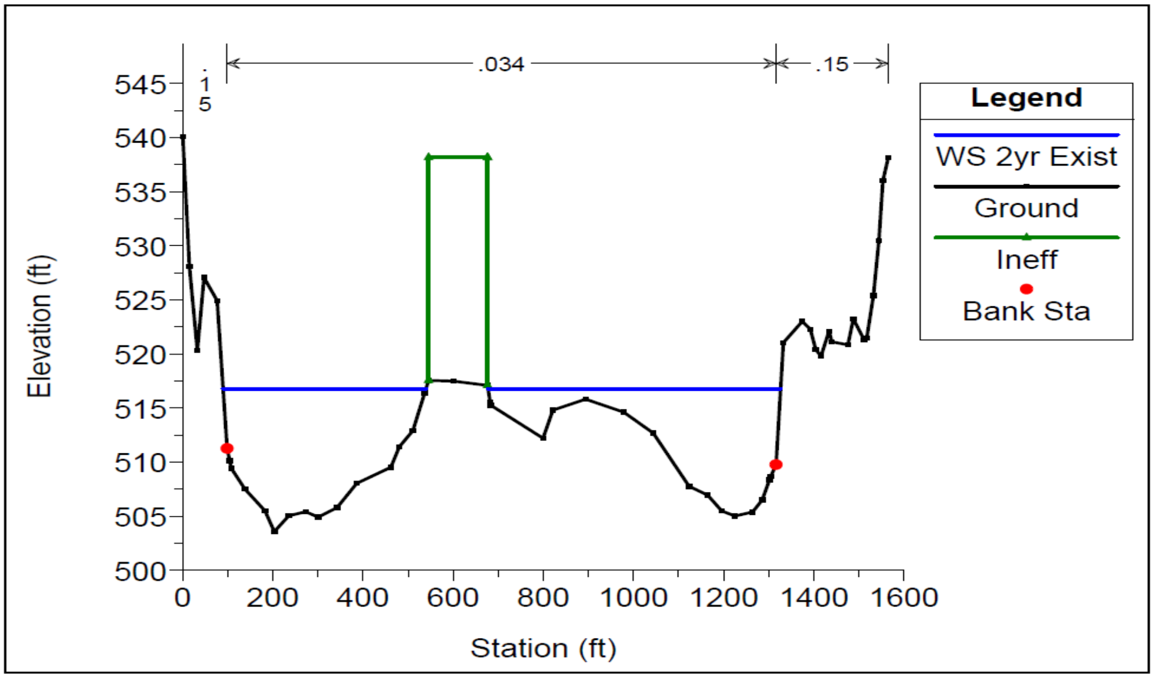


Figure 4.1-1. Existing conditions channel geometry at PRM122.1 with in-channel vegetation simulated with ineffective flow area.

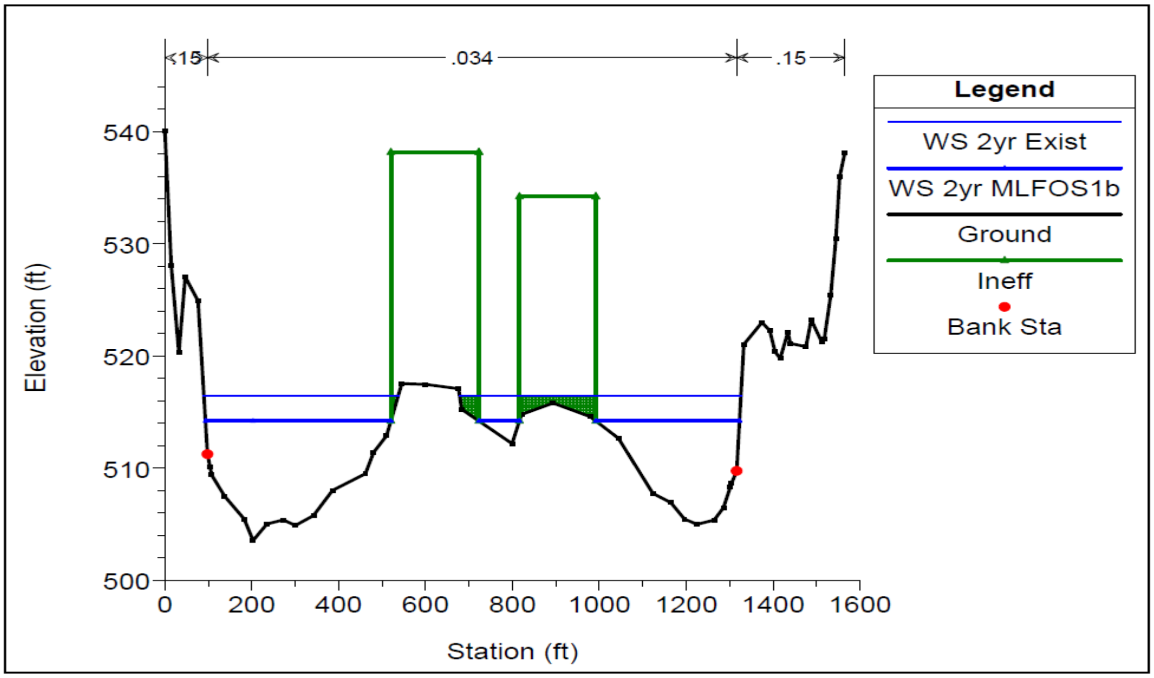


Figure 4.1-2. With-Project channel geometry at PRM 122.1 with in-channel vegetation simulated with ineffective flow area above 2-year water surface.

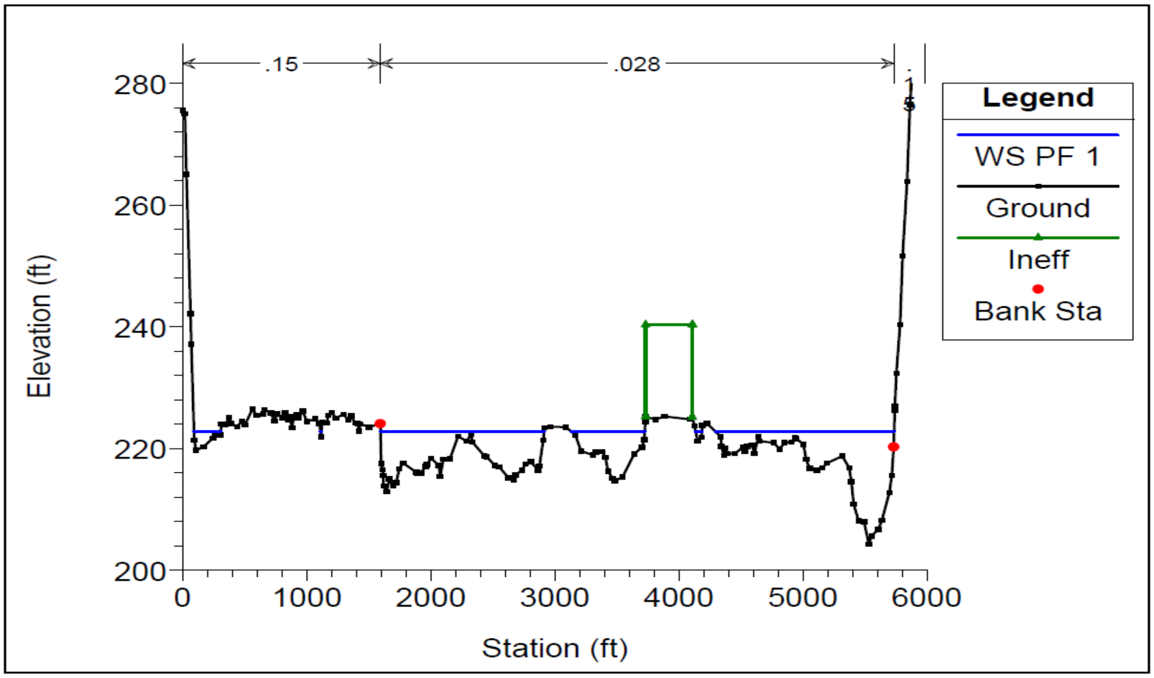


Figure 4.1-3. Existing conditions channel geometry at PRM 78.0 with in-channel vegetation simulated with ineffective flow area.

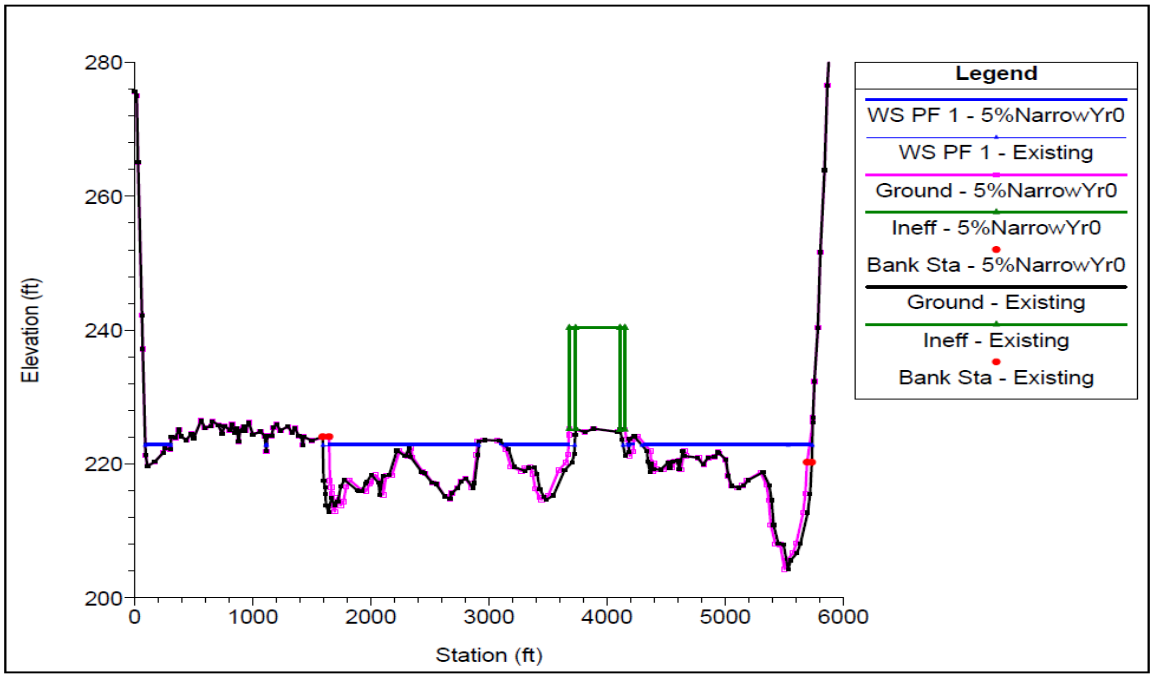


Figure 4.1-4. Year 0 with-Project channel geometry at PRM 78.0 with 5% narrowing.

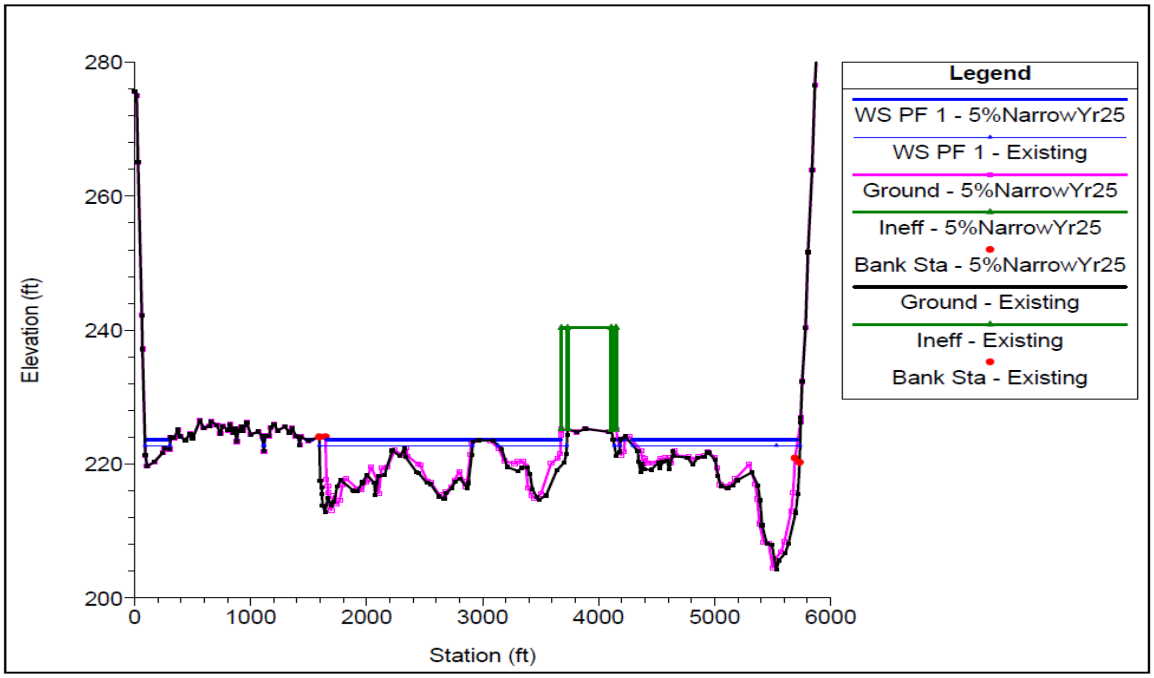


Figure 4.1-5. Year 25 with-Project channel geometry at PRM 78.0 with 5% narrowing.

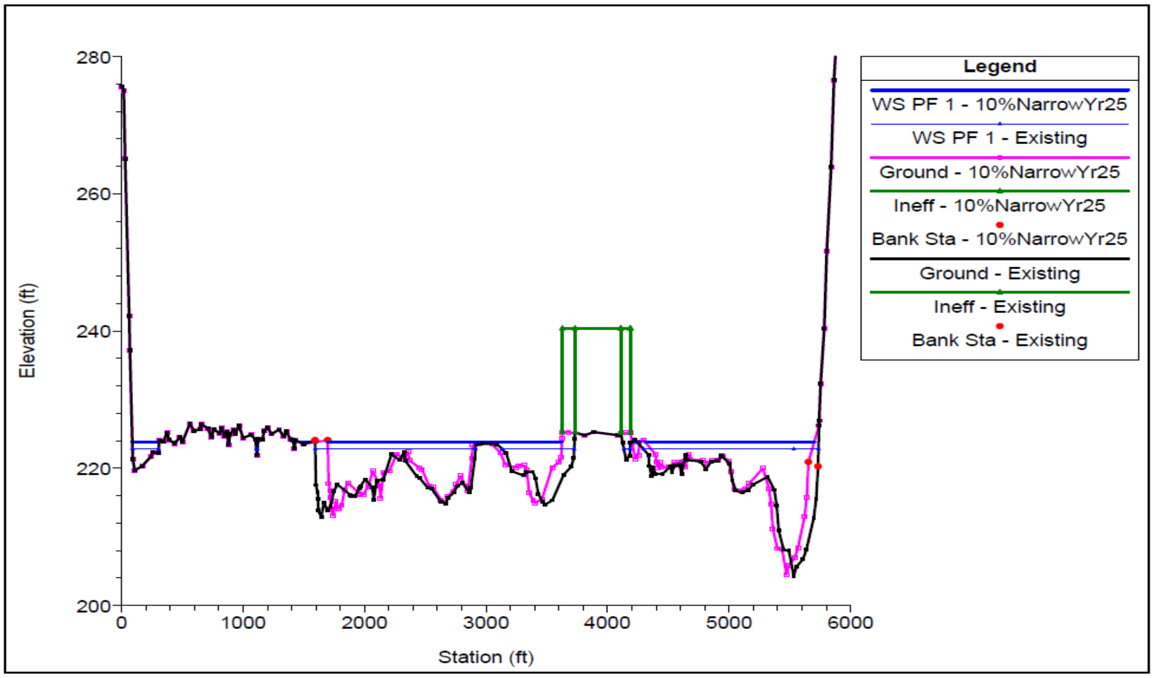


Figure 4.1-6. Year 25 with-Project channel geometry at PRM 78.0 with 10% narrowing.

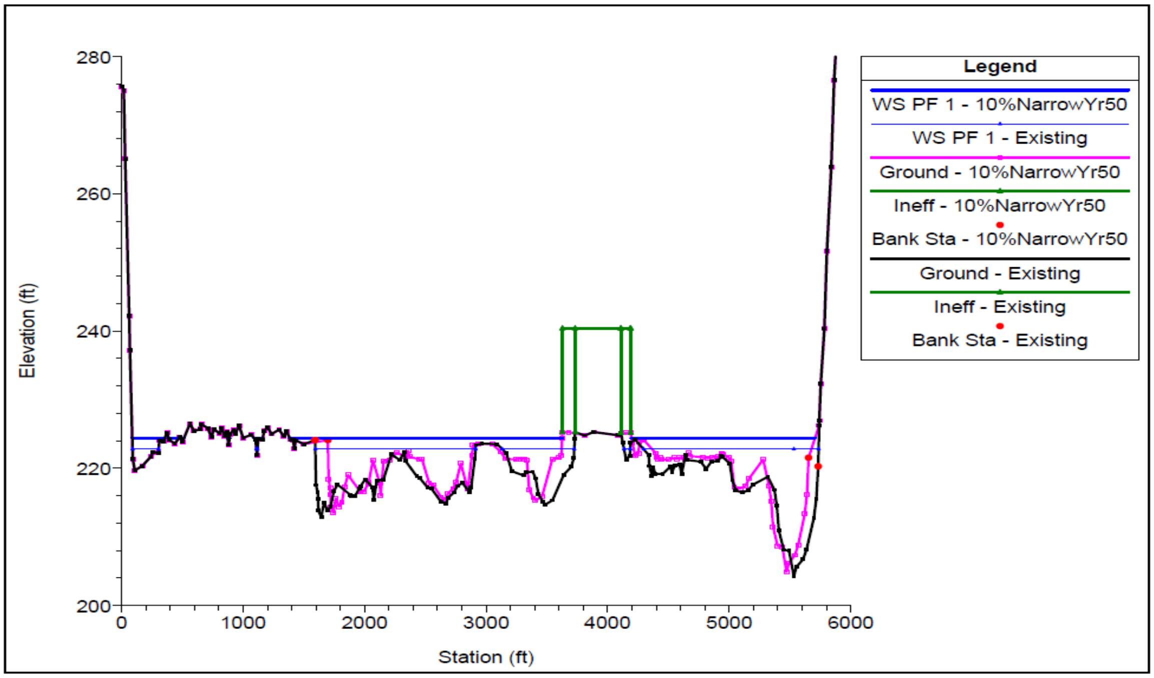


Figure 4.1-7. Year 50 with-Project channel geometry at PRM 78.0 with 10% narrowing.

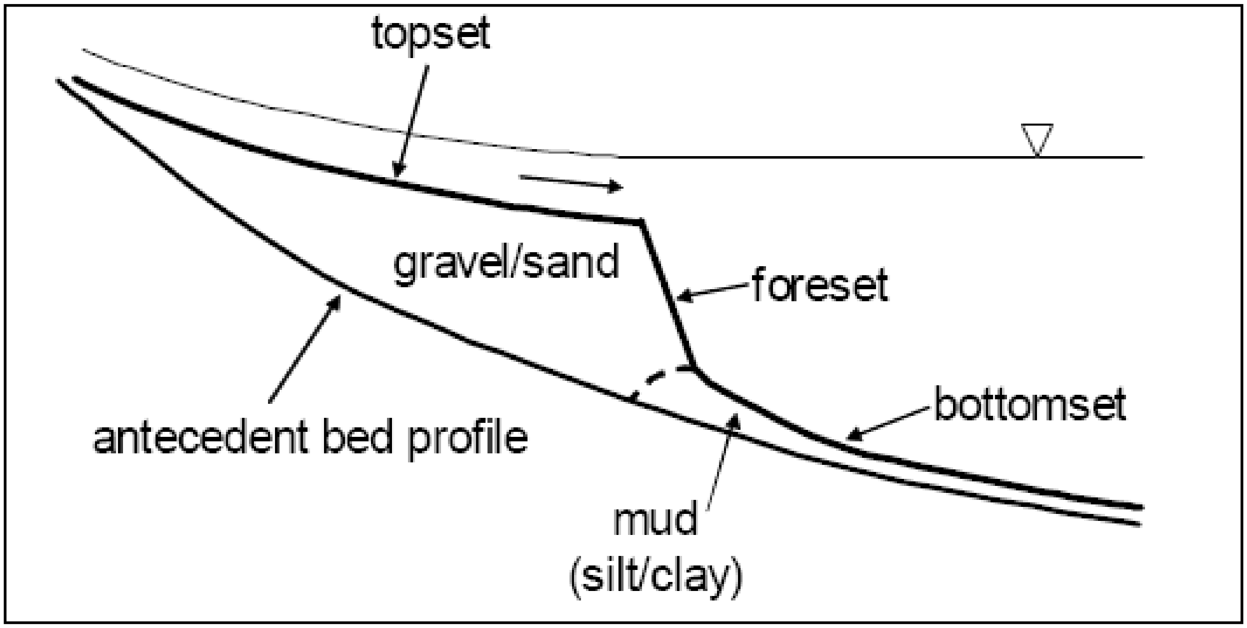


Figure 4.1-8. Conceptual schematic of tributary delta morphology.

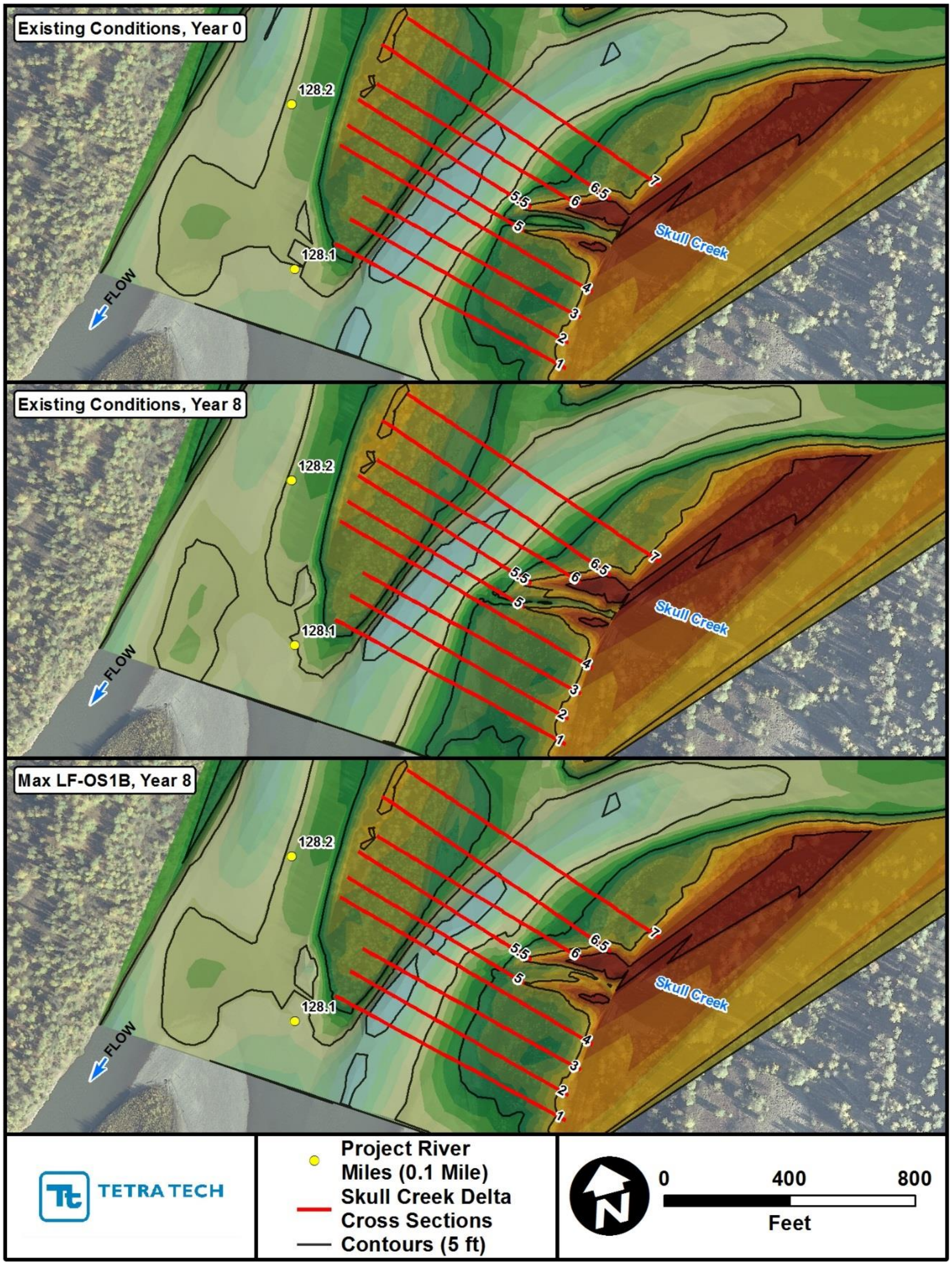


Figure 4.1-9. Skull Creek delta cross section alignments for simplified modeling approach.

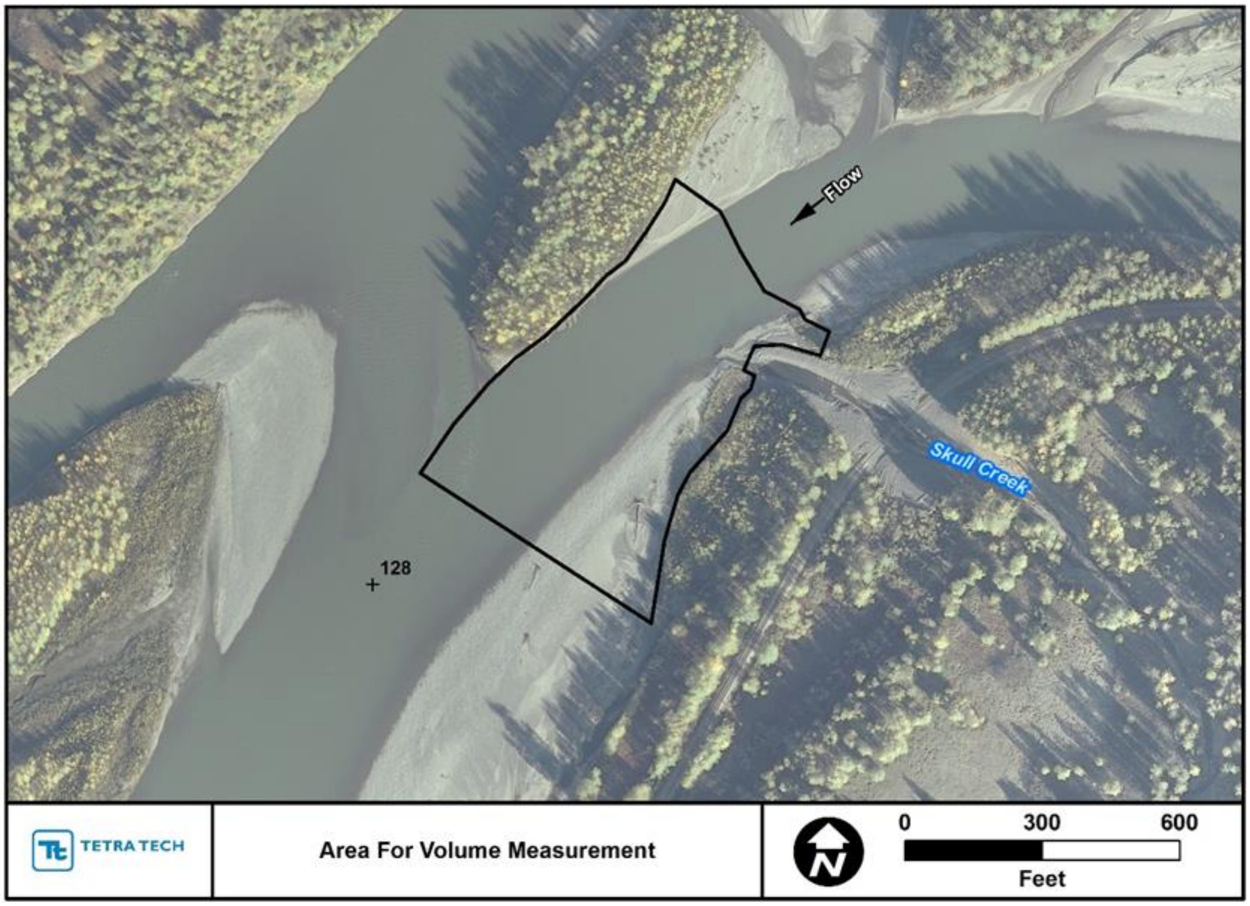


Figure 4.2-1. Delineated area for volume change calculations.

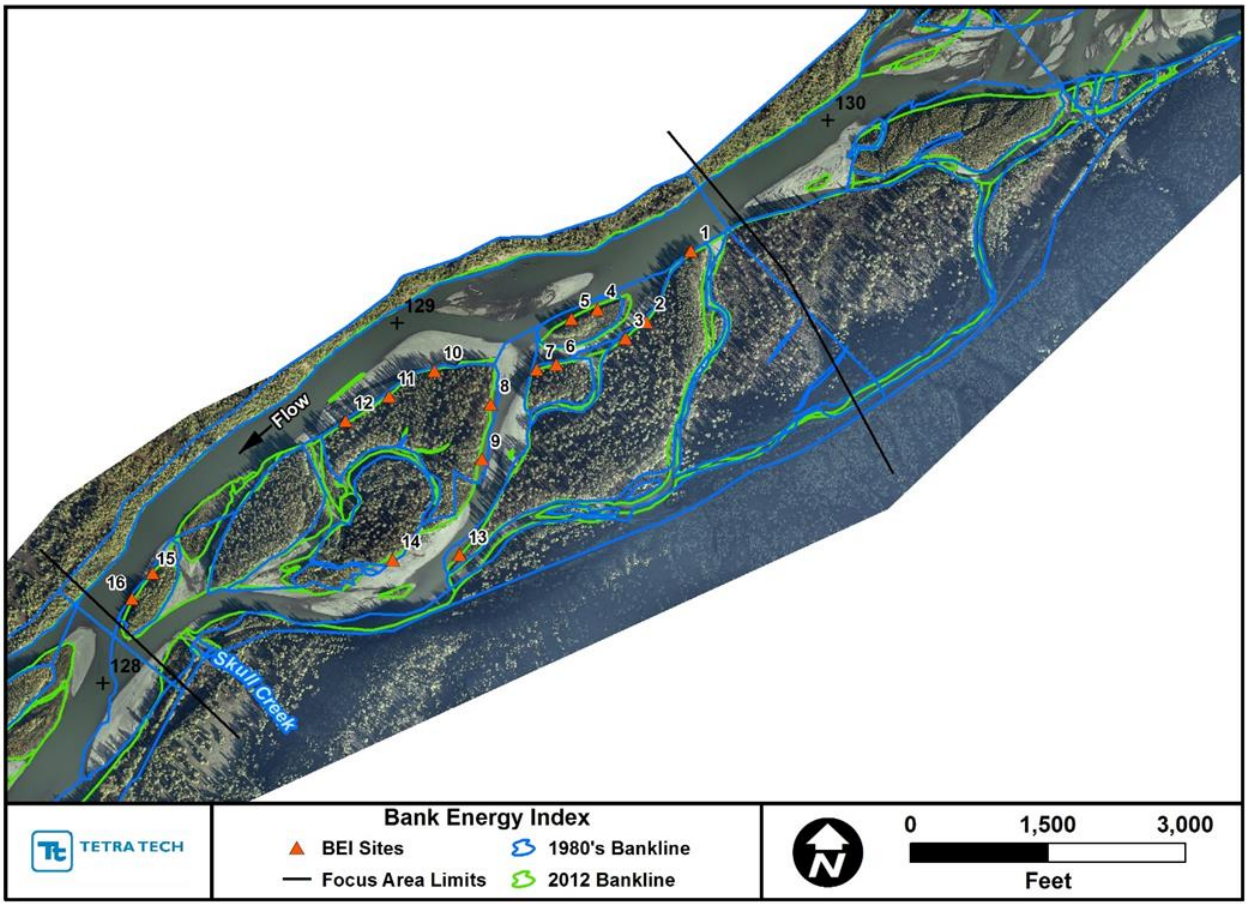


Figure 4.2-2. Location of the selected sites for the BEI analysis and bank lines for the 1980's and 2012 conditions.

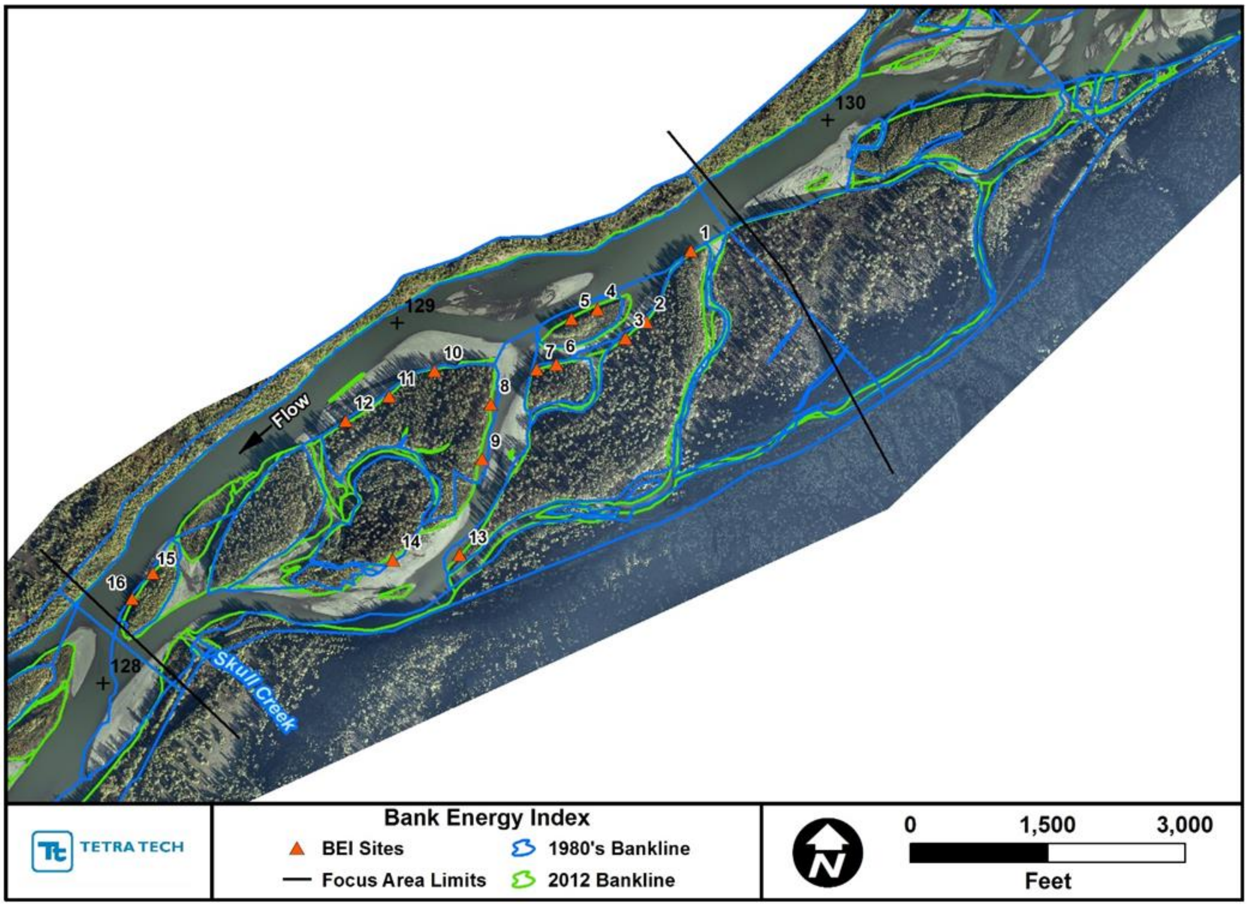


Figure 4.2-3. Predicted ground-surface overtopping discharge for identified geomorphic features at FA-128 (Slough 8A).

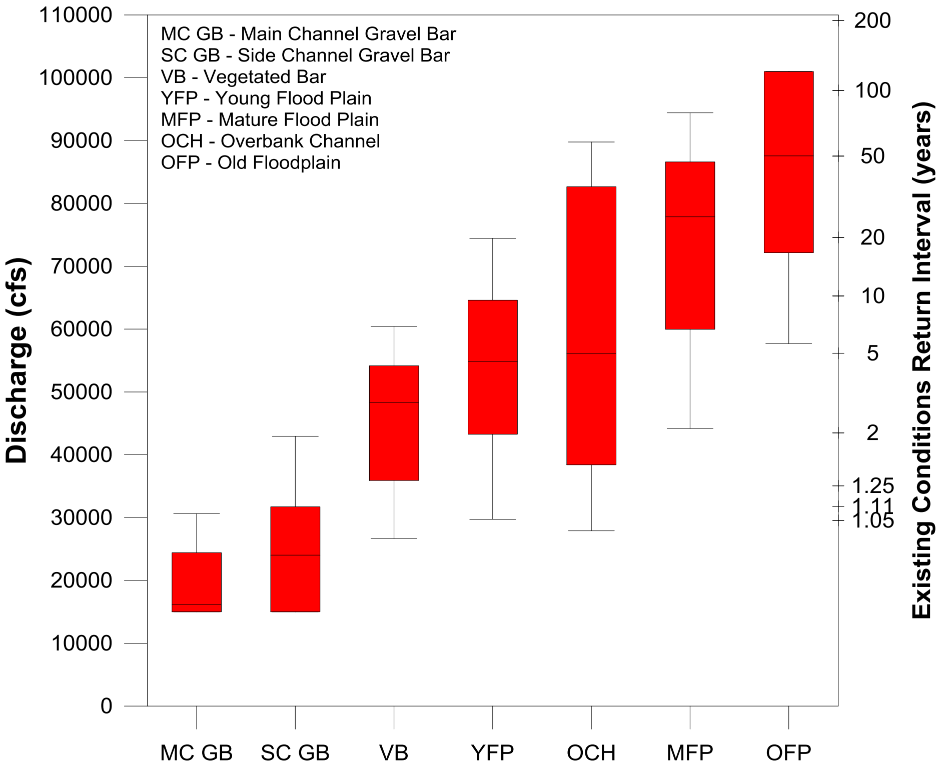


Figure 4.2-4. Box-plot showing the overtopping discharge and associated overtopping recurrence interval for each geomorphic feature. The center line of the red box is the median overtopping discharge, the bounds of the box represent the 10- and 90-percent values, and the whiskers represent the minimum and maximum values.

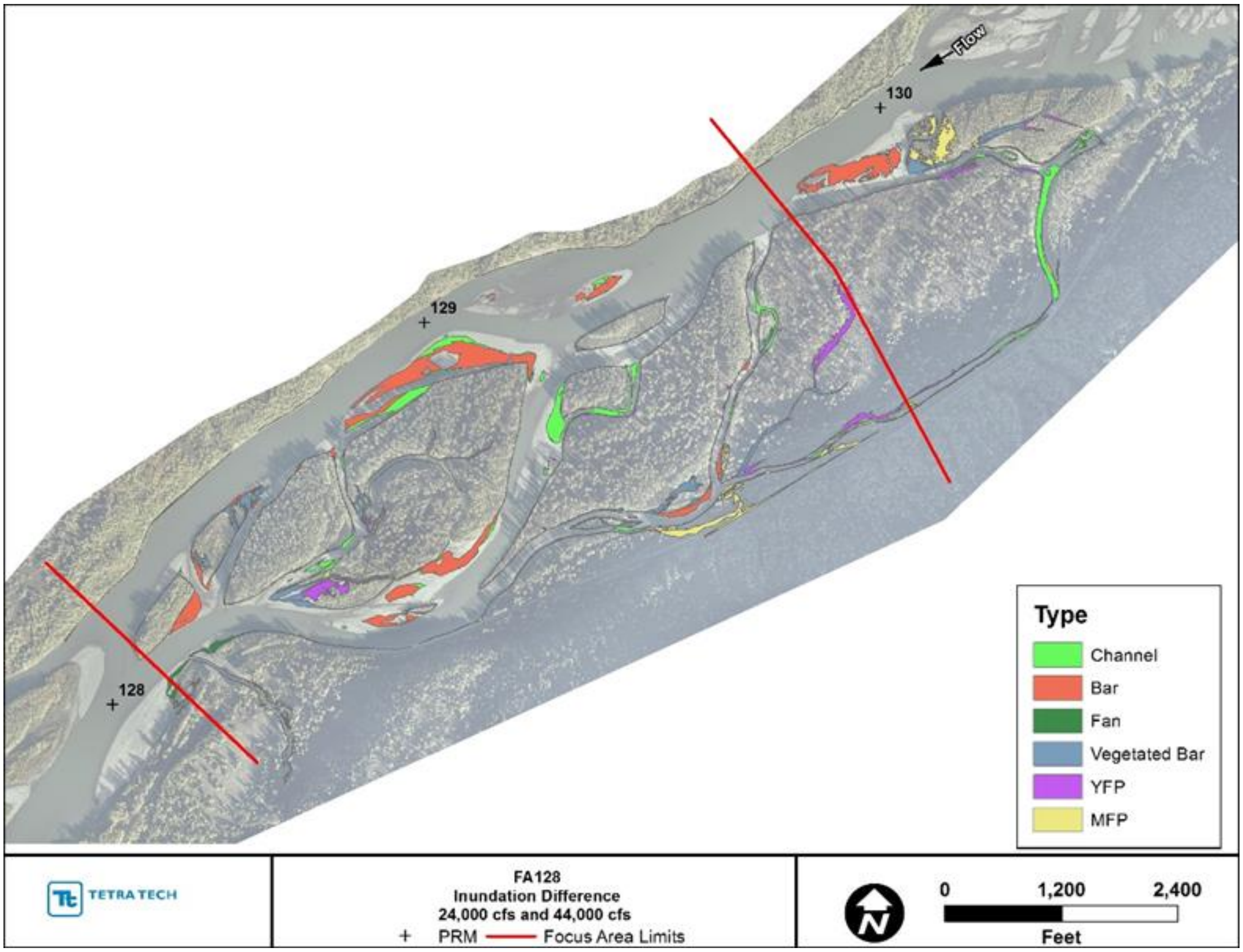


Figure 4.2-5. FA-128 (Slough 8A) inundation differences between Existing and Max LF OS-1b approximate 2-year flows.

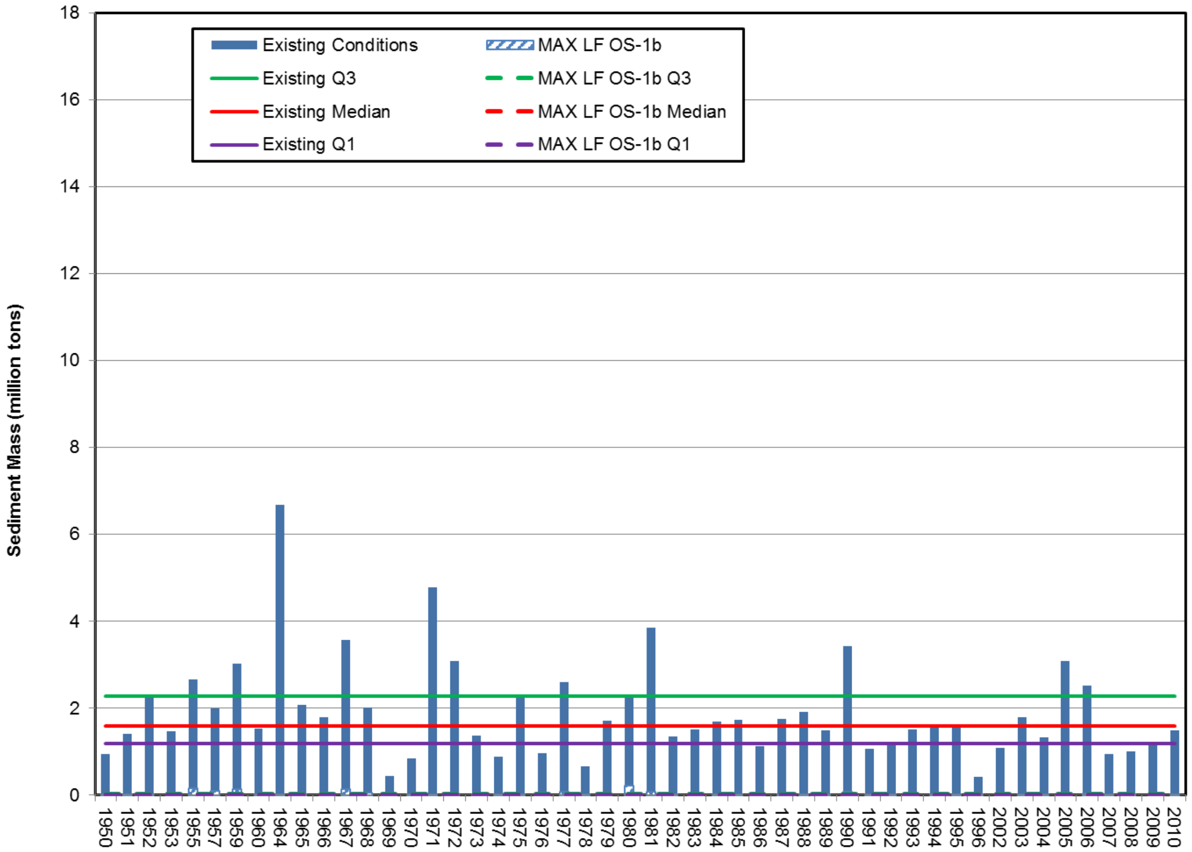


Figure 5.1-1. Open-water flow period sediment mass (sand and larger materials) transported past Gold Creek (PRM 140.0) under existing conditions and Max LF OS-1b.

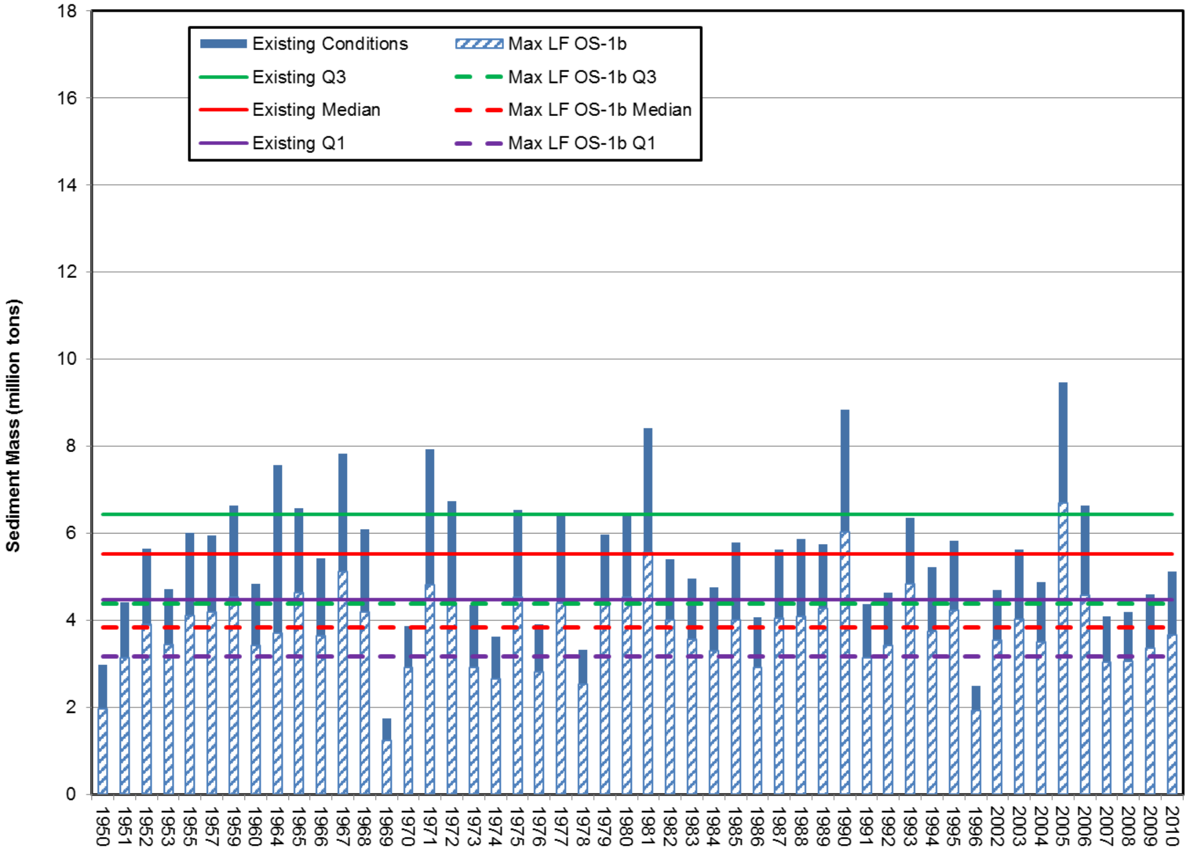


Figure 5.1-2. Open-water flow period sediment mass (sand and larger materials) transported past Sunshine (PRM 88.0) under existing conditions and Max LF OS-1b.

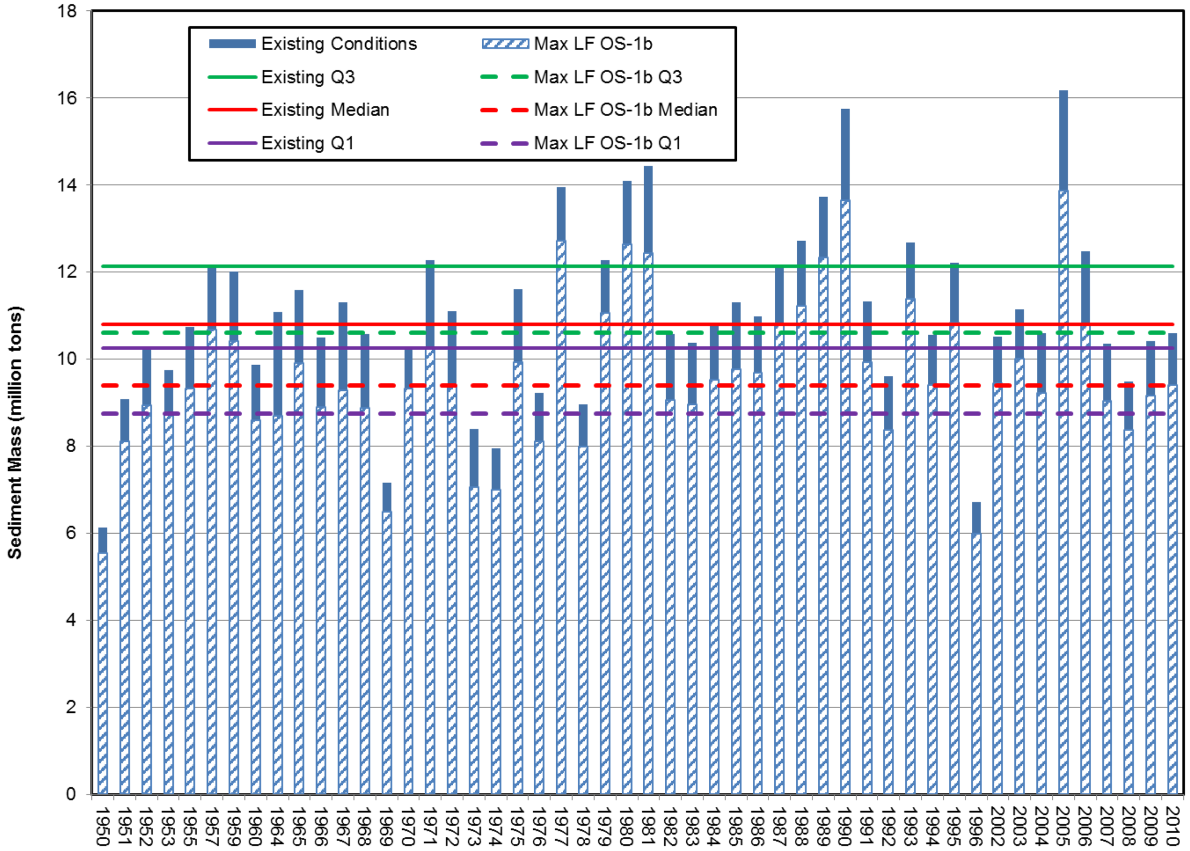


Figure 5.1-3. Open-water flow period sediment mass (sand and larger materials) transported past Susitna Station (PRM 29.9) under existing conditions and Max LF OS-1b.

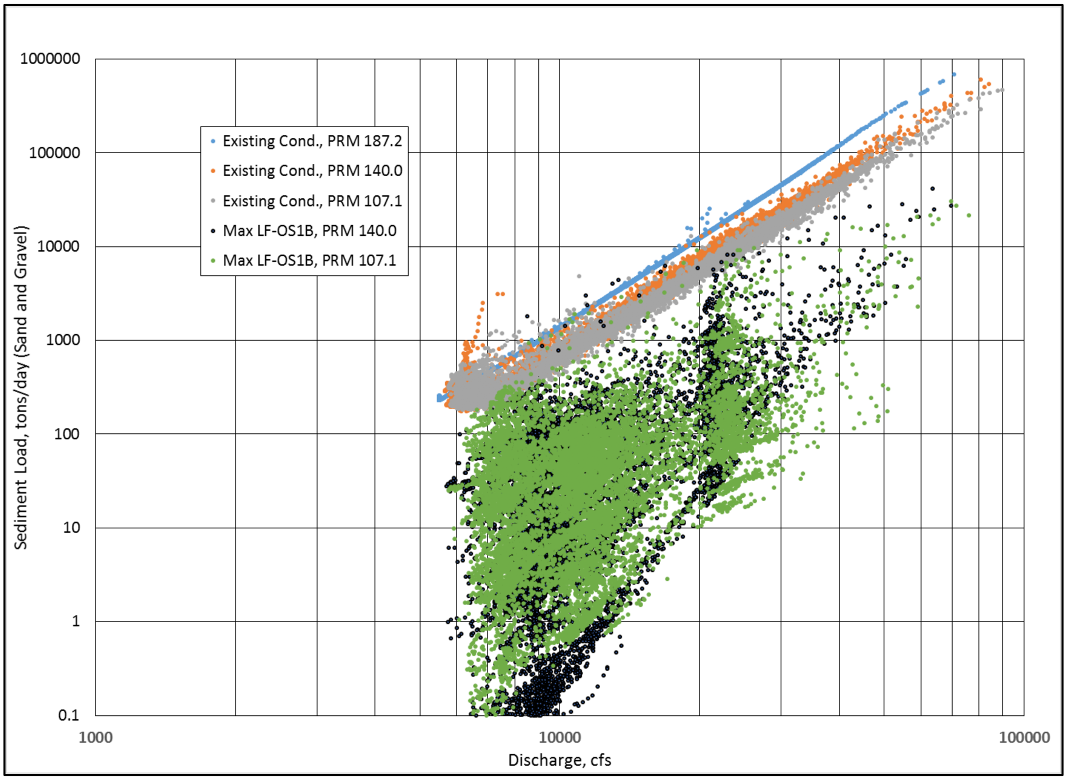


Figure 5.1-4. Sediment load (sand and coarser) versus discharge along the Middle Susitna River.

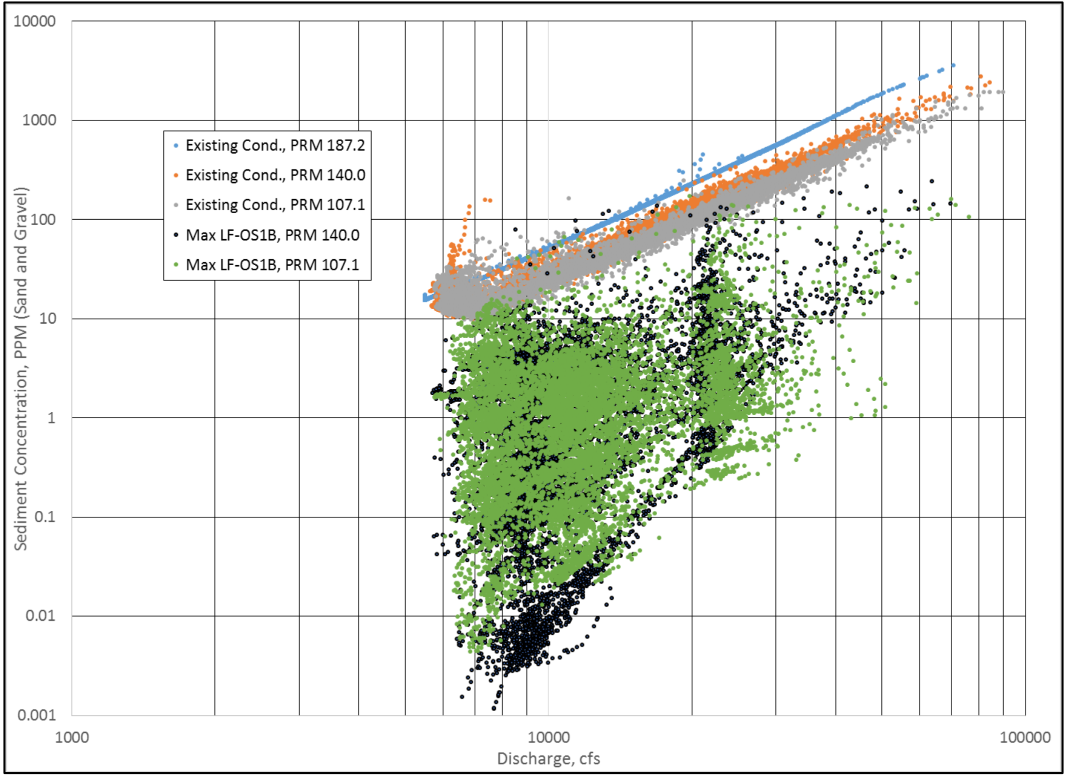


Figure 5.1-5. Sediment concentration (sand and coarser) versus discharge along the Middle Susitna River.

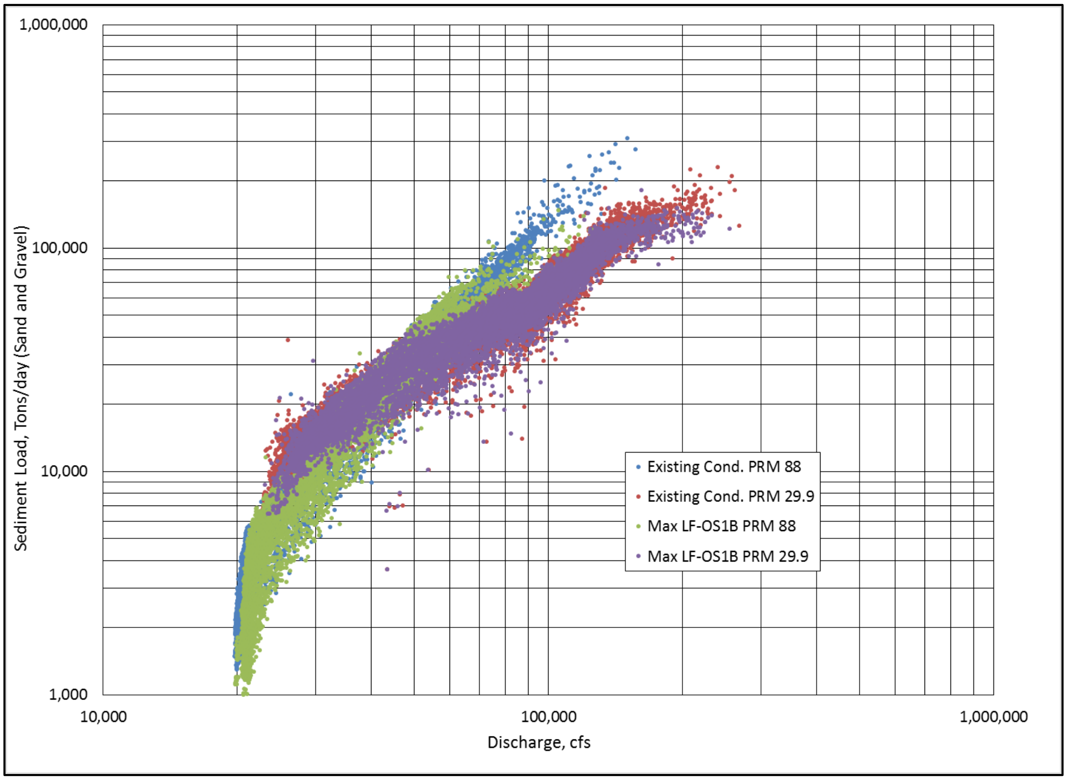


Figure 5.1-6. Sediment load (sand and coarser) versus discharge along the Lower Susitna River.

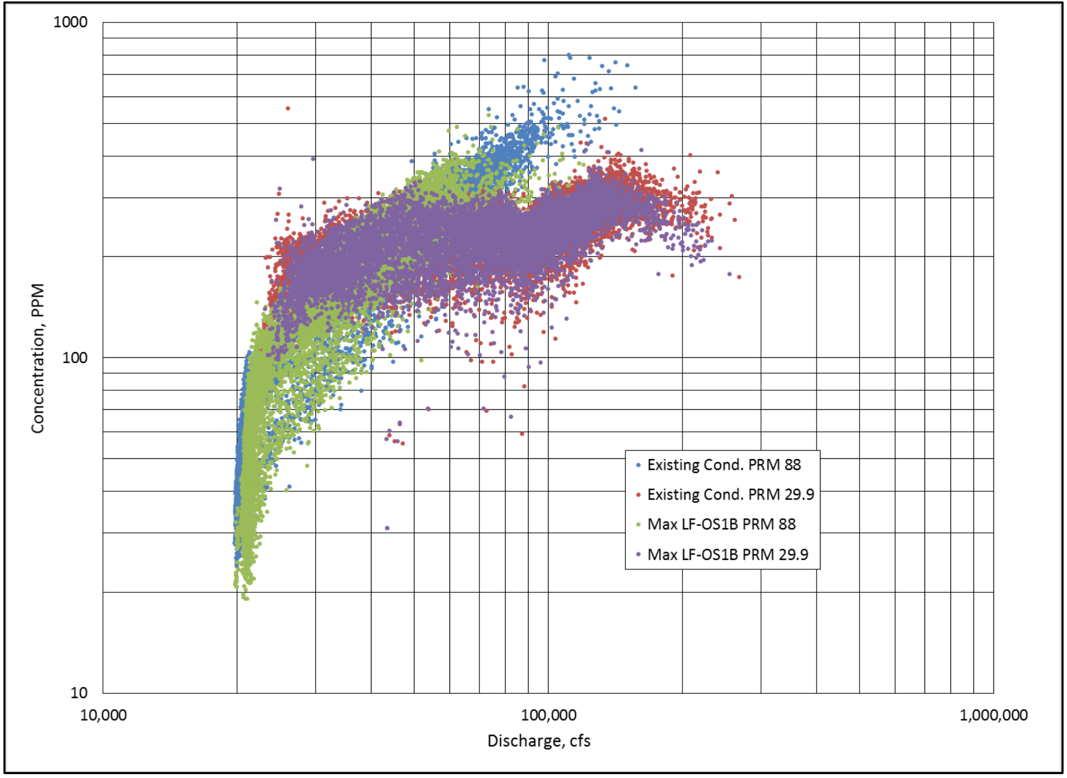


Figure 5.1-7. Sediment concentration (sand and coarser) versus discharge along the Lower Susitna River.

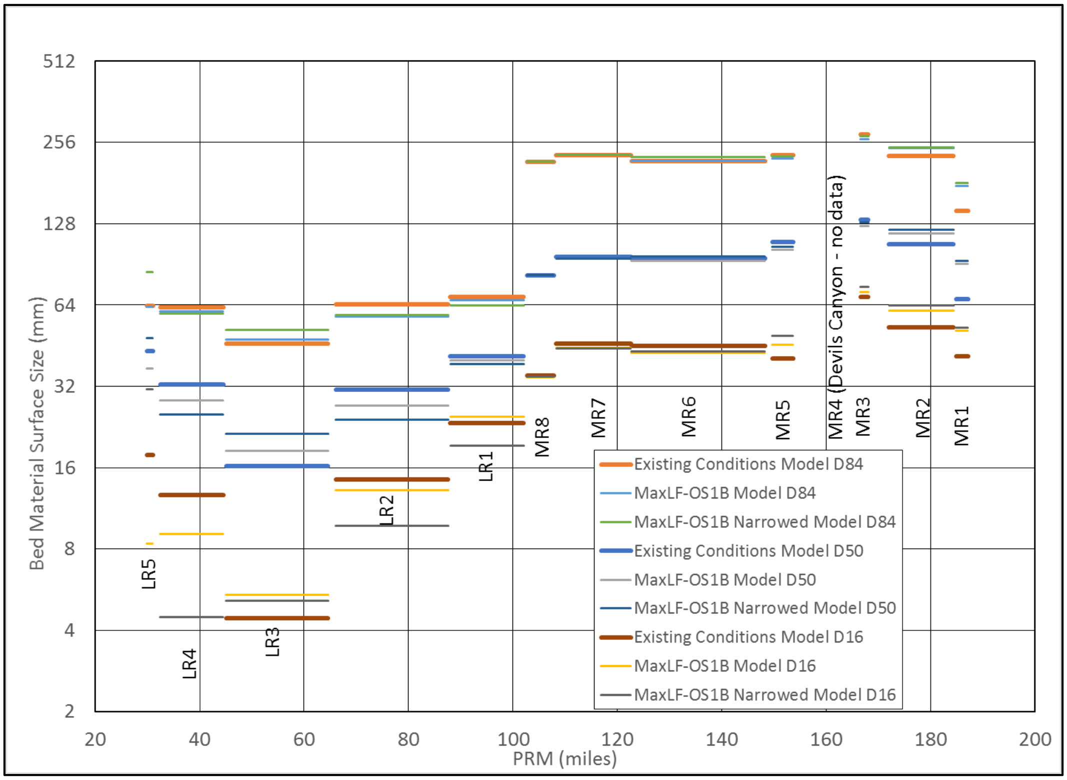


Figure 5.1-8. Model bed material surface sizes at year-50 for Existing and Max LF OS-1b. simulations.

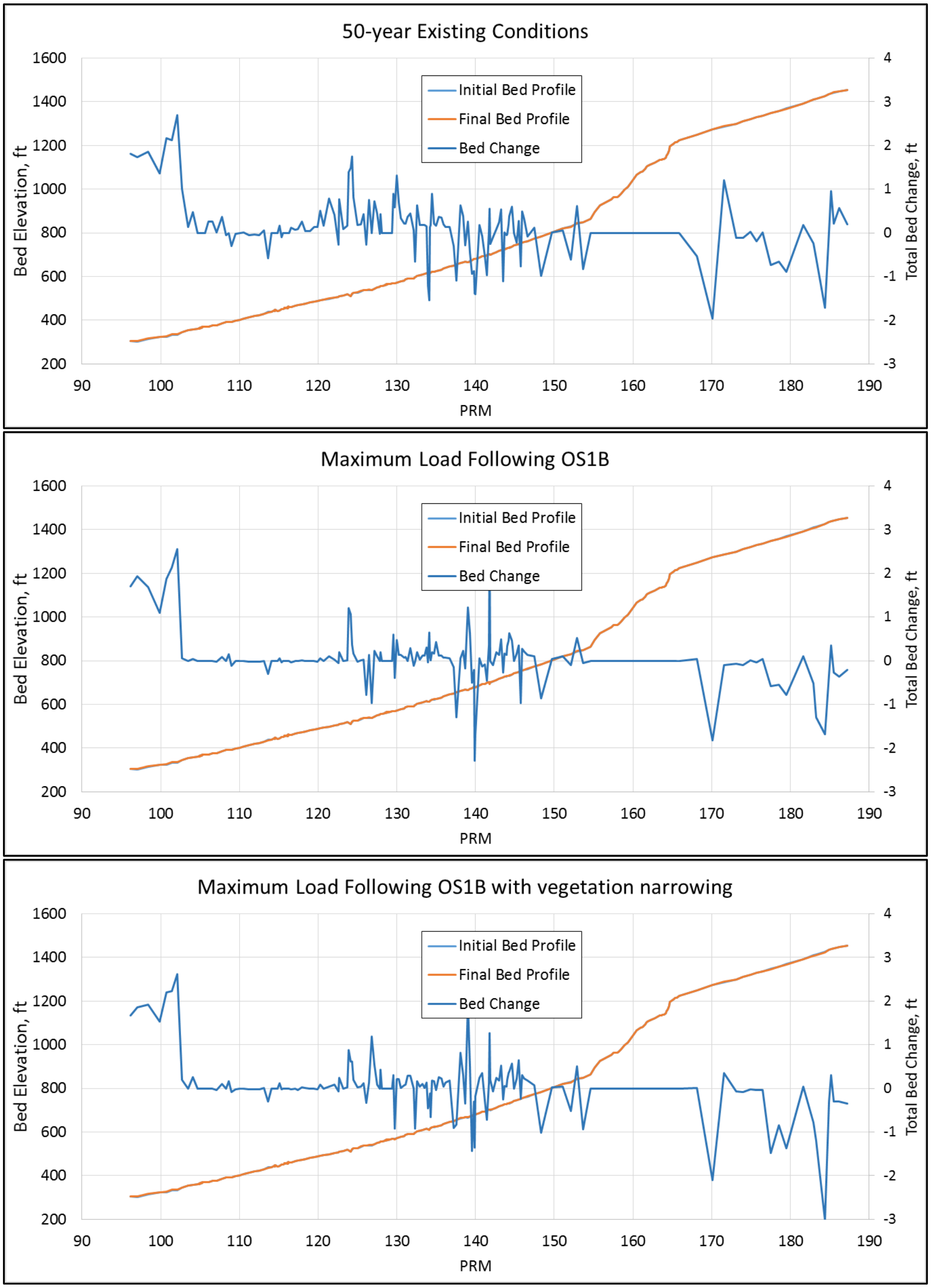


Figure 5.1-9. Bed elevation change along the Middle Susitna River in 50-years.

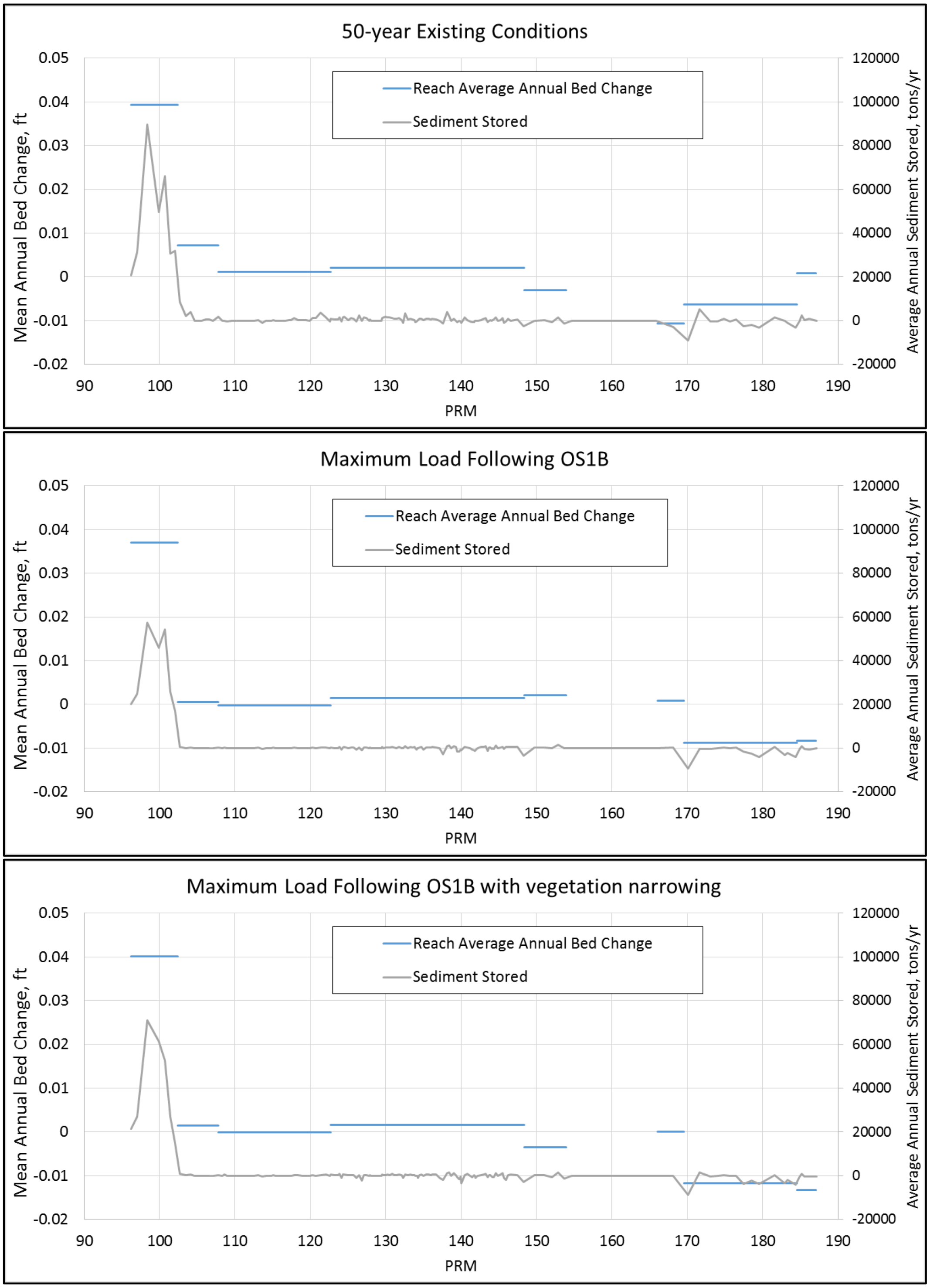


Figure 5.1-10. Reach-average bed elevation change and sediment storage along the Middle Susitna River in 50-years.

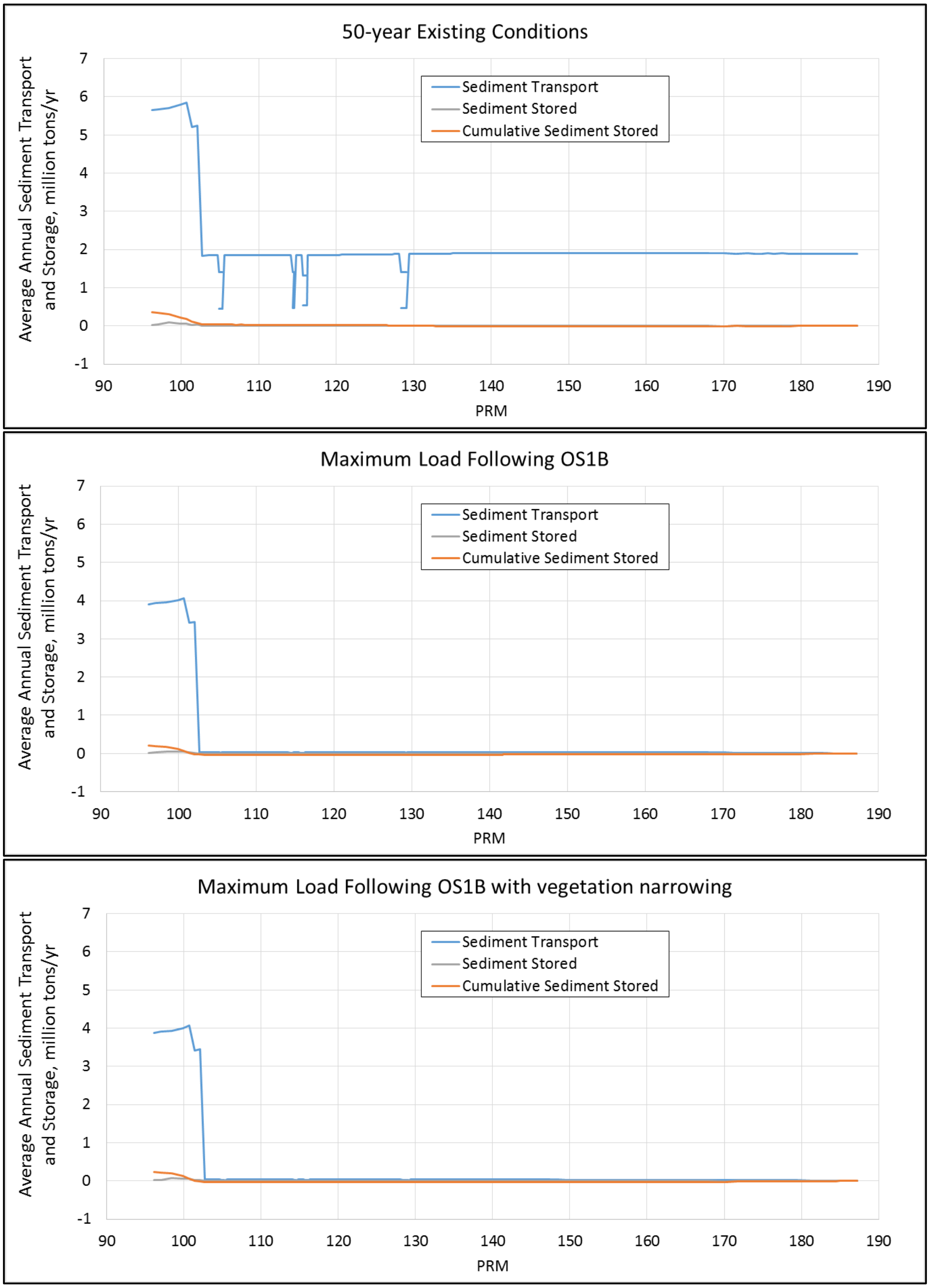


Figure 5.1-11. Sediment transport and storage along the Middle Susitna River in 50-years.

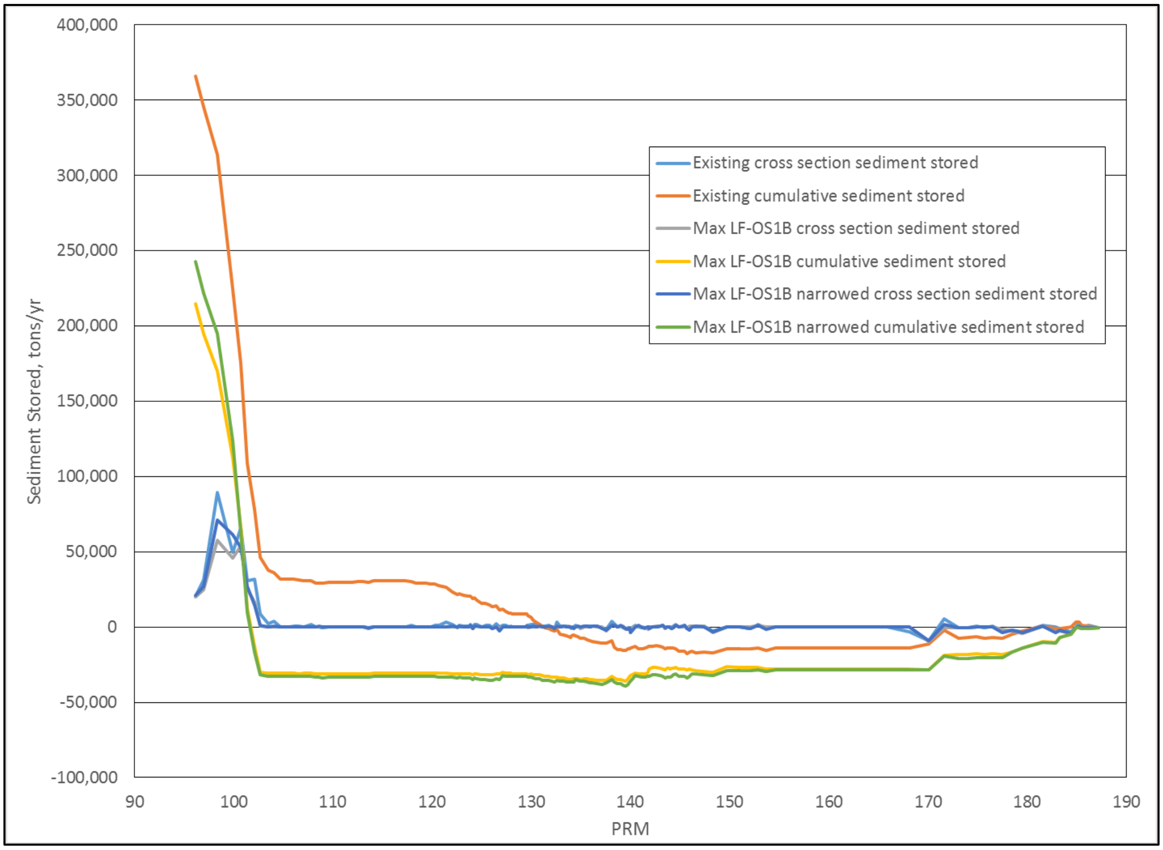


Figure 5.1-12. Comparison of cross section and cumulative sediment storage along the Middle Susitna River in 50-years.

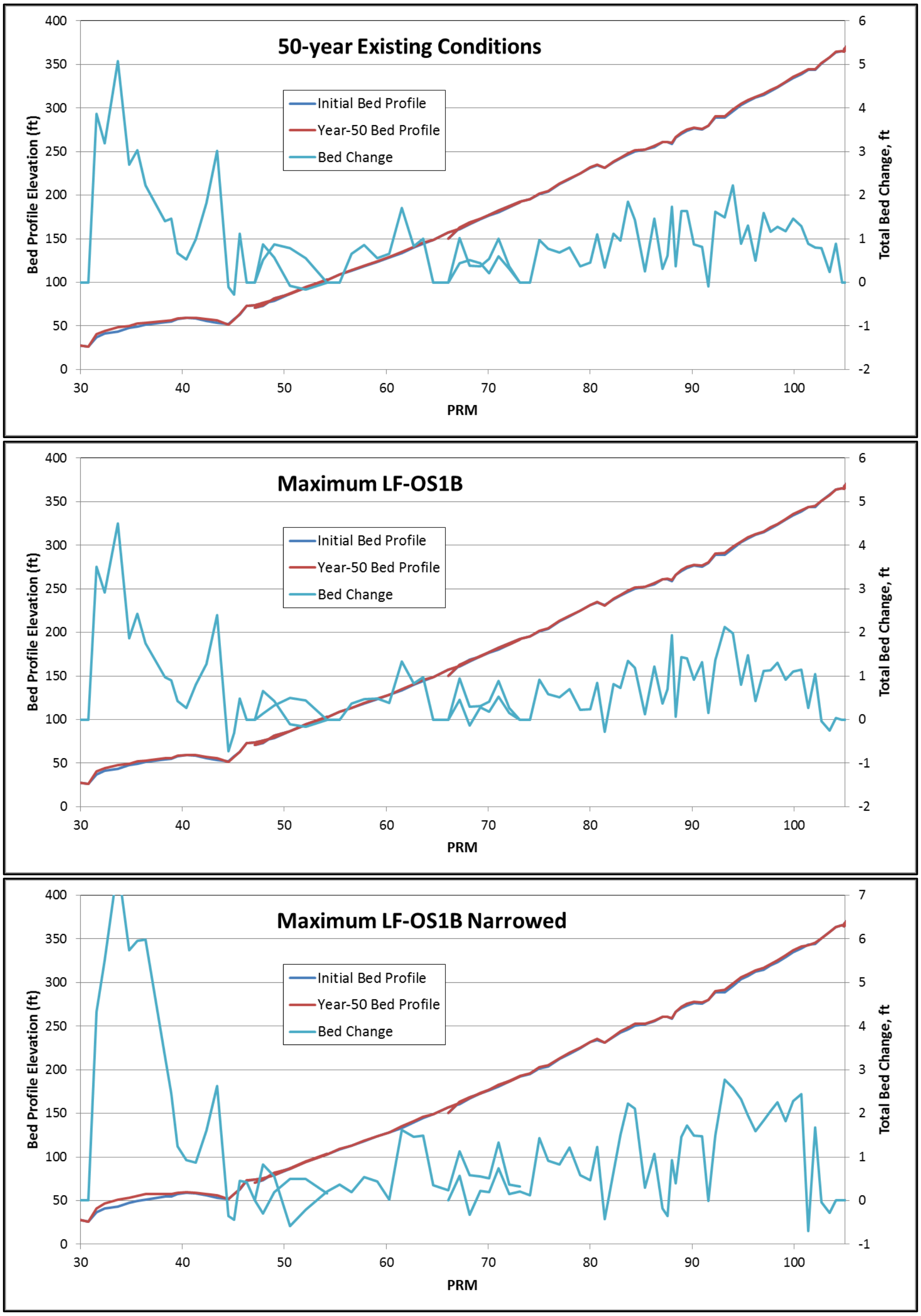


Figure 5.1-13. Bed elevation change along the Lower Susitna River in 50-years.

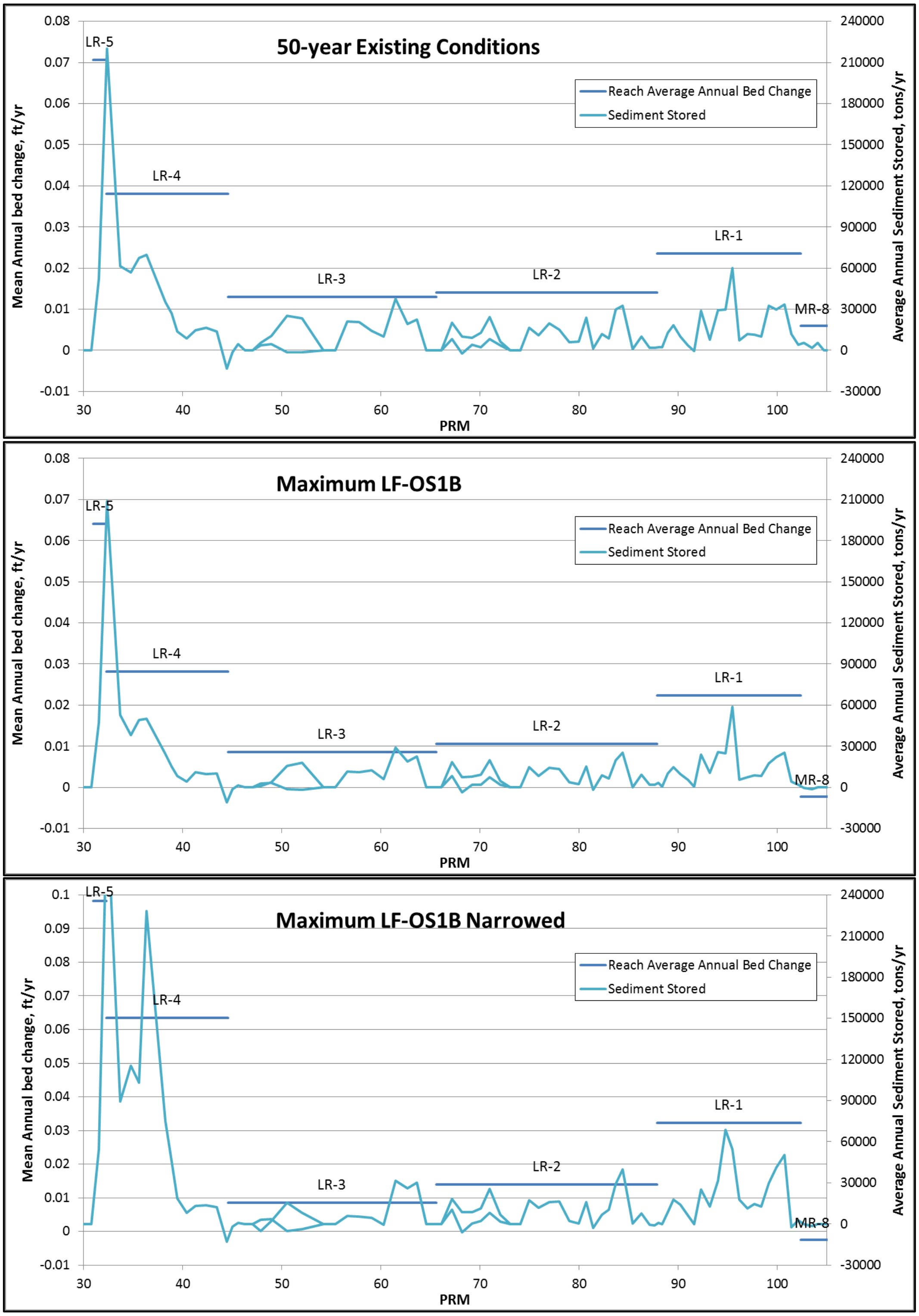


Figure 5.1-14. Reach-average bed elevation change and sediment storage along the Lower Susitna River in 50-years.

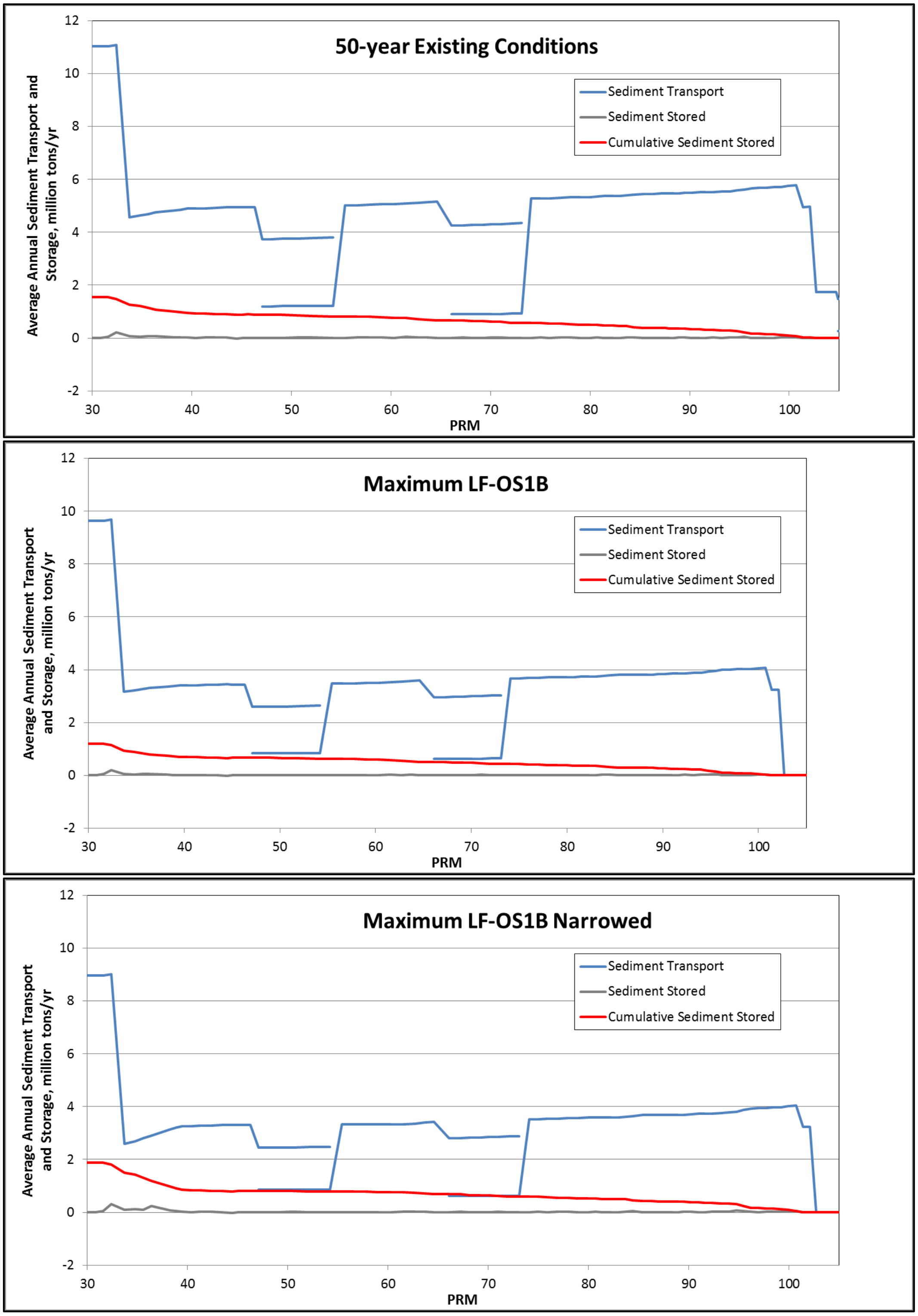


Figure 5.1-15. Sediment transport and storage along the Lower Susitna River in 50-years.

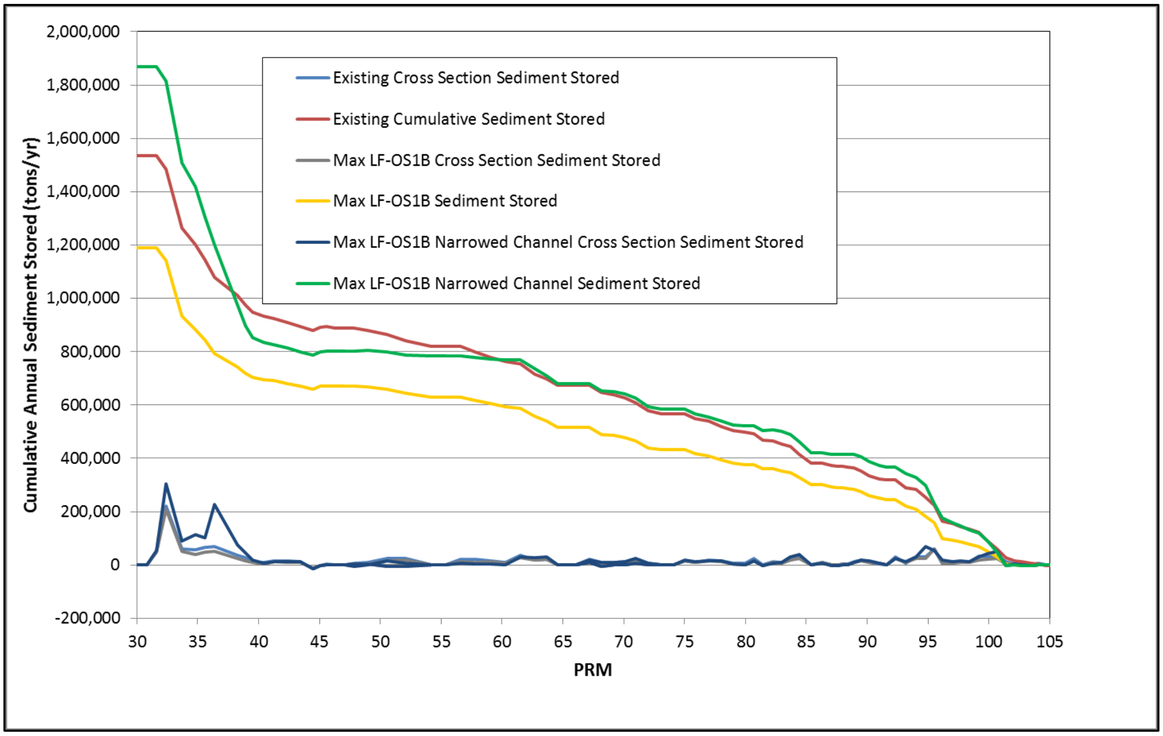


Figure 5.1-16. Comparison of cross section and cumulative sediment storage along the Lower Susitna River in 50-years.

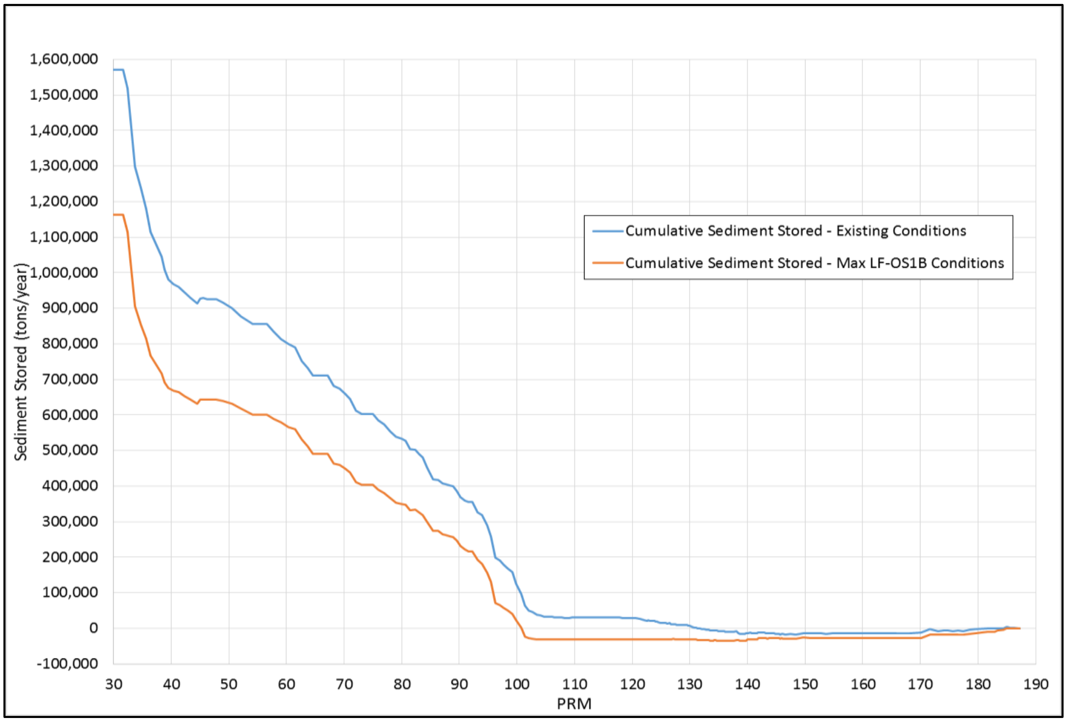


Figure 5.1-17. Comparison of cumulative sediment storage along the Middle and Lower Susitna River Segments in 50-years.

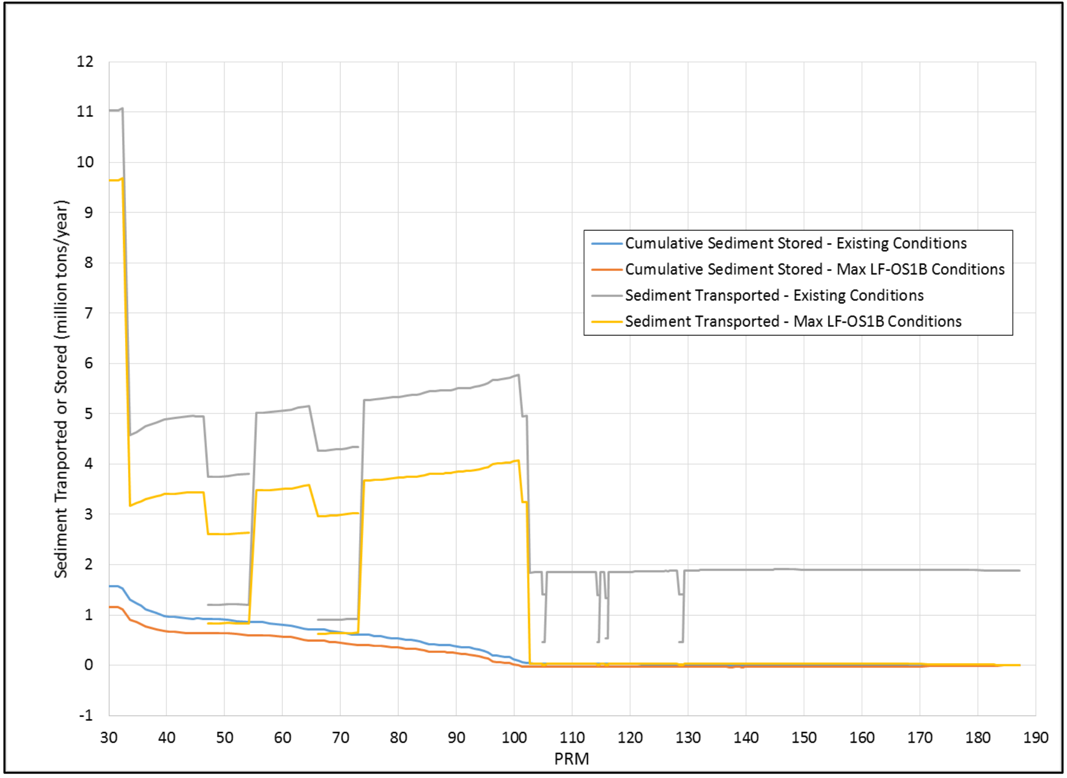


Figure 5.1-18. Comparison of sediment transport and cumulative sediment storage along the Middle and Lower Susitna River Segments in 50-years.

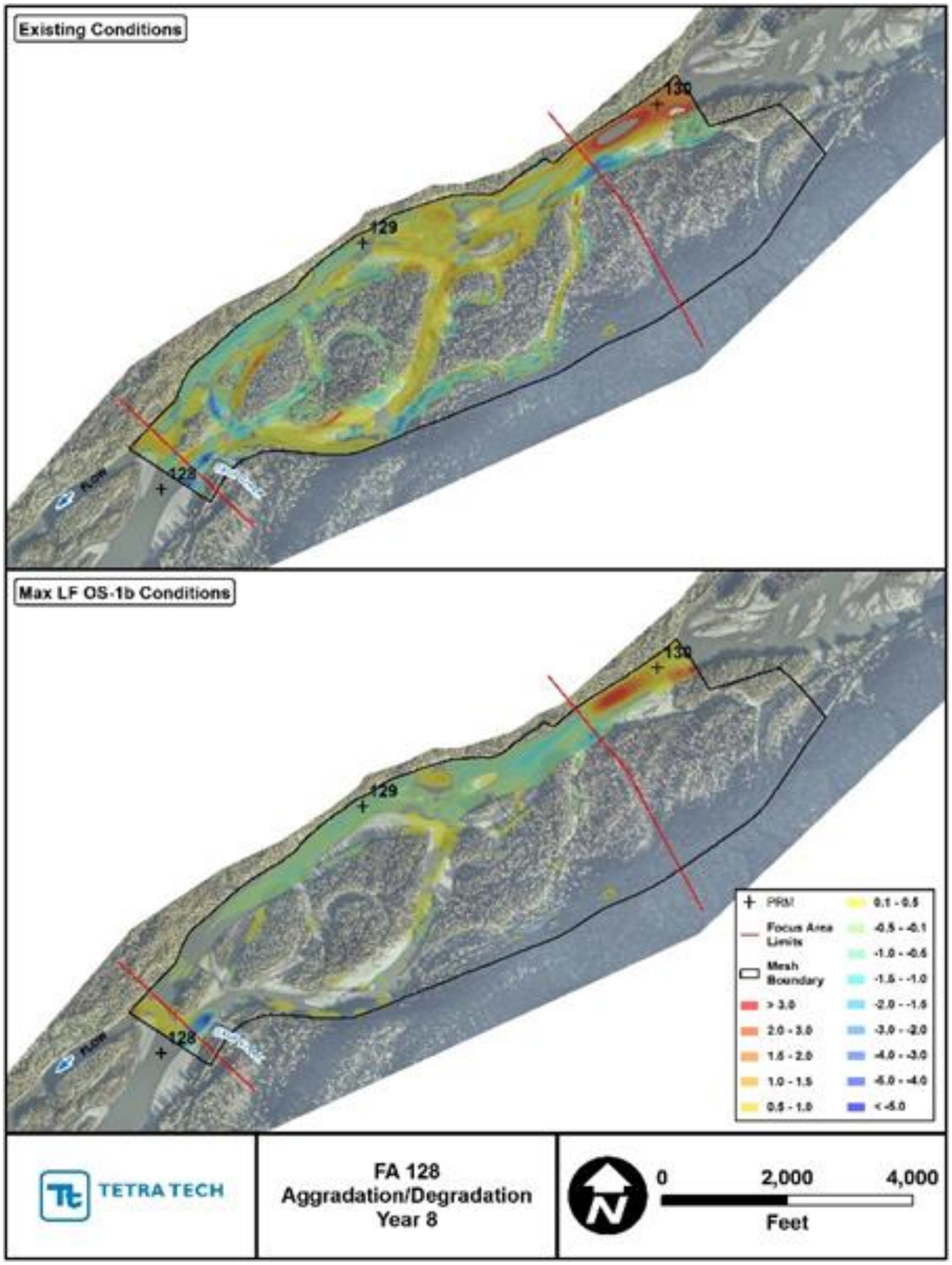


Figure 5.2-1. Change in bed elevation at the end of Year 8 under Existing and Max LF OS-1b conditions.

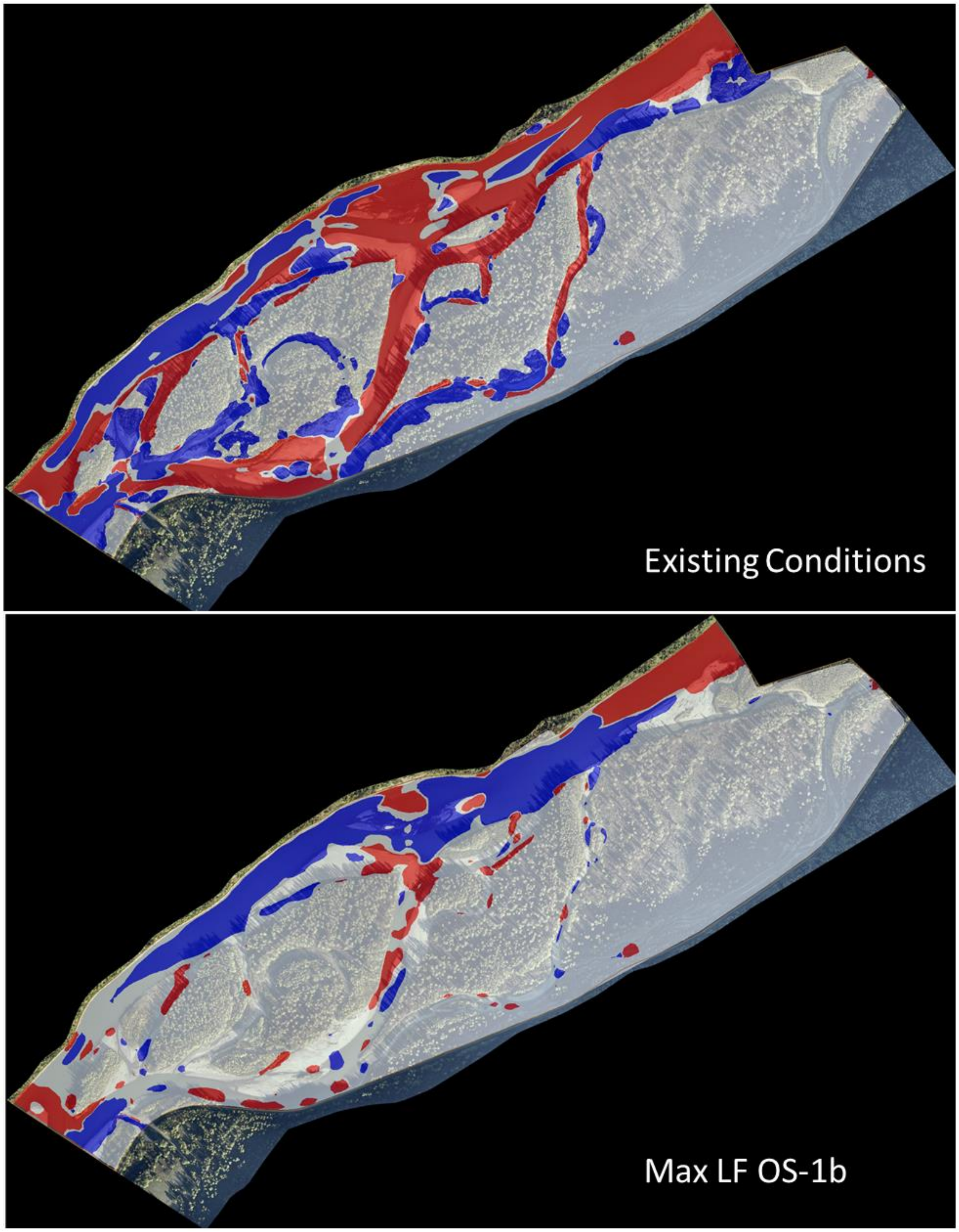


Figure 5.2-2. Screen capture showing the areas of channel degradation (red) and aggradation (blue) at the end of the Existing conditions 8 year simulation.

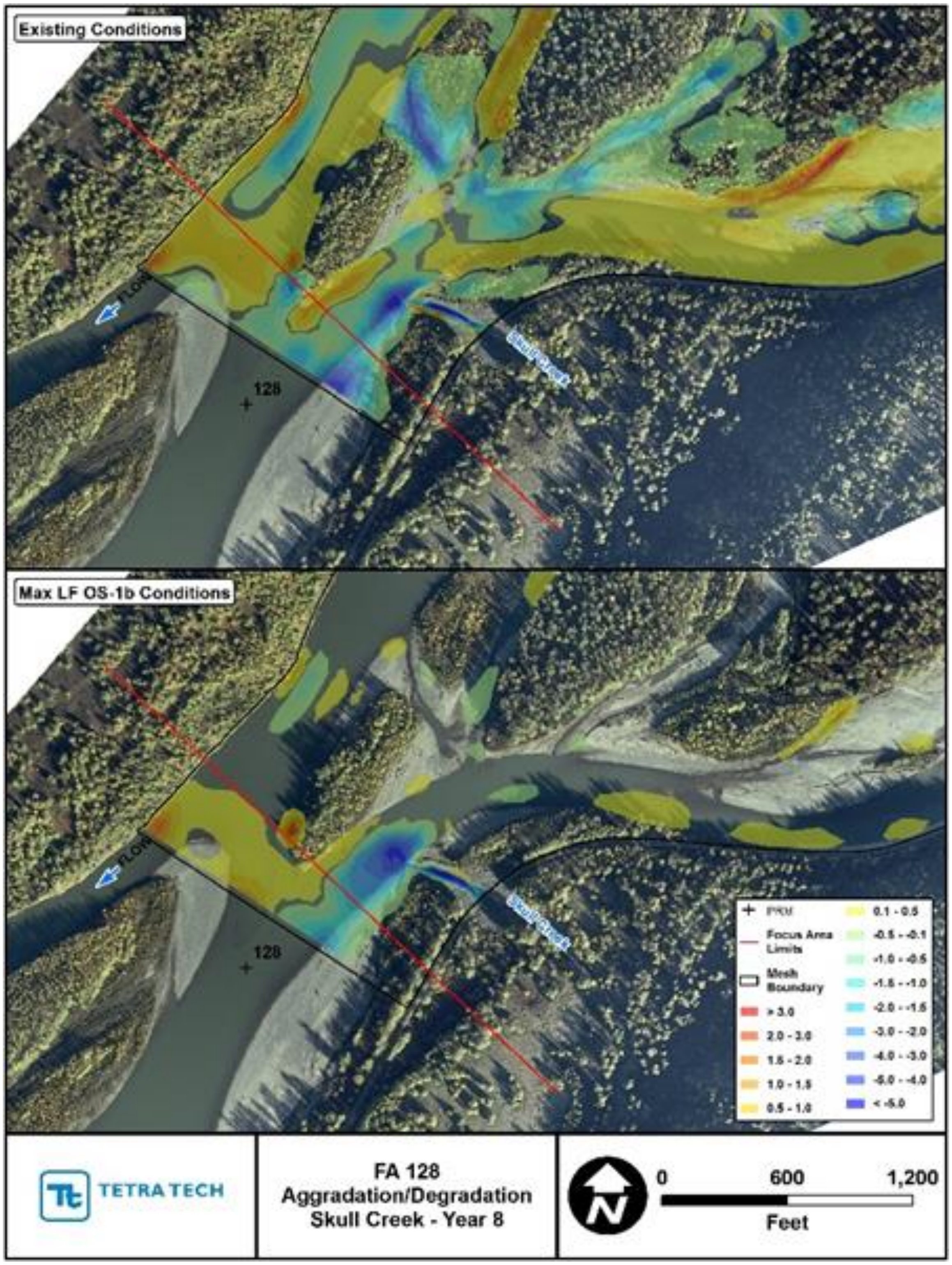
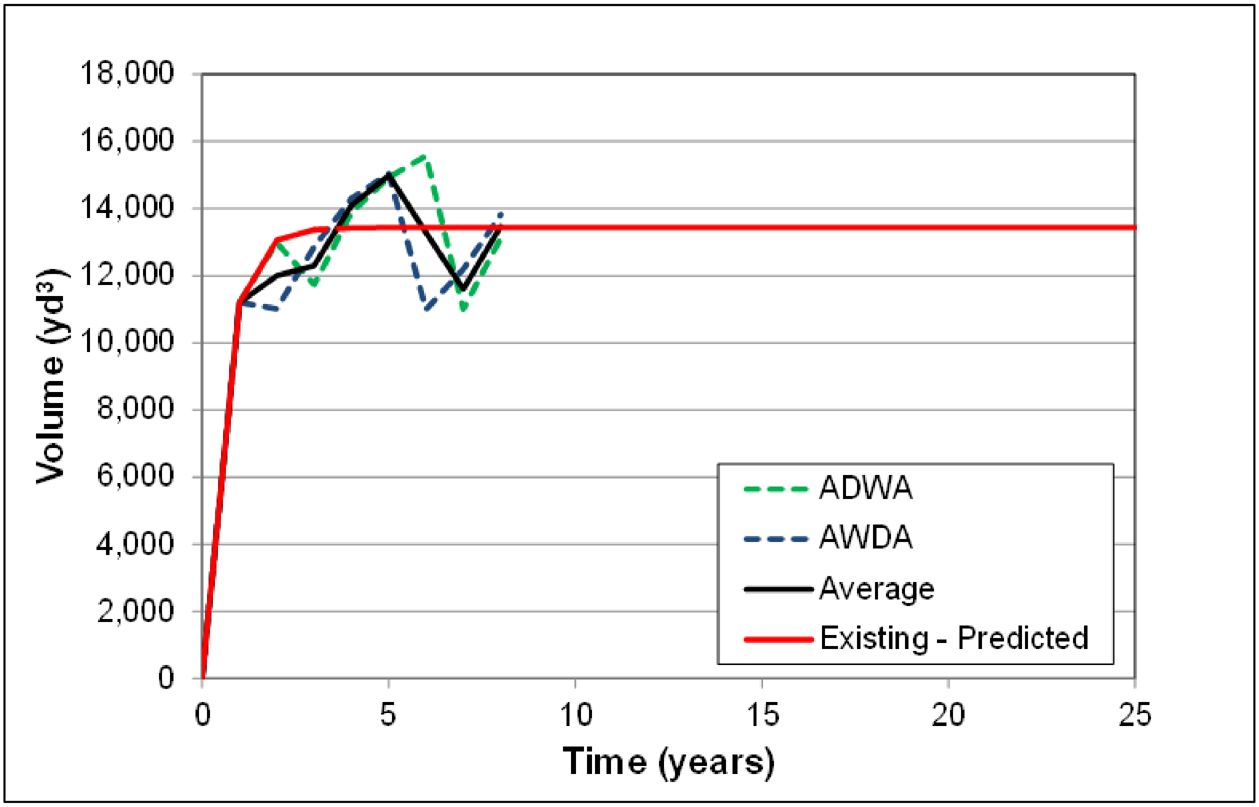


Figure 5.2-3. Change in bed elevation in the vicinity of Skull Creek Existing and Max LF OS-1b conditions at the end of Year 8 under existing conditions.



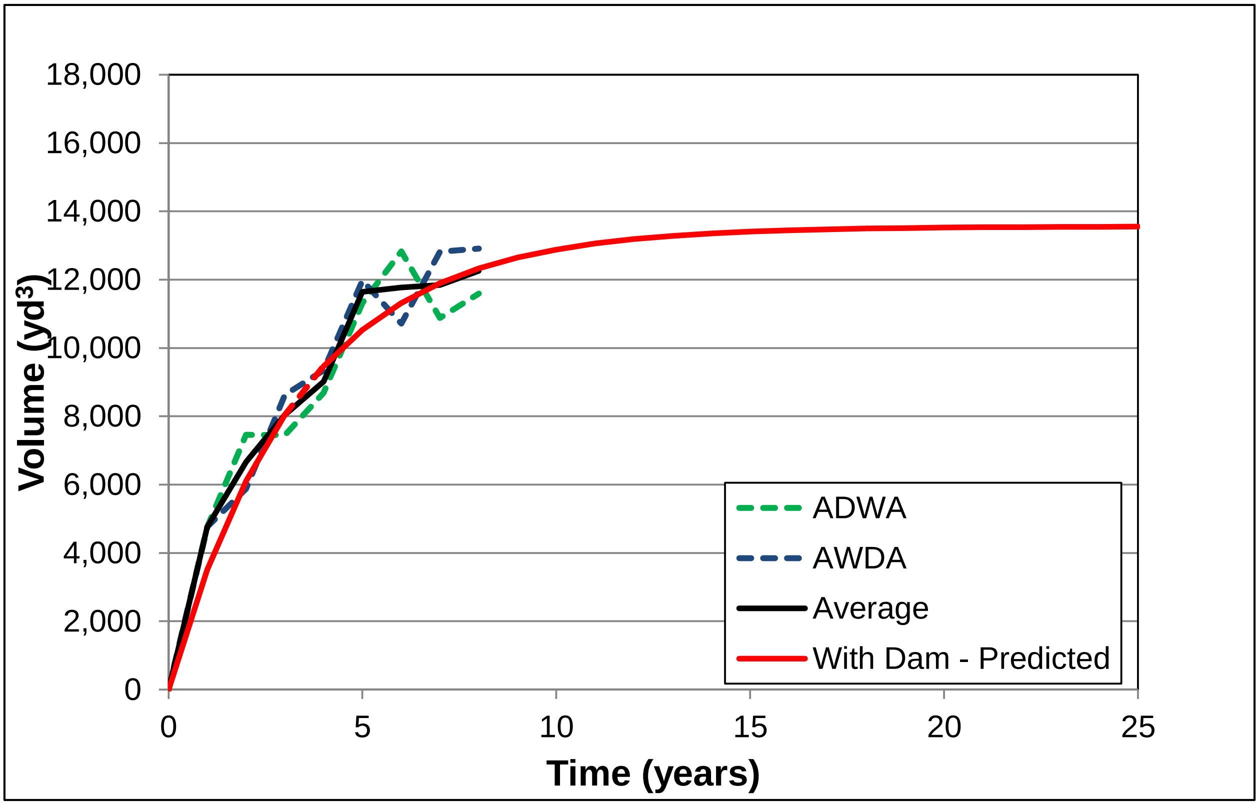


Figure 5.2-4. Comparison of change in volume over 8 years for different sequences of Average, Wet, and Dry years and the predicted volume for Existing and Max LF OS-1b conditions.

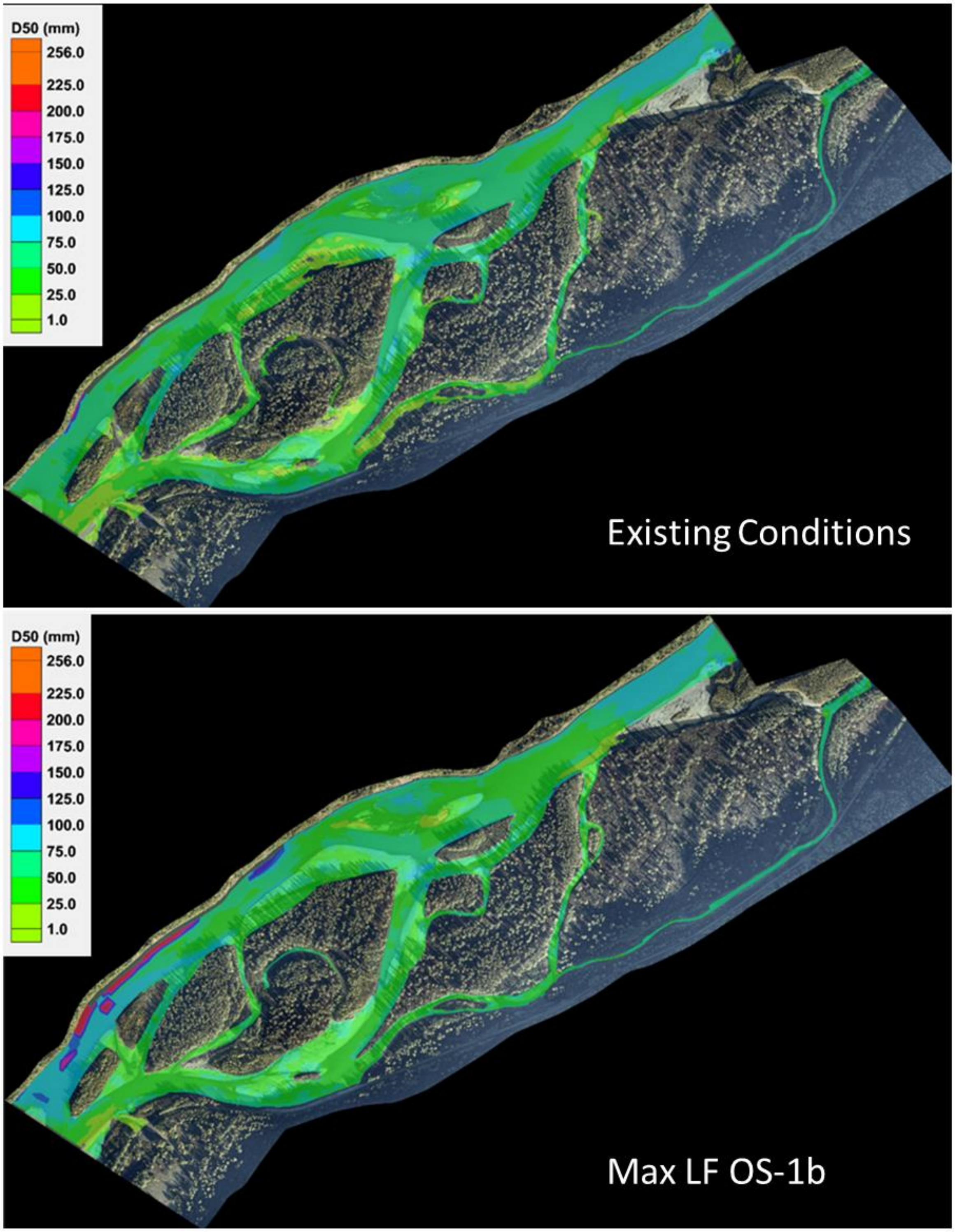


Figure 5.2-5. Screen capture from SMS showing the distribution of the median bed material size for the Existing conditions simulation at the end of Year-8.

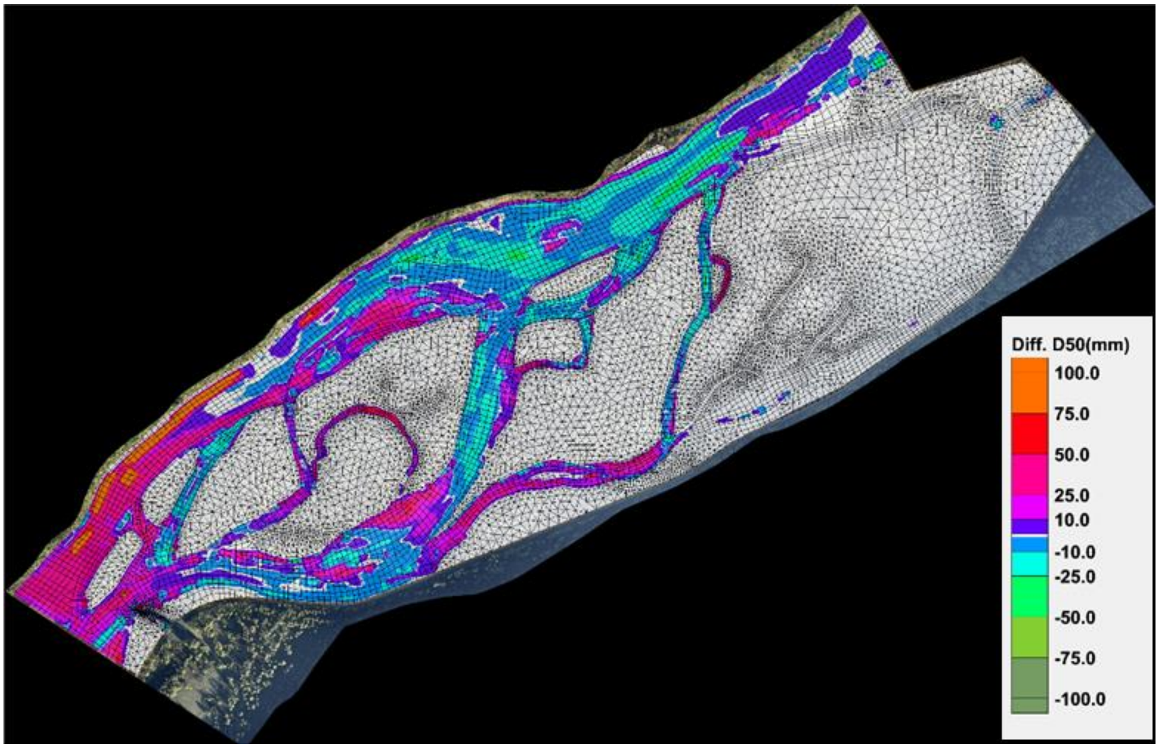


Figure 5.2-6. Screen capture showing difference (Max LF OS-1b minus Existing conditions) in median bed material size (D_{50} mm) at the end of 8 year simulation.

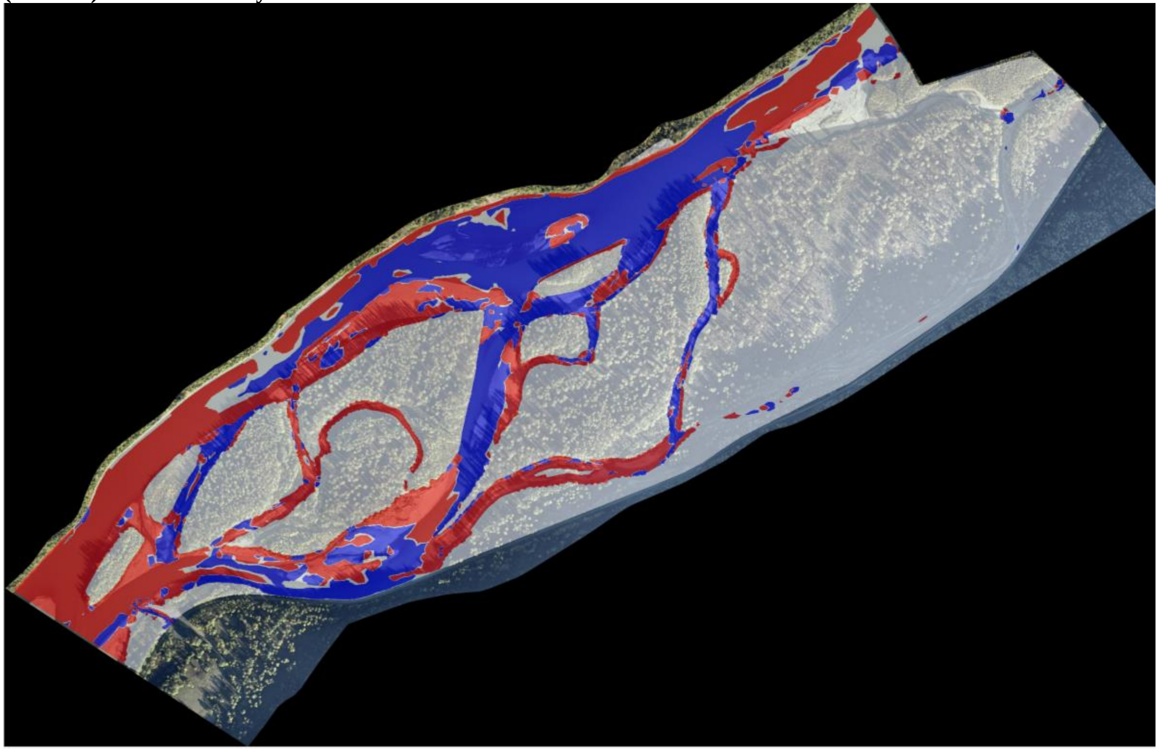


Figure 5.2-7. Screen capture from SMS showing the difference (Max LF OS-1b minus Existing conditions) in median bed material size at the end of the 8 year simulation. The red colors indicate the bed material is coarser under Max LF OS-1b compared to existing conditions, and the blue colors indicate the bed material is finer under Max LF OS-1b compared to existing conditions.

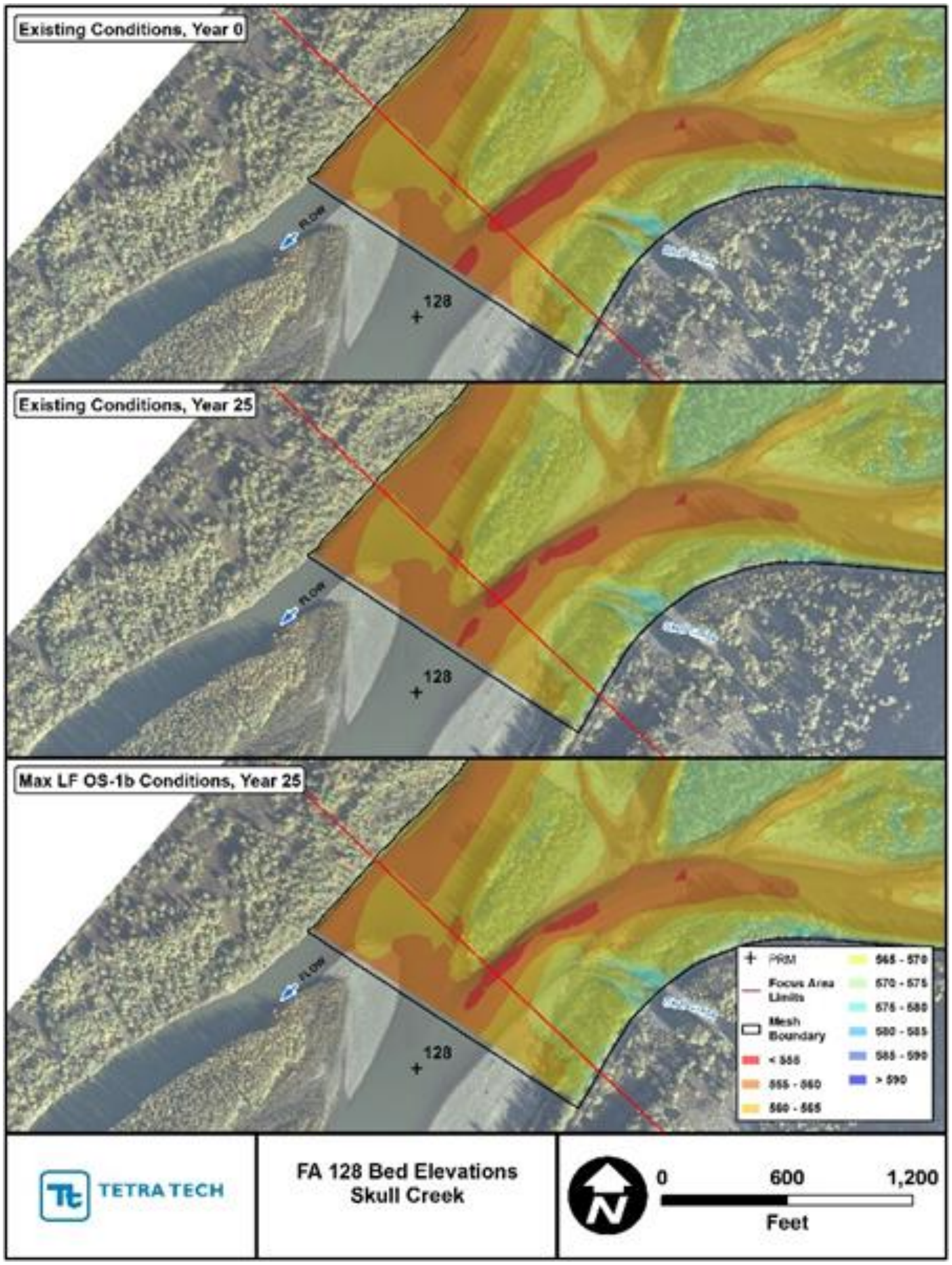


Figure 5.2-8. Bed elevations in the vicinity of Skull Creek at Year 25 under Existing and Max LF OS-1b conditions.

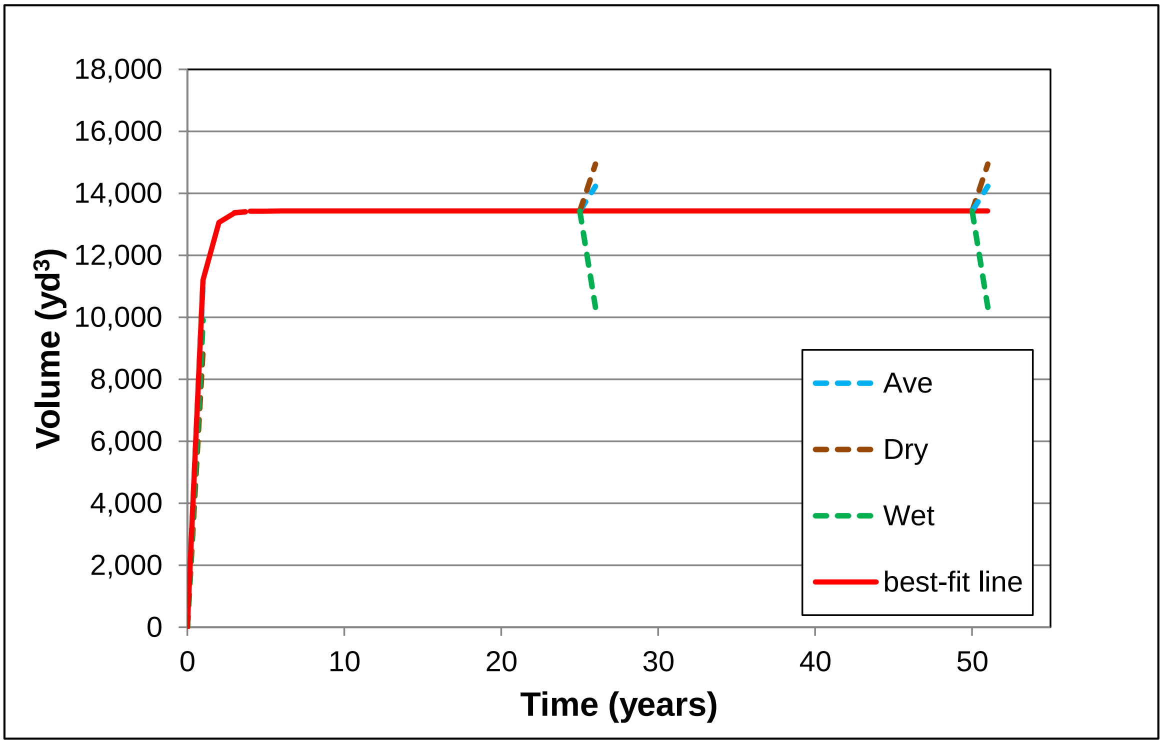


Figure 5.2-9. Comparison of change in volume under Existing conditions at Year-25 and Year-50 over the dry, average and wet year hydrographs.

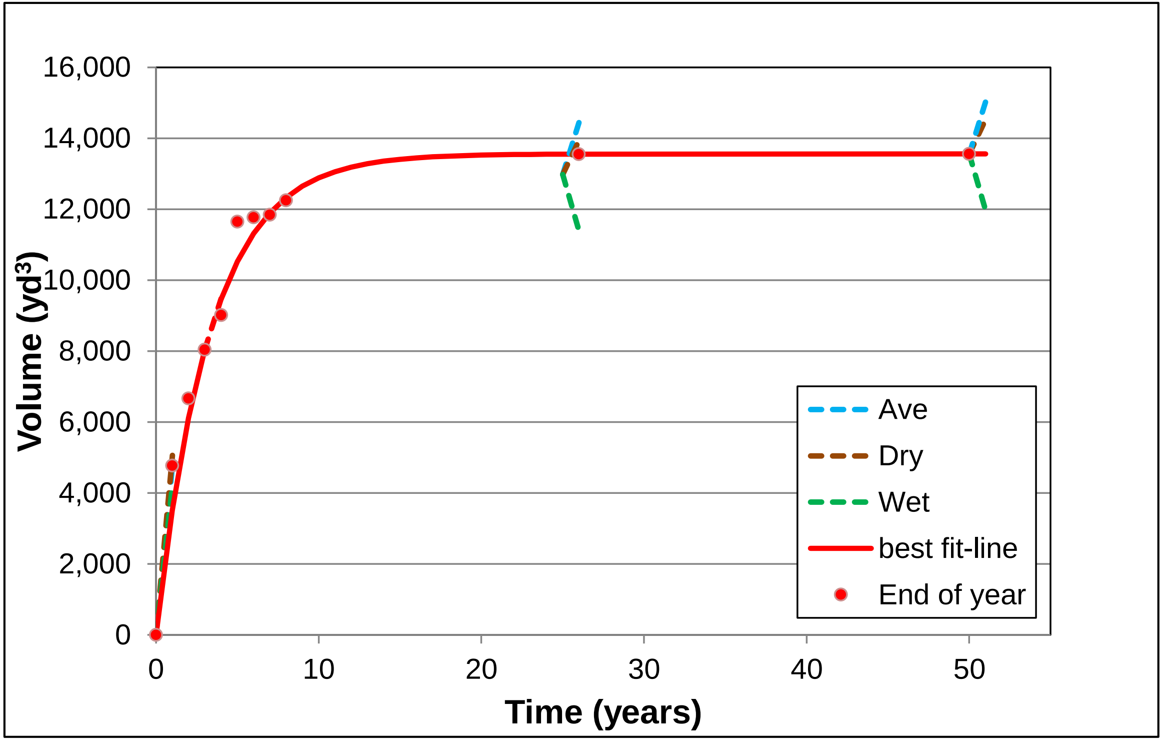


Figure 5.2-10. Comparison of change in volume under Max LF OS-1b existing conditions at Year-25 and Year-50 over the dry, average and wet year hydrographs.

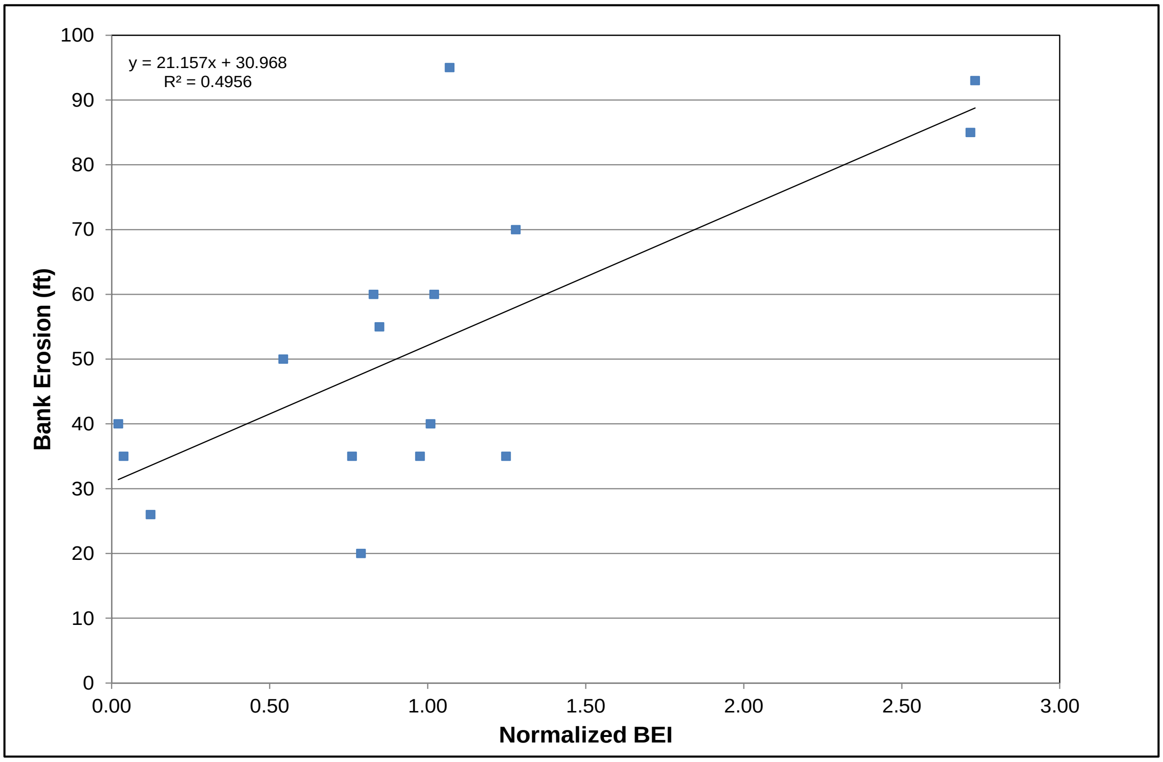


Figure 5.2-11. Comparison between the normalized Bank Energy Index (BEI) values for existing conditions and bank erosion for the period from the 1983 to 2012.

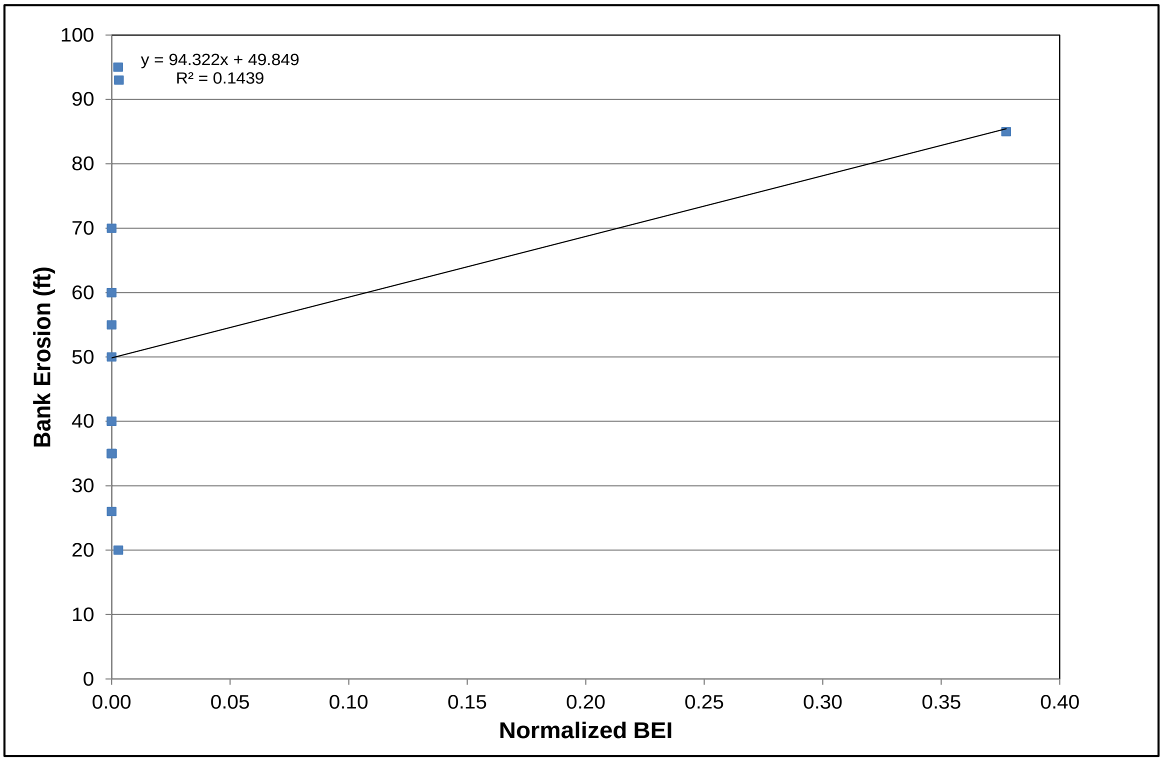


Figure 5.2-12. Comparison of the normalized Bank Energy Index (BEI) values applied with an incipient motion criteria and the amount of bank erosion for the period from the 1983 to 2012.

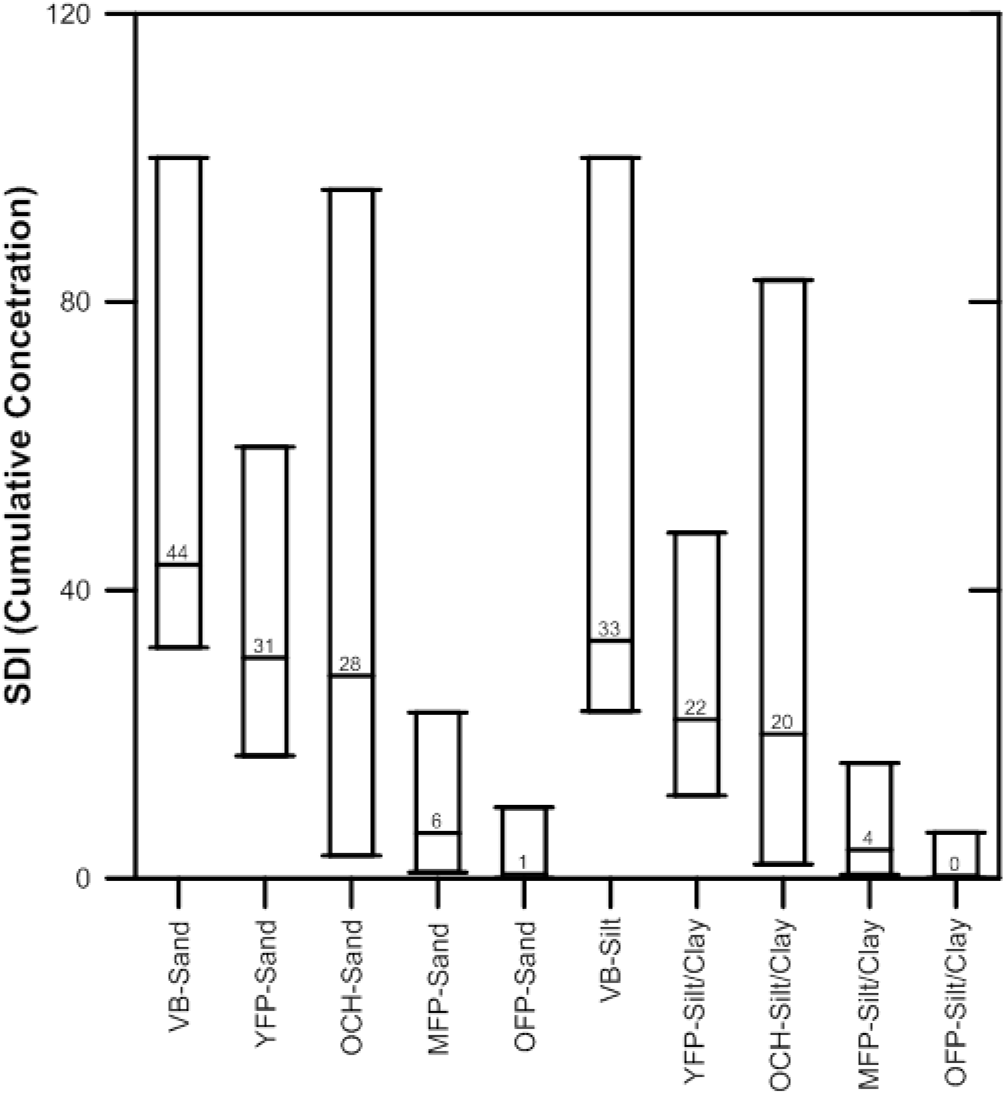


Figure 5.2-13. Box plot of the average annual SDI values for the existing Conditions for the sand and silt/clay sized material. The reported value represents the median value and the upper and lower limits of the boxes represent the 10t^{h} and 90th percentile.

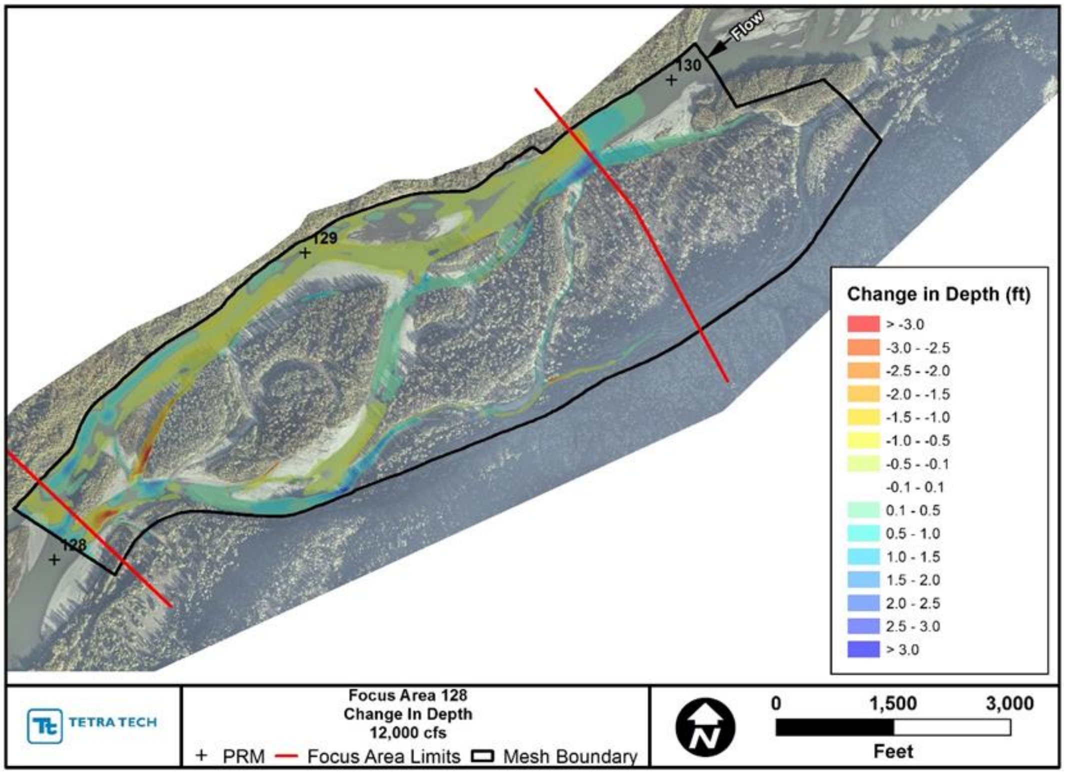


Figure 5.2-14. Change in flow depth between the Year-25 Max LF OS-1b and Existing Conditions models at 12,000 cfs.

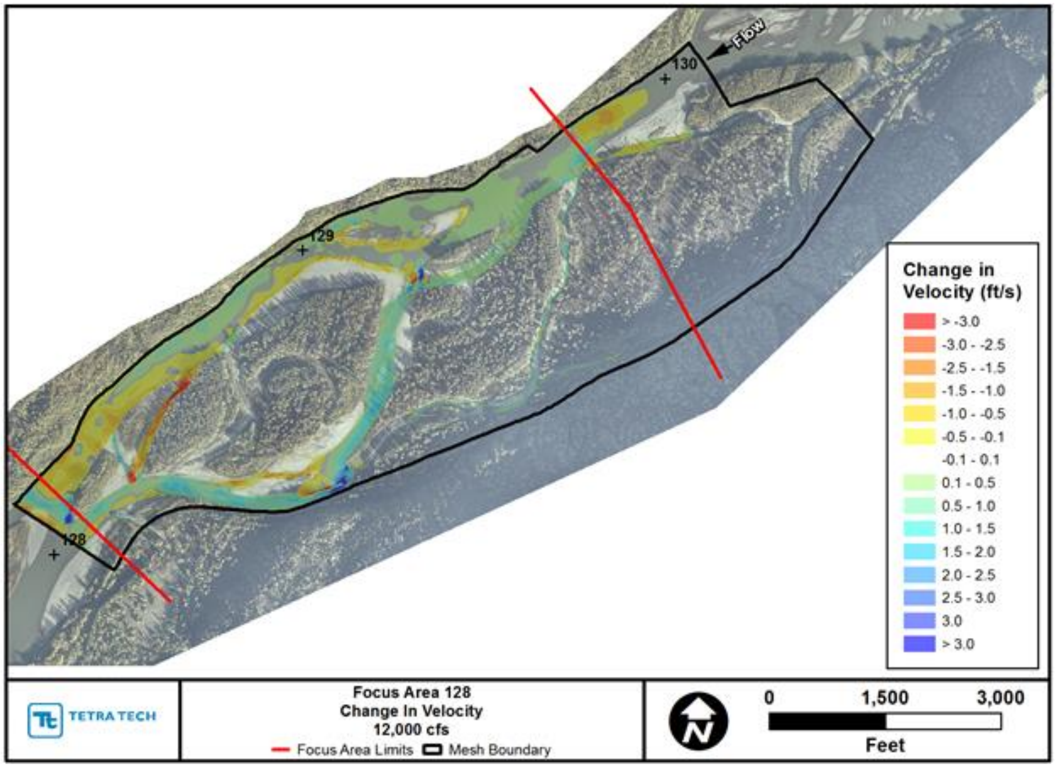


Figure 5.2-15. Change in velocity between the Year-25 Max LF OS-1b and Existing Conditions models at 12,000 cfs.

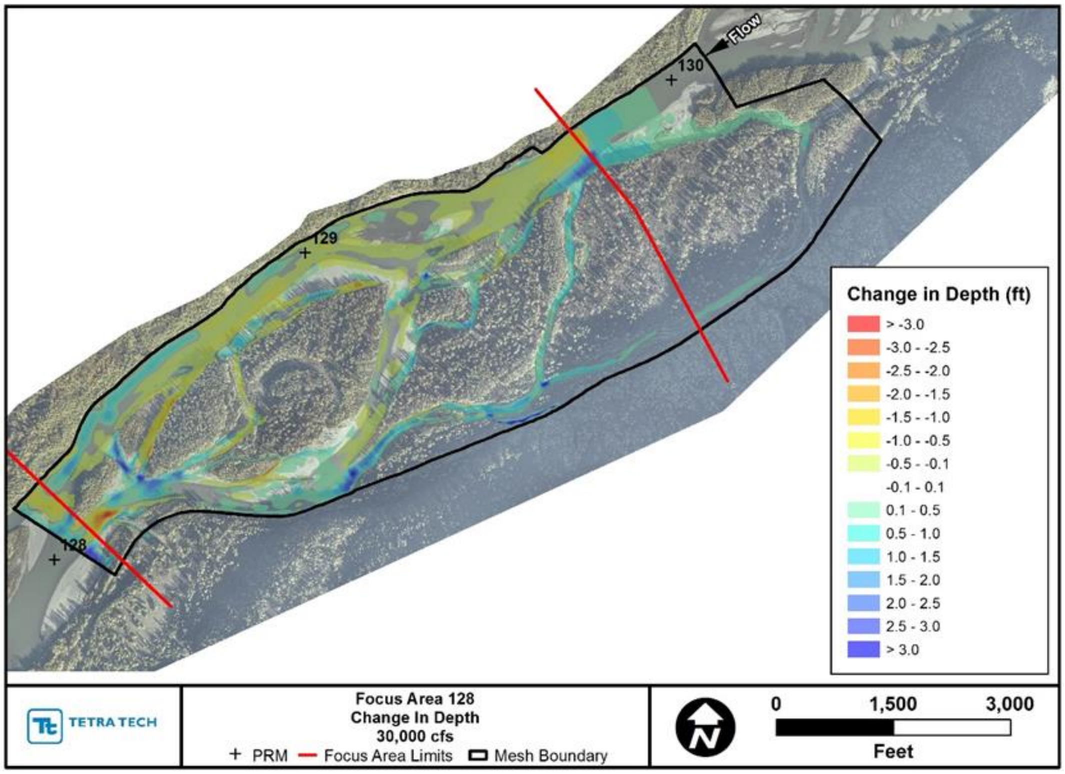


Figure 5.2-16. Change in depth between the Year-25 Max LF OS-1b and Existing Conditions models at 30,000 cfs.

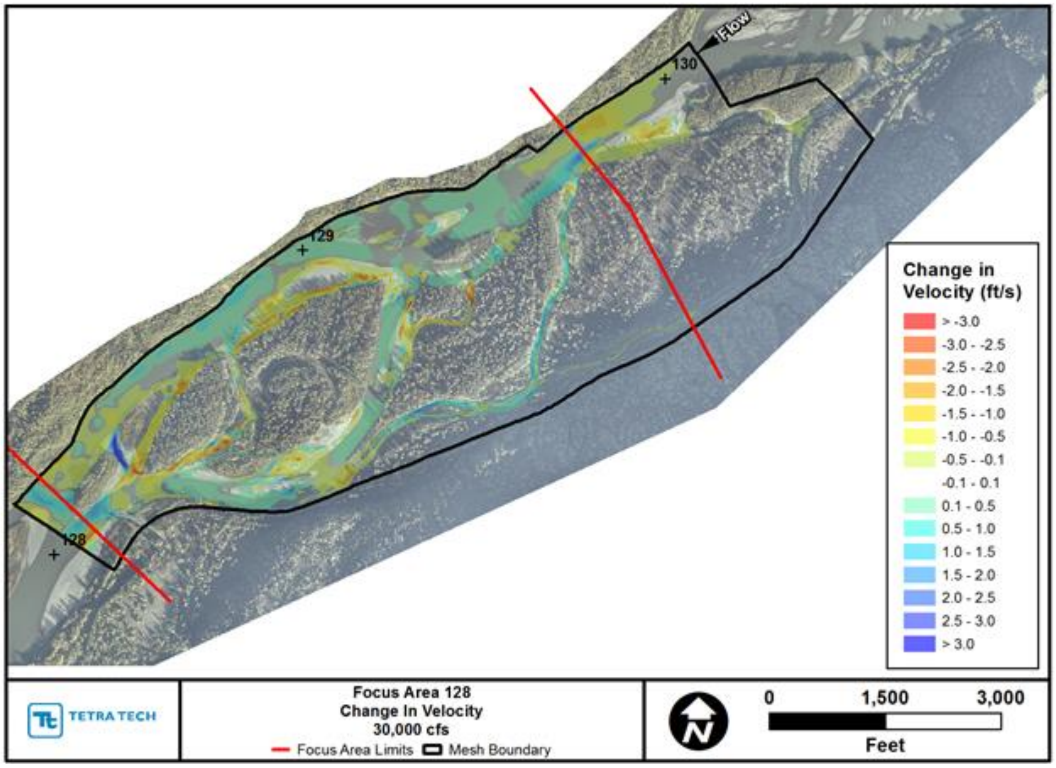


Figure 5.2-17. Change in velocity between the Year-25 Max LF OS-1b and Existing Conditions models at 30,000 cfs.