Appendix D

Hydrological Information

Geosyntec Consultants, Inc., Stantec Consulting Services Inc., and Watercourse Engineering Inc.

Presentation: Mono Basin Tributaries Special Studies – Stream Flow and Operations Plan Recommendations

May 2018

Geosyntec Consultants

Mono Basin Channel Bed Degradation Estimates Technical Memorandum

May 2019

Mono Basin Tributaries Special Studies

DECEMBER 14, 2018

Stantec

Watercourse Engineering Inc.

Geosyntec consultants

engineers | scientists | innovators


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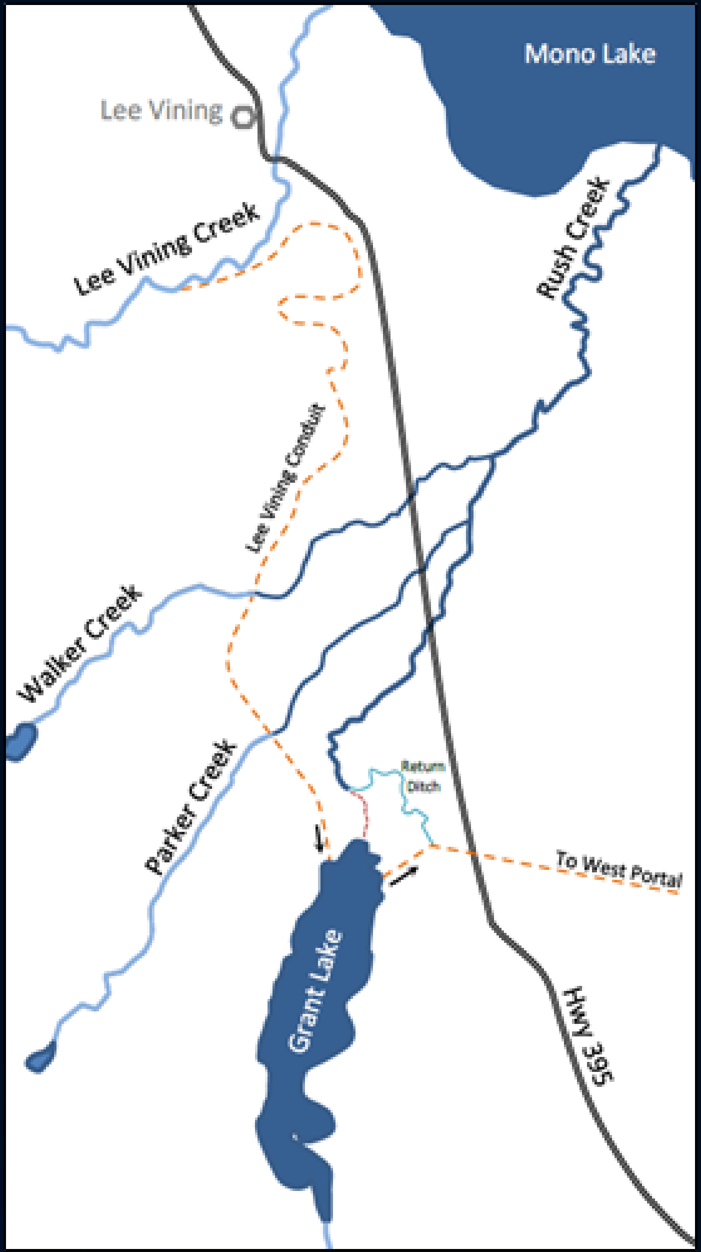
Presentation Outline

1. Introduction
2. Field Studies and Technical Analyses
3. Discussion



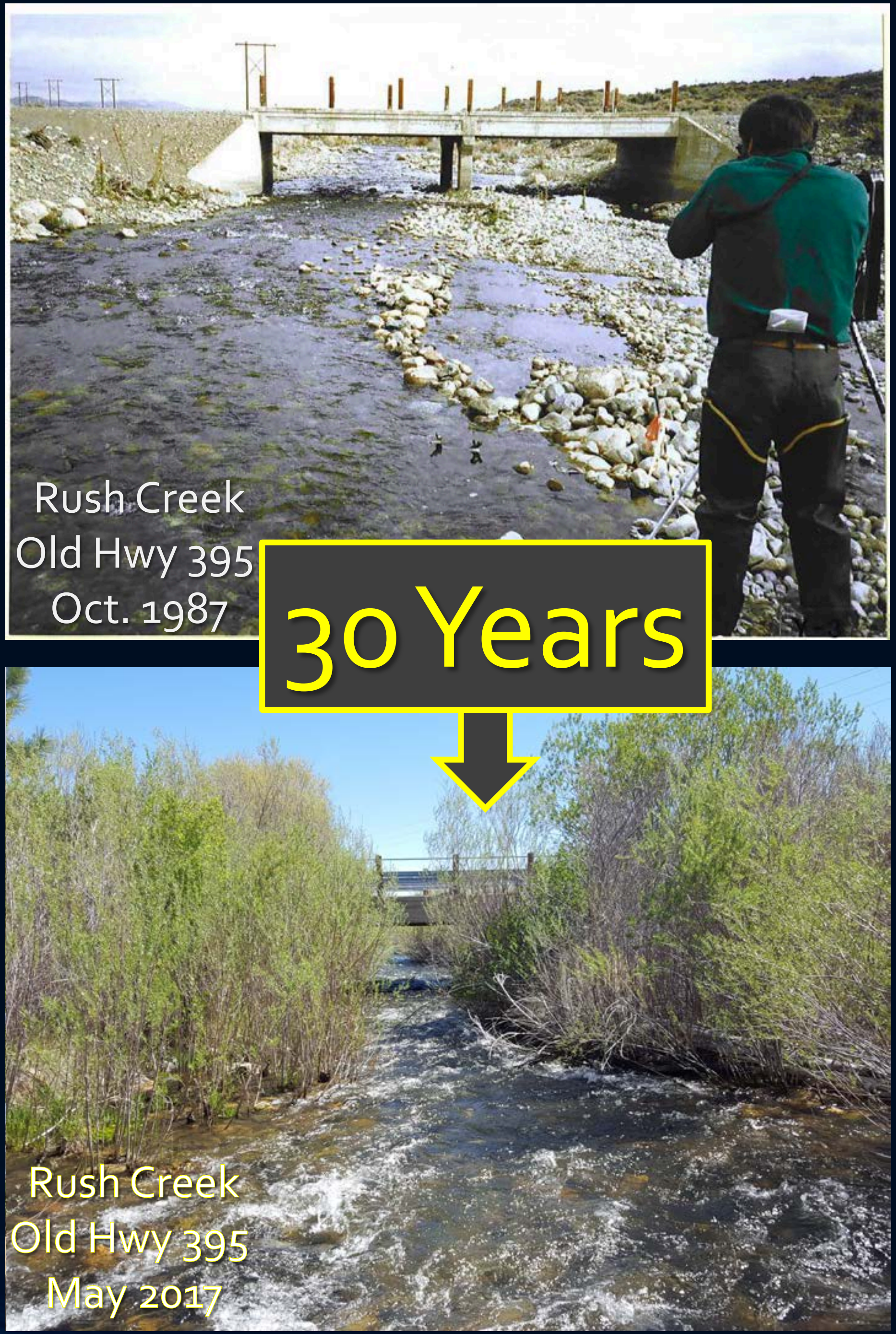
Current Status

Through implementation of State-Appointed Stream Scientist Recommended SRFs from D1631/Order 98-05:

- The Stream Restoration Program has been a <u>Success</u>
- Status of Restoration Compliance (SORC) is <u>Complete</u>
- Termination Criteria have effectively been achieved and restoration is on target

In 2010, the Stream Scientists Recommended a New Stream Flow Regime, the SEFs, to complete restoration.

- **CEQA required to implement a new flow regime**



Integrated field work & analyses performed to address the status of creek response to 20+ years of SRFs and to study unique 2017 hydrology to test SEFs

Analyses	Restoration Metrics		
	Riparian Vegetation	Fish Conditions	Channel Morphology
Hydrology	X	X	X
Operations	X	X	X
Hydraulics	X	X	X
Floodplain Connectivity	X	X	X
Sediment Transport	X	X	X
Geomorphology	X	X	X
Water Temperature		X	

Purpose of Special Studies

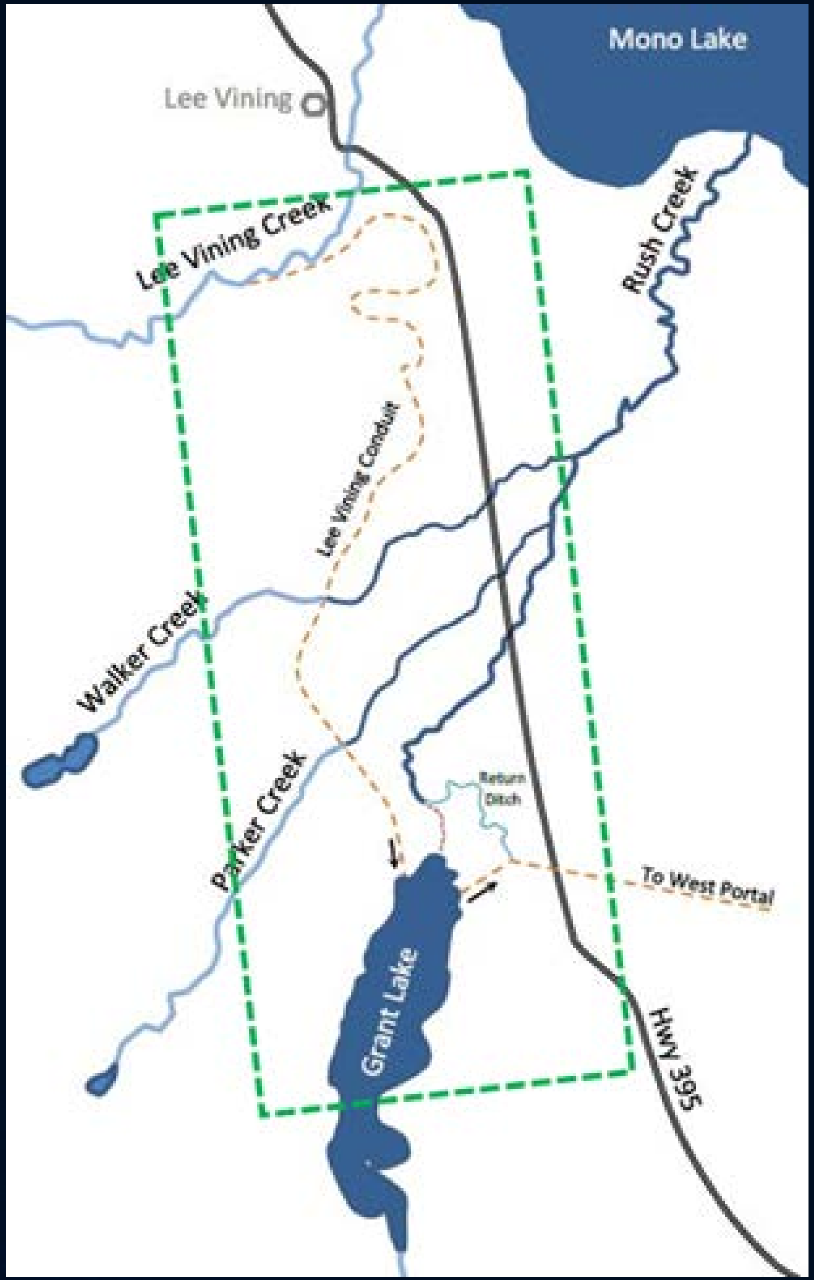
- Understand the baseline condition after 20+ years of SRFs
- Support analysis of potential effects of implementation of the Stream Ecosystem Flow (SEF) regime
- Unique opportunity to study current ecosystem response pre- to post-peak 2017 following historic drought from 2012-2016
- Quantify geomorphic change in the ecosystem related to the extremely wet year
- Fill some known data gaps
  - Stream temperature differences (SRF vs SEF operations)
  - Floodplain connectivity for all stream reaches
  - Geomorphic stability and sediment transport processes

Analyses

- Operational Considerations
  - (eSTREAM)
- Water Temperature
- Hydrology/Exports
- Hydraulics
- Floodplain Connectivity
- Sediment Transport
- Geomorphic Analyses – RY 2017/2018

Operations – *e*STREAM Scenarios

- Two *e*STREAM modeled flow scenarios:
  - Stream Restoration Flows (SRFs) [D1631/98-05]
  - Stream Ecosystem Flows (SEFs), with Spillway Modification [Synthesis Report, 2010]
- Model period and starting conditions
  - Simulation Period: April 1, 1990 to March 31, 2018
  - Mono Lake starting elevation: 6,376.0 ft
  - Grant Lake starting storage: 19,220 acre-feet (af)



Water Temperature – Simulation Modeling

- Flow and Temperature Models
  - Grant Lake Reservoir
  - Stream models (Lee Vining, Walker, Parker, and Rush Creeks)
  - Hourly flow/water temperature: June 1 to September 30 for representative dry, normal, and wet years
- Sub-Optimal Temperature Criteria
  - Temperature metrics:
    - Daily Maximum Temperature: 72 degrees F
    - Daily Average Temperature: 67 degrees F

<u>Results</u>

Lee Vining Creek: All scenarios, in all year types, did not exceed temperature criteria

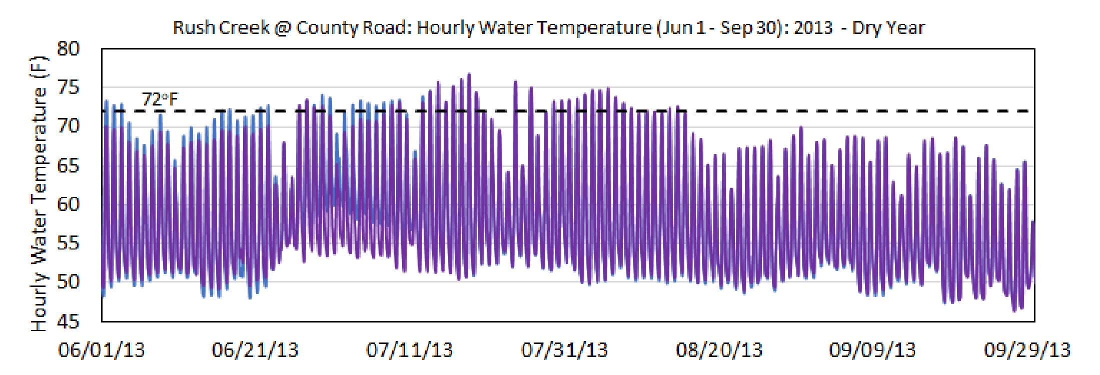
Rush Creek: All scenarios, in wet years, did not exceed criteria. In normal and dry years exceedances did occur for both existing (SRF) and proposed (SEF) flow regimes.

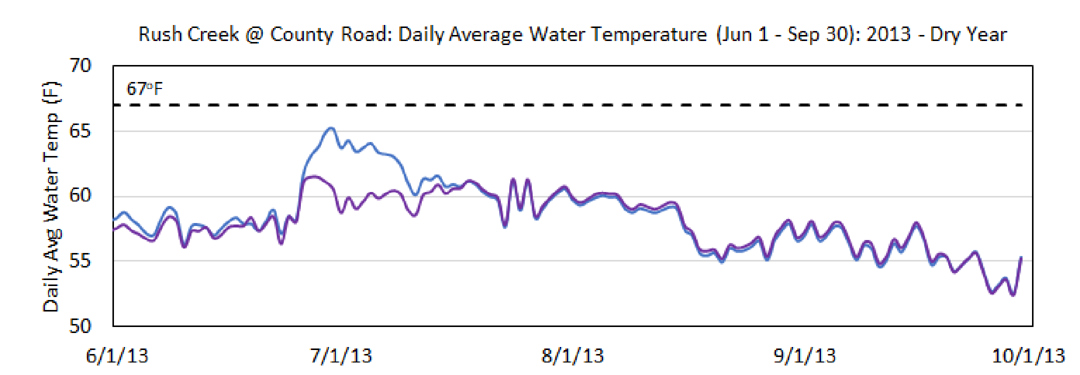
Analyses

Water Temperature – Lower Rush Creek

SRF

SEF





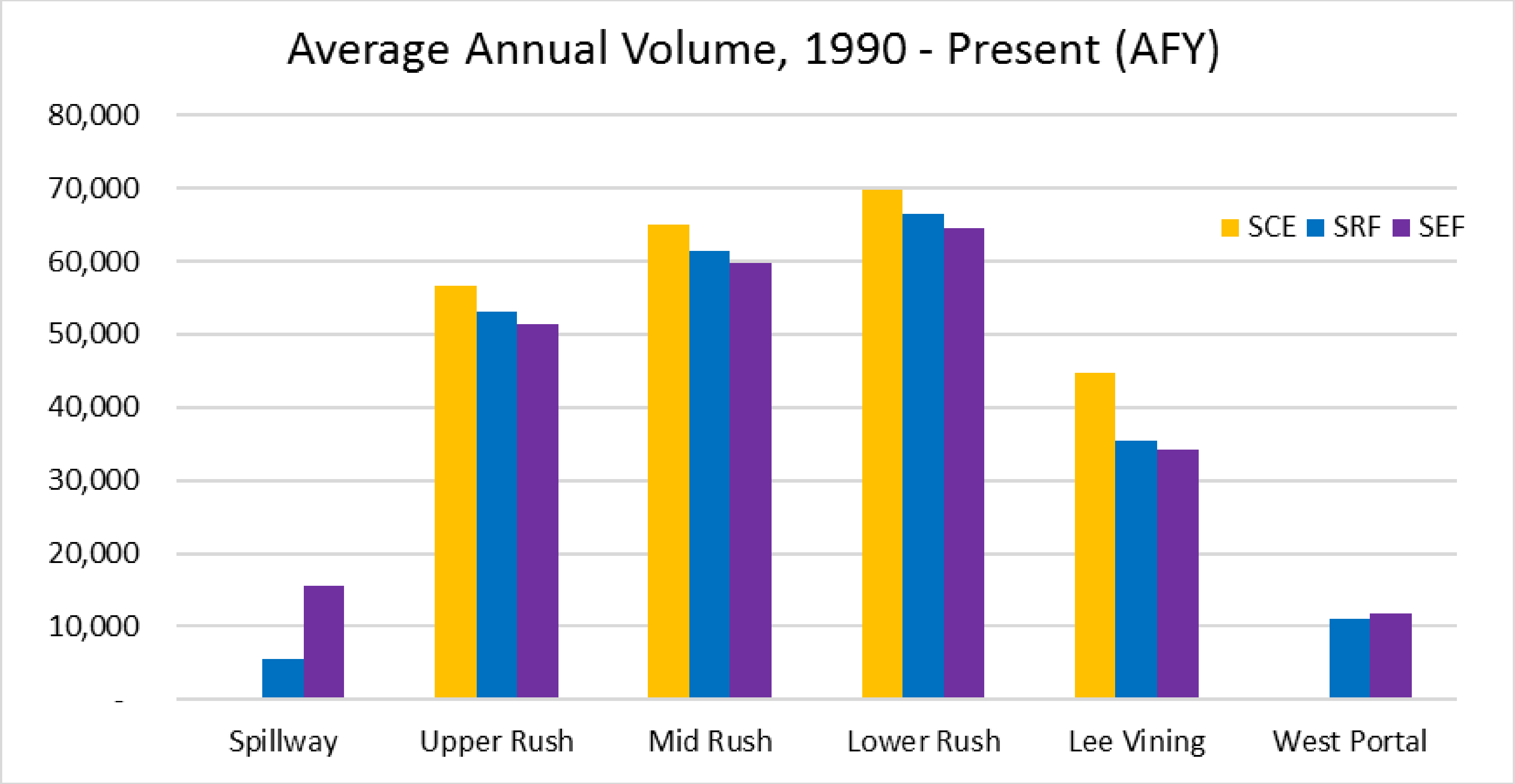
Days with Daily Maximum Greater than 72F	SRF			SEF		
	2013 (Dry)	2016 (Normal)	2011 (Wet)	2013 (Dry)	2016 (Normal)	2011 (Wet)
Rush Creek at County Road	41	30	0	31	29	0
Rush Creek Below Walker Creek	5	8	0	8	5	0
Rush Creek Above Parker Creek	0	10	0	0	4	0
Rush Creek Below Return Ditch	0	0	0	0	3	0

SEF and SRF flow regimes result in similar exceedances in maximum water temperatures metric (72°F).

SEF and SRF flow regimes do not exceed the average daily temperature metric (67°F).

Hydrology

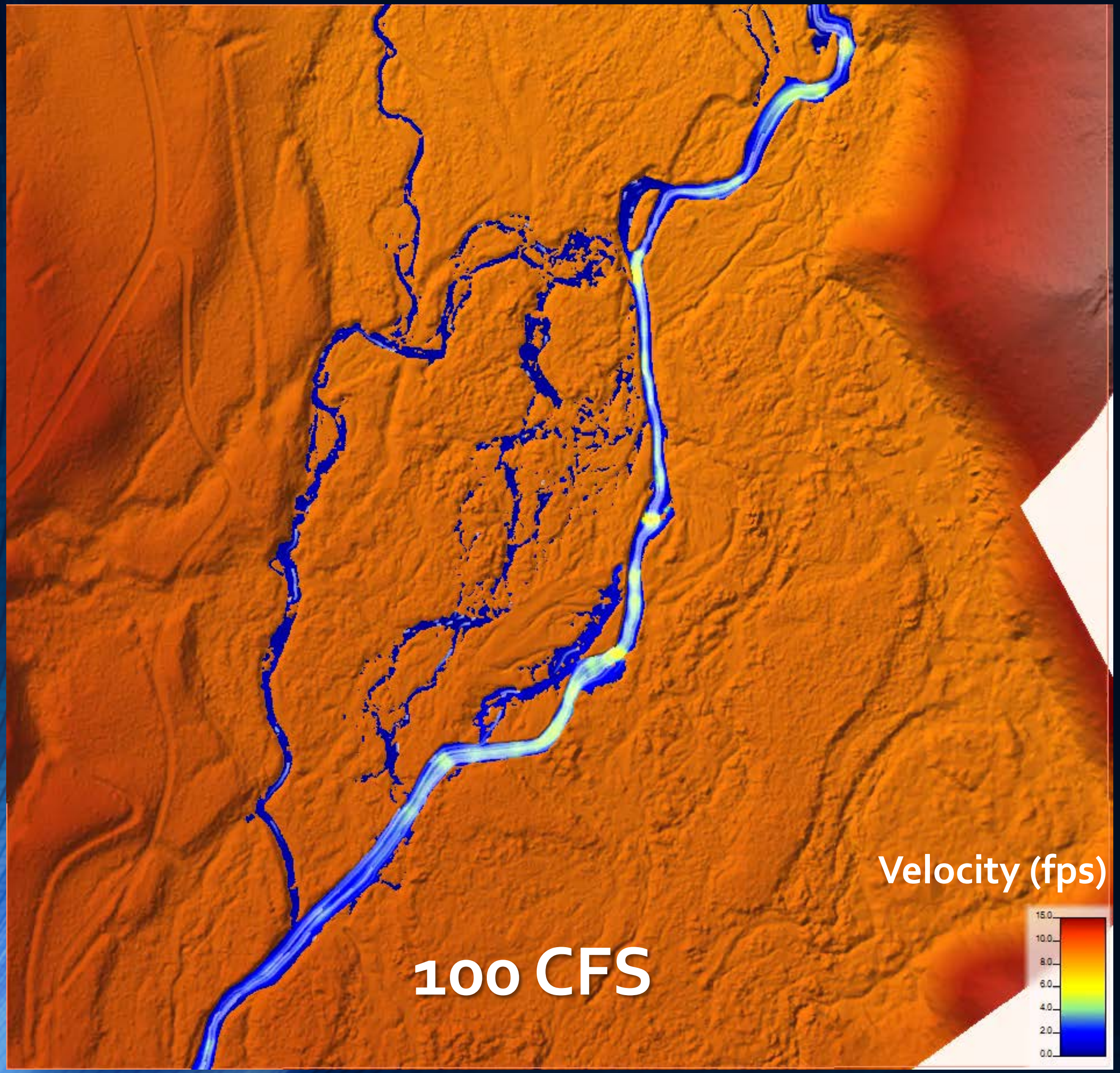
Pre-Transition

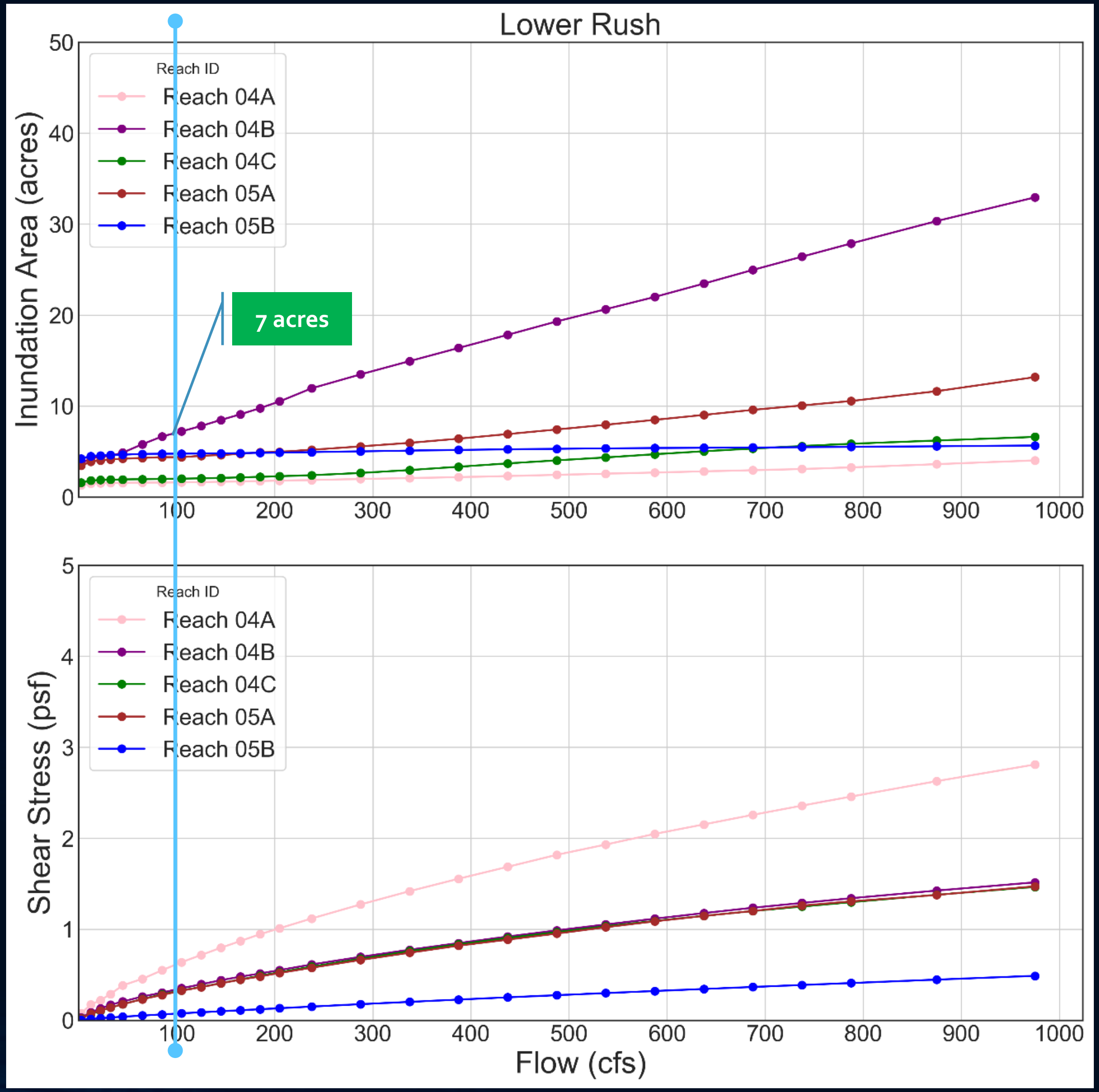


SCE data provided to illustrate water delivered to LADWP's facilities

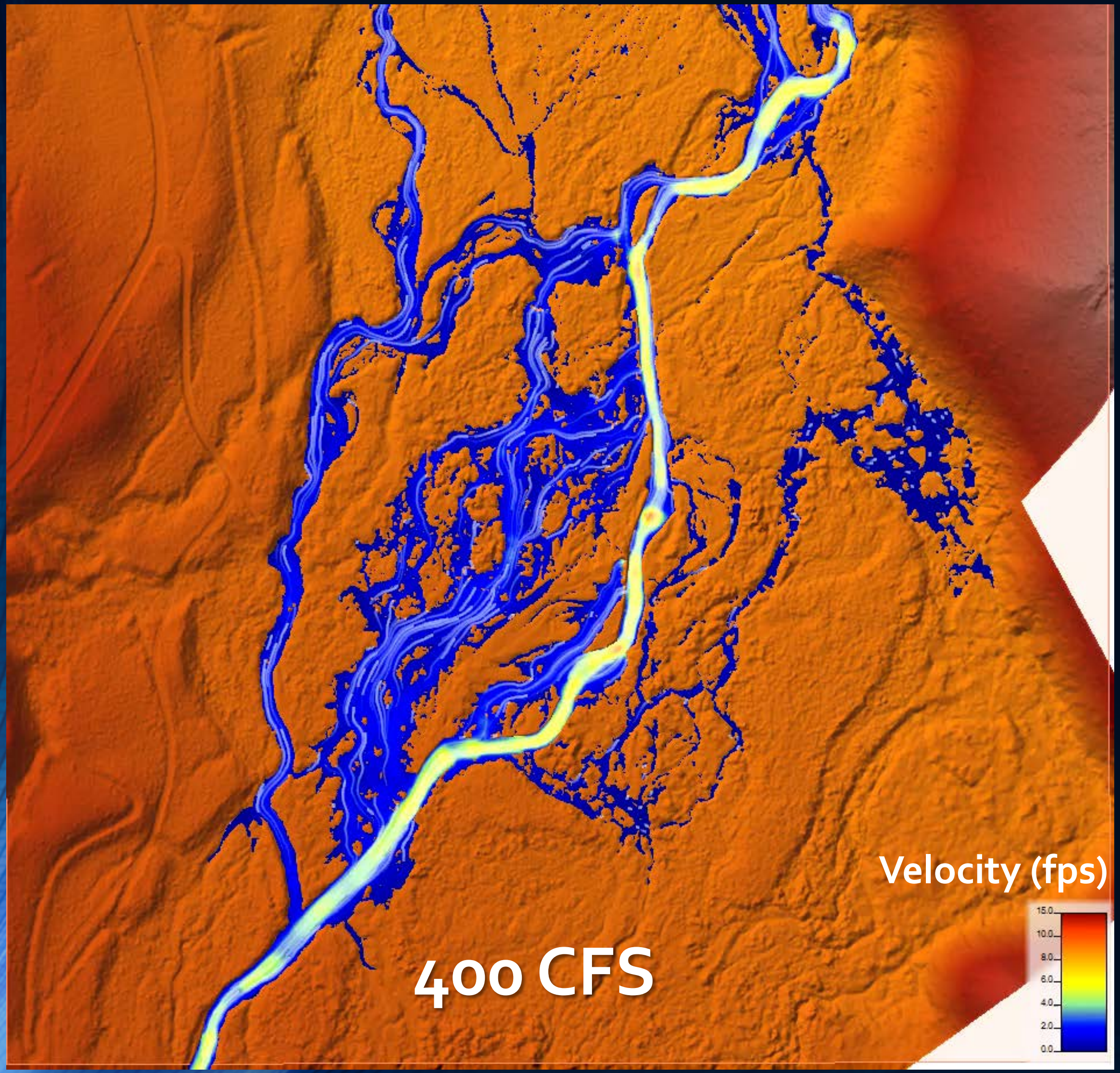
Limited differences between SRF and SEF scenarios; SEFs allow for slightly more export

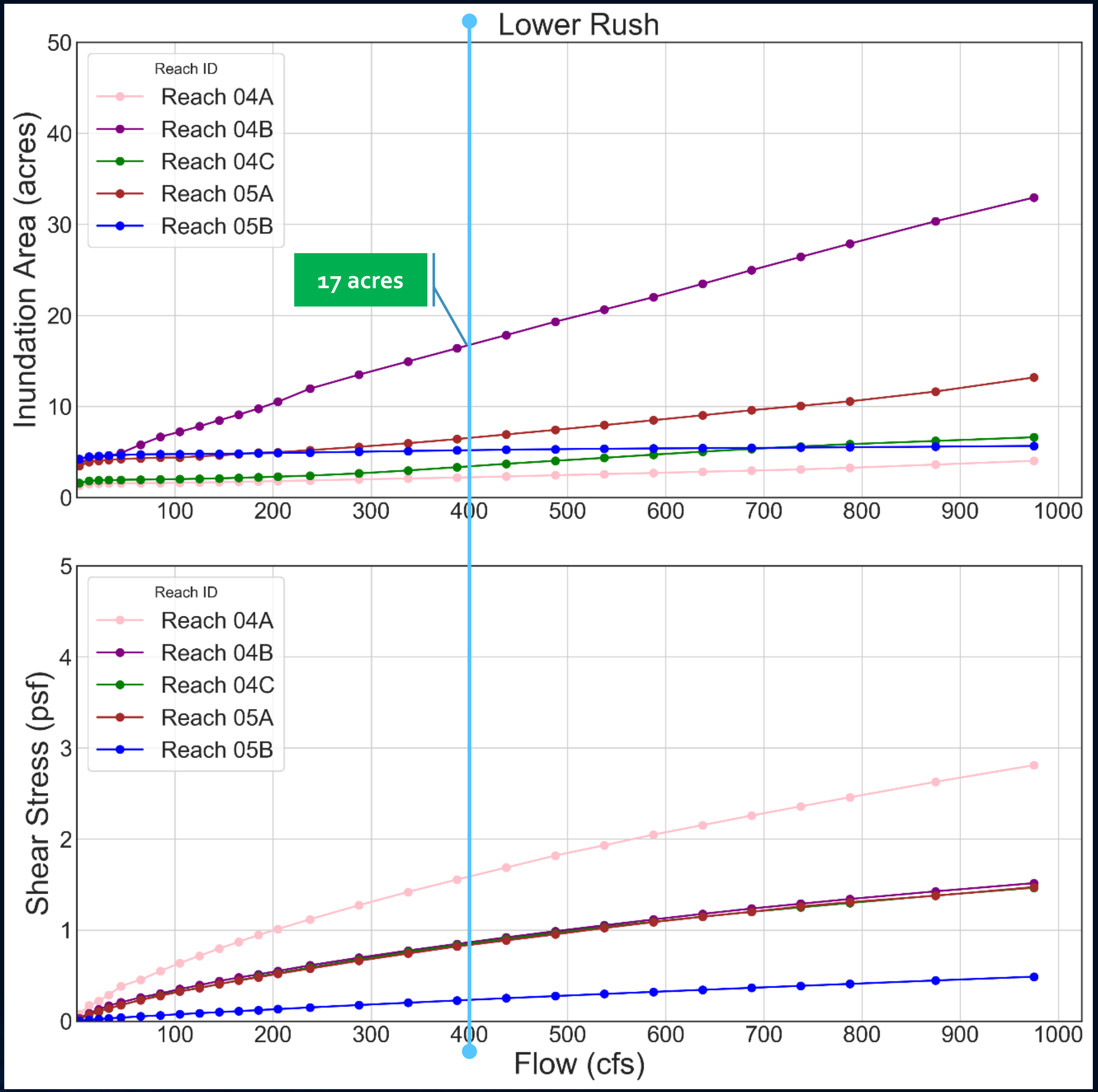
Hydraulics – Lower Rush Creek Example



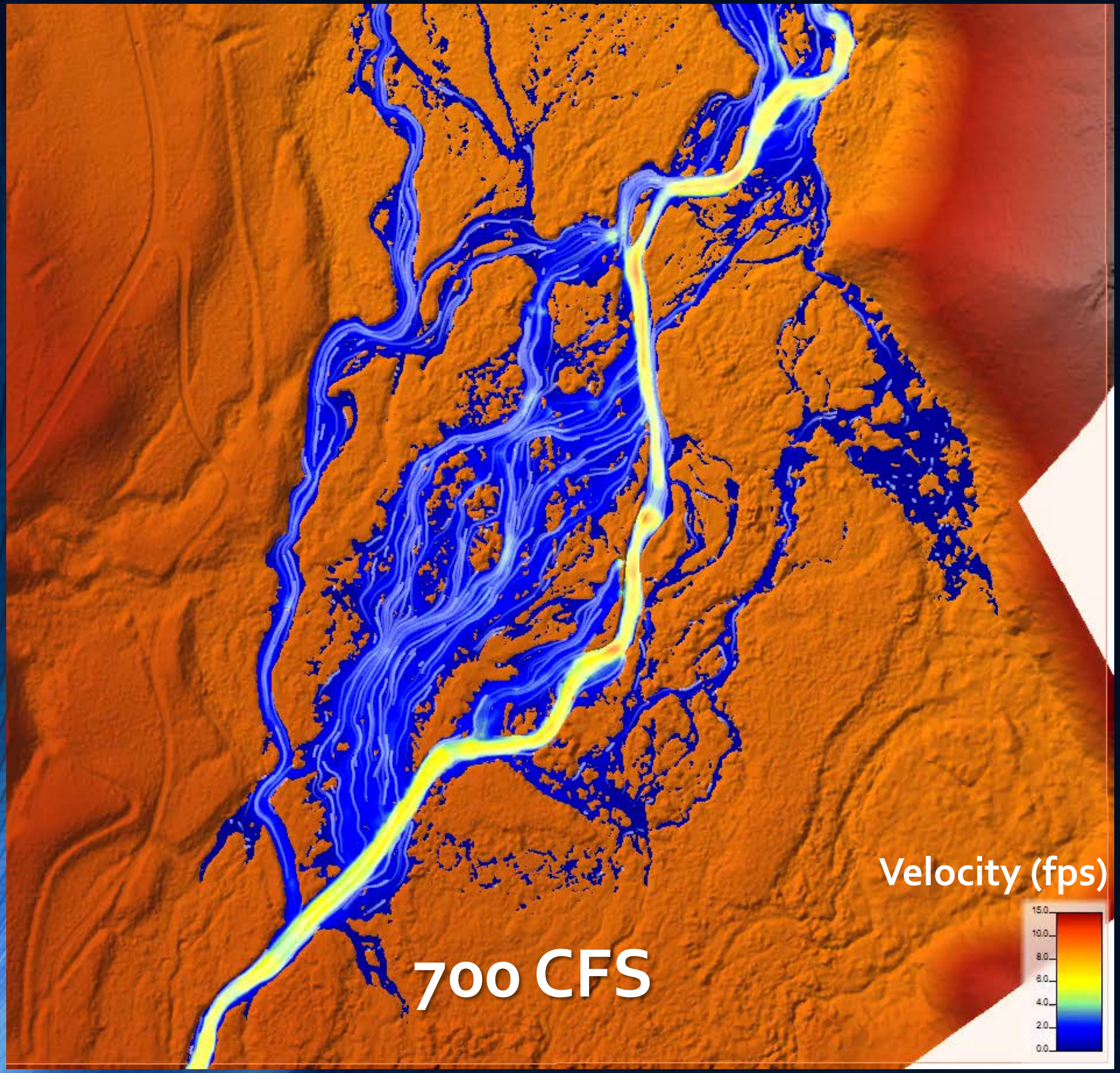


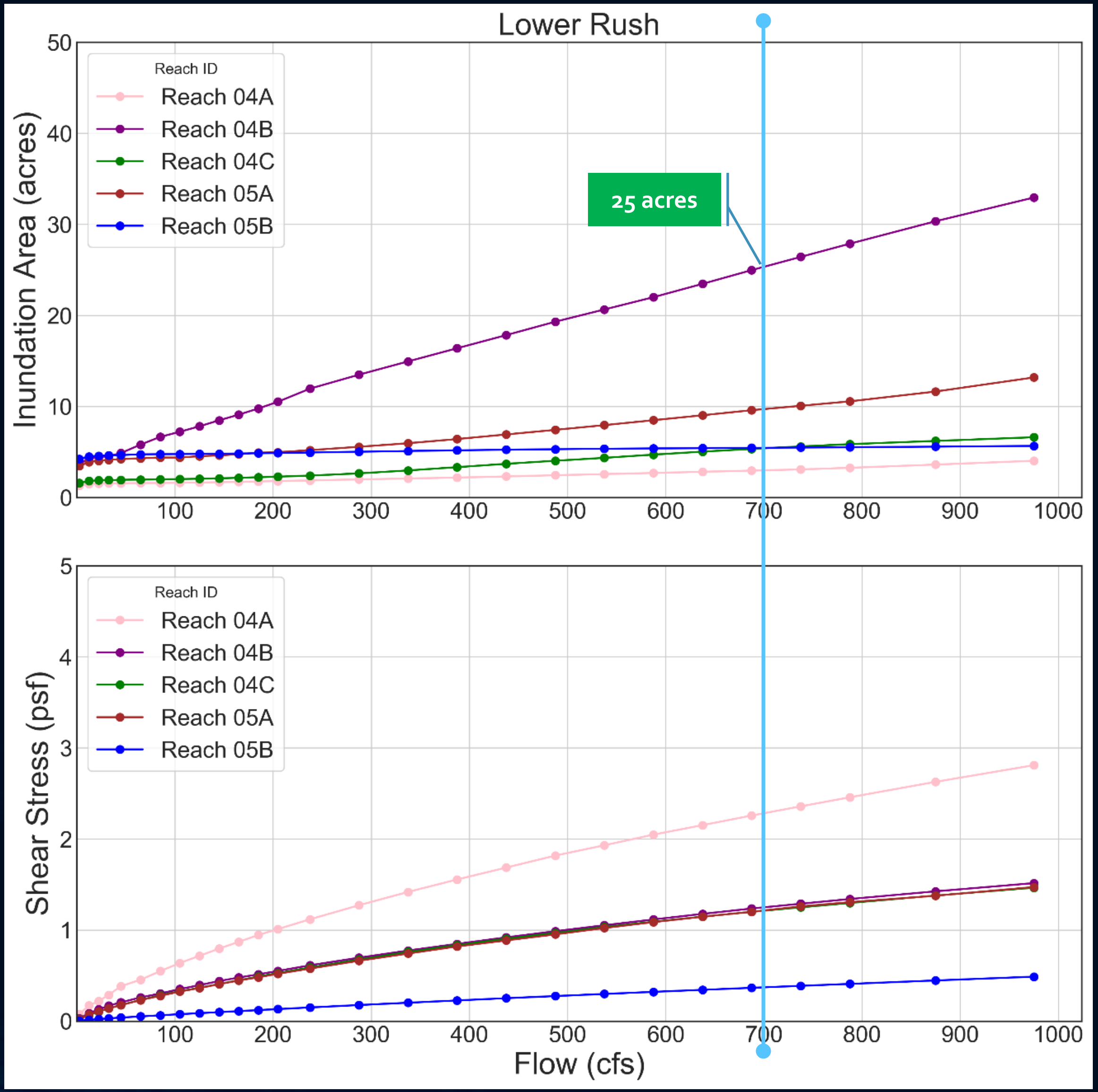
Hydraulics – Lower Rush Creek Example





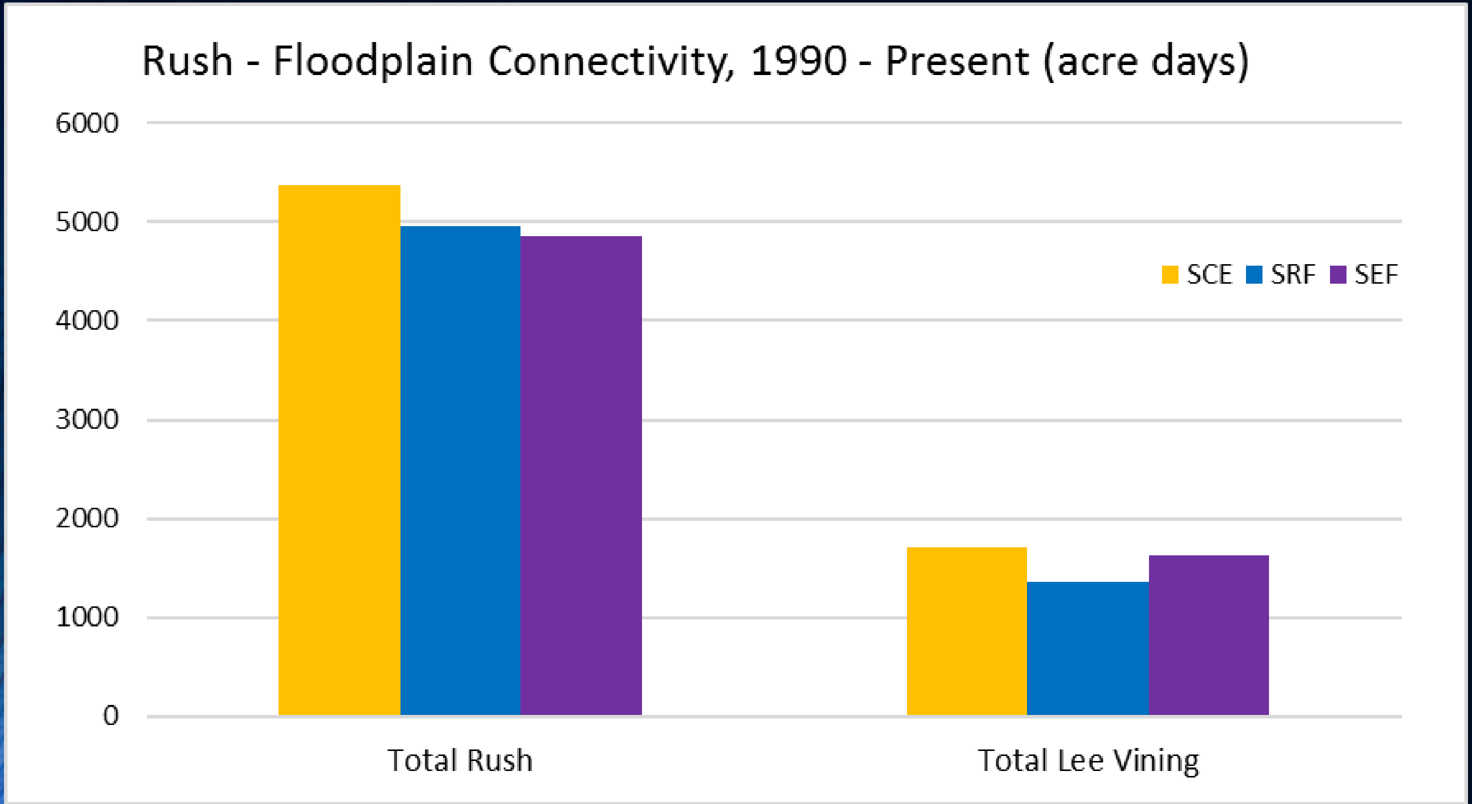
Hydraulics – Lower Rush Creek Example





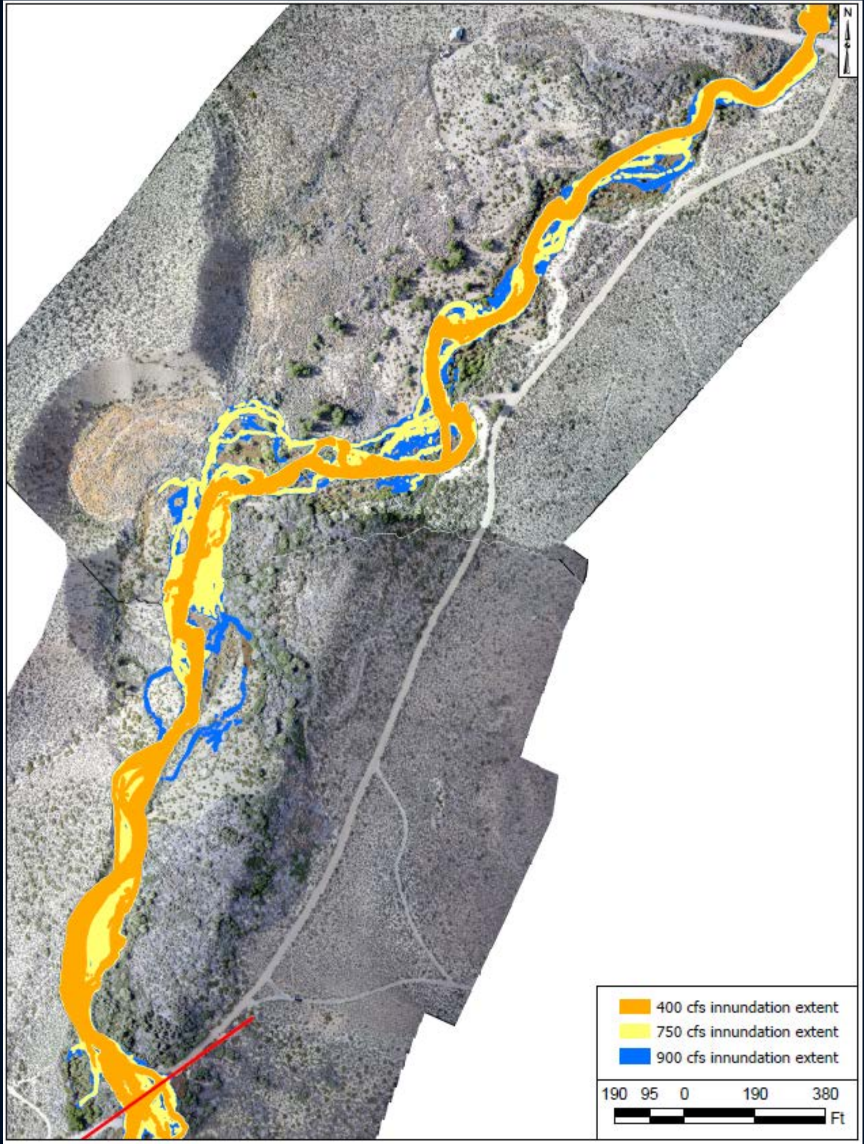
Analyses

Floodplain Connectivity



Pre-Transition

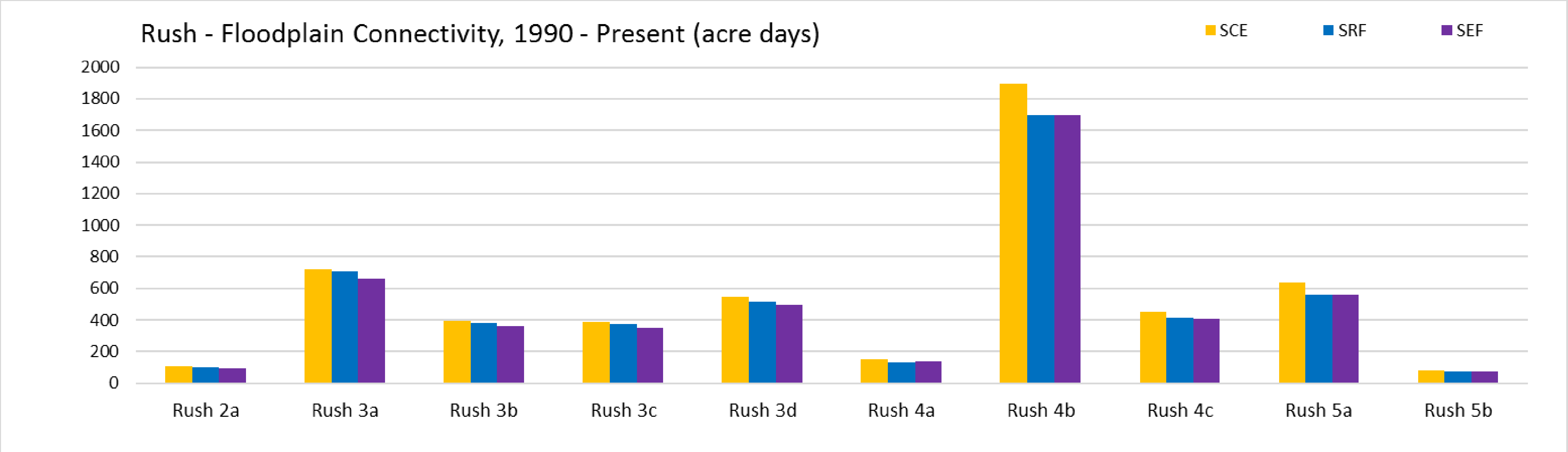
Inundation Map: Rush Creek (Reach 5A)

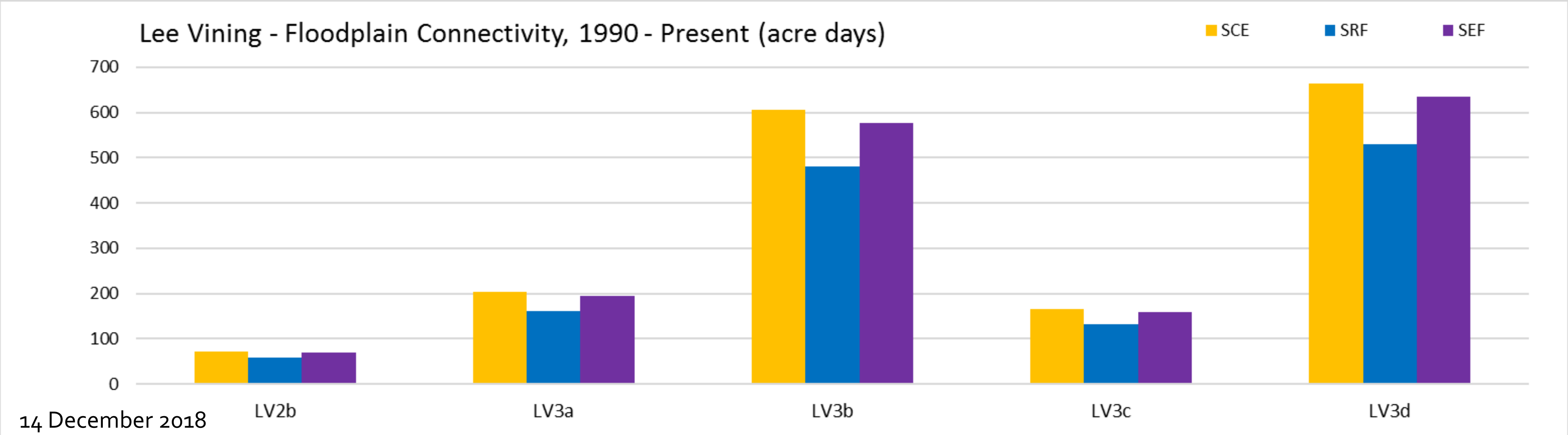


Analyses

Floodplain Connectivity

Pre-Transition

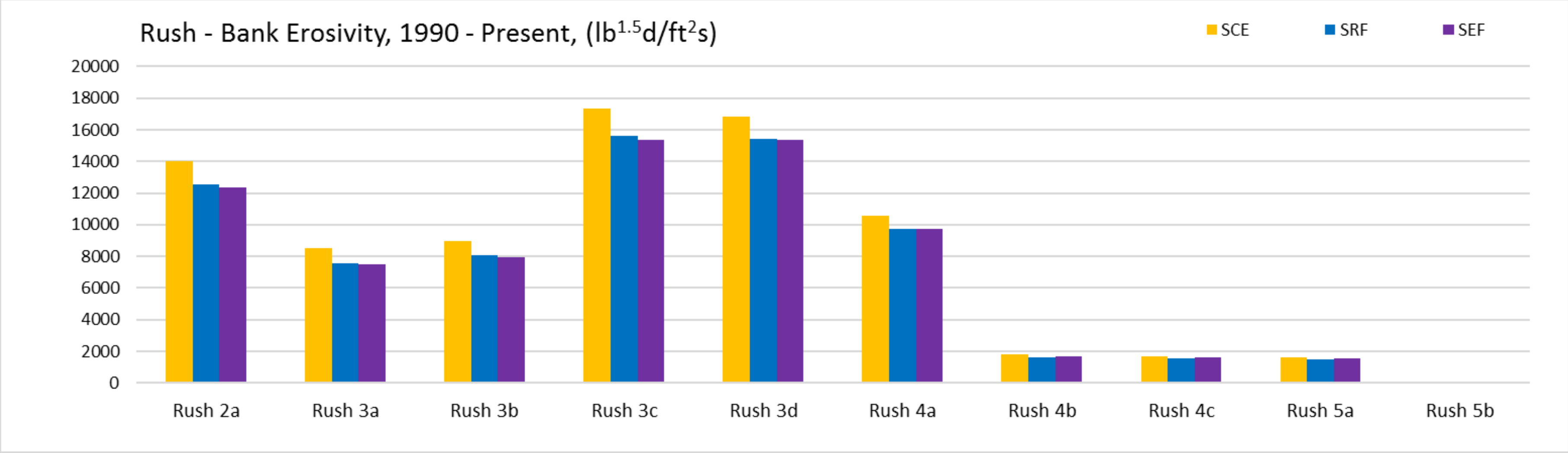


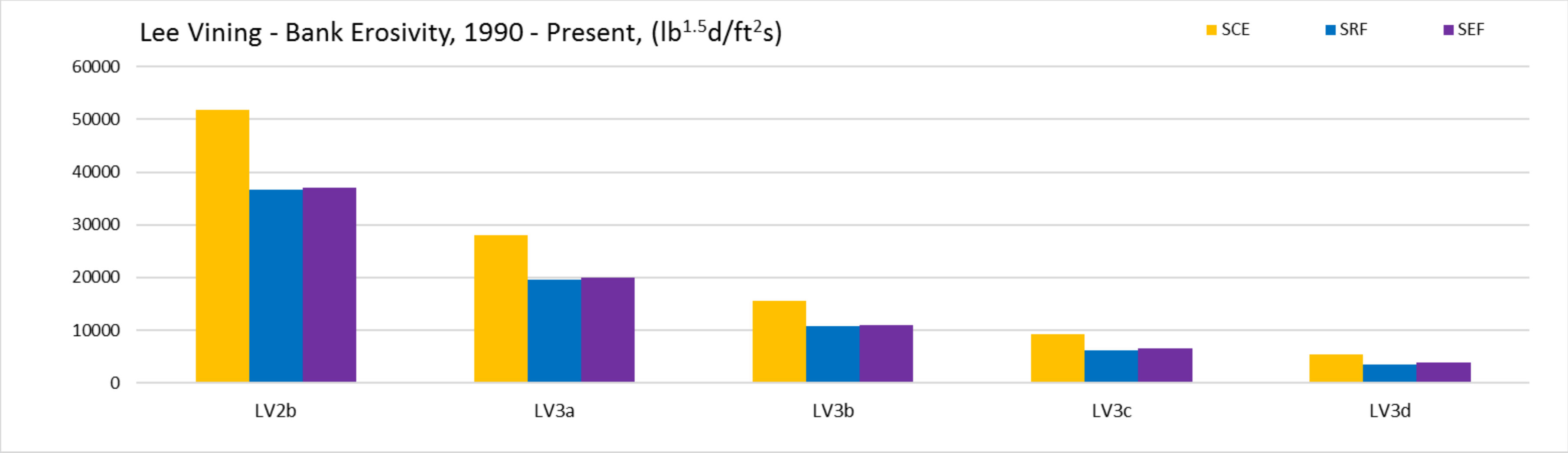


Rush Creek: SRF and SEF are similar to one another.

Lee Vining Creek: SEF results in more floodplain connectivity than SRF.

Sediment Transport – Bank Erosivity

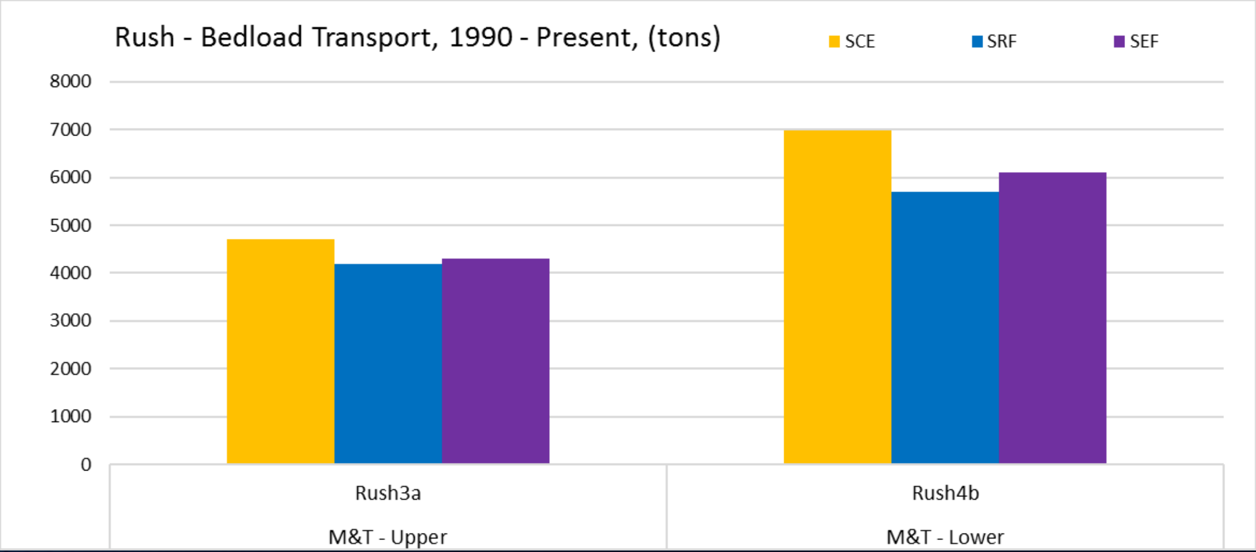


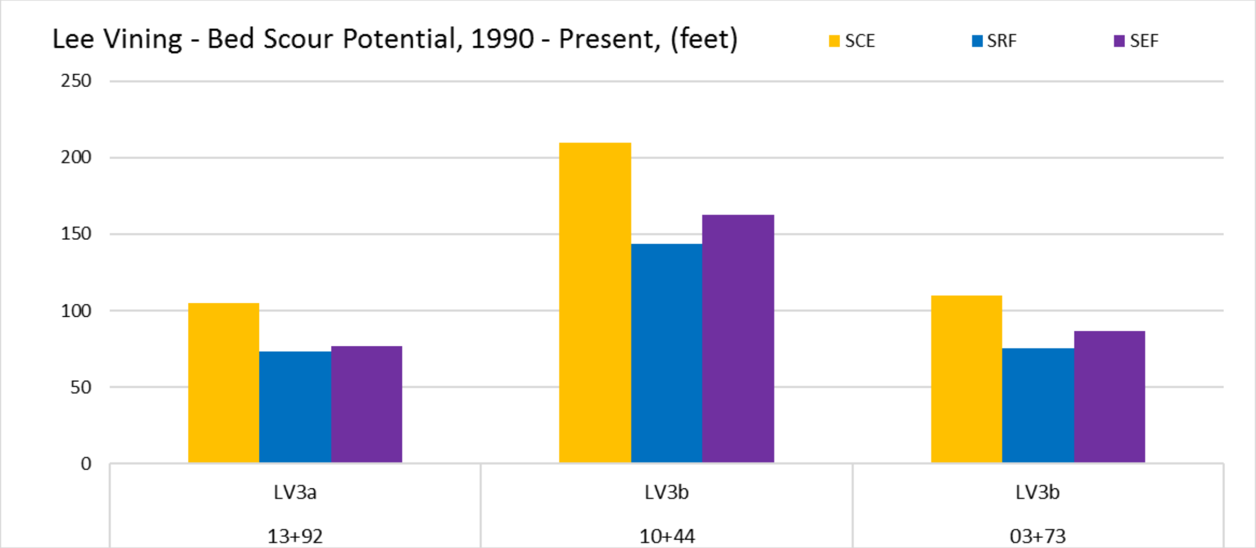


Pre-Transition

Rush and Lee Vining Creeks: Bank erosivity is similar for SEF and SRF.

Sediment Transport – Bedload Transport and Bed Scour





Pre-Transition

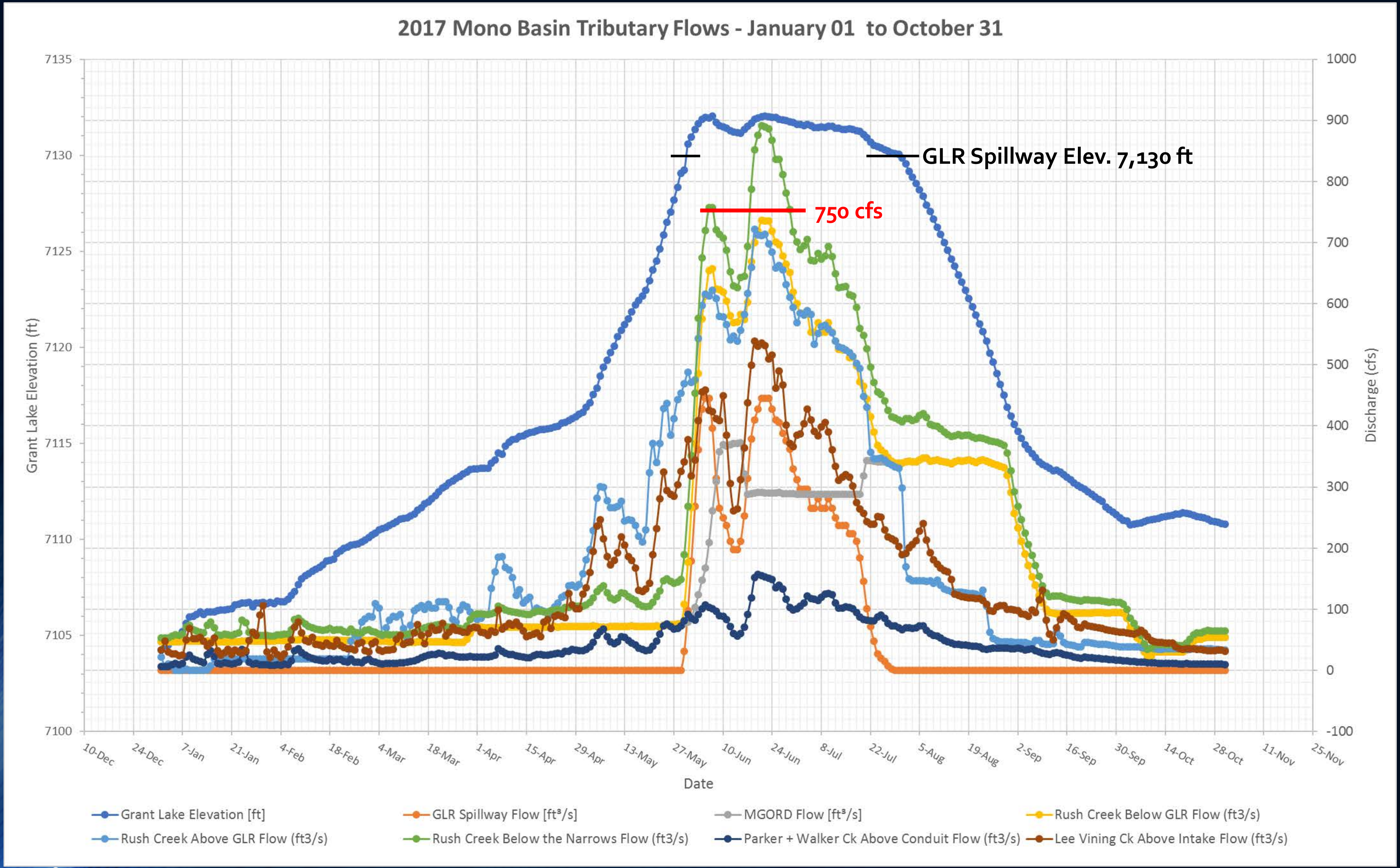
Rush Creek: Bedload transport for SEF is slightly higher than SRF. Upper Rush is more resistant to incision; however, Lower Rush is more susceptible to increased vertical instability with the SEF since it possesses a less course substrate and has a limited sediment supply.

Lee Vining Creek: Bedload transport is higher for SEF than SRF.

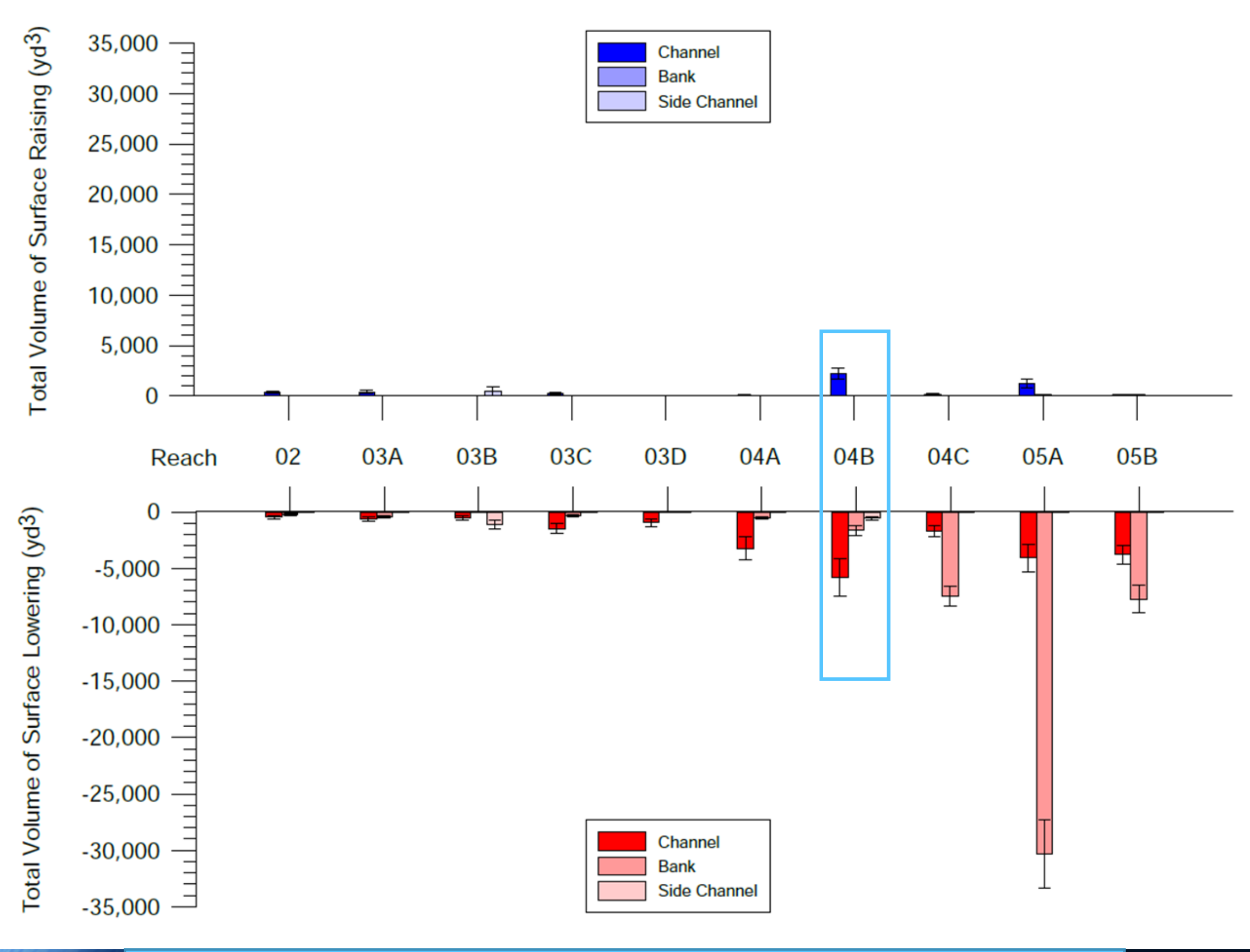
Geomorphology – Field Work (RY2017/2018)

- Pre- Peak (May 2017) and Post-Peak (Oct 2017)
  - LiDAR and Aerial Imagery Acquisition (Phases 1, 2 and 3)
    - Coordinate with Skytec's UAV crew

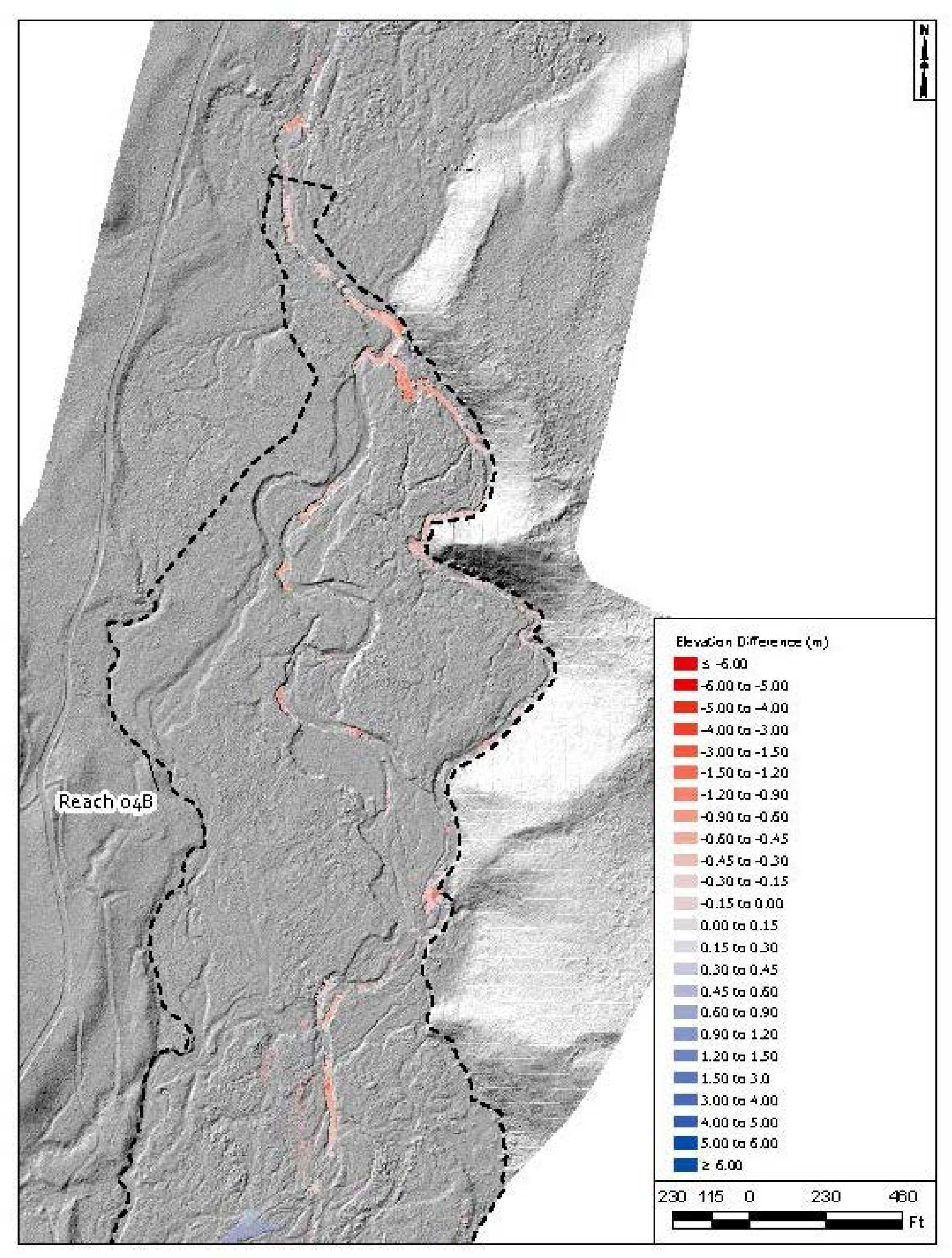
  - Geomorphic observations and field photographs
    - Infrastructure
    - Restoration sites
    - Monumented cross-sections
  - Stream Flow Stage Monitoring
    - Rush Creek: XS -9+40 (downstream of XS -9+82)
    - Lee Vining Creek: XS 6+61


2017 Mono Basin Tributary Flows - January 01 to October 31
GLR Spillway Elev. 7,130 ft
750 cfs
Grant Lake Elevation (ft)
Discharge (cfs)
Date
7135
7130
7125
7120
7115
7110
7105
7100
1000
900
800
700
600
500
400
300
200
100
0
-100
10-Dec
24-Dec
7-Jan
21-Jan
4-Feb
18-Feb
4-Mar
18-Mar
1-Apr
15-Apr
29-Apr
13-May
27-May
10-Jun
24-Jun
8-Jul
22-Jul
5-Aug
19-Aug
2-Sep
16-Sep
30-Sep
14-Oct
28-Oct
11-Nov
25-Nov
Grant Lake Elevation [ft]
GLR Spillway Flow [ft³/s]
MGORD Flow [ft³/s]
Rush Creek Below GLR Flow (ft3/s)
Rush Creek Above GLR Flow (ft3/s)
Rush Creek Below the Narrows Flow (ft3/s)
Parker + Walker Ck Above Conduit Flow (ft3/s)
Lee Vining Ck Above Intake Flow (ft3/s)

Geomorphic Change Detection (RY2017/2018)

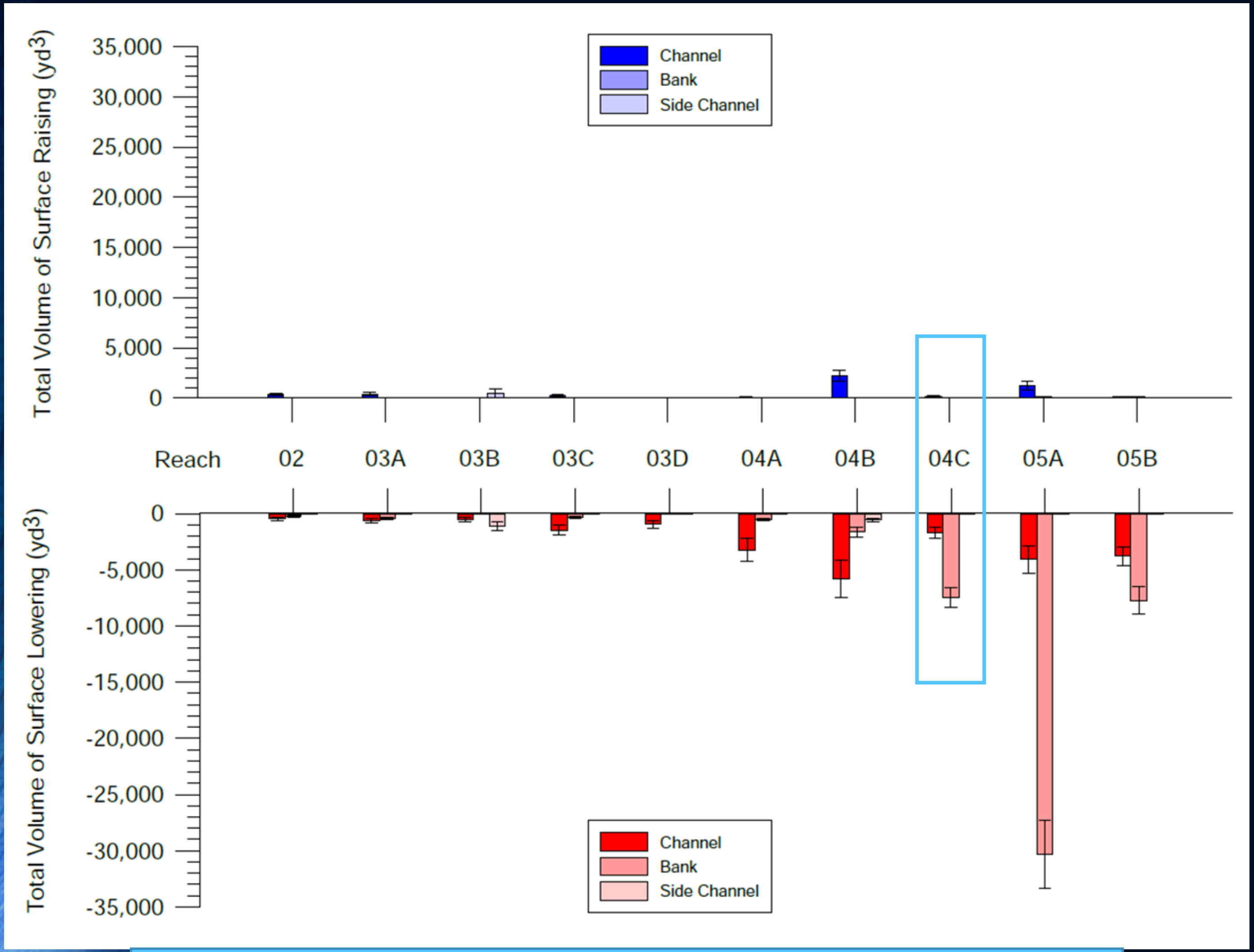


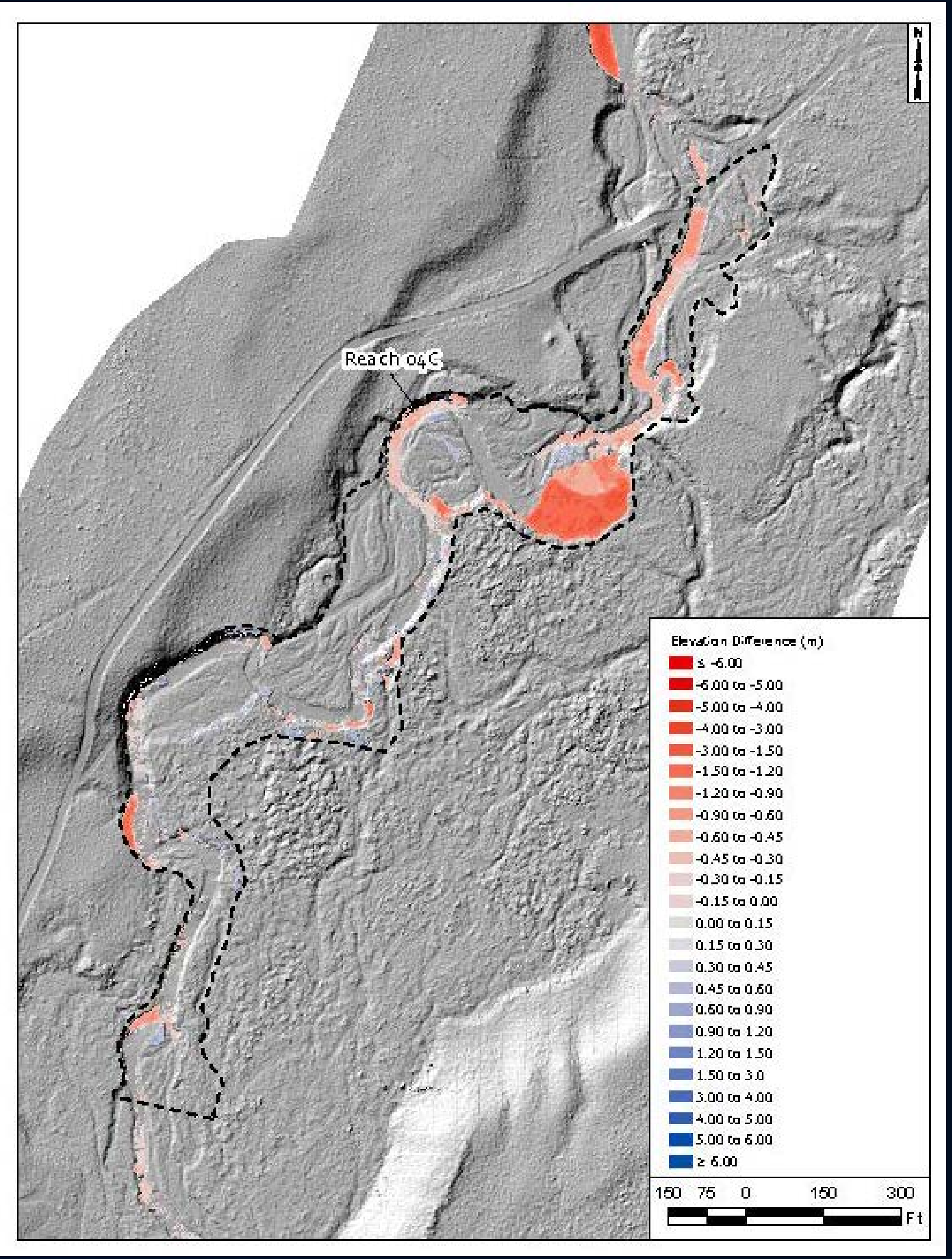
RY 2017/2018 → significant changes in bed and banks



Analyses

Geomorphic Change Detection (RY2017/2018)

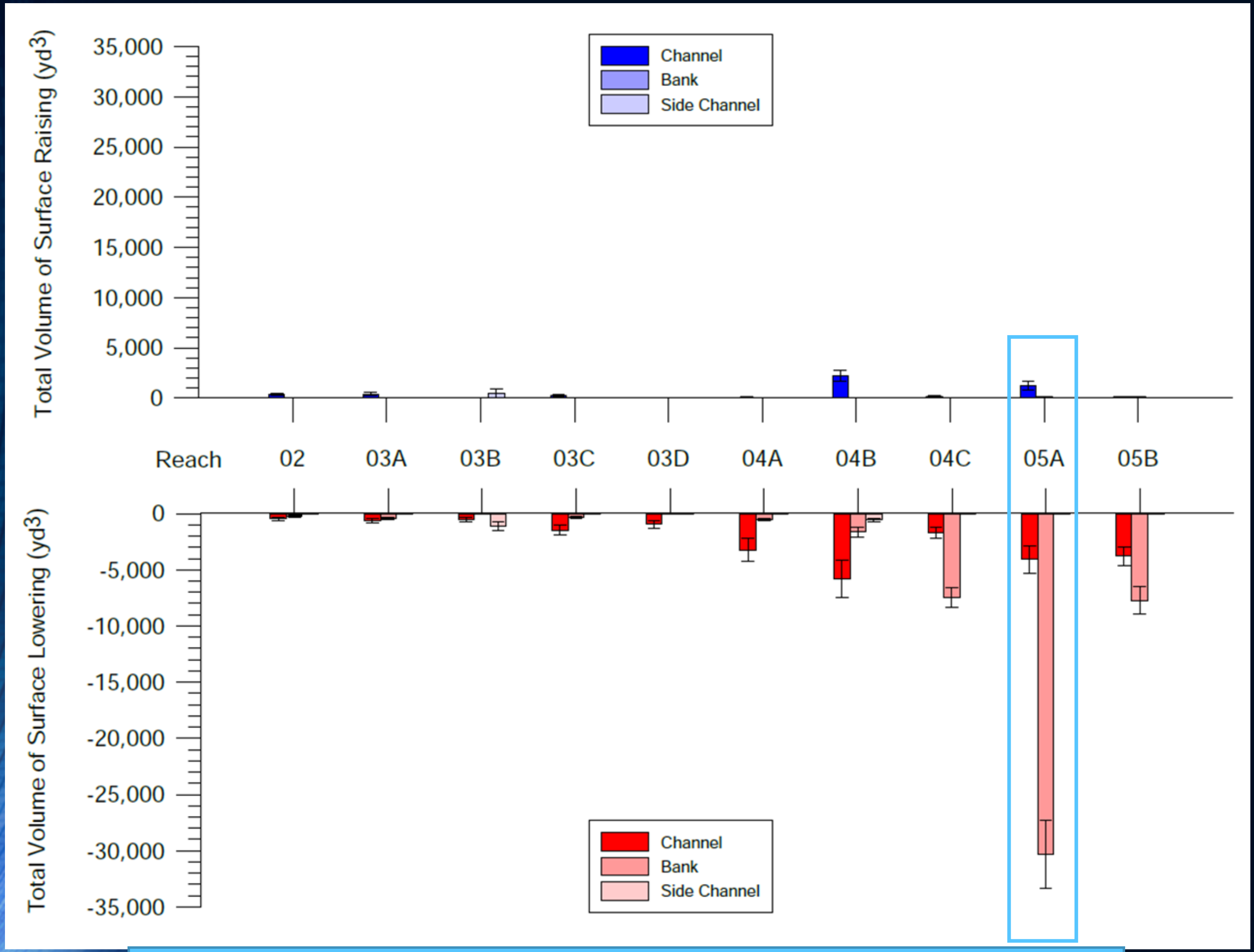




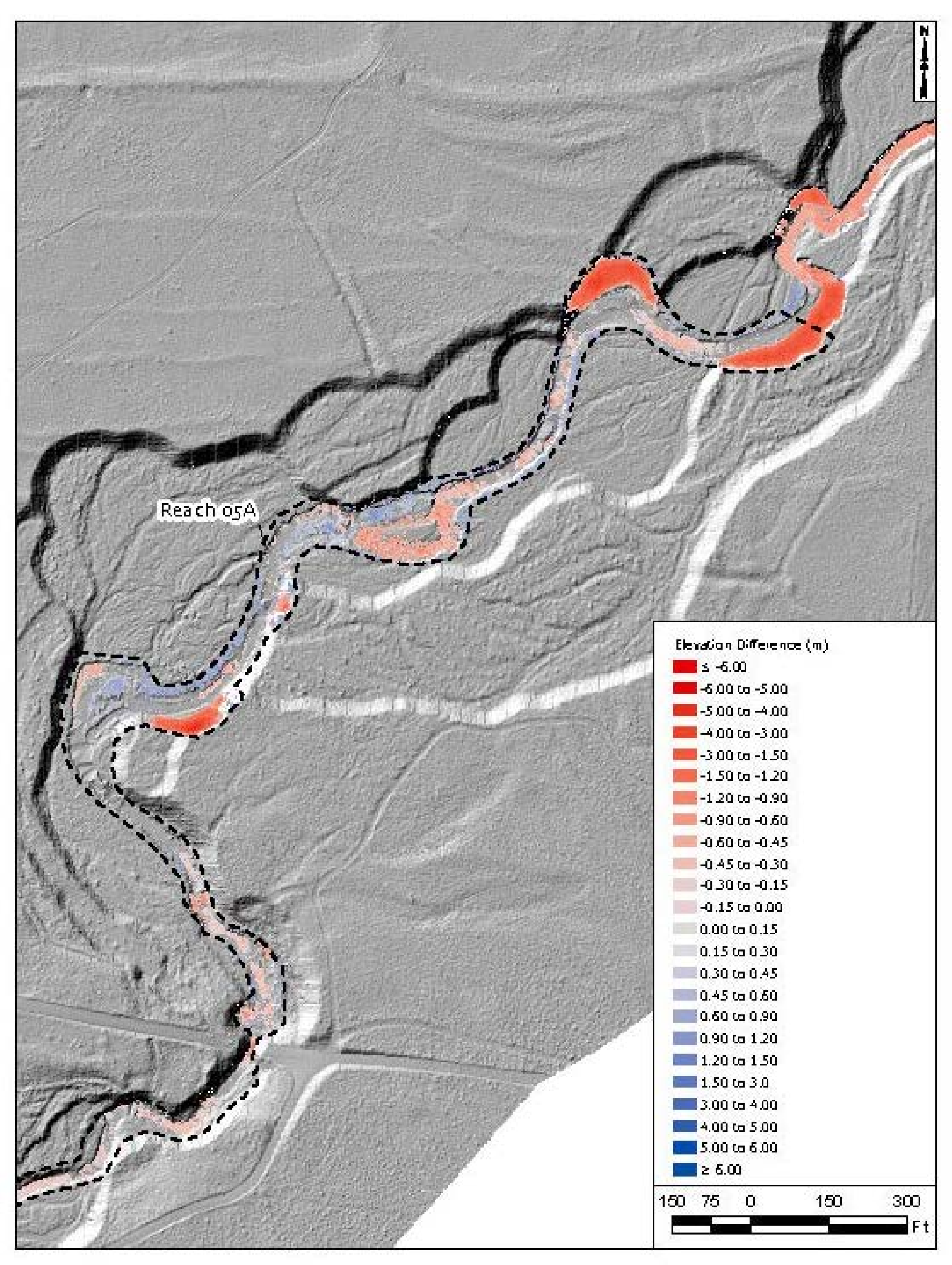
RY 2017/2018 → significant changes in bed and banks

Analyses

Geomorphic Change Detection (RY2017/2018)



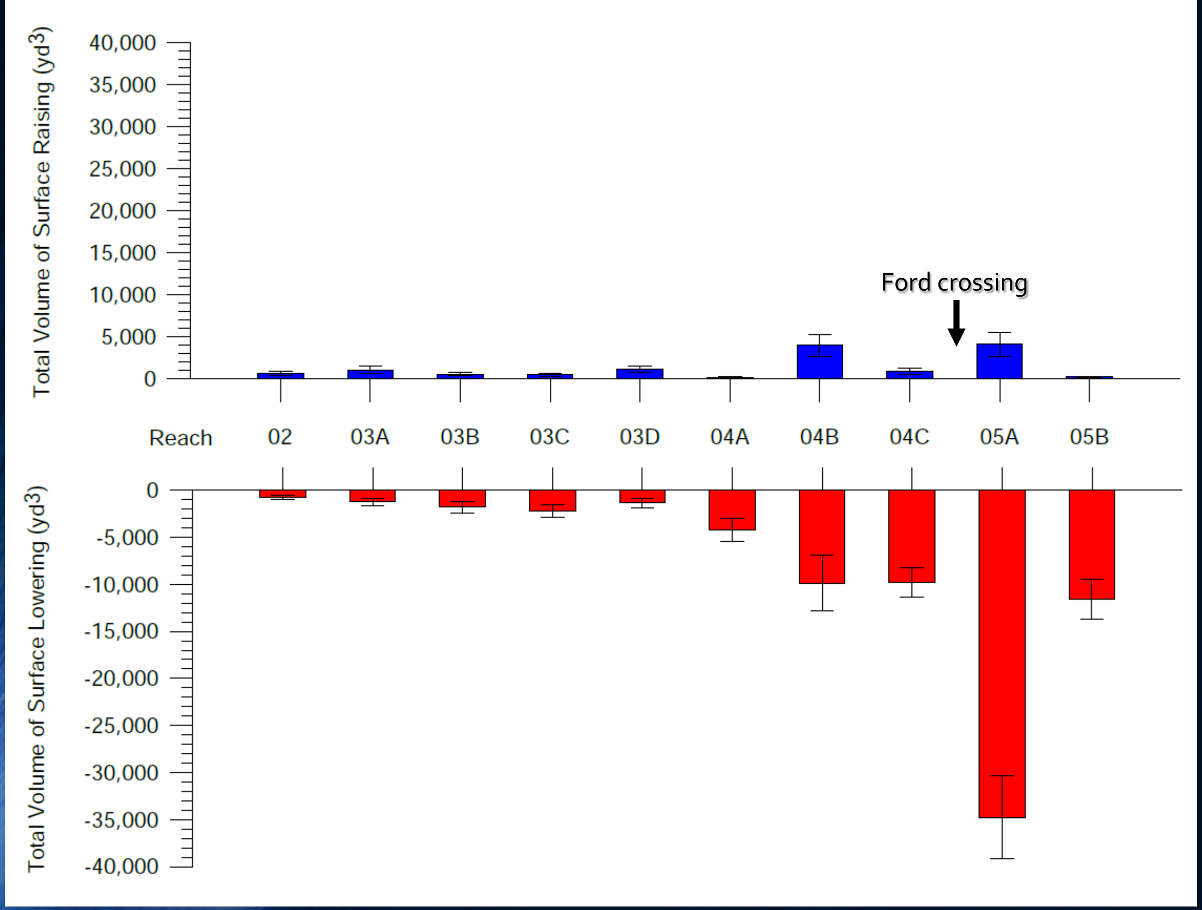
RY 2017/2018 → significant changes in bed and banks



Geomorphic Change Detection (RY2017/2018)

Rush Creek

Cumulative Volume of Erosion (red) and Deposition (blue)



Rush Creek: Sediment transport imbalance illustrates that the vast majority of sediment moving through Upper and Lower Rush is exported to Mono Lake. Therefore, net channel lowering and riparian stranding is a primary consequence of increased peak flows associated with higher peak flows similar to the SEFs.

Rush Creek lost a total of 64,090 cubic yards of bed and bank material in 2017

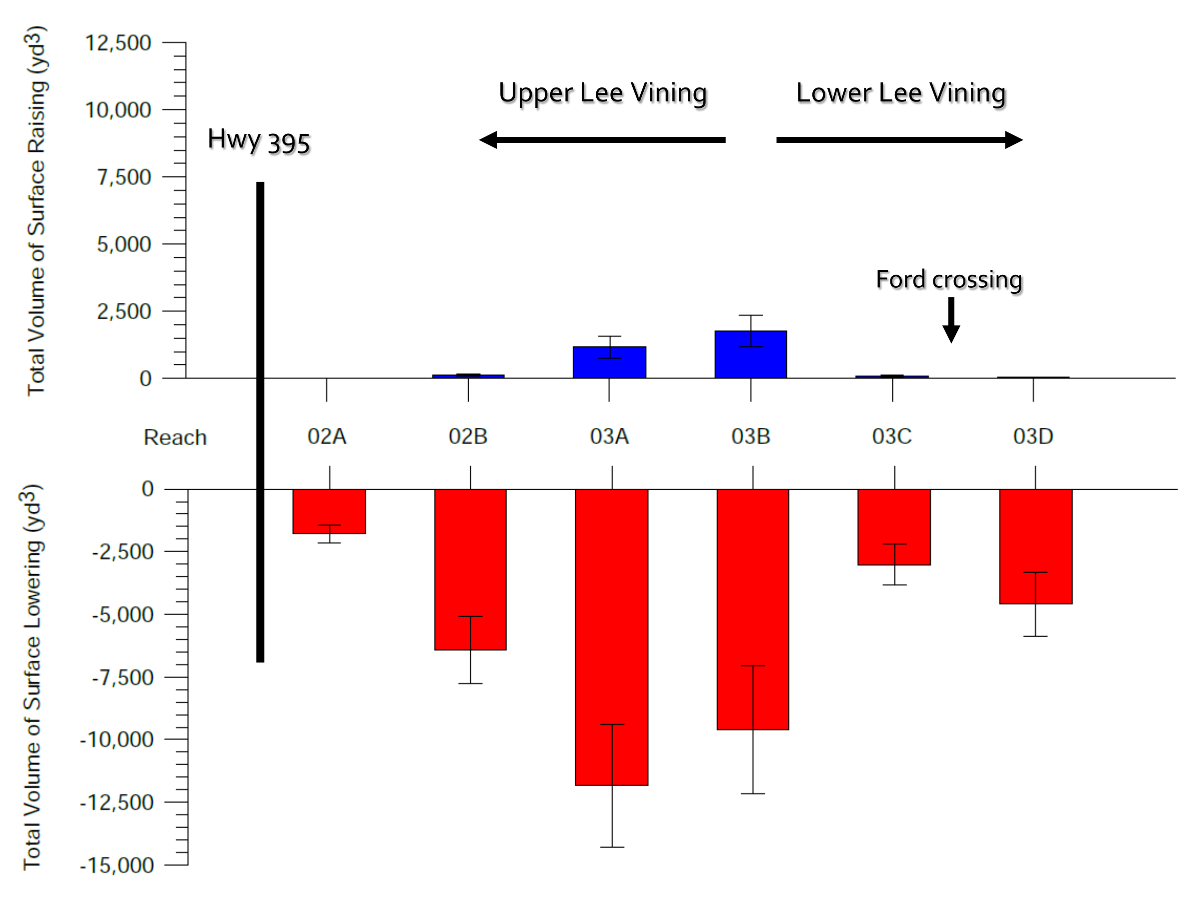
Analyses

Geomorphic Change Detection (RY2017/2018)

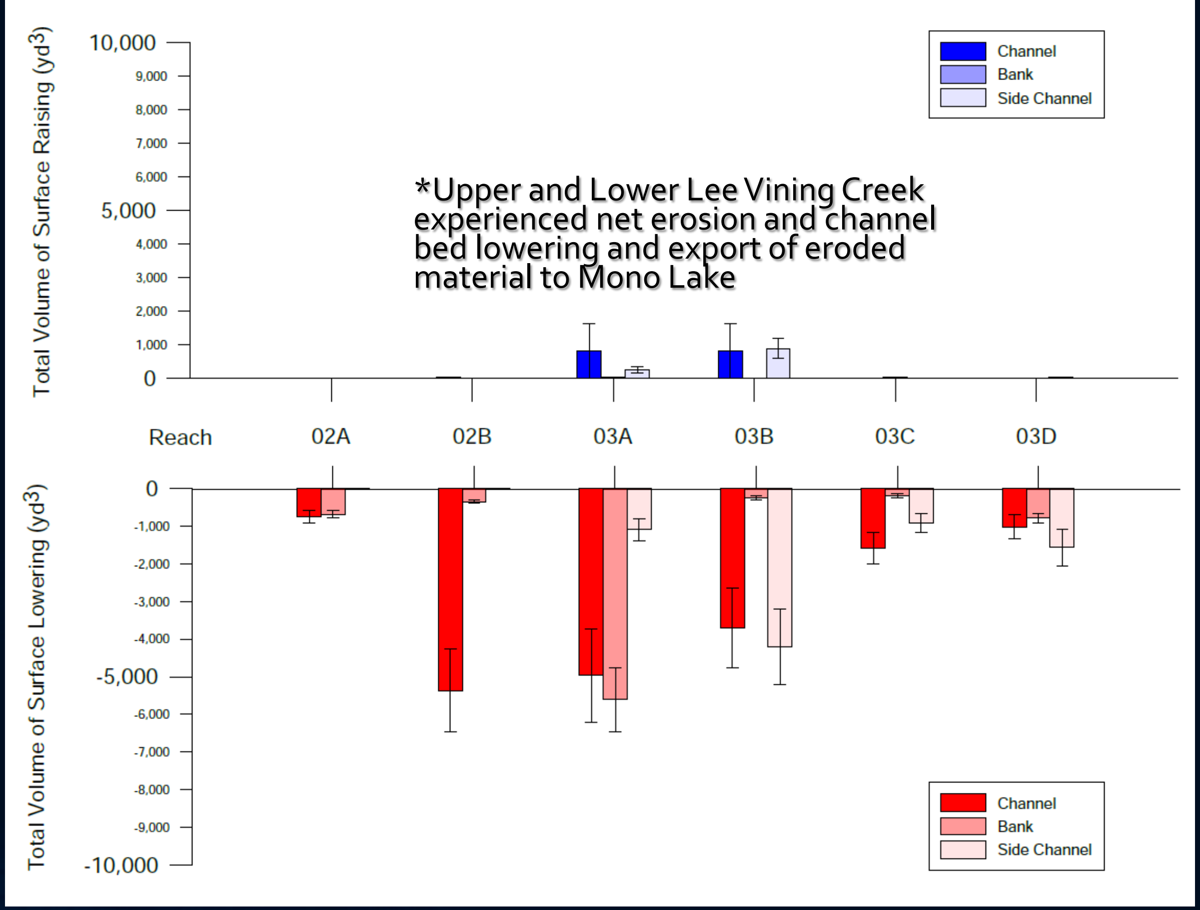
Lee Vining Creek: Sediment transport imbalance illustrates that the vast majority of sediment moving through Lee Vining is exported to Mono Lake. Therefore, net channel lowering and riparian stranding is a primary consequence of increased peak flows associated with implementation of the SEF.

Lee Vining Creek

Cumulative Volume of Erosion (red) and Deposition (blue)



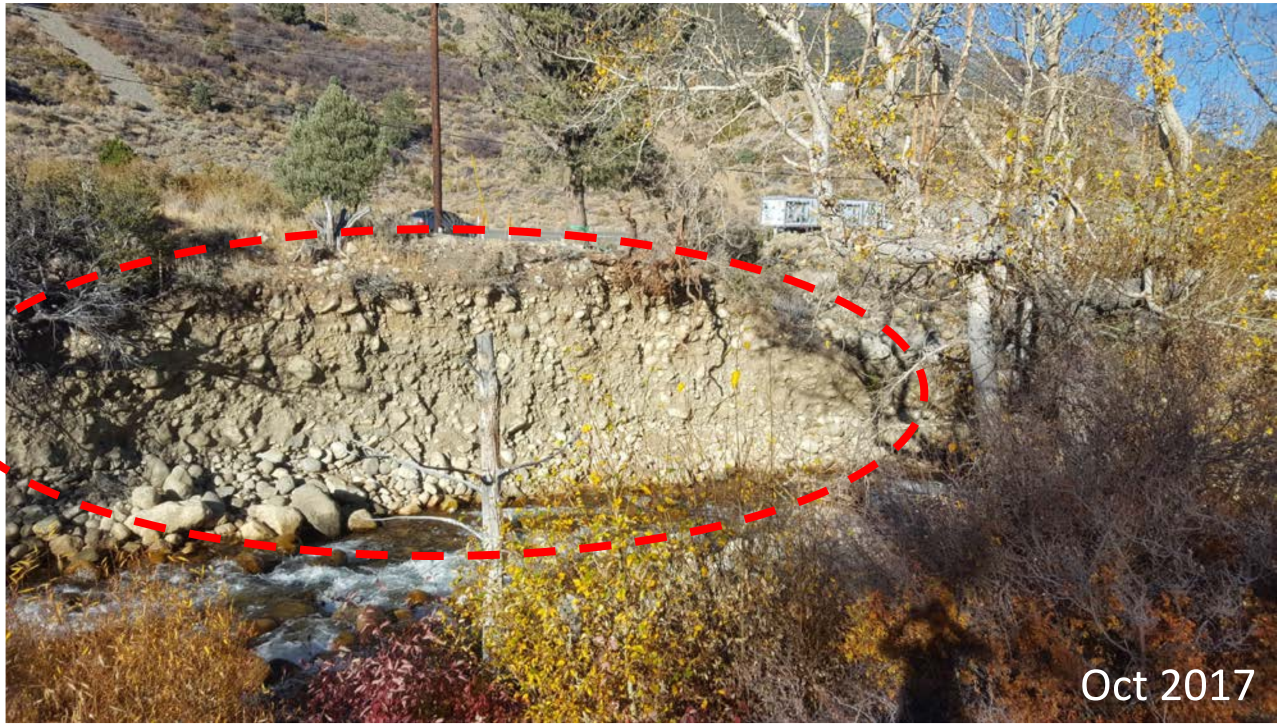
Erosion and Deposition Volume By Geomorphic Unit



Impacts to Streams from Higher Peak Flows

Impacts to Infrastructure from Higher Peak Flows

Lee Vining Creek - Significant bank failure along highway



Impacts to Infrastructure from Higher Peak Flows

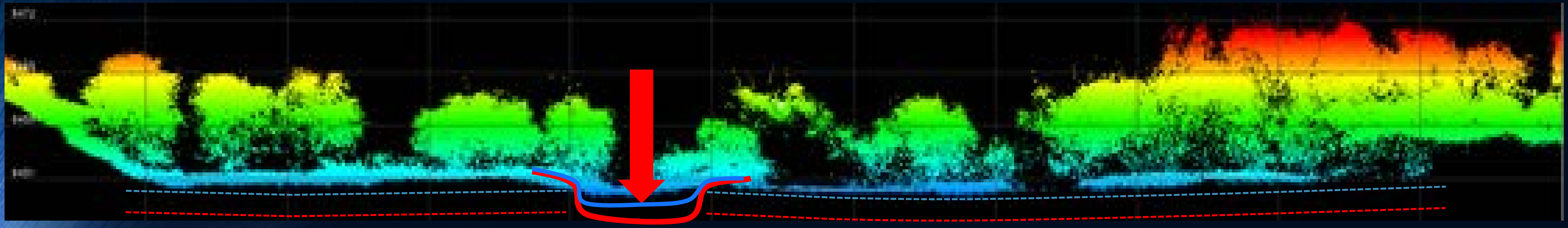
Lee Vining Creek – Significant bank failure at SCE Power Station

SEF vs. SRF Comparison

1. Stream temperatures aren't materially different between SEF and SRF.
2. Floodplain connectivity isn't materially different between SEF and SRF based on the 2017 Post-Peak (October) stream/riparian topography, except for Lee Vining Creek.
3. GCD and Hydraulic Analysis of channel geomorphology for Rush and Lee Vining Creeks indicate the following unmitigable effects:
   A. SEFs will increase sediment transport rate of bed material relative to the SRFs
   B. Each stream has limited sediment storage potential for coarse bedload, which results in net export of sediment from stream and riparian system (streams are efficient at transporting sediment)
   C. Potential long-term effect of stream bed lowering on riparian system (wetlands and floodplains) and fisheries (habitat quality) from implementation of SEF peak flows exists (Rush Creek is most sensitive)
   D. Relative to the SRFs, SEF peak flows possess the potential to disrupt the established dynamic equilibrium (i.e., self-sustaining processes) of the stream system (Rush Creek is most sensitive) established over last 25+ years.

Summary of Potential Impacts to Streams, Ecosystems and Habitat from Higher Peak Flows

- Current geomorphic dynamic equilibrium will be changed by SEF
- Significant negative impacts will likely include:
  - Accelerated (long-term) degradation of the stream
  - Reduction in floodplain access
  - Increased stress on riparian ecosystem by reduced access to groundwater
  - Potential impacts to fisheries from negative feed-back loops tied to the above



Stream Bed Degradation → Groundwater Lowering → Stressed Riparian Vegetation

Summary of Impacts to Infrastructure from Higher Peak Flows

- Geomorphic adjustment from SEFs has potential to threaten infrastructure
- Infrastructure impacts have the potential to be severe
  - Roadway embankment collapse
  - SCE substation embankment undermining and collapse
- Other noted impacts
  - Flanking of the Parshall flume for the Grant Lake Reservoir (GLR) spillway channel
  - Chipping and pitting on the bottom of the Grant Lake concrete spillway
  - In-stream road crossings deepened and channelized

Geosyntec consultants

1111 Broadway, 6th Floor
Oakland, California 94607
PH 510.836.3034
FAX 510.836.3036
www.geosyntec.com

TECHNICAL MEMORANDUM

Date:	May 3, 2019
To:	David Edwards, Los Angeles Department of Water and Power (LADWP)
Copies to:	Jane Hauptman, LADWP; David Martin, PhD, LADWP; Chuck Holloway, LADWP; Sarah Garber, Stantec Consulting Services Inc.
From:	Judd Goodman, PE, Senior Engineer; David Vance, Senior Fluvial Geomorphologist; Mark Hanna, PhD, PE, Senior Principal; Geosyntec Consultants, Inc.
Subject:	Mono Basin Channel Bed Degradation Estimates Technical Memorandum Geosyntec Project Number: LA0490

1. INTRODUCTION

The purpose of this memorandum is to provide LADWP with analysis and results of predicted long-term average bed degradation (channel bed lowering) for Rush Creek (below the Narrows) and Lee Vining Creek (below Hwy 395) in the Mono Basin. Specifically, the analyses evaluated the average long-term bed degradation for existing and proposed flow regimes described below, using recent and historical geomorphic and hydrologic data to quantify the difference in bed degradation potential between the two flow regimes approximately 30 years into the future[1] at the reach-scale. The flow regimes evaluated are:

- Stream Restoration Flows (SRF) – without Grant Dam spillway modification, pre-transition[2]
- Stream Ecosystem Flows (SEF) – with Grant Dam spillway modification, pre-transition
- SRF with Climate Change (four climate scenarios)
- SEF with Climate Change (four climate scenarios)

[1] Forward projection of these flow regimes considered climate as unchanged from the historical and four climate scenarios to identify the effect of each climate change scenario on each flow regime's degradation potential. Because climate scenarios are uncertain, the results are provided as a comparison between scenarios.
[2] Mono Lake is currently in a long-term transition to higher lake levels. When Mono Lake reaches a water surface elevation of 6391-feet above mean sea level (NGVD 29 vertical datum), changes in water export rules will occur.

The results of this analysis provide a projection of the range of potential average long-term bed degradation potential by reach (i.e., reach-scale) for each flow regime. Therefore, bed degradation and aggradation (at the habitat scale of riffles, runs, pools and glides) can surpass the upper and lower bounds of the average ranges presented within. While fluvial systems such as Rush and Lee Vining Creek are naturally complex, and ranges of values are more representative of the fluvial character, we have provided the averages for the average bed degradation ranges presented herein. However, we do not recommend focusing the comparison of bed degradation between the SRF and SEF based solely on these averages, since this oversimplifies the results. In nearly all cases and scenarios evaluated, the potential for degradation is greater under the SEFs than the SRFs and this is especially true when comparing the upper limits of the data ranges which are more reflective of the magnitude of the average bed degradation potential.

The analysis, results, and conclusions are presented in the following sections. A list of enclosures to this memorandum, including tables, figures, and exhibits is provided at the end of this memorandum.

2. ANALYSIS AND RESULTS

Geosyntec estimated long-term bed degradation for the flow scenarios of interest by:

(1) calculating bed degradation / aggradation over the recent and historical monitoring record where repeat measurements of cross sections, longitudinal profiles, and light detection and ranging (LiDAR) topographic surveys were conducted using technologies such as auto-level, total station, real-time kinematic (RTK) global positioning system (GPS), and LiDAR survey methods by multiple observers;

(2) calculating geomorphic metrics (i.e., bedload transport) for the time periods between surveys;

(3) developing relationships between the calculated geomorphic metrics and observed bed degradation;

(4) estimating long-term average bed degradation for the SRF and SEF scenarios in proportion to calculated geomorphic metrics; and

(5) estimating long-term bed degradation for the climate change scenarios in proportion to forecasted shifts in water year type.

The methods and results associated with each of these steps are provided in the following Sections 2.1 to 2.5. The domain of this analysis for Rush Creek (Reaches 4A, 4B, 4C, and 5A) and Lee Vining Creek (Reaches 3A, 3B, 3C, and 3D) is shown on Exhibit 1.

2.1 Historical Survey Comparison

2.1.1 Cross Section Surveys

Historical cross section survey data (McBain & Trush, Inc., and Ross Taylor and Associates, 2010; herein after referred to as the Synthesis Report, 2010) were used for the main channels of Rush Creek and Lee Vining Creek to calculate change in the average bed elevation. Cross sections were surveyed by McBain and Trush, Inc. (M&T), between 1997 and 2010, and LADWP, 2017. The LADWP survey data were adjusted slightly, where necessary, to best line up with the M&T datum(s) and data (i.e., based on surveyed monuments and, to a lesser extent, similar overbank elevations)[3]. For those cross sections that were not resurveyed by LADWP in 2017, Geosyntec used LiDAR topographic data to create cross sections representative of conditions after the summer peak flow of 2017. The 11 cross section locations evaluated for Rush Creek are shown on Exhibits 2A and 2B. The nine cross section locations for Lee Vining Creek are shown on Exhibit 3.

Average bed elevation[4] was computed by: (1) selecting an elevation above which bed changes were not generally observed; (2) selecting horizontal stations outside which bed changes were not generally observed or avoided changes in bank geometry; (3) calculating the cross-sectional area of the channel within those vertical and horizontal bounds of analysis; (4) dividing the cross-sectional area by the assumed bed width (i.e., between the horizontal limits) to yield an average depth; and (5) subtracting the average depth from the upper bound elevation limit. The change in average bed elevation between surveys results in a net bed degradation or aggradation in units of feet. The surveyed cross sections as well as the vertical and horizontal bounds of analysis can be provided upon request. An example is shown in Figure 1.

2.1.2 Longitudinal Profile Surveys

Historical longitudinal profile survey data were used for the main channels of Rush Creek and Lee Vining Creek to calculate change in the average bed elevation. Longitudinal profiles surveyed by M&T between 1997 and 2004 were used on sub-reaches of Rush Creek (Lower Main Channel sub-reach within Reach 4B and County Road sub-reach of Reach 5A) and Lee Vining Creek (Upper Main Channel sub-reach covering a portion of Reach 3A and 3B). Reach-scale longitudinal surveys were completed by LADWP before and after the 2017 summer peak flow that covers the

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[3] The McBain & Trush, Inc. data for cross-sections and longitudinal profiles presented in the historical annual monitoring reports (pre-2011) and the Synthesis Report (2010) state that the vertical datum is NAVD 88. Based on additional analysis the vertical datum is in fact NGVD 29. Therefore, all data presented within this technical memorandum are illustrated using the NGVD 29 vertical datum, unless otherwise noted.

[4] This method was developed specifically for this analysis to evaluate change across the bed of the channel, rather than simply comparing the thalweg elevations between survey periods.

entirety of each reach[5]. The LADWP surveys overlap with the M&T survey locations which are shorter in longitudinal extent.

Longitudinal profiles were resurveyed less frequently than cross sections. The two M&T longitudinal survey extents evaluated for Rush Creek are shown on Exhibits 2A and 2B (noted in legend as "M&T Long Profile"). The one M&T longitudinal survey extent evaluated for Lee Vining Creek is shown on Exhibit 3. Using the LADWP surveys for Water Year 2017, four reach-scale longitudinal profiles were evaluated for Rush Creek (Reaches, 4A, 4B[6], 4C, and 5A[7]) (Exhibits 4 and 5) and one for Lee Vining Creek (Reach 3A) (Exhibits 6 and 7). Although the sub-reach longitudinal profiles are shorter in length than the reach-scale longitudinal profiles, there are more surveys available for comparison for the sub-reach longitudinal profiles.

Average bed elevation[8] was computed by: (1) applying a linear trendline to the extent of the longitudinal profile evaluated; (2) calculating the bed elevations at the downstream and upstream limits of the profile using the trendline equation; and (3) averaging the calculated elevations of the downstream and upstream limits. The change in average bed elevation between surveys results in a net bed degradation or aggradation in units of feet. The surveyed longitudinal profiles showing the downstream and upstream limits of analysis can be provided upon request. An example is shown in Figure 2.

It should be noted that the method used for assessing degradation along the longitudinal profile focuses on the average bed elevation change. The magnitude of major aggradation (approximately 800 linear feet of Reach 4B in vicinity of the 8-Channel with a maximum aggradation of 4.1 feet) or degradation events (approximately 3,500 linear feet of 10-Channel headcut ranging from 1.2 to 2.25 feet of maximum degradation at riffles) are not used for computing the long-term bed degradation[9]. These geomorphic events are notable and are not illustrated in the results due to averaging of the profile which includes riffle, run, pool, and glide geomorphic units. A longitudinal assessment of degradation at the habitat-scale (individual geomorphic unit) was not

[5] The Lee Vining Creek post-peak 2017 LADWP longitudinal profile survey only covers Reach 3A and a portion of Reach 3B.
[6] The LADWP longitudinal profile survey in Reach 4B used the new main channel location within the 10-channel for comparison of pre- to post-peak degradation.
[7] The longitudinal profile analysis of Reach 5A LADWP data was only conducted for the portion of the reach upstream of the County Road culvert (i.e., also referred to as, Test Station Road).
[8] This method was chosen specifically for this analysis to evaluate average change across the bed of the channel over an entire reach which typically ranges between approximately 3,000 and 8,000 linear feet on Rush Creek and 1,000 and 4,000 linear feet on Lee Vining Creek. M&T longitudinal profile surveys typically covered approximately 1,500 to 1,700 linear feet for the sub-reach data sets analyzed in this study. Therefore, the method selected allows for contemporaneous analysis of the full reach to the sub-reach data of M&T.
[9] The major aggradation and degradation events discussed on Rush Creek were a result of the 2017 peak flow.

performed. This memorandum acknowledges that these high-magnitude events are present in the system and would further expand the upper and lower bounds of the ranges presented.

2.1.3 LiDAR Topographic Surveys

Geosyntec used repeat LiDAR topographic survey data as input to a geomorphic change detection (GCD) analysis for the main channels of Rush Creek and Lee Vining Creek to calculate change in the average bed elevation[10]. LiDAR surveys were completed by Skytec, LLC (Skytec) in 2017. A pre-peak LiDAR survey was performed from May 22nd to June 5th, 2017 and a post-peak survey was performed from October 9th to 27th, 2017. Using the Skytec surveys for Water Year 2017, four reach-scale GCD evaluations were performed for Rush Creek (Reaches 4A, 4B, 4C, and 5A) and four for Lee Vining Creek (Reaches 3A, 3B, 3C, and 3D).

Average bed elevation difference was computed by: (1) creating a GCD map (plan view perspective) showing ground elevation difference based on the 2017 pre- and post-peak LiDAR surveys; (2) delineating the active channel for the pre-peak condition; (3) clipping the GCD results to the delineated active channel; (4) summing the volume of GCD by reach; (5) dividing the volume by the area of the active channel. The GCD maps as well as the extent of the active channel assumed can be provided upon request. An example is shown in Figure 3.

2.2 Geomorphic Metric Computation

Historical geomorphic monitoring data (M&T, 2006 and StreamWise, 2004) were used to create discharge-dependent bedload transport rating curves, which relate to channel bed erodibility. Bedload data from five sites, two sampled by M&T (M&T, 2006) and three sampled by StreamWise (StreamWise, 2004), were used to generate the rating curves shown on Figure 4. While the bedload sampling sites were located on Rush Creek, they were applied for analysis on both Rush Creek and Lee Vining Creek[11]. The bedload monitoring locations are shown on Exhibit 8.

When the developed rating curves are integrated with a time series of daily flow data, then cumulative bedload transport can be computed for a given period of interest. These geomorphic metrics allow for long-term comparisons of channel bed erodibility for different flow scenarios, as was done for the special study completed and presented in May 2018 (Geosyntec, 2018a).

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[10] GCD software reports results in meters as a default. 2017 LiDAR data references NAVD 88 vertical datum.
[11] The M&T Lee Vining Creek scour data had a poor correlation with the discharge dependent rating curve and produced a greater range of variability in the long-term degradation estimates. Therefore, the Rush Creek bedload rating curves were applied to Lee Vining Creek which produced a narrower range of bed degradation estimates.

2.3 Relationships Between Geomorphic Metrics and Historical Bed Degradation

The bedload rating curves were integrated with the historical daily flow record for the time periods between historical surveys (i.e., cross sections, long profiles, and LiDAR). This allowed for a comparison between the computed geomorphic metric (i.e., bedload transport, in tons) and net bed degradation. Figure 5 provides an example of the relationships, which were derived for each of the cross sections, longitudinal profiles, and reach-scale GCD maps considered. The geomorphic metrics (on the x-axis) are normalized by the values associated with the long-term record (i.e., 28-years associated with Water Years 1990 to 2017, 4/1/1990 to 3/31/2018). For example, a normalized metric of 0.50 between 5/27/2017 and 11/27/2017 means that 50-percent of the calculated geomorphic metric total for the 28-year period of record occurred between those dates. The coefficients associated with the linear trend lines represent an estimate of the long-term historical average bed degradation for the 28-year flow record used, in feet.

The magnitude of calculated bedload transport varies greatly between the five monitoring datasets. This analysis, however, emphasizes the relative magnitude of results (i.e., the normalized geomorphic metric), which are relatively similar, instead of the absolute magnitude. As a result, the bedload metrics are used for relative comparisons in this analysis rather than relying upon the absolute magnitude.

2.4 Application to SRF and SEF Scenarios

As part of the special study presented in May 2018, Watercourse Engineering, Inc. developed simulated daily flow records (i.e., 28-years associated with Water Years 1990 to 2017, 4/1/1990 to 3/31/2018) for the Mono Basin tributaries using the eSTREAM program. Several flow management scenarios were simulated as part of this exercise. Two of these flow scenarios included the: SRF, without Grant Dam spillway modification and pre-transition; and SEF, with spillway modification and pre-transition. These SRF and SEF simulated daily flow records were integrated with the bedload rating curves. This resulted in computed geomorphic metrics for SRF and SEF, similar to what was calculated for the historical flow record, as described in Section 2.2.

Two example plots comparing cumulative bedload transport for Historical, SRF and SEF relative to the historical flow releases are presented in Figures 6 and 7. Figure 6 illustrates the Lower Rush Creek (below the Narrows) cumulative bedload transport over the period of record using the M&T Lower Rush Creek bedload site rating curve. Figure 7 illustrates the Lee Vining Creek (below intake) cumulative bedload transport over the period of record using the M&T Upper Rush Creek bedload site rating curve.

Erosion Potential ratios for the SRF and SEF scenarios were then calculated by dividing the respective geomorphic metric by the computed historical geomorphic metric (i.e., SRF/Historical and SEF/Historical, respectively). These ratios were then multiplied by the estimated historical long-term average degradation to yield estimates of bed degradation for the SRF and SEF scenarios over the 28-year simulation period. Bed degradation results are provided by reach and by creek in Figures 8 and 9, respectively, and on Tables 1 and 2. The difference in bed degradation between the two scenarios (SEF – SRF) provides one line of evidence of the geomorphic impact associated with changing flow releases from SRF to SEF. These degradation difference results are provided by reach and by creek in Figures 10 and 11, respectively, and on Tables 3 and 4.

2.5 Application to Climate Change Scenarios

Long-term net bed degradation was estimated accounting for the effects of climate change (2020 to 2050) using a suite of four climate change projections of monthly total runoff depth. The climate model gridcell was the same for all four models and was chosen to be representative of the headwaters of the streams of interest. The four models included in the analysis are for the Representative Concentration Pathway (RCP) 4.5 projection scenario in which greenhouse gas emissions peak near 2040 and then begin to decline, and include HadGEM2-ES, CNRM-CM5, CanESM2, MIROC5. This suite of models is the same as the set chosen by Cal-Adapt (2018) and was chosen for this analysis to help bracket the variability in the climate models. All four sets of model data are from the Intergovernmental Panel on Climate Change (IPCC) model ensemble known as the Climate Model Intercomparison Project (CMIP), released in 2013, and have been downscaled using the Bias Correction Spatial Disaggregation (BCSD) methodology. Central tendencies for the four climate models are described by Cal-Adapt (2018) as:

- HadGEM2-ES: Warm/Drier
- CNRM-CM5: Cooler/Wetter
- CanESM2: Average
- MIROC5: Complementary model, included to expand the coverage of the range of possibilities since it is significantly different than the other three.

From each climate model, the monthly runoff (US Bureau of Reclamation, 2014) was used to estimate the future change in frequency of Runoff Year Type (i.e., Dry, Dry-Normal, Normal, Wet-Normal, Wet, and Extreme-Wet). The following steps were used to accomplish this: (1) the historical distribution of Runoff Year Type for the 28-year period of analysis (Water Year 1990 to 2017) was used as a basis to develop a 30-year modeled historical distribution (1990 to 2020); (2) for each climate model, thresholds of modeled historical runoff volume (or depth) were established to reproduce the 30-year modeled historical distribution (1990 to 2020) of Runoff Year Type; (3) for each climate model, the established thresholds of modeled runoff volume were applied to future climate projections to generate an estimated distribution of Runoff Year Type for the next 30 years (2020 to 2050). The resulting distributions of Runoff Year Type are provided on Figure 12.

The average annual geomorphic metric (i.e., bedload transport) was calculated for each Runoff Year Type and flow scenario (i.e., Historical, SRF, and SEF). These average annual totals were multiplied by the climate model-specific Runoff Year Type counts, to calculate geomorphic metrics of channel erodibility over 30 years. Erosion Potential ratios for the climate change scenarios were then calculated by dividing the modeled climate change geomorphic metric by the modeled historical geomorphic metric (i.e., 2020 to 2050 / 1990 to 2020). These ratios were then multiplied by the estimated SRF and SEF long-term average degradation results (see Section 2.4) to yield estimates of long-term average bed degradation associated with climate change over a 28-year period. Box and whisker plots of estimated net degradation associated with climate change, for all four models, are provided in Figures 13 and 14 for Rush Creek and Lee Vining Creek, respectively. Box and whisker plots for the difference in degradation (SEF – SRF) are provided in Figures 15 and 16 for Rush Creek and Lee Vining Creek, respectively.

3. RESULTS SUMMARY

Key findings of the bed degradation analysis are provided below.

1. The geomorphic metric results indicate that a substantial portion of bedload transported during the 28-year historical flow record (Water Year 1990 to 2017) occurred during the summer of 2017, between May 27th and November 27th. This is reflected in the cumulative plots of bedload transport on Figures 6 and 7. For Rush Creek this proportion is estimated between 30- and 70-percent of the total. For Lee Vining Creek this proportion is estimated between 20- and 45-percent of the total.

2. For both creek systems, the SEF results in approximately 14-percent more bedload transport over the long-term, on average, than the SRF. This is reflected on the box and whisker plots on Figure 9.

3. The calculated long-term 28-year net bed degradation is greater for estimates based on cross sections and GCD data than for longitudinal profiles (due to averaging of the profile).

4. Long-term bed degradation results by reach may not be fully reflective of distinct geomorphic processes occurring in each reach. This is because certain reaches have more data available for analysis than others and the distribution of data types (i.e., cross section, longitudinal profile, and GCD) is not similar for each reach. This is reflected in the difference in sample size by reach, as shown in Tables 1 to 4. The most appropriate comparison of results by reach is with the GCD data, although this data type is the most limited (temporally) because LiDAR surveys were only performed twice, before and after the summer peak flow in 2017.

5. Estimates of the 28-year net average bed degradation, without climate change, for Rush Creek have a range between -0.6- to 3.1-feet, an interquartile range (IQR)[12] between 0.6- and 1.3-feet, and an average of 0.8- to 0.9-feet for the SRF. For the SEF, estimates have a

[12] The interquartile range (IQR), also called the midspread or middle 50%, is a measure of statistical dispersion, being equal to the difference between 75th and 25th percentiles, or between upper and lower quartiles.

range between -0.6- to 3.2-feet, an IQR between 0.7-feet and 1.4-feet, and an average of 0.9- to 1.0-feet. These results are reflected in Table 1 and Figure 9.

6. Estimates of the 28-year net average bed degradation, without climate change, for Lee Vining Creek have a range between -0.2- and 7.7-feet, an IQR between 0.4- and 2.8-feet, and an average of 1.8-feet feet for the SRF. For the SEF, estimates have a range between -0.3- and 8.7-feet, an IQR between 0.4-feet and 3.2-feet, and an average of 2.0- to 2.1-feet. These results are reflected in Table 2 and Figure 9.
7. Results indicate that more bed degradation would be expected for the SEF than the SRF flow regime. The magnitude of this increase, over 28 years (without climate change), has a range between -0.05- and 0.5-feet, an IQR between 0.05- and 0.15-feet, and an average of 0.1-feet for Rush Creek. For Lee Vining Creek, estimates have a range between -0.05- and 1.0-feet, an IQR between 0.05- and 0.4-feet, and an average of 0.25-feet. These results are reflected in Tables 3 and 4 as well as Figure 11.
8. The four climate models applied to the data illustrate the variability in the results and magnitude of potential change in long-term bed degradation, which are heavily dependent on the climate model used. This result is reflected in Figures 13 and 14. Three of the four climate models analyzed result in increased long-term bed degradation. The remaining scenario modeled under HadGEM2-ES climate model, which represents warmer and drier conditions, is the only model of the four that estimates a decrease in long-term bed degradation.

4. CONCLUSION

Key conclusions of the bed degradation analysis are provided below.

1. The historical data collected by McBain and Trush, Inc. from 1997 through 2010 reported in the Annual Runoff Year Monitoring Reports and further in the Synthesis Report (2010) covered three primary sub-reaches in the Mono Basin tributaries of Rush and Lee Vining Creeks that are the subject of this memorandum. Comparison of this geomorphic data in the context of the reach-scale survey data and GCD data illustrate that long-term bed degradation as a geomorphic process is present within all reaches and to varying degrees within each reach than previously understood or documented.
2. The results illustrated herein are limited by the sample size of historical (reaches without historical data have fewer data points to measure geomorphic change at cross sections and along longitudinal profiles) and recent data within each reach. Cross section data in each reach proved to increase the sample size and range for degradation estimates.
3. The comparison of SEF to SRF long-term bed degradation indicates that in nearly all cases the SEFs increase bed degradation potential at the reach-scale, with even greater degradation potential at the local level (sub-reach and habitat-scale). Therefore, the reach-

scale degradation values should not be extrapolated to the sub-reach and habitat-scale due to the higher magnitude of variability and potential for degradation at these finer scales.

4. Operational management of snowmelt flood and peak spills from Grant Lake Reservoir that exceeds the prescribed flow durations would lead to greater degradation on Rush Creek than presented in this technical memorandum under either flow regime. The 2017 peak flow and duration of the snowmelt flood flow illustrated the effect of flow duration on magnitude of geomorphic change (Figures 6 and 7).

5. The evaluation of cross sections, longitudinal profiles, and the GCD data for 2017 illustrate that aggradation as a bed change process is localized, and that degradation is the primary vertical reach-scale process. The implications of this finding are that existing riparian systems on floodplain surfaces will be separated farther from the riparian groundwater table with long-term bed degradation. Headcut propagation will further complicate the riparian habitat connection to groundwater and these indirect impacts would be greater for the SEF than the SRF.

6. Riparian groundwater response to changes in flow stage height have shown that stage changes even as small as 0.1 to 0.25 ft can lower the local groundwater between 2.15 ft (in fall) and 0.56 ft (in summer), respectively (Synthesis Report, 2010). Therefore, even a small change (e.g., tenths of a foot) in average bed elevation through degradation could potentially cause indirect impacts to existing riparian vegetation and wetland systems through spatial and temporal changes in groundwater access.

7. Three of the four climate models analyzed result in increased long-term average bed degradation where the SEF has greater potential for bed degradation relative to the SRF. The remaining scenario modeled under HadGEM2-ES climate model, which represents warmer and drier conditions, is the only model of the four that estimates a decrease in long-term bed degradation for the SEF and SRF (Figures 15 and 16).

5. REFERENCES

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ENCLOSURES

TABLES

FIGURES

EXHIBITS

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TABLES

Table 1. Rush Creek Long-Term (28-Year) Average Net Bed Degradation Results (feet)

Reach	Combined		4A		4B		4C		5A	
Flow Scenario	SRF	SEF	SRF	SEF	SRF	SEF	SRF	SEF	SRF	SEF
Sample Size	105	105	10	10	50	50	10	10	35	35
Maximum Outlier	3.11	3.20	2.75	N/A	2.77	2.85	N/A	N/A	N/A	N/A
Upper Limit	2.09	2.37	1.86	2.83	1.89	1.95	1.57	1.62	3.11	3.20
3rd Quartile	1.29	1.38	1.43	1.70	1.15	1.25	0.70	0.83	1.51	1.70
Mean	0.93	1.03	1.25	1.39	0.92	1.02	0.28	0.31	1.03	1.15
Median	0.81	0.92	1.11	1.24	0.78	0.90	0.15	0.20	0.84	0.99
1st Quartile	0.58	0.70	0.82	0.93	0.59	0.77	-0.25	0.29	0.43	0.47
Lower Limit	-0.32	-0.33	0.54	0.72	0.16	0.21	-0.55	-0.57	-0.33	-0.33
Minimum Outlier	-0.55	-0.57	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 2. Lee Vining Creek Long-Term (28-Year) Average Net Bed Degradation Results (feet)

Reach	Combined		3A		3B		3C		3D	
Flow Scenario	SRF	SEF	SRF	SEF	SRF	SEF	SRF	SEF	SRF	SEF
Sample Size	75	75	15	15	50	50	5	5	5	5
Maximum Outlier	7.73	8.70	N/A	N/A	7.73	8.70	4.85	N/A	3.11	N/A
Upper Limit	6.17	7.09	2.99	3.44	6.17	7.50	3.25	5.58	2.08	3.57
3rd Quartile	2.78	3.20	1.55	2.02	2.79	3.20	3.25	4.66	2.08	2.98
Mean	1.83	2.09	0.85	0.97	1.97	2.25	3.18	3.64	2.04	2.33
Median	1.76	2.02	0.60	0.79	1.86	2.14	2.85	3.26	1.83	2.09
1st Quartile	0.35	0.39	-0.12	-0.16	0.31	0.32	2.83	2.81	1.81	1.80
Lower Limit	-0.23	-0.27	-0.23	-0.27	-0.10	-0.11	2.83	2.38	1.81	1.52
Minimum Outlier	N/A	N/A	N/A	N/A	N/A	N/A	2.12	N/A	1.35	N/A

Table 3. Rush Creek Long-Term (28-Year) Average Net Bed Degradation Difference Results (SEF-SRF in feet)

Reach	Combined	4A	4B	4C	5A
Sample Size	105	10	50	10	35
Maximum Outlier	0.52	N/A	0.42	N/A	0.52
Upper Limit	0.28	0.27	0.25	0.15	0.35
3rd Quartile	0.15	0.17	0.14	0.09	0.18
Mean	0.11	0.13	0.11	0.03	0.12
Median	0.09	0.12	0.10	0.01	0.09
1st Quartile	0.05	0.09	0.05	-0.03	0.04
Lower Limit	-0.05	0.05	0.01	-0.05	-0.04
Minimum Outlier	N/A	N/A	N/A	N/A	N/A

Table 4. Lee Vining Creek Long-Term (28-Year) Average Net Bed Degradation Difference Results (SEF-SRF in feet)

Reach	Combined	3A	3B	3C	3D
Sample Size	75	15	50	5	5
Maximum Outlier	0.97	N/A	0.97	N/A	N/A
Upper Limit	0.92	0.45	0.94	0.73	0.46
3rd Quartile	0.40	0.25	0.41	0.61	0.39
Mean	0.26	0.12	0.28	0.46	0.29
Median	0.25	0.10	0.26	0.41	0.26
1st Quartile	0.05	-0.02	0.04	0.33	0.21
Lower Limit	-0.05	0.05	0.01	-0.05	-0.04
Minimum Outlier	N/A	N/A	N/A	N/A	N/A

FIGURES

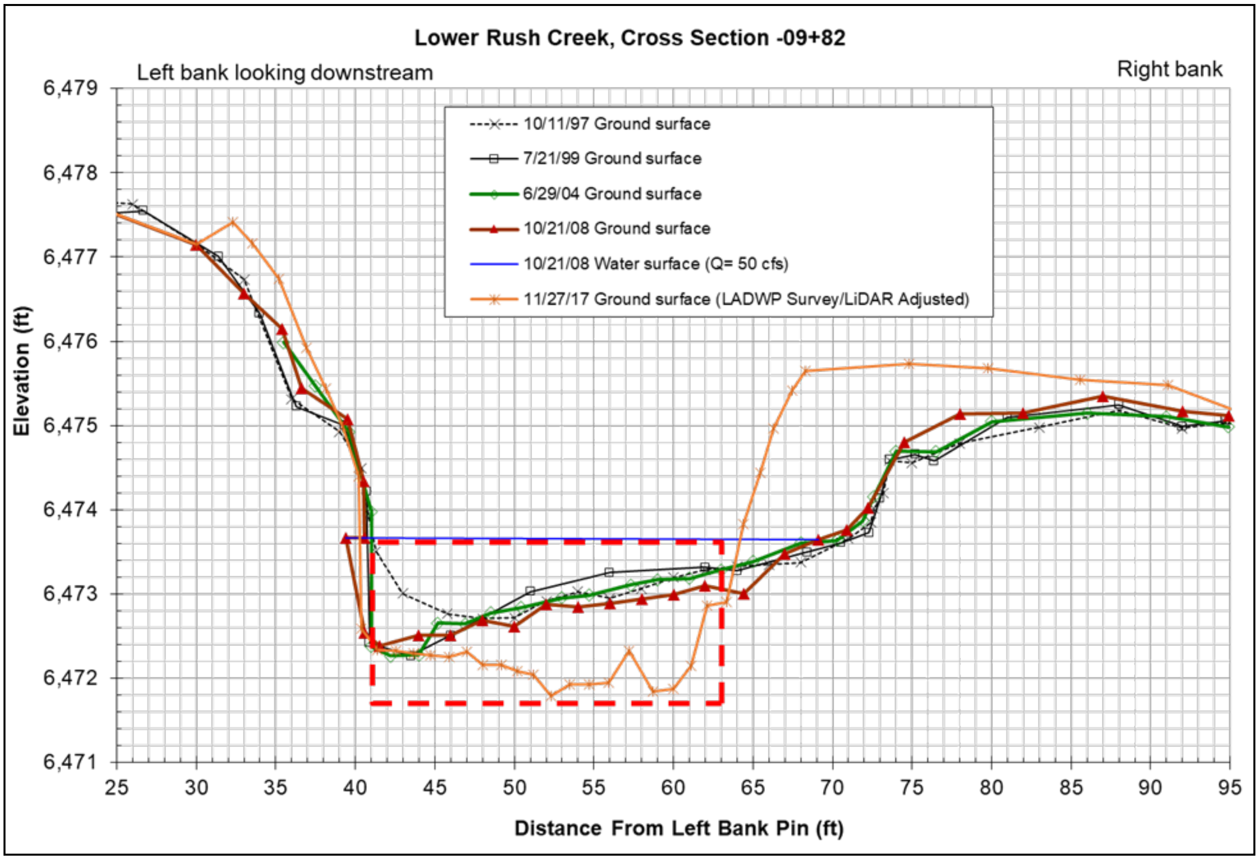


Figure 1. Example Historical Cross Section Survey Comparison - Rush Creek XS -09+82

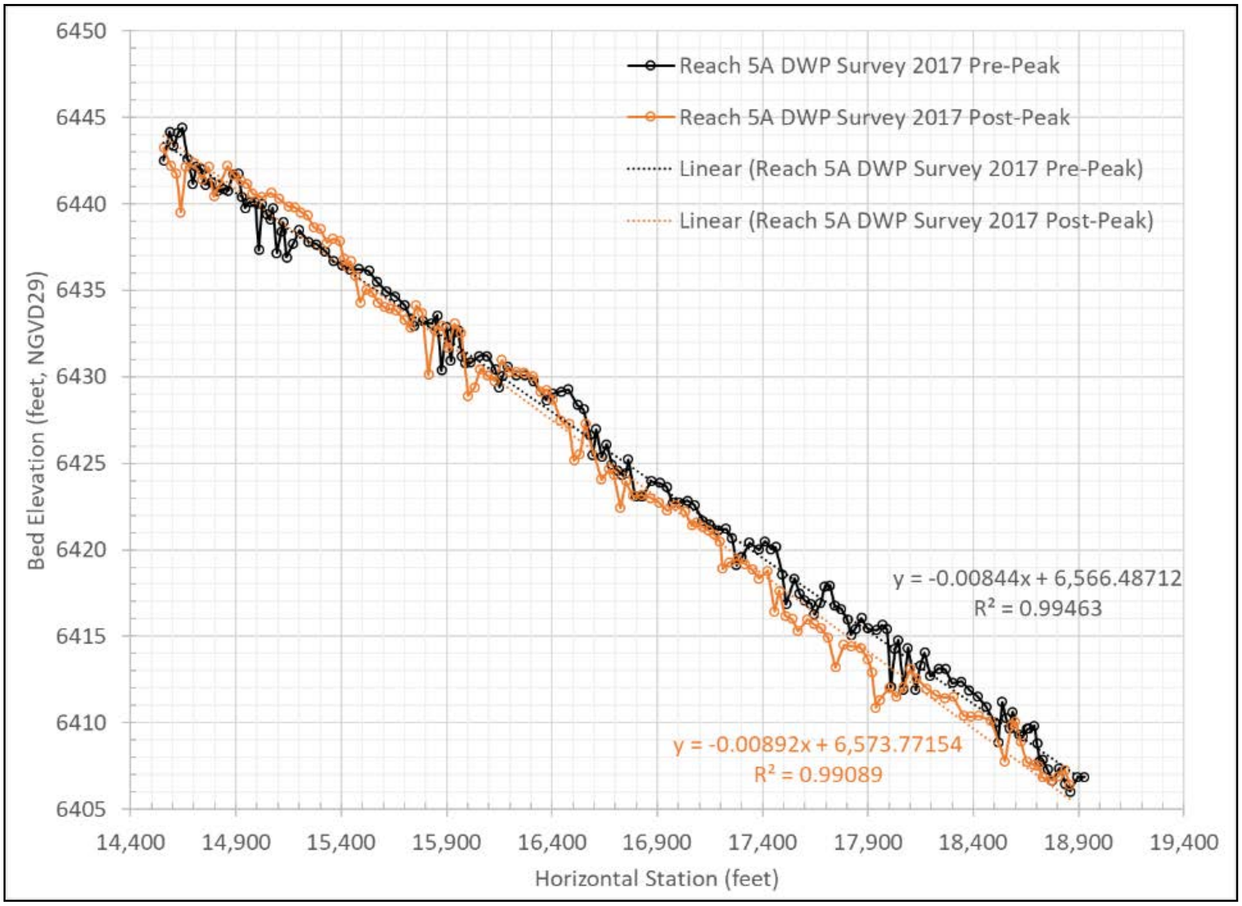


Figure 2. Example Historical Longitudinal Profile Survey Comparison – Rush Creek Reach 5A

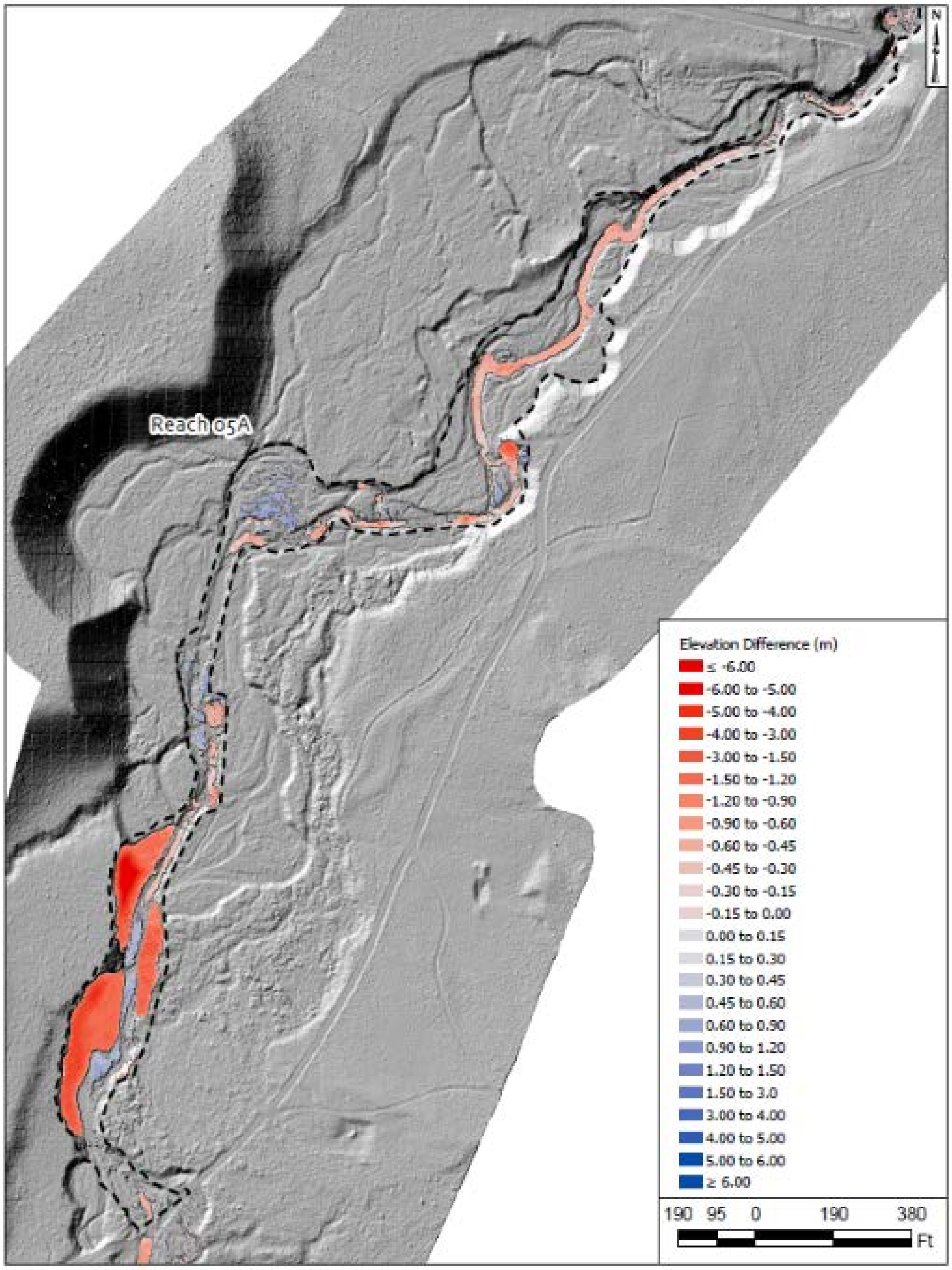


Figure 3. Example Geomorphic Change Detection Map (from Pre- and Post-Peak 2017) – Rush Creek Reach 5A (Upper Portion)

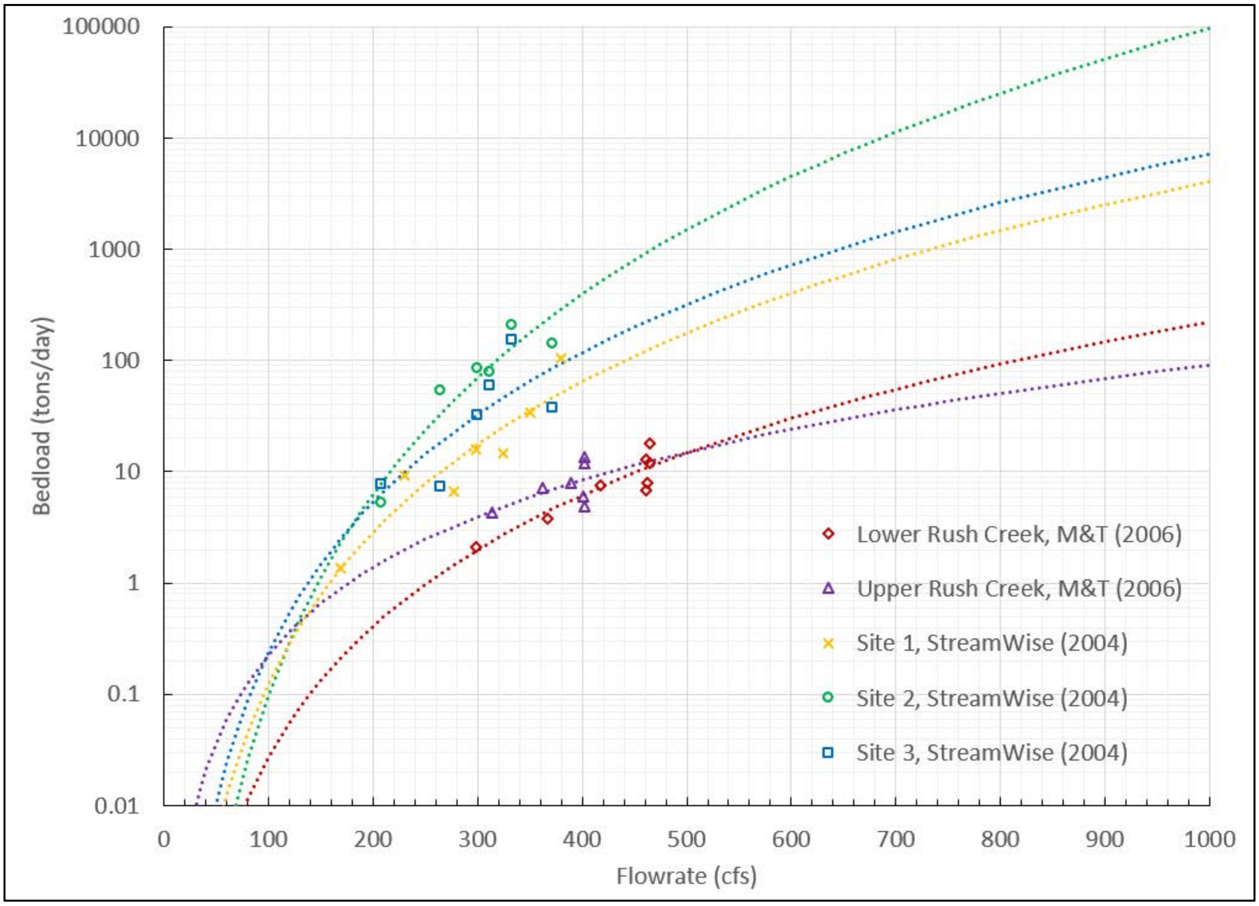


Figure 4. Bedload Data and Rating Curves

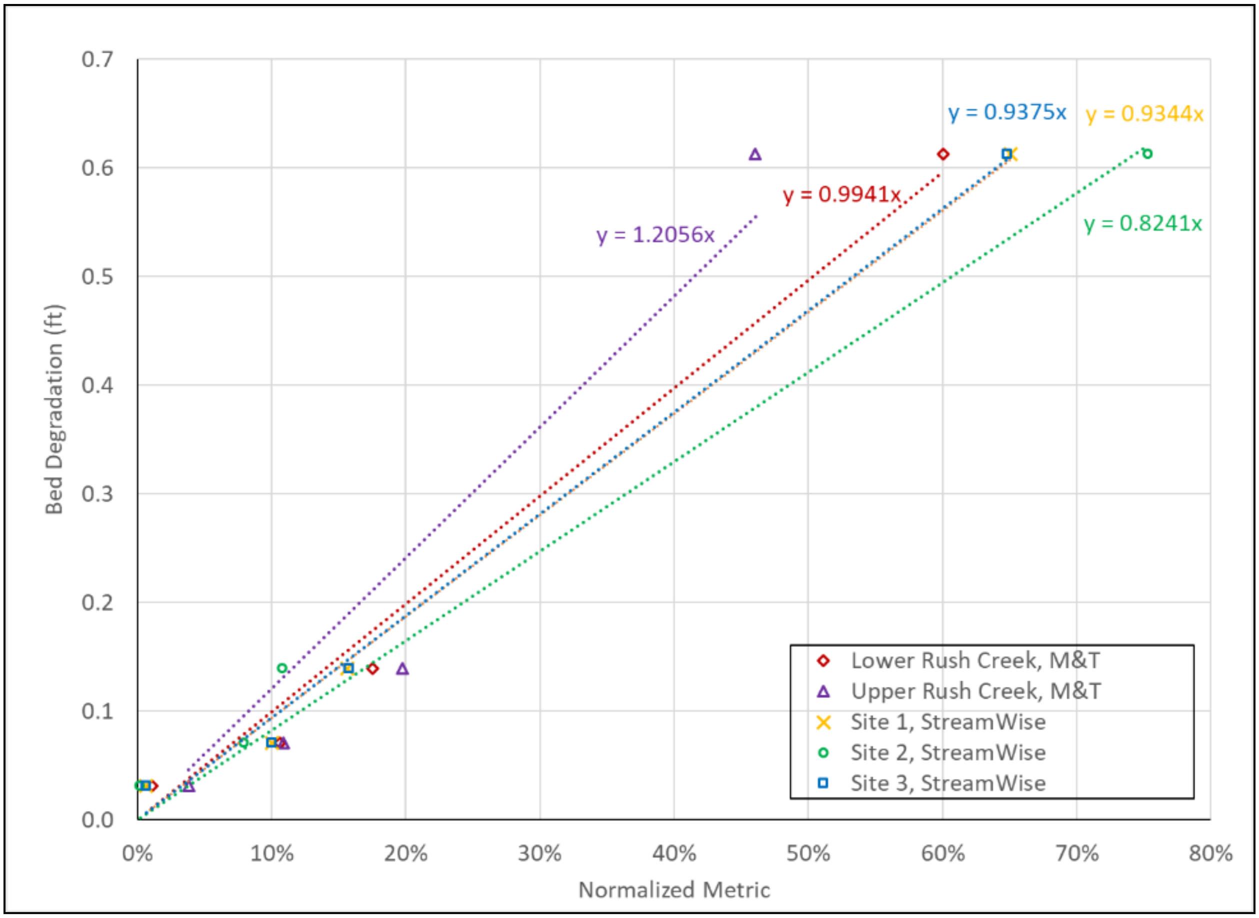


Figure 5. Example Relationship Between Normalized Bedload Transport and Bed Degradation – Rush Creek XS -09+82

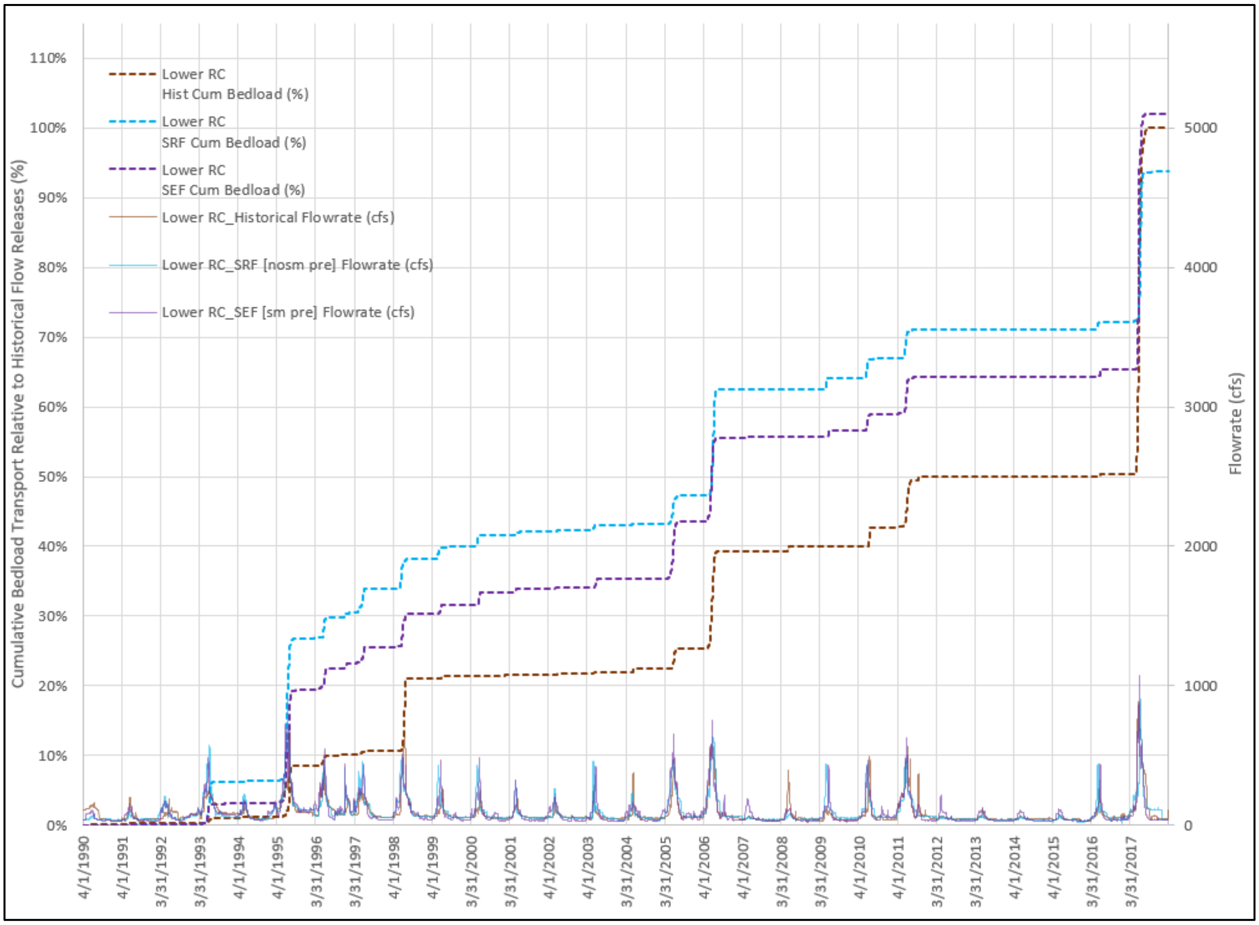


Figure 6. Lower Rush Creek, Below the Narrows, Cumulative Bedload Transport for Flow Regimes Relative to Historical Flow Releases using M&T Lower Rush Creek Bedload Site

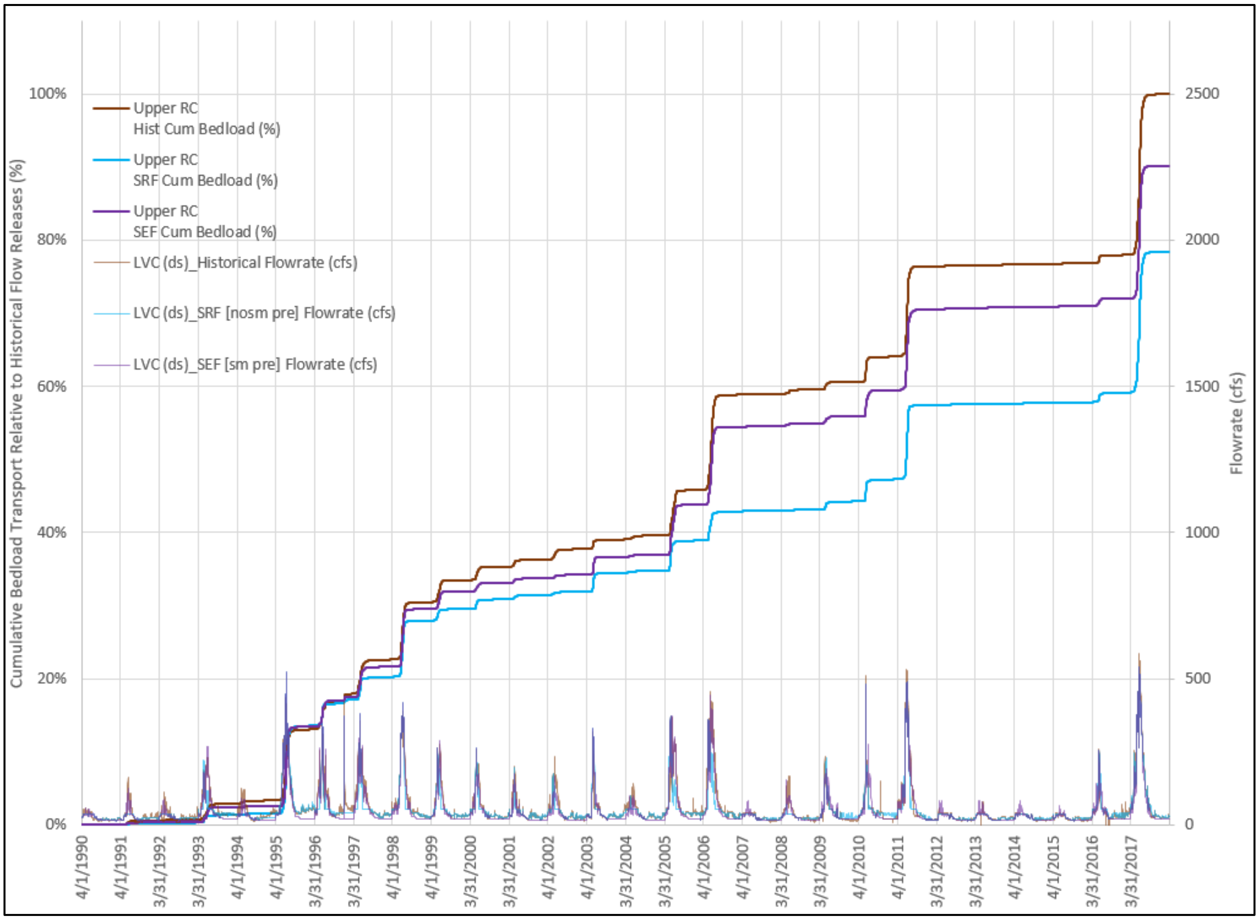


Figure 7. Lee Vining Creek, Below Intake, Cumulative Bedload Transport for Flow Regimes Relative to Historical Flow Releases using M&T Upper Rush Creek Bedload Site

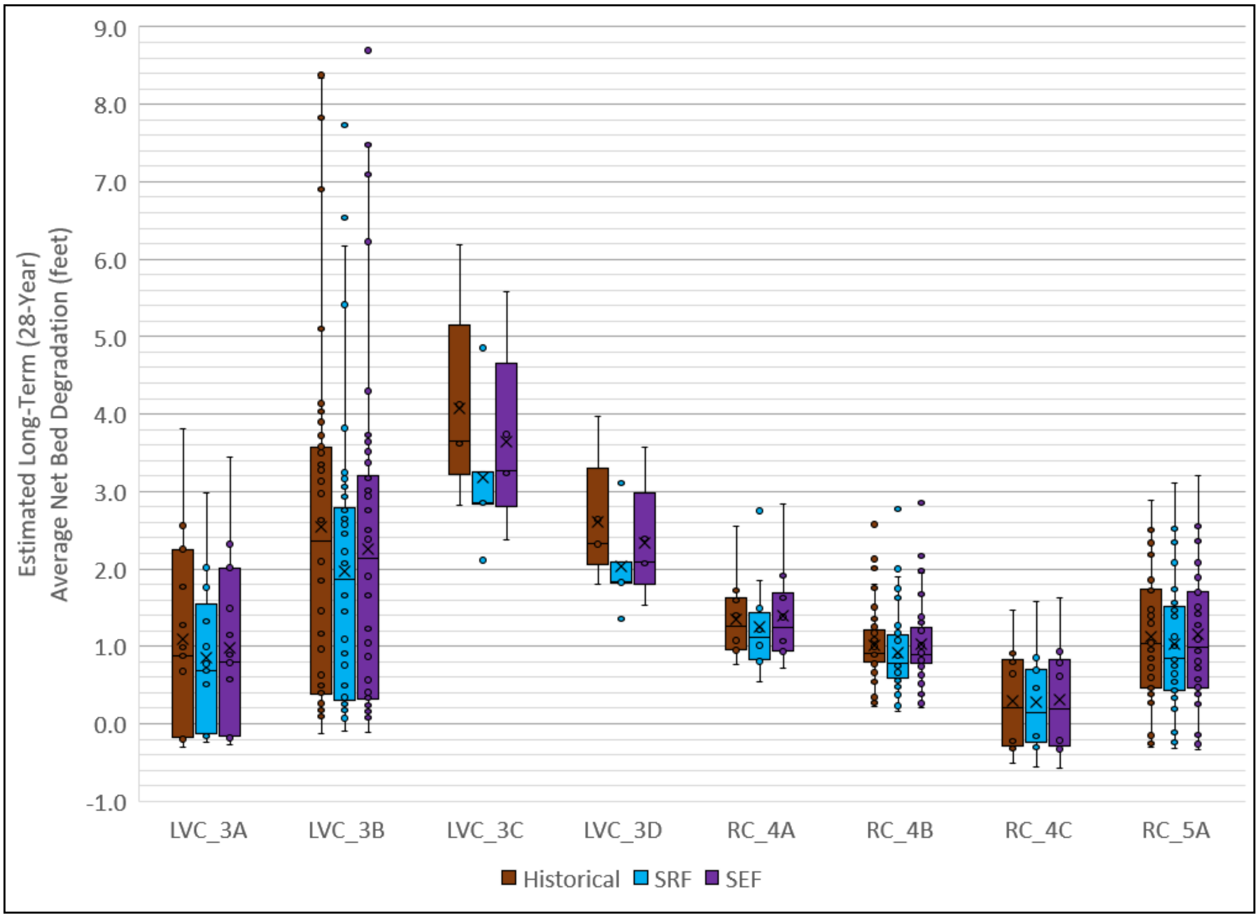


Figure 8. Box and Whisker Plots of Long-Term (28-Year) Average Net Bed Degradation Results by Reach

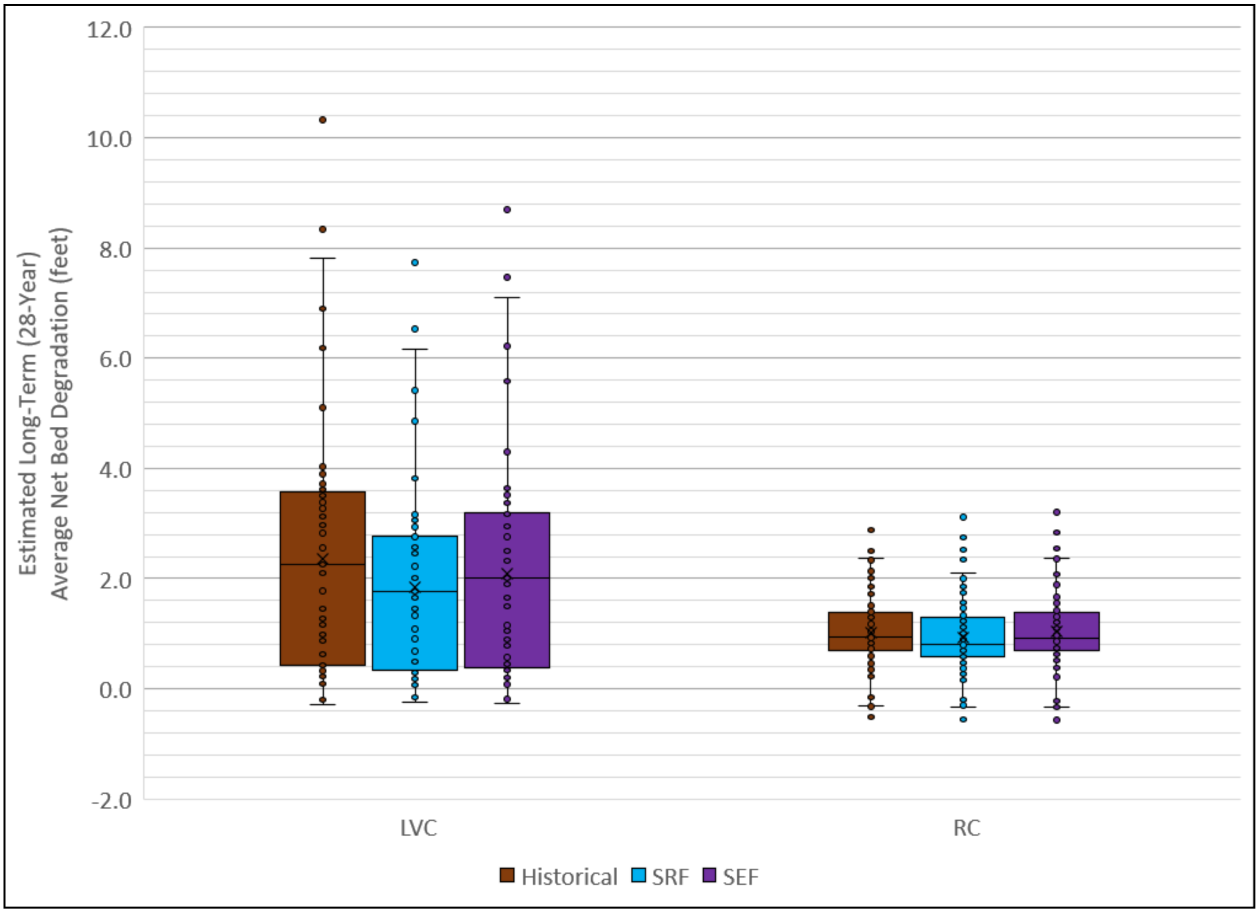


Figure 9. Box and Whisker Plots of Long-Term (28-Year) Average Net Bed Degradation Results by Creek

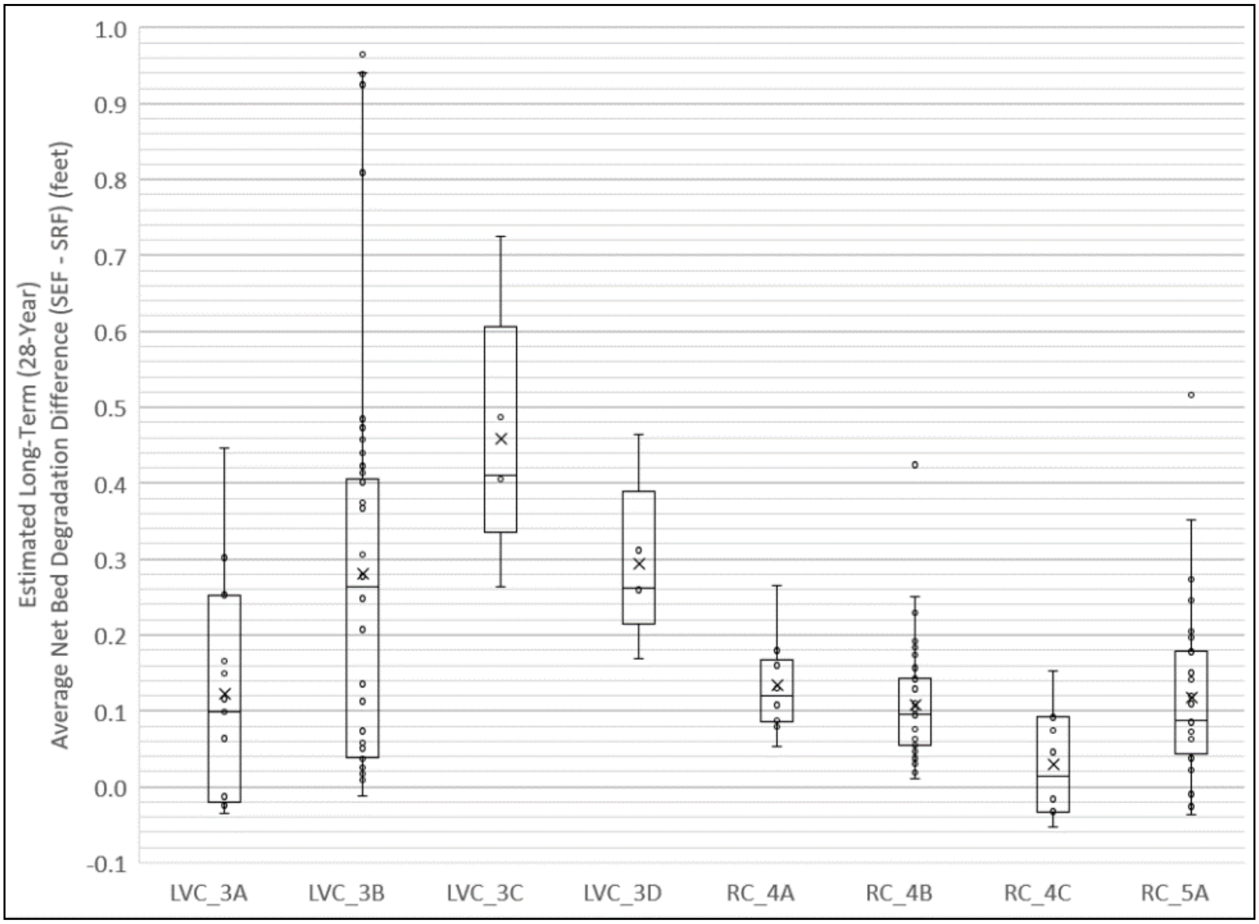


Figure 10. Box and Whisker Plots of Long-Term (28-Year) Average Net Bed Degradation Difference Results (SEF – SRF) by Reach

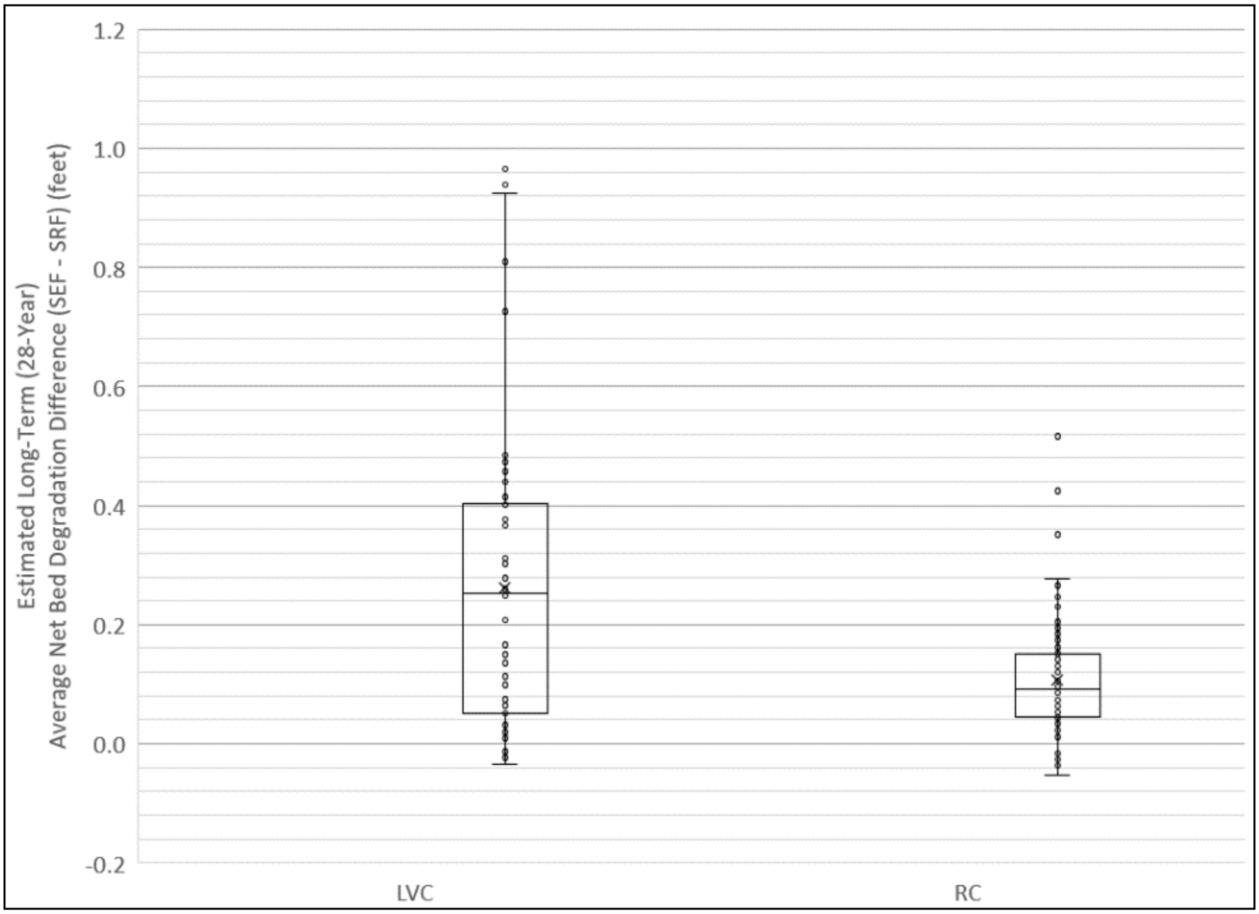


Figure 11. Box and Whisker Plots of Long-Term (28-Year) Average Net Bed Degradation Difference Results (SEF – SRF) by Creek

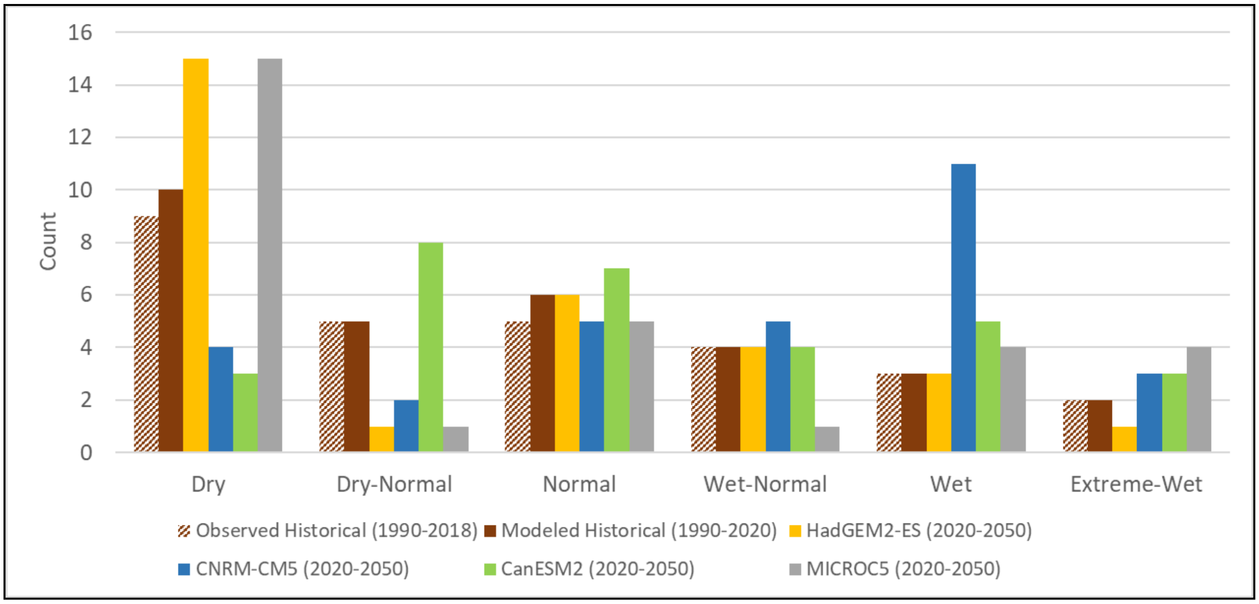


Figure 12. Runoff Year Type Distributions for Historical Conditions and Climate Models

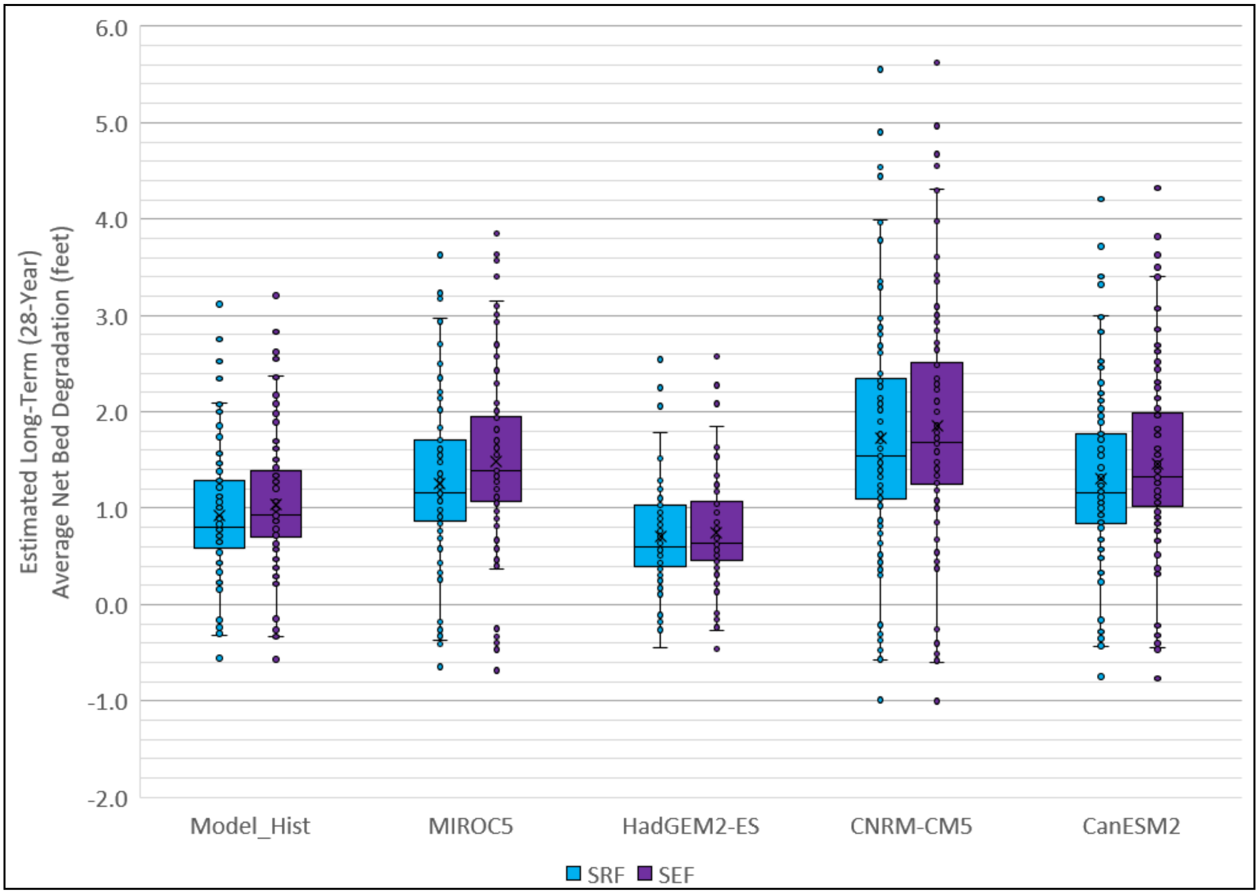


Figure 13. Box and Whisker Plots of Rush Creek Long-Term Bed Degradation Results for Climate Models

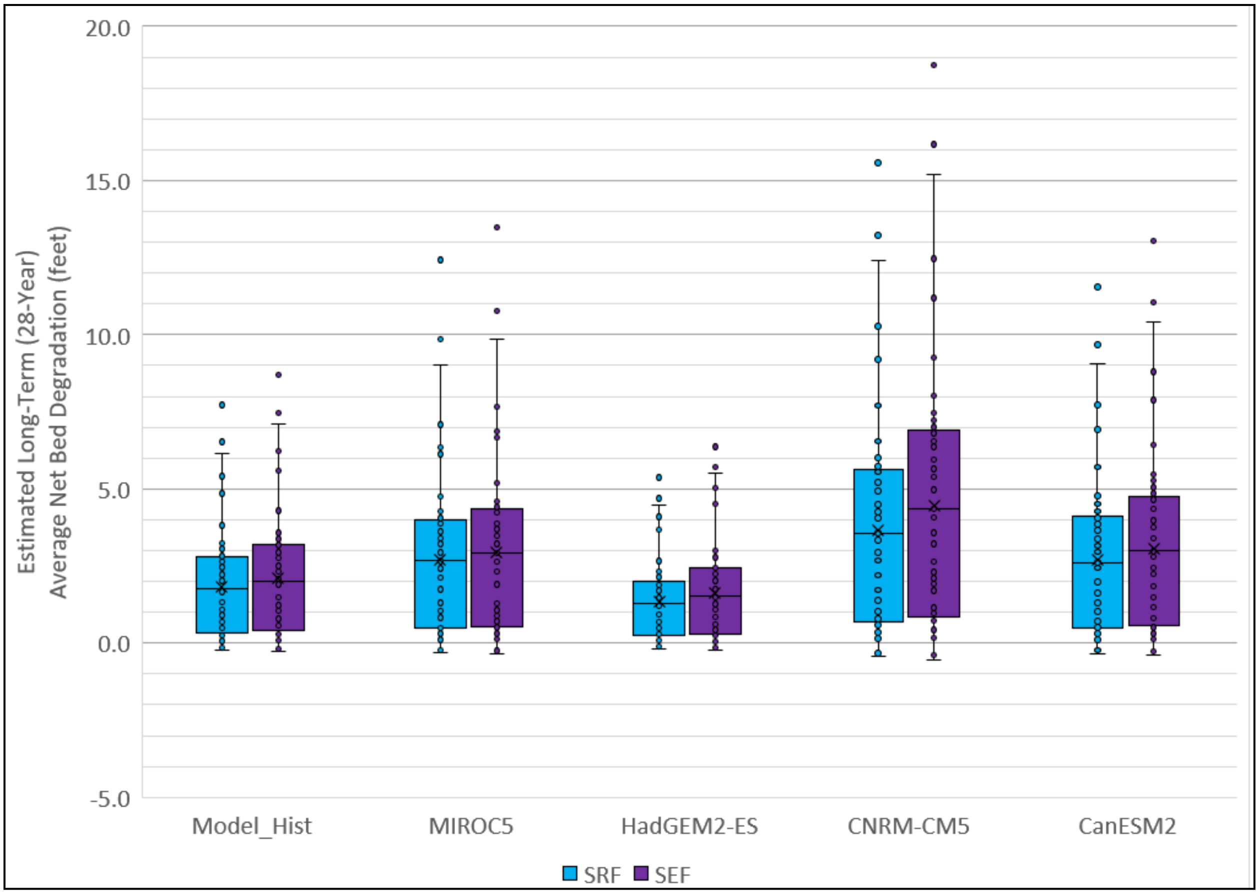


Figure 14. Box and Whisker Plots of Lee Vining Creek Long-Term Bed Degradation Results for Climate Models

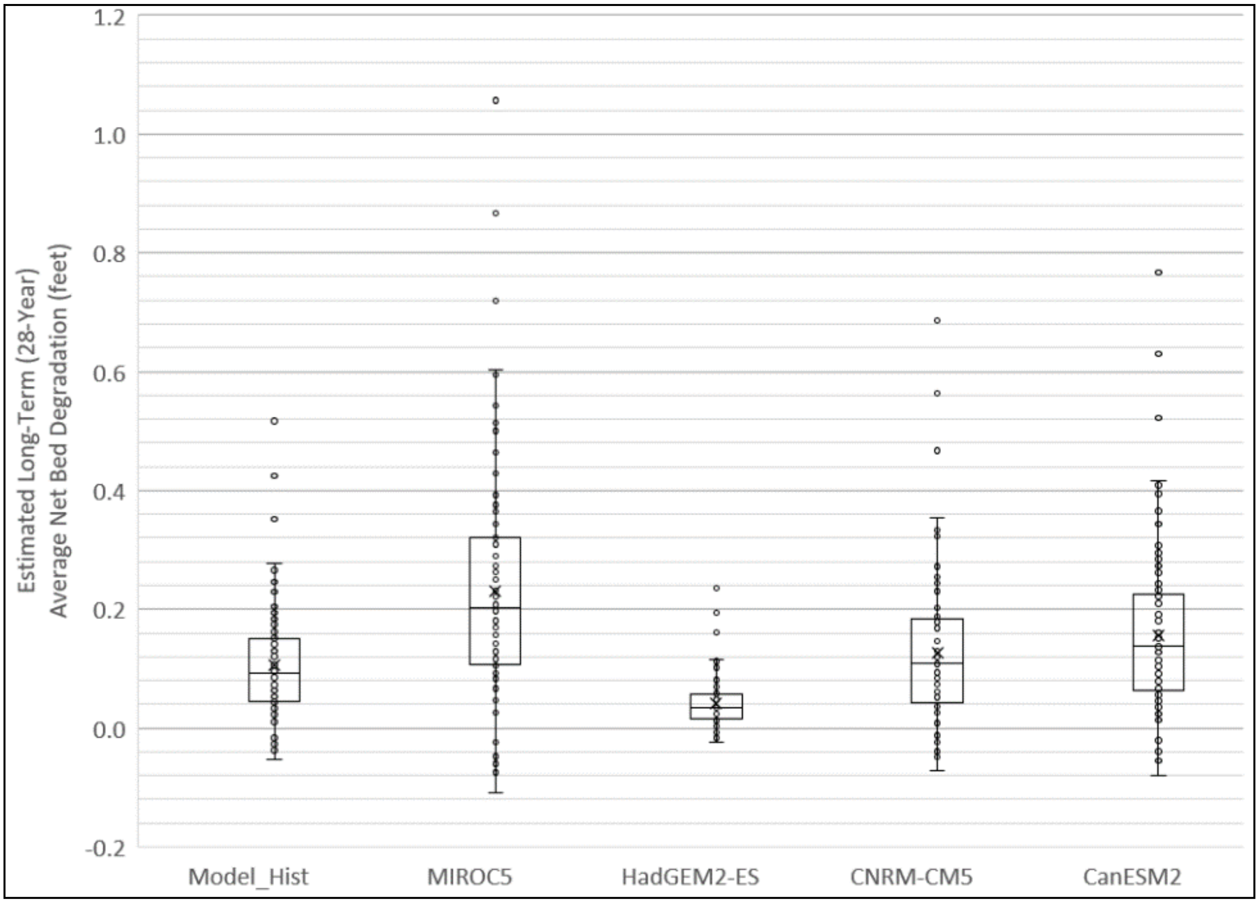


Figure 15. Box and Whisker Plots of Rush Creek Long-Term Bed Degradation Difference Results (SEF – SRF) for Climate Models

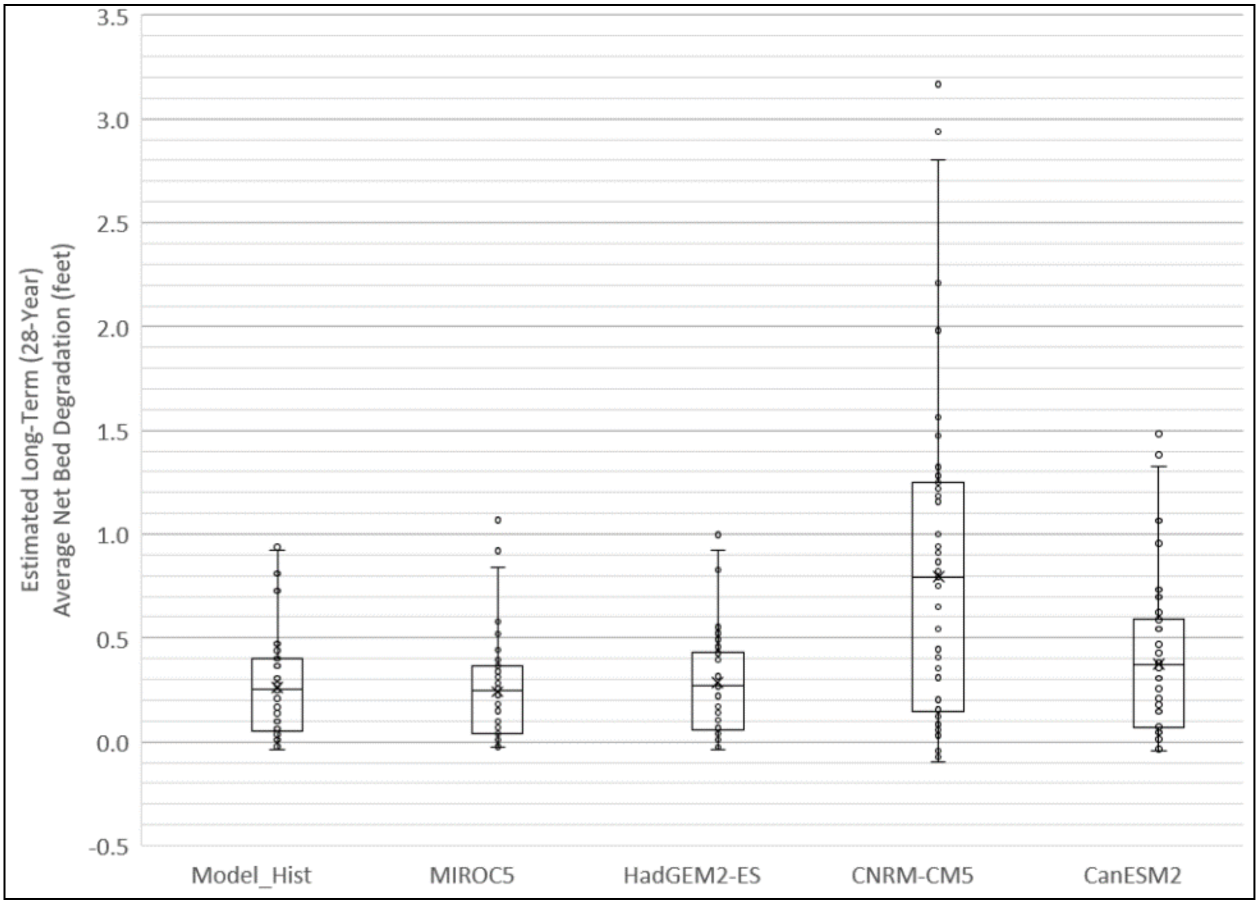
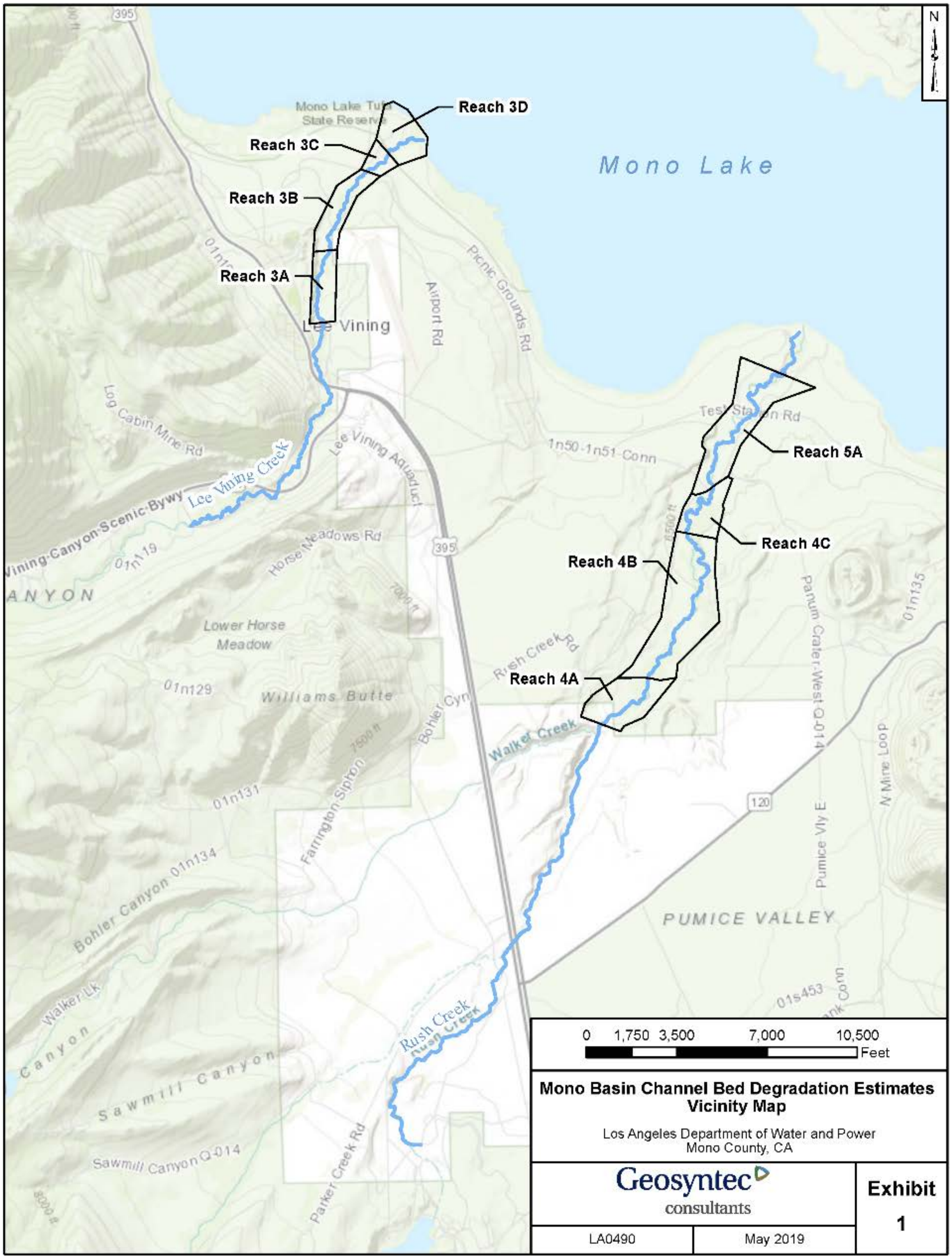
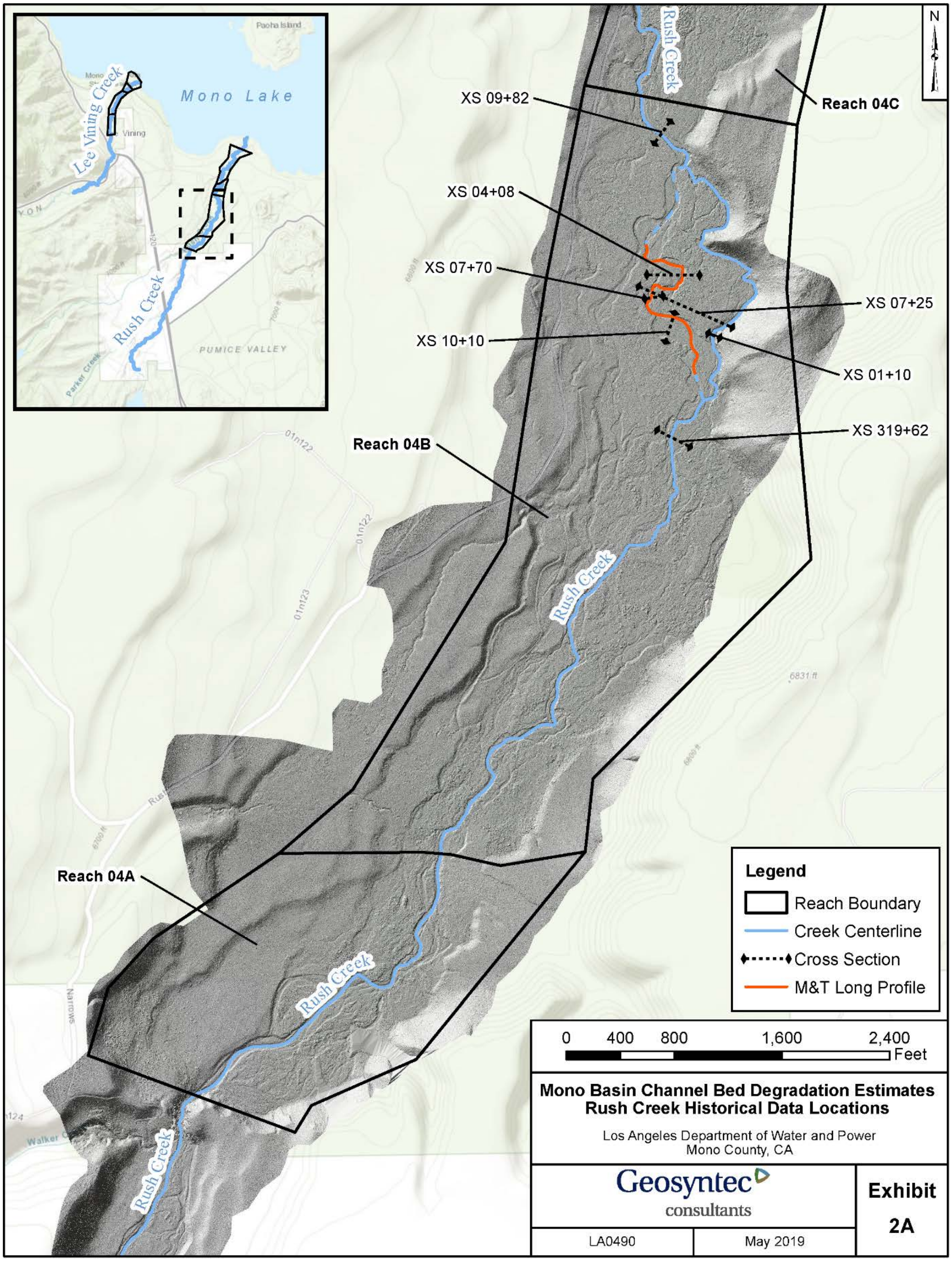
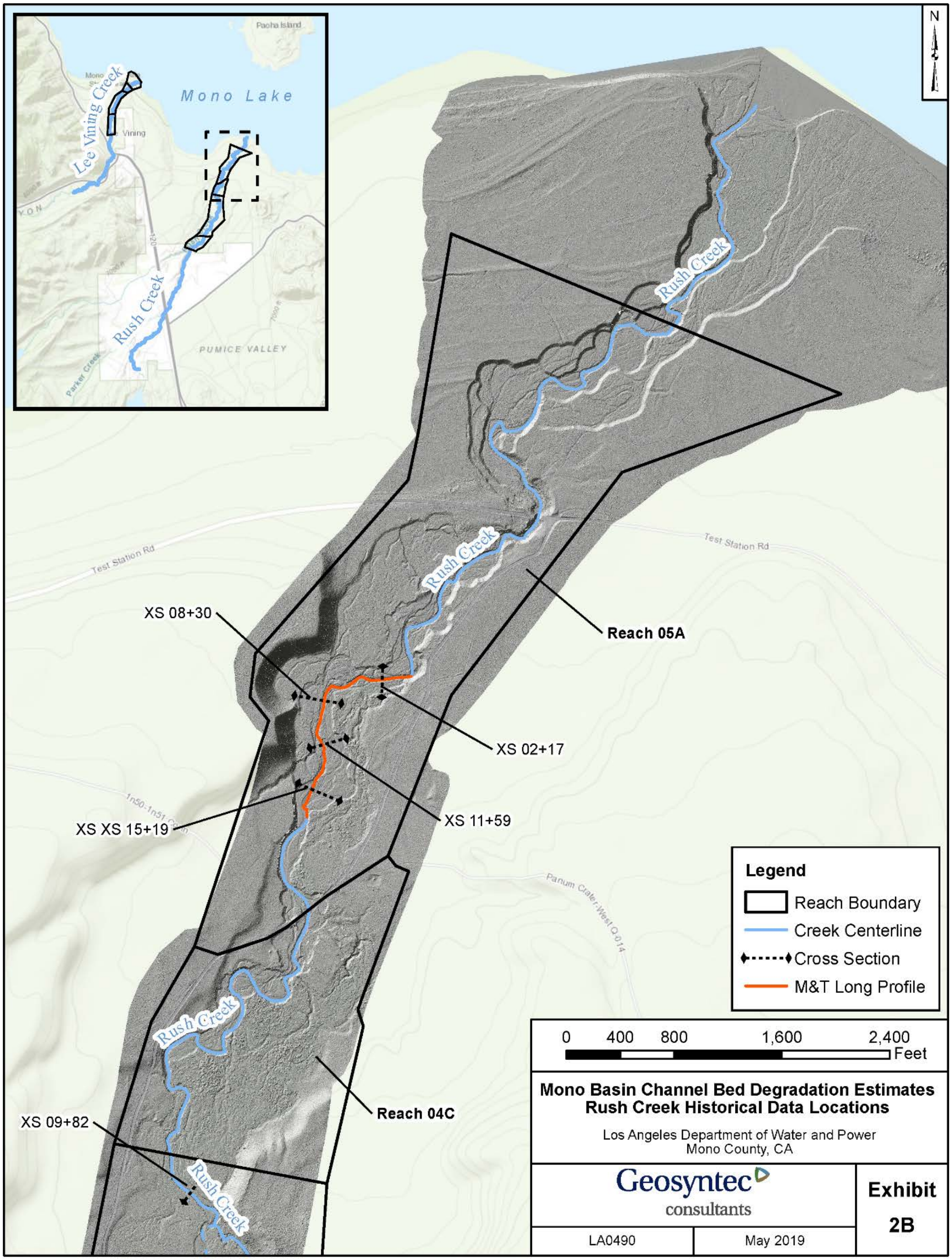


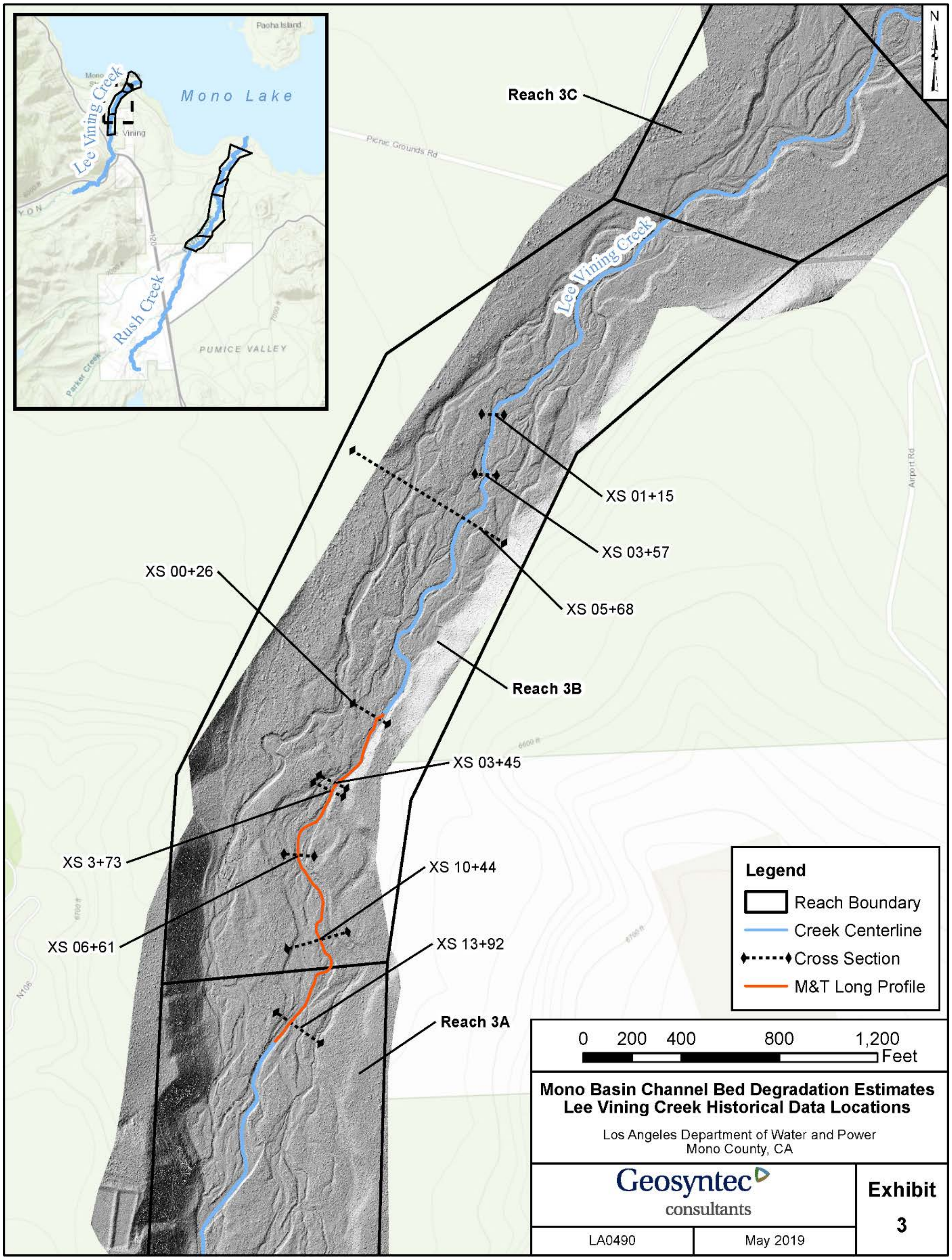
Figure 16. Box and Whisker Plots of Lee Vining Creek Long-Term Bed Degradation Difference Results (SEF – SRF) for Climate Models

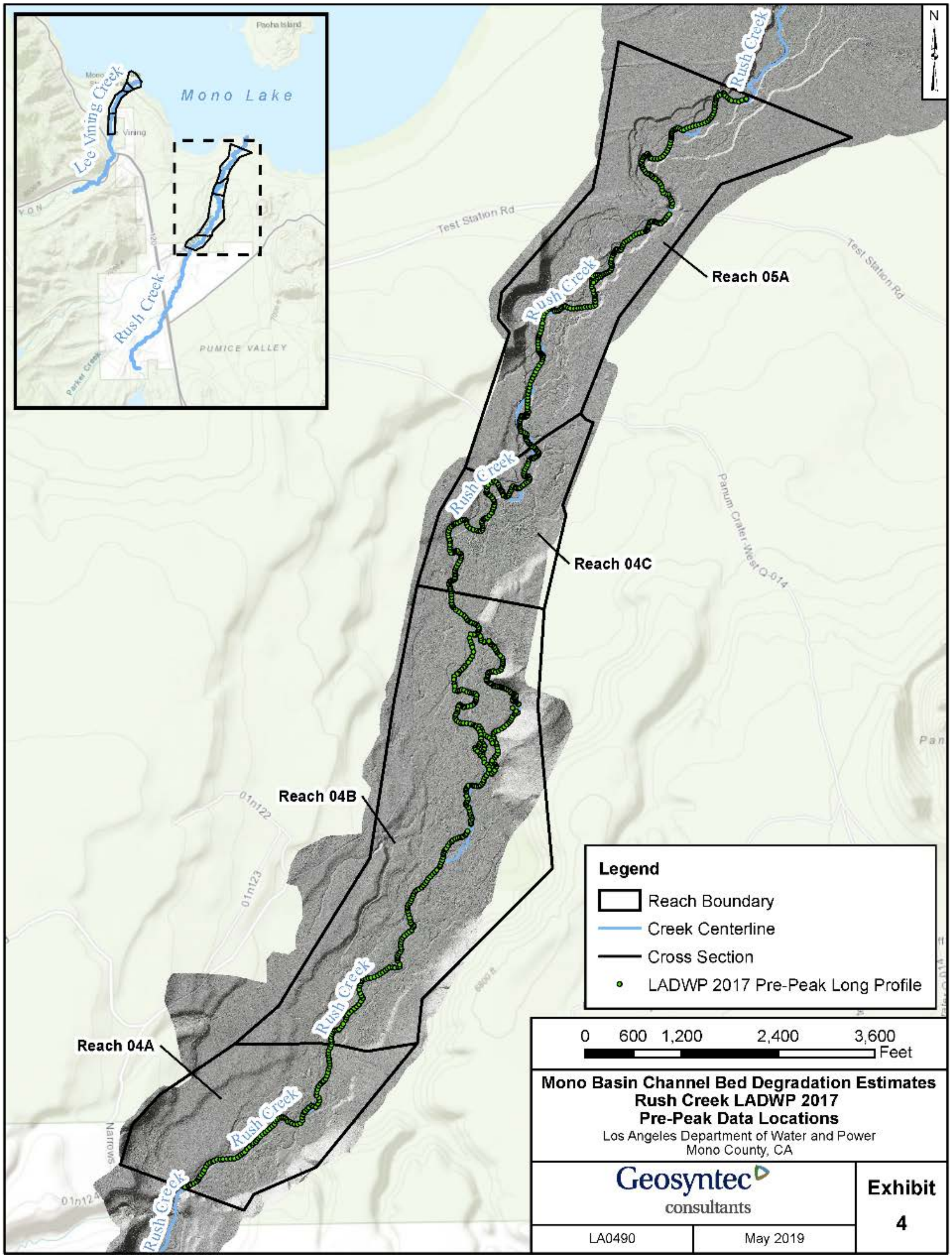
EXHIBITS

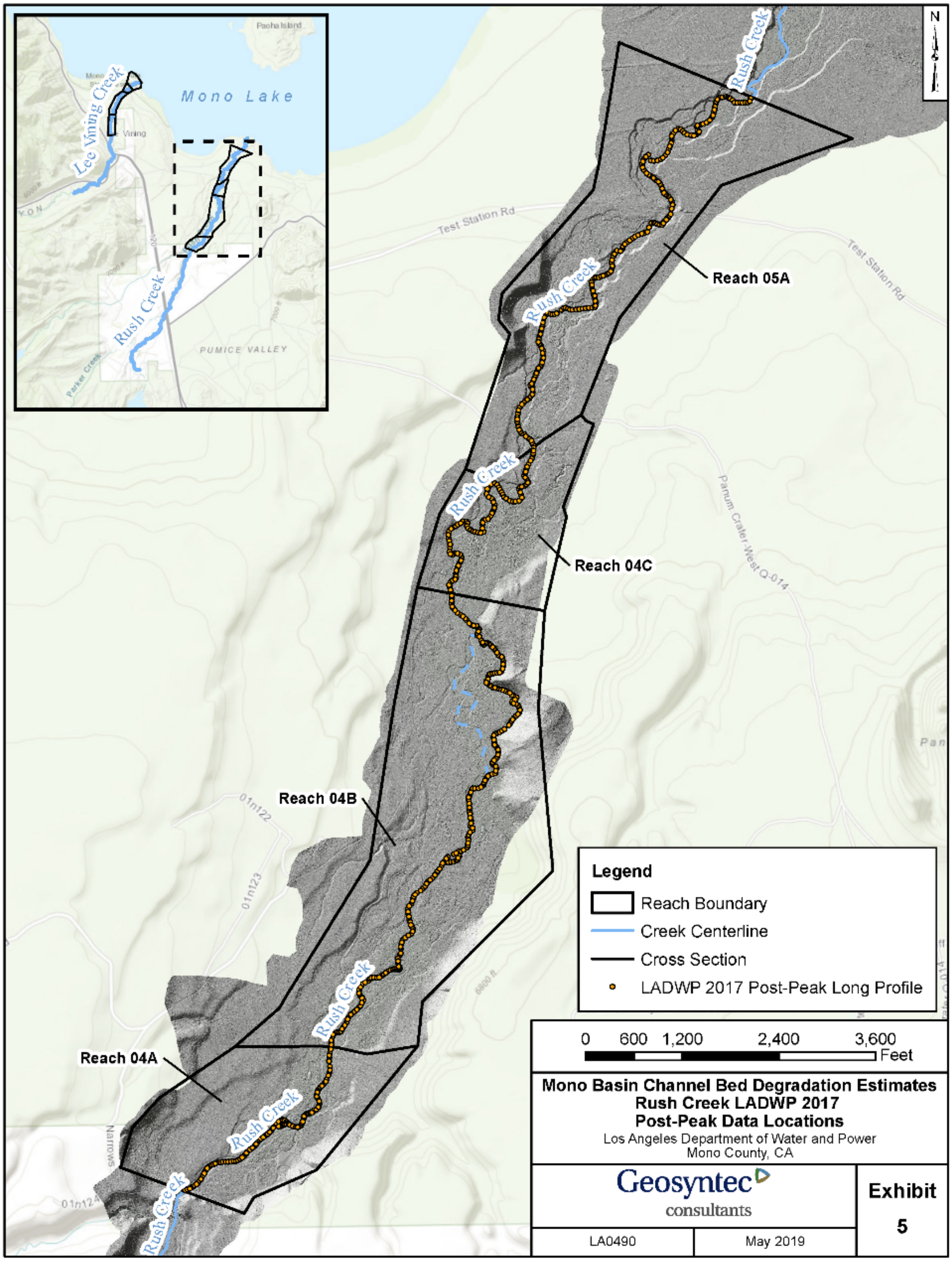

Reach 3D
Reach 3C
Reach 3B
Reach 3A
Mono Lake Tufa State Reserve
Mono Lake
Lee Vining
Airport Rd
Picnic Grounds Rd
Lee Vining Creek
Lee Vining Aqueduct
Log Cabin Mine Rd
Test Station Rd
1n50-1n51-Conn
Reach 5A
Reach 4C
Reach 4B
Reach 4A
Rush Creek Rd
Walker Creek
Rush Creek
Horse Meadows Rd
Lower Horse Meadow
Williams Butte
Bohler Cyn
Farrington Siphon
Bohler Canyon
Sawmill Canyon
Parker Creek Rd
Panum Crater-West-Q-014
Pumice Vly E
N Mine Loop
PUMICE VALLEY
0 1,750 3,500 7,000 10,500 Feet
Mono Basin Channel Bed Degradation Estimates
Vicinity Map
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec consultants
Exhibit 1
LA0490
May 2019

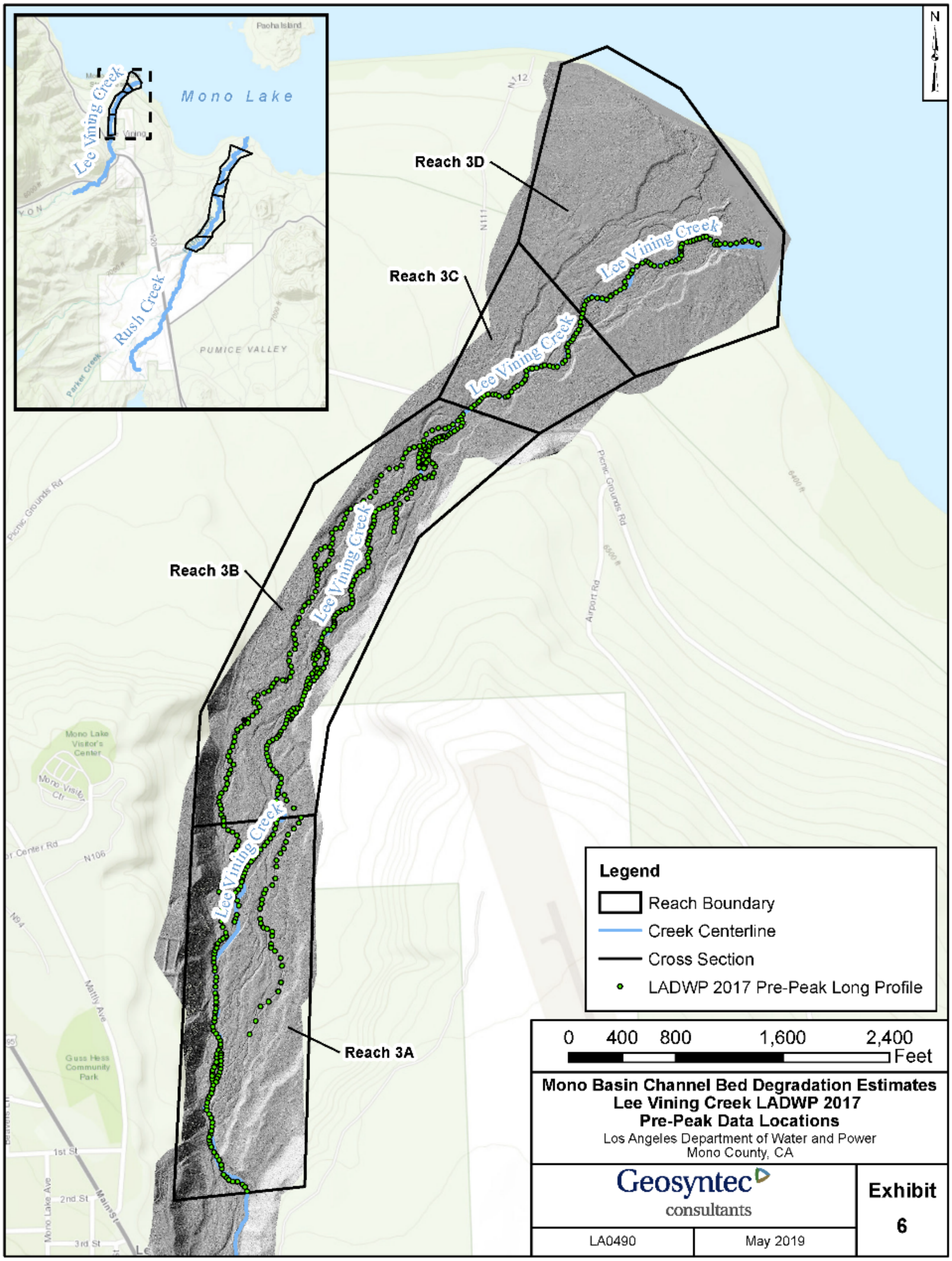

Mono Lake
Paoha Island
Lee Vining Creek
Vining
Rush Creek
PUMICE VALLEY
Parker Creek
N
Rush Creek
XS 09+82
Reach 04C
XS 04+08
XS 07+70
XS 07+25
XS 10+10
XS 01+10
XS 319+62
Reach 04B
Rush Creek
Reach 04A
Rush Creek
Rush Creek
Legend
Reach Boundary
Creek Centerline
Cross Section
M&T Long Profile
0 400 800 1,600 2,400 Feet
Mono Basin Channel Bed Degradation Estimates
Rush Creek Historical Data Locations
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec
consultants
Exhibit
2A
LA0490
May 2019

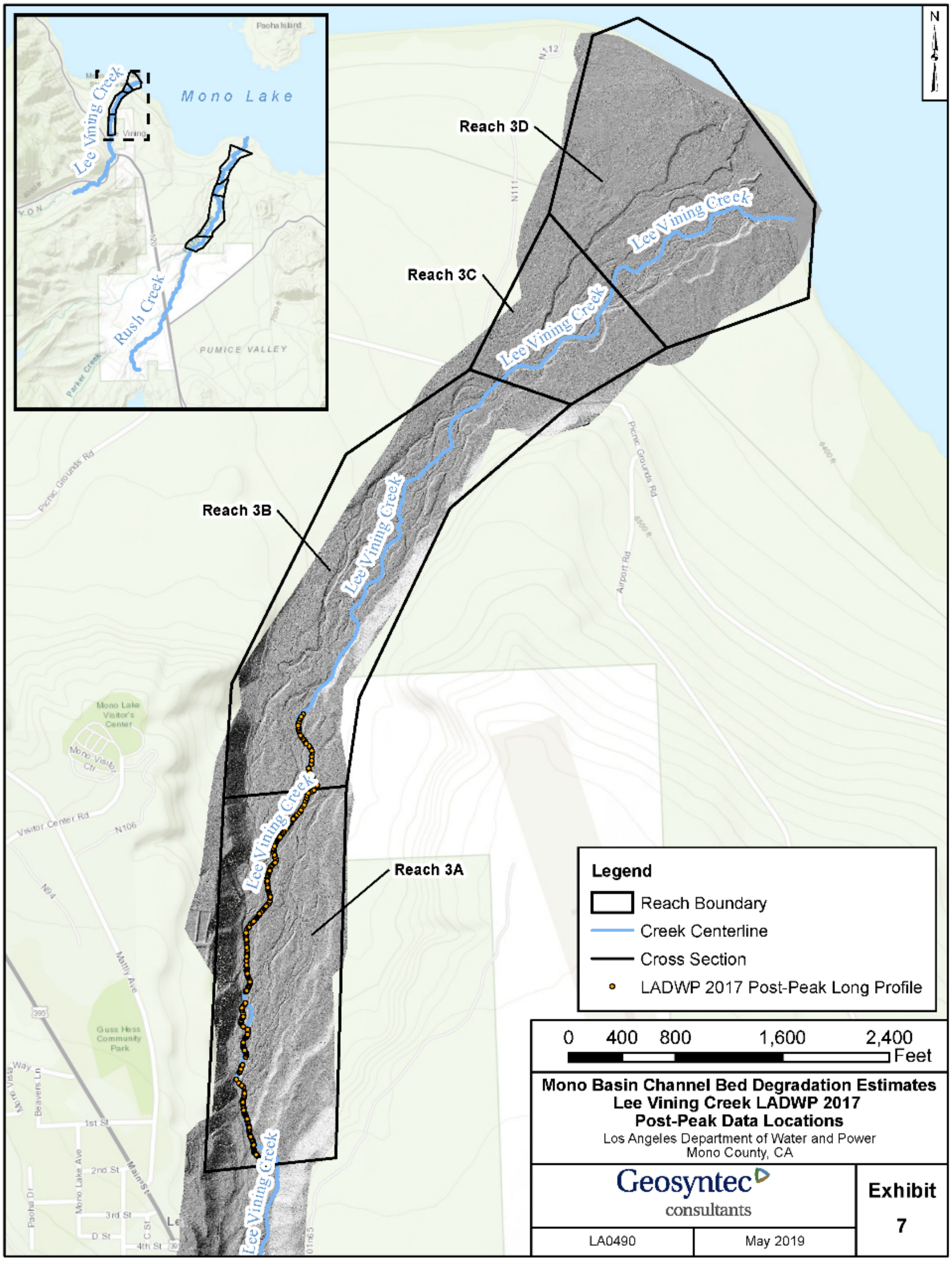

Mono Lake
Lee Vining Creek
Rush Creek
Vining
PUMICE VALLEY
Paoha Island
N
Rush Creek
Test Station Rd
XS 08+30
Reach 05A
XS 02+17
XS 11+59
XS XS 15+19
Panum Crater-West O-014
Legend
Reach Boundary
Creek Centerline
Cross Section
M&T Long Profile
0 400 800 1,600 2,400 Feet
Reach 04C
XS 09+82
Mono Basin Channel Bed Degradation Estimates
Rush Creek Historical Data Locations
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec consultants
Exhibit 2B
LA0490
May 2019

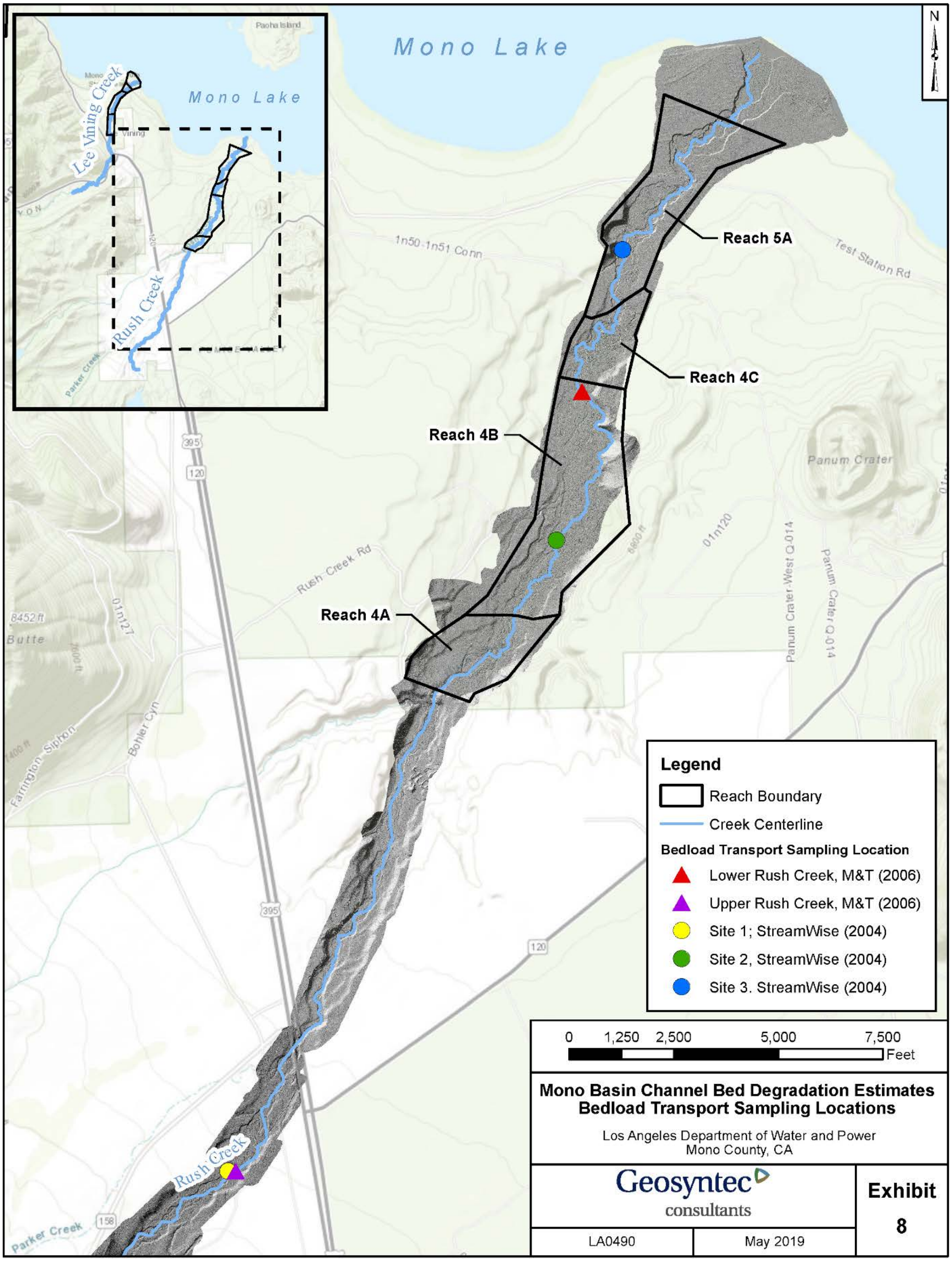

Mono Lake
Lee Vining Creek
Rush Creek
PUMICE VALLEY
Reach 3C
Reach 3B
Reach 3A
XS 01+15
XS 03+57
XS 05+68
XS 00+26
XS 03+45
XS 3+73
XS 10+44
XS 06+61
XS 13+92
Legend
Reach Boundary
Creek Centerline
Cross Section
M&T Long Profile
0 200 400 800 1,200
Feet
Mono Basin Channel Bed Degradation Estimates
Lee Vining Creek Historical Data Locations
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec
consultants
Exhibit
3
LA0490
May 2019


Mono Lake
Lee Vining Creek
Rush Creek
Paoha Island
Pumice Valley
Test Station Rd
Reach 05A
Reach 04C
Reach 04B
Reach 04A
Panum Crater-West Q-014
01n122
01n123
01n124
Narrows
Legend
Reach Boundary
Creek Centerline
Cross Section
LADWP 2017 Pre-Peak Long Profile
0 600 1,200 2,400 3,600 Feet
Mono Basin Channel Bed Degradation Estimates
Rush Creek LADWP 2017
Pre-Peak Data Locations
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec consultants
Exhibit
4
LA0490
May 2019


Paoha Island
Mono Lake
Lee Vining Creek
Vining
Rush Creek
PUMICE VALLEY
Parker Creek
Test Station Rd
Reach 05A
Reach 04C
Reach 04B
Reach 04A
Panum Crater-West Q-014
01n122
01n123
01n124
Narrows
Legend
Reach Boundary
Creek Centerline
Cross Section
LADWP 2017 Post-Peak Long Profile
0 600 1,200 2,400 3,600
Feet
N
Mono Basin Channel Bed Degradation Estimates
Rush Creek LADWP 2017
Post-Peak Data Locations
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec
consultants
Exhibit
5
LA0490
May 2019


Mono Lake
Lee Vining Creek
Rush Creek
PUMICE VALLEY
Reach 3D
Reach 3C
Reach 3B
Reach 3A
Picnic Grounds Rd
Airport Rd
Mono Lake Visitor's Center
Legend
Reach Boundary
Creek Centerline
Cross Section
LADWP 2017 Pre-Peak Long Profile
0 400 800 1,600 2,400 Feet
Mono Basin Channel Bed Degradation Estimates
Lee Vining Creek LADWP 2017
Pre-Peak Data Locations
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec consultants
Exhibit
6
LA0490
May 2019


Mono Lake
Lee Vining Creek
Rush Creek
PUMICE VALLEY
Reach 3D
Reach 3C
Reach 3B
Reach 3A
Picnic Grounds Rd
Visitor Center Rd
Mono Lake Visitor's Center
Legend
Reach Boundary
Creek Centerline
Cross Section
LADWP 2017 Post-Peak Long Profile
0 400 800 1,600 2,400
Feet
Mono Basin Channel Bed Degradation Estimates
Lee Vining Creek LADWP 2017
Post-Peak Data Locations
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec
consultants
Exhibit
7
LA0490
May 2019


Mono Lake
Reach 5A
Reach 4C
Reach 4B
Reach 4A
Lee Vining Creek
Rush Creek
Parker Creek
Test Station Rd
1n50-1n51 Conn
Rush Creek Rd
Panum Crater
Legend
Reach Boundary
Creek Centerline
Bedload Transport Sampling Location
Lower Rush Creek, M&T (2006)
Upper Rush Creek, M&T (2006)
Site 1; StreamWise (2004)
Site 2, StreamWise (2004)
Site 3. StreamWise (2004)
0 1,250 2,500 5,000 7,500 Feet
Mono Basin Channel Bed Degradation Estimates
Bedload Transport Sampling Locations
Los Angeles Department of Water and Power
Mono County, CA
Geosyntec consultants
Exhibit 8
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May 2019

End of Technical Memorandum

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