THE RANCH PLAN PLANNED COMMUNITY

PLANNING AREAS 3 AND 4 RUNOFF MANAGEMENT PLAN

Michael Baker INTERNATIONAL

TECHNICAL APPENDIX O.1

ARM Study Memorandum for More Frequent Storm Events

OC Public Works
Integrity, Accountability, Service, Trust
Shane L. Silsby, Director

Memorandum

DATE: February 20, 2018

TO: Khalid Bazmi, P.E., Assistant Director/County Engineer, OC Public Works

FROM: Robert McLean, P.E., Senior Civil Engineer, Infrastructure Programs

SUBJECT: RMV – Summary of ARM Study results and findings related to FEIR 589 MM 4.5-1 (G).

Introduction

This memorandum collectively gathers the findings of several studies which cumulatively identified, examined, and quantified potential impacts along San Juan Creek resulting from development within the Rancho Mission Viejo (RMV) Ranch Plan. Specifically, the studies examined matters concerning Mitigation Measure (MM) 4.5-1 (G) as identified within Final Environmental Impact Report 589. For reference purposes, these previous studies are included as attachments to this memo. MM 4.5-1 (G) is defined as follows:

The ROMP shall analyze and demonstrate that development of the Ranch Plan will not produce adverse impacts during the 2, 5, 10, 25, 50 and 100-year events, including but not limited to increases in runoff peak discharge, increases in runoff volume, channel aggradation/degradation, erosion and channel stability within the project site and off-site from the headwaters of the watershed to the La Novia Bridge for the development within the San Juan Creek watershed, and to the County boundary for development within the San Mateo watershed for portions of the streamcourse potentially impacted by the project development. The analysis set forth in the ROMP shall be for existing conditions and for all phases of development, including with and without required mitigation measures.

The effort of these studies focused upon addressing potential non-compliance issues identified within RMV's 2013 ROMP which stated that full mitigation of increased discharges and volumes resulting from the developed condition for smaller storm events (2, 5, and 10-year) could not be achieved. That is, the specific values related to discharge rates and volumes associated with these smaller storm events increased beyond their existing pre-development condition. These changes in discharge and volume forced the need for an assessment and technical analysis to identify any adverse impacts associated with these increases that would need to be addressed under MM 4.5-1 (G). **It shall be noted, as identified within the 2013 ROMP and required under MM 4.5-1 (G) of FEIR 589, full mitigation is achievable and require for the 25, 50, and 100-year expected value storm events.**

The primary concerns and drivers under MM4.5-1 (G) are related to flood control, streambed morphology, and erosion potential. It has been demonstrated that San Juan Creek has adequate capacity to safely convey the existing condition 100-year storm event. Further, the developed condition 100-year storm event is adequately mitigated within the Ranch Plan. As such, it is deduced that any remaining potential impacts are related to erosion and streambed morphology. Therefore, the efforts conducted under this study focused upon erosion and streambed morphology and any associated risks and adverse impacts attributable to the Ranch Plan and the increases in the smaller storm events.

Background

The initial assessment of potential erosion and streambed morphology impacts conducted as part of this study were prepared by Dr. Howard Chang (Chang); Technical Review of San Juan Creek Stream Monitoring by PACE, dated November 21, 2016 with further updates in January 2017. This assessment examined the San Juan Creek Watershed from its headwaters located well above RMV's project in the Cleveland National Forest, through the Ranch Plan, and onward beyond the development toward the Pacific Ocean.

The overall conclusions of Chang's analysis determined that erosion and stream morphology impacts resultant from the Ranch Plan were expected to be negligible and that the primary source of sediment supply within the San Juan Creek watershed lay far up in the erosion producing areas within the Cleveland National Forest. Chang's study further concluded that the primary channel-forming discharge for downstream changes in channel geometry are governed by the bankfull discharge which is instead attributable to the less frequent larger storm events. As such, Chang's findings concluded that the impacts to streambed morphology due to the Ranch Plan are de minimis in nature. Chang further concluded that RMV's Streambank Monitoring Program and Adaptive Response Measures (ARM) provide an added layer of protection against unforeseen outcomes and potential localized issues should they arise. While favorable, this reliance upon adaptive response measures was deemed to be a reactionary response to adverse conditions. It was determined that further study should be required to forecast these potential localized needs.

RMV, through its consultant PACE, developed a Technical Memorandum dated April 25, 2017 which summarized not only the reporting prepared by Chang, but also identified key challenges in the methodologies for preparing hydrologic modeling within this unique watershed. The document also identified the partially mitigated expected value discharges and runoff volumes associated with the 2, 5, and 10-year developed conditions within the Ranch Plan (see Table 3 on Page 5 of 10 within the PACE Technical Memorandum dated April 25, 2017); **these are the target values for these storm events for any future Ranch Plan ROMP submittals and form the basis of this analysis**. The document concluded that RMV was in compliance with the intent of Stormwater Mitigation Measure 4.5-1 (G) and outlined a method to identify and forecast any potential needs for implementing adaptive response measures (ARM) in the future, the *ARM Study*. The purpose of the ARM Study was to forecast those areas that may require implementation of adaptive response measures as a result of stream alteration or confirm that the lateral erosion setbacks were adequate protection. RMV and OC Public Works agreed to further negotiate funding obligations and/or early implementation for any locations identified within the study. Estimates and quantities would be developed for any ARMs identified in the study. It was also agreed that Dr. Howard Chang would prepare the ARM Study.

ARM Study Results

Prepared by Dr. Howard Chang and submitted in October 2017, the ARM Study (see Sediment Study for San Juan Creek, dated October 2017, Chang) provided a technical assessment of San Juan Creek stream channel stability during the more frequent storm events and made recommendations regarding the appropriate use of adaptive response measures as defined within the Rancho Mission Viejo Stream Monitoring Program. The study utilized a flood series that emulated the expected conditions of the long-term flood flow up to a 25-yr expected value flood event for the developed condition as defined within PACE's 2017 Technical Memorandum. This flood series was chosen since it adequately represents the smaller storm events and the expected time horizon of RMV's obligations. The results of Chang's analysis were mapped as the lateral erosion extent resultant from the modeled flood series. These results were compared against the pervious lateral erosion studies prepared by PACE.

The results of this assessment and comparison showed favorable agreement amongst the portions of San Juan Creek within Planning Areas (PA) 3 & 4. However, discrepancies were noted within the portions of San Juan Creek downstream of the Antonio Parkway Bridge. The analysis performed by Chang showed significant erosion beyond that predicted by PACE along the concave bank (north-west bank) of San Juan Creek, located adjacent to the previously constructed PA 1. The results of this analysis indicated that an additional 60,000 cubic yards of erosion could be expected along this bank. These results where shared with RMV and their consultant PACE in November 2017. At this time, RMV and PACE informed the County that a less stringent erosion modeling technique had been applied to the reach downstream of Antonio Parkway Bridge and that an improved technique had been used throughout the PA 3 and PA 4 lateral erosion studies. RMV and PACE further discussed how their lateral erosion model failed to utilize the updated hydrology values contained within their 2017 Technical Memorandum. RMV and PACE agreed that the discrepancies between the Chang and PACE models and the flow data needed to be addressed and that RMV and PACE would develop a revised lateral erosion model which applied the correct flow rates and updated methodology; see PACE Technical Memorandum, dated February 9, 2018.

The results of the revised lateral erosion study prepared by PACE under the efforts of the 2018 Technical Memorandum reflected an expected increase in lateral erosion within the concave bank of San Juan Creek downstream of the Antonio Parkway Bridge. This increased lateral erosion zone was in keeping with the similar findings developed by Chang as part of the ARM Study. When properly identified, these lateral erosion extents define the assumed natural meander processes of a non-engineered natural watercourse; they establish a zone beyond which the influence of stream morphology should not be able to reach under the design storm circumstances. They represent an outer bound beyond which it should be safe to develop. All proposed development has been moved out beyond this zone of influence for the Ranch Plan.

Conclusions

Thorough technical investigation has been conducted into the topic of potential increased risks to life and property resulting from increases to discharges and volumes for the more frequent storm events. The analysis demonstrates that the risk resulting from streambed alteration and erosive actions within San Juan Creek as a result of the development within the Ranch Plan should not exceed what is expected from the natural undeveloped condition for these smaller and more frequent storm events. As such, it has been demonstrated that the risks to the County are de minimis in nature. The requirements to continue monitoring the Streambed and the potential to implement future ARMs as defined within RMV's Streambank Monitoring Program and FEIR 589 should continue. Responsibility for these activities shall continue to reside with RMV as defined within FEIR 589 and the related Streambank Monitoring Program.

Attachments:

- RMV Ranch Plan – Compliance with Development Hydrologic Mitigation Requirement A906E, PACE, April 25, 2017
- Sediment Study for San Juan Creek, Howard H Chang, October 2017
- RMV Ranch Plan Updated Assessment for Lateral Streambank Erosion Analyses for PA1/PA2, PACE, February 6, 2018

RMV Ranch Plan – Compliance with Development Hydrologic Mitigation Requirement

Approval

Prepared By:

4/25/2017

Bruce Phillips, P.E. RE# 38635

PACE – Pacific Advanced Civil Engineering, Inc.

REGISTERED PROFESSIONAL ENGINEER
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This document and corresponding analysis were reviewed for compliance with the stormwater mitigation measure 4.5-1 (g) in the Ranch Plan Final Environmental Impact Report No. 589 (FEIR) and in conformance with the requirements of OC Public Works Standards and Guidelines. Additionally, County and Rancho Mission Viejo (RMV) shall solicit a study (ARM Study) as outlined within this document to determine future funding and/or pre-payment requirements to County from RMV.

Accepted By:

Rancho Mission Viejo Representatives

Jeff Thompson and Richard Broming

4/25/17

Date

Recommended By:

Robert McLean, P.E.

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Hydrology Section, OC Public Works

4/25/17

Date

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Date

APPROVED:

Khalid Bazmi, P.E.

Assistant Director/County Engineer, OC Public Works

4/27/17

Date

PACE
Advanced Water Engineering

Technical Memorandum

Date: April 25, 2017

From: Bruce M. Phillips, PE

Re: RMV Ranch Plan – Compliance with Development Hydrologic Mitigation Requirement A906E

Introduction

The intended purpose of this technical memorandum is to discuss the technical findings regarding potential impacts to stream stability resulting from development within the Rancho Mission Viejo (RMV) Development's Ranch Plan (Ranch Plan) and how they relate to the mitigation requirements of FEIR 589 as certified in 2004. This document discusses the timeline of FEIR 589, the work performed at that time, and the results of recent studies and findings. Specifically, this document clarifies topics related to Mitigation Measure 4.5-1(g) as defined within FEIR 589.

Mitigation Measure 4.5-1(g): *The ROMP shall analyze and demonstrate that development of the Ranch Plan will not produce adverse impacts during 2, 5, 10, 25, 50 and 100-year events, including but not limited to increases in runoff peak discharge, increases in runoff volume, channel aggradation/degradation, erosion and channel stability within the project site and off-site from the headwaters of the watershed to the La Novia Bridge for development within the San Juan Creek watershed, and to the County boundary for development within the San Mateo watershed for portions of the streamcourse potentially impacted by the project development. The analyses set forth in the ROMP shall be for existing conditions and for all phases of development, including with and without required mitigation measures.*

This technical memorandum identifies several challenges encountered within this unique watershed, demonstrates how the Ranch Plan can achieve full compliance with the mitigation measure, discusses options to ensure future streambed stability, and provides documentation memorializing a path forward regarding Regional Hydrology Methods for future and previous Runoff Management Plan submittals (PA1 – PA2 included) related to the Ranch Plan and associated planning areas.

Executive Summary

The Ranch Plan, within the San Juan Creek (SJC) watershed was developed through a comprehensive planning program that incorporated various strategies to provide appropriate levels of mitigation in the areas of (1) hydrology, (2) floodplain hydraulics, (3) water quality, and (4) stream stability; the program will ensure the long-term protection of the watershed resources by addressing development impacts. The stormwater and drainage infrastructure being implemented as part of the RMV Ranch Plan development provides hydrologic mitigation for the 2-, 5-, 10-, 25-, 50-, and 100-year storm events in order to address potential urbanization impacts. Since the certification of FEIR 589 in 2004, numerous detailed technical analyses have been performed [see *San Juan Creek Watershed Study* (PACE, 2008) and *RMV ROMP* (PACE, 2013)] to support the engineering design of the various stormwater infrastructure elements and justify the conclusion that the hydrologic mitigation requirements have been achieved. However, the regional hydrology analyses performed for the SJC watershed as part of the *RMV ROMP* (PACE, 2013) demonstrated that full hydrologic mitigation of development runoff to existing conditions for all storm events using the proposed detention storage basins cannot be achieved despite utilizing the unique hydrology calculation procedures / methodology adopted specifically for this challenging watershed. In particular, the hydrology analyses indicated that even if all of the proposed regional basins were constructed, the peak discharges for the smaller storm events (2-, 5-, and 10-year storms) cannot be reduced to levels at or below the existing condition peak discharges along the mainstem SJC. However, all peak discharges for the larger storm events (25-, 50-, and 100-year) can be fully mitigated below existing conditions. Despite not achieving full mitigation of development runoff using the adopted procedures specific to SJC, **substantial compliance with the mitigation measure has been achieved** with the proposed Ranch Plan stormwater facilities since it has been demonstrated that the development will "not produce adverse impacts" through the following:

- **Construction of Various Stormwater Infrastructure Elements**: The Ranch Plan provides for a significant investment in various planned stormwater management infrastructure specifically focused on hydrologic mitigation (*RMV ROMP*, PACE 2013). See RMV Ranch Plan Hydrologic Mitigation Facilities section for more details regarding specific infrastructure.
- **Artificial Increase in Volumes resulting from the Procedures Adopted for SJC**: Challenges encountered in the hydrologic modeling include uncertainty in the magnitudes of the hydrologic response generated by the models for smaller storm events, specifically the artificial increase in runoff volumes attributable to the adopted calculation procedures for the SJC watershed. (San Juan Creek RMV ROMP Hydrology, PACE 6/20/16 and RMV Ranch Plan Hydrologic Mitigation of Smaller Storm Events, PACE 9/27/16)
- **No Flood Impacts from Small Storms**: Development runoff for the smaller storm events (2-, 5-, and 10-year) does not adversely impact "flood protection" since the runoff from the larger flood events, the 25-, 50-, and 100-year storms, is fully mitigated by the proposed and existing stormwater facilities. Peak discharges for the smaller storm events are contained within the channel and are lower than the bankfull discharges. Furthermore, previously approved studies by the County of Orange demonstrate that sediment transport is not an adverse impact to the long-term stream stability. (*San Juan Creek Watershed Study*, 2008)
- **Measures for Streambank Erosion Monitoring**: Since 2006, RMV has implemented an annual "Stream Monitoring Program" which includes annual reporting to address potential future changes to stream stability not predicted by the adopted streambed morphology methods/models when using the discharges calculated within the SJC watershed; this measure of evaluation is a requirement of FEIR 589. (*Baseline Stream Monitoring Data Inventory Report*, PACE 2006) The results of this study have been favorable. No unaccounted for significant impacts have been identified through this continued monitoring effort.
- **County Concurrence**: The County's consultant, Howard Chang, Ph.D., performed a review of (1) 2016 SJC Additional Reference Cross-Section Locations, (2) 2016 SJC Annual Stream Monitoring Report, and (3) 2011 SJC Stream Monitoring Program and indicated the following which support the conclusion of adequate hydrologic mitigation compliance of the smaller storm events related to FEIR 589 Mitigation Measure 5.4-1(g): (*Technical Review of San Juan Creek Monitoring*, Chang 2017)
    - The "...program (RMV Stream Monitoring Program) demonstrates that development of the Ranch Plan will not produce adverse impacts from those storm events."
    - "The increases in discharge due the Ranch Plan are still small. The increased discharges are still lower than the bank-full discharge. Such small discharge increase has insignificant effects on the formation of channel morphology."
    - "The existing Stream Monitoring Program by PACE is extensive and comprehensive; therefore, the program is effective in monitoring stream responses."

The foregoing indicates substantial compliance with Mitigation Measure 5.4-1(g).

Background

The RMV Ranch Plan addresses the mitigation requirements for adverse hydrologic impacts resulting from the development. The stormwater and drainage infrastructure being implemented as part of the RMV Ranch Plan urban development is being designed to provide hydrologic mitigation in order to address potential urbanization impacts. The stormwater management infrastructure includes both regional and local detention basins which attenuate peak flowrates as well as retention facilities for runoff volume infiltration and water quality treatment. Local mitigation has been demonstrated to be fully achievable; however, the regional hydrology analyses performed for the SJC watershed as part of the *RMV ROMP*

(PACE, 2013) presented challenges in being able to achieve full hydrologic mitigation for all storm events using the proposed detention storage basins in order to attenuate peak discharges to levels at or below existing conditions. In particular, results of the analyses show that with all the proposed detention basins in place, development peak discharges for the smaller and more frequent storm events (2-, 5-, and 10-year storms) are not reduced to levels at or below the existing condition peak discharges along the mainstem SJC. As a result additional study was conducted to determine the full extent and impact of these only partially mitigated increases on stream stability and flood protection. Through this analysis, it has been demonstrated that **the intent of the original mitigation measure has been achieved with the proposed Ranch Plan stormwater facilities since for these smaller storm events (1) regional flood protection is achieved downstream of the project, and (2) stream stability is maintained and erosion is not being increased.** The objective of the mitigation measure 4.5-1(g) (shown below) is achieved by analyses which demonstrate that the development will "not produce adverse Impacts," and not necessarily by just relying on a quantitative comparison between existing and proposed conditions as the defining benchmark for compliance.

The Ranch Plan Final Environmental Impact Report No. 589 (FEIR) requires the implementation of specific mitigation measures that address flood protection, surface hydrology, water quality, and stream stability for future RMV development and establishes the framework of the corresponding backbone stormwater runoff infrastructure. Mitigation Measure 4-5.1(g) can generally be divided into three specific areas which include (1) hydrology runoff volume impacts, (2) hydrology runoff peak flowrate impacts, and (3) stream erosion impacts; these specific requirements are presented below:

Mitigation Measure 4.5-1(g): *The ROMP shall analyze and demonstrate that development of the Ranch Plan will not produce adverse impacts during 2, 5, 10, 25, 50 and 100-year events, including but not limited to increases in runoff peak discharge, increases in runoff volume, channel aggradation/degradation, erosion and channel stability within the project site and off-site from the headwaters of the watershed to the La Novia Bridge for development within the San Juan Creek watershed, and to the County boundary for development within the San Mateo watershed for portions of the streamcourse potentially impacted by the project development. The analyses set forth in the ROMP shall be for existing conditions and for all phases of development, including with and without required mitigation measures.*

Background on the hydrology calculation complexities for this particular watershed was unknown at the time of EIR 589 preparation and the development of mitigation measure 4.5-1(g).

RMV Ranch Plan Hydrologic Mitigation Facilities

The *Runoff Management Plan* (ROMP) document, which was based on the earlier San Juan Creek Watershed Study (PACE 2008), was approved by the County of Orange in April 2013. The ROMP provides a comprehensive watershed scale planning study for the portion of the proposed Rancho Mission Viejo (RMV) development within the San Juan Creek watershed. The RMV Ranch Plan development, based on the ROMP recommendations, includes significant backbone stormwater management infrastructure which provides hydrologic mitigation at the local and regional watershed levels, as well as flood protection and standard urban drainage amenities. A brief overview of the scale of stormwater management infrastructure facilities identified for The Ranch Plan development as part of the planning effort includes the following:

- Approximately 32 miles of backbone underground storm drain pipes
- 21 storm drain outfalls from PA-2 through PA-5 into the natural creeks (27 total number of outfalls previously reserved in environmental permitting, so 6 available for future use)
- 22 stormwater flood control detention basins, with 6 of these detention basins being regional flood mitigation basins including the Gobernadora Basin.
- Stormwater quality infiltration facilities located at each storm drain outfall
- Hydromodification control facilities

- Surface area identified for stormwater mitigation facilities is approximately 241 acres (excluding the Gobernadora Basin) for (1) local flood control detention (26.2 acres), (2) regional flood control detention (79.5 acres), and (3) water quality and hydromodification basins (135 acres).

Hydrologic Mitigation for Large Storm Events

Analysis of the "regional" runoff hydrology for the larger San Juan Creek watershed, as well as Cañada Gobernadora and Cañada Chiquita, were evaluated as a central part of the *RMV ROMP* (PACE, 2013) to assess the potential urbanization impacts due to the increase in runoff peak flowrate and volume. The mitigation of development runoff peak flowrate utilized detention storage and the mitigation of runoff volume increases was provided through infiltration/retention. The proposed mitigation measure for impacts due to increased peak discharge were addressed through both regional and local flood control mitigation detention basins to attenuate peak discharges ranging from the 2-year to the 100-year events at (1) each of the twenty-one (21) outfalls, and (2) the six (6) different regional basins. The regional hydrology analyses demonstrated that development impacts for the larger storm events (100-, 50-, and 25-year return periods), were fully mitigated with the regional basins implemented as illustrated in the Tables 1 and 2 below for mainstem SJC at the downstream Ranch boundary. Attenuation of the peak flowrates for the larger storm events below the existing conditions within the mainstem of San Juan Creek demonstrated that the development project would not impact existing levels of "flood protection" downstream of the project.

Table 1: San Juan Creek Regional Summary Hydrologic Peak Flowrate Impacts and Mitigation – Large Storm Events[1]

Summary of Regional Peak Flowrates at RMV Boundary – Calibrated Complex Unit Hydrograph (Watershed Area = 105.95 square miles)			
Storm Return Period	**Existing Peak Flow (cfs)**	**Developed Peak Flow (cfs)**	**Mitigated Development (cfs)**
25-year	16,865	16,894	16,415
50-year	20,253	20,296	19,635
100-year	23,098	23,185	22,352

[1] Reference: *RMV ROMP* (PACE, 2013). Table 14-8

Table 2: Regional San Juan Creek Hydrology – Runoff Volume Impacts & Mitigation – Large Storm Events

RMV Development San Juan Creek Runoff Volume Impact at RMV Boundary (105.95 sq. miles)									
Return Period	**Runoff Volume (ac ft)**		**Impact**		**Mitigation Infiltrated Runoff Volume (ac-ft)**				
	Existing	**Development Unmitigated**	**Change (ac-ft)**	**% Change**	**WQ**	**HM[2]**	**Local Detention**	**Regional Detention**	**Total**
25-year	14,162	14,191	**32**	0.2%	136	165	33	149	**483**
50-year	16,932	16,949	**17**	0.1%	136	166	33	151	**486**
100-year	19,213	19,241	**28**	0.1%	136	166	33	153	**488**

[2] Hydromodification (HM) reflects the requirements for the "tributaries" to SJC and the analyses performed generating this table for the ROMP reflected the "large river exemption" for areas draining directly to San Juan Creek (per Geosyntec)

Assessment of Hydrologic Mitigation for Small/Frequent Storm Events

The regional hydrology model results for the mainstem San Juan Creek indicated that development peak flowrates for the smaller and more frequent storm events, which include the 10-, 5-, and 2-year events, are not attenuated to the existing conditions with the implementation of the proposed regional detention basins. While development peak flowrates were reduced, the model results showed a slight increase of the peak flowrates from the existing condition (see *Table 3* below). However, the changes associated with the development runoff volume for these smaller storm events would be fully mitigated with the proposed stormwater management facilities (see *Table 4* below). It appears that the hydrology calculation procedures applied as part of this watershed study create artificial changes in the hydrology, as well as the unique hydrologic characteristics of this large regional watershed related to hydrologic timing and response effects. Although the smaller storm event development peak flowrates are not attenuated to levels at or below the existing conditions, these hydrologic impacts do not influence existing levels of "flood protection" since those have been fully mitigated for the larger storm events. Additionally, the peak flowrates for the more frequent events are fully contained within the channel and are lower than bankfull discharges. The development induced hydrologic impacts for the 2-, 5-, and 10-year storms were also evaluated in the sediment transport analysis to assess any potential impacts related to stream stability. Results demonstrate that sediment transport due to the increase in peak discharge for the more frequent events has no adverse impact on the long-term stability of the creek. This is partially attributable to the Ranch Plan's location along San Juan Creek. The upper (natural) portions of the watershed are contained within the Cleveland National Forest. This upper portion of the watershed is the primary mechanism for generating replenishing sediment yields within this watershed. As a result, it provides a source of sediment supply within the portions of the creek located within and downstream from the Ranch Plan.

Table 3: San Juan Creek Regional Summary Hydrologic Peak Flowrate Impacts and Mitigation Smaller Storm Events[3]

Summary of Regional Peak Flowrates at RMV Boundary – Calibrated Complex Unit Hydrograph (Watershed Area = 105.95 square miles)			
Storm Return Period	**Existing Peak Flow (cfs)**	**Developed Peak Flow (cfs)**	**Mitigated Development (cfs)**
2-year	608	816	732
5-year	2,496	2,846	2,796
10-year	7,236	7,596	7,433

[3] Reference: *RMV ROMP* (PACE, 2013). Table 14-8

Table 4: Regional San Juan Creek Hydrology – Runoff Volume Impacts & Mitigation Smaller Storm Events

RMV Development San Juan Creek Runoff Volume Impact at RMV Boundary (105.95 sq. miles)									
Return Period	**Runoff Volume (ac ft)**		**Impact**		**Mitigation Infiltrated Runoff Volume (ac-ft)**				
	Existing	**Development Unmitigated**	**Change (ac-ft)**	**% Change**	**WQ**	**HM[4]**	**Local Detention**	**Regional Detention**	**Total**
2-year	708	879	**171**	24.2%	117	80	0	0	**197**
5-year	2,284	2,535	**250**	10.9%	136	135	20	52	**343**
10-year	5,599	5,931	**332**	5.9%	136	162	31	145	**474**

[4] Hydromodification (HM) reflects the requirements for the "tributaries" to SJC and the analyses performed generating this table for the ROMP reflected the "large river exemption" for areas draining directly to San Juan Creek (per Geosyntec)

Obstacles Encountered in Performing Hydrologic Analysis of Small Storm Events

The original *RMV ROMP* (PACE, 2013) hydrology calculations / modeling indicated that the results from the watershed hydrology models may not accurately reflect the anticipated magnitudes of the hydrologic response for smaller storm events as the modeling outputs show artificially increased runoff volumes. It appears the issues in the hydrology analyses and exaggerated need for hydrologic mitigation originated from the application of specific hydrology procedures, which included the following:

- The hydrograph "calibration" process for adjusting the "complex" free-draining hydrograph model to match the single area hydrograph peak flowrate that is accomplished by adjusting or increasing the rainfall causes a change in the shape of the hydrograph and a model induced increase in the total storm runoff volume. The model induced runoff volume influences design of storage based detention basins. This anomaly is exaggerated within this large and complex watershed.
- The basis of soil loss rate calculations is not the same for existing and proposed conditions within this watershed. The approved procedure specific to the San Juan Creek watershed only involves using different Antecedent Moisture Conditions (AMC) for existing and developed landuse conditions for the natural areas slated for development. This impacts the peak discharge calculations when comparing the existing and proposed watershed conditions due to changes in impervious cover from urbanization.

The *OCHM* uses a "calibration" process for adjusting the "complex" free-draining hydrograph model peak flowrate to match the single area hydrograph peak flowrate through adjusting, or increasing the rainfall. The net effect from the rainfall adjustment causes a change in the volume of the runoff hydrograph from the complex free-draining model that is not the same as the single area hydrograph volume. This is a concern particularly when using the complex hydrograph to analyze and design volume-based hydrologic mitigation facilities appropriately. This issue results in creating larger than actually needed storage volume requirements for detention basin facilities.

This issue was clearly demonstrated through a sensitivity analysis which was performed for the 2-year complex hydrograph model to determine the effect of completely "retaining" or eliminating the proposed development runoff which would essentially be the maximum possible mitigation that the RMV development could achieve. This simple test was performed with the 2-year calibrated complex model to determine if full hydrologic mitigation of the 2-year storm was possible. The results of the modeling effort indicated that the developed condition 2-year peak flowrate with "complete retention" of development runoff would still yield a higher peak flowrate in SJC than the existing conditions when comparing the different hydrographs as illustrated in the following figure.

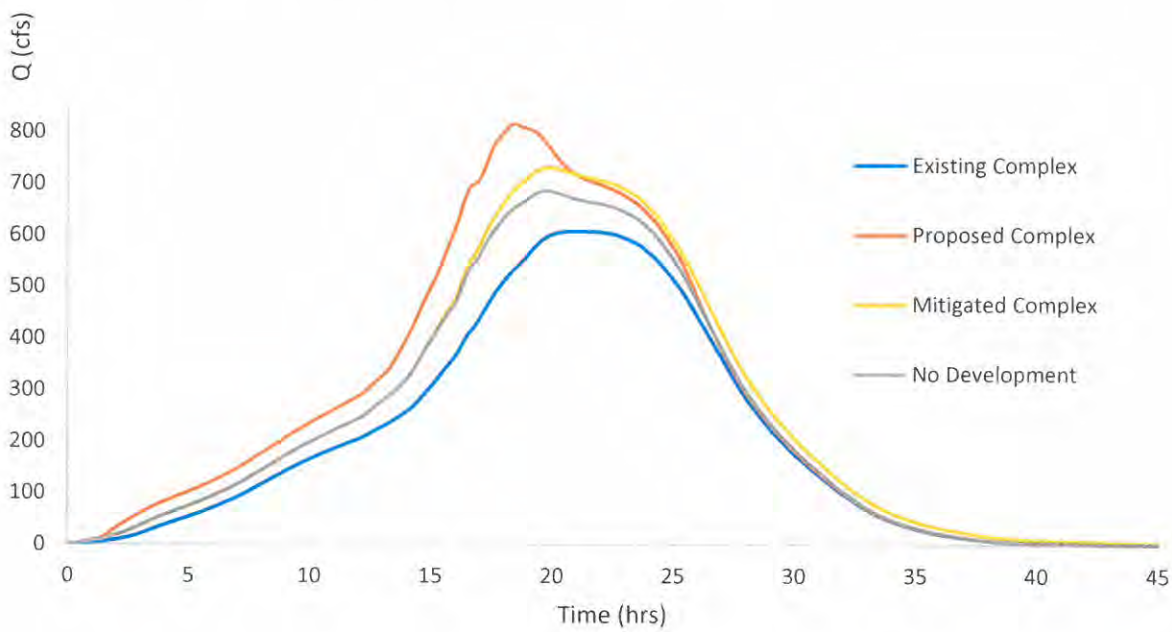

Figure 1 – 2-year Sensitivity Analysis at Downstream RMV Boundary (Node 137) Removing All Proposed RMV Development

A variety of alternative procedures were investigated in order to attempt to correct and adjust the artificial increase in the runoff volume resulting from the calculation procedures applied to this particular watershed for the smaller storm events. PACE developed a procedure to eliminate the artificial fattening (or increase) of the hydrograph runoff volume through a hydrograph time ordinate adjustment procedure. Although this procedure accurately corrected the runoff volume, it did not completely eliminate the difference or increase in peak discharges between existing and proposed mitigated conditions for the smaller storm events. The County had recommended an investigation using a "dual single area hydrograph approach" in an attempt to maintain rainfall values in the upper watersheds and the corresponding runoff volumes above Node 118C (upstream natural watershed). PACE and Michael Baker, Inc. (MBI) attempted the application of this procedure independently for the PACE ROMP hydrology models and the current MBI watershed models respectively. The results from applying this procedure at watershed model nodes 133C and 134C indicated increased flow rates for the proposed conditions due to an increased need for calibration. Calibration was required on both the existing and proposed hydrographs, however, the calibration of the existing was relatively minor. The development flowrates for smaller or more frequent storm events were still not fully mitigated with all the proposed basins in place, but the unmitigated percentages from the existing condition had been reduced similar to the other procedures applied by PACE (see previous *Technical Memo* (January, 2017) summarizing results of those sensitivity analyses for the dual single area calibration procedure – frequent storm events). It appeared from the results of applying "dual single area hydrograph approach that the timing effects between the mainstem hydrograph and the tributary development hydrograph, after combing these hydrographs, was responsible for a significant portion of the issue not matching the single area hydrograph peak discharge.

<u>Streambed Stability and Comprehensive Field Monitoring Program</u>

The results of the San Juan Creek fluvial analysis and detailed sediment transport modeling indicate that the portion of San Juan Creek within the RMV development boundary and downstream to La Novia Bridge trends toward aggradation which also reflects the creek's actual historical geomorphic conditions.

These most recent fluvial studies include (1) *San Juan Creek Watershed Study* (PACE, July 2010), (2) *ROMP* (PACE, April 2013), and (3) the current San Juan Creek Stabilization Study prepared by PACE under contract with the County of Orange. The results of these models as well as the historical geomorphic evidence by multiple investigators assist in demonstrating that The Ranch Plan development induced changes within the San Juan Creek watershed will not adversely modify the stability of the creek because of the large upstream sediment supply being delivered as water flows from the higher to lower elevations along the creek. The large upstream natural portion of the watershed will not be affected by the development thus the sediment production zone (source), which is the primary influence of the creek's geomorphic adjustments, will remain intact. The results of the long term fluvial modeling with HEC-6T analysis for SJC provide a good indicator/predictor of stream stability effects from development over a range of storm events for an extended period of time. The methodology and results of the analyses were consistent with previous studies prepared for the County and by the Army Corps of Engineers. In addition, the HEC-6T modelling incorporated sensitivity analyses evaluating reduction in sediment supply from the lateral tributaries which also illustrated that this did not result in additional erosion. The results of the long term HEC-6T models are also consistent with the historic fluvial response for this portion of San Juan Creek which validates the models. The deposition response for this portion of the creek is because of the high sediment yield from the upper watershed which generates a much larger supply of sediment than the creek has the capacity to transport. This differential between sediment supply and transport capacity causes the reaches within the RMV boundary and downstream to the I-5 freeway to be depositional.

Directly related to the streambed stability, RMV has also implemented an annual "Stream Monitoring Program" since 2011 which includes comprehensive annual reporting. The monitoring program was approved by the County in February 2007. The objective of this program is to monitor potential negative erosion effects from the development which may adversely affect the streambed stability and implement corrective measures when needed. Erosion is expected to occur as a natural process within the creek system; however, monitoring and responding to additional erosion beyond normal river trends as a result of development is the target of this monitoring program. This extensive field monitoring effort is an additional level of confirmation to ensure that compliance with the mitigation measure is achieved. The monitoring program also includes an adaptive management plan to correct identified causes of erosion within the development watershed. The "Stream Monitoring Program - Appendix E – Adaptive Streambank Erosion Corrective Measures Guidelines" provides guidance on the different potential triggers for implementing the different type of erosion countermeasures. The guidelines define the careful examination of the type of failure mechanism and the different site or reach based causes that must be explored in detail when applying the corrective measures since there is no one solution that fits each situation. This monitoring program is being funded by RMV (see *Financial Funding* Section) during the implementation/construction period of the Ranch Plan development, with additional funding for a period after the completion of the development.

<u>Achieving Compliance with Mitigation Measure</u>

The stormwater management facilities proposed with the RMV Ranch Plan development meets the objectives and intent of Mitigation measure 4.5-1(g) and achieves substantial compliance therewith since multiple levels and types of analyses indicate that with the proposed stormwater management activities, the development <u>will not result in adverse impacts during 2, 5, 10, 25, 50 and 100-year storm events</u>. Using a quantitative comparison of the pre- and post- project "regional" hydrology runoff peak flowrates and volumes to assess compliance may not be appropriate in this case, in light of potential issues associated with the regional hydrology model for this watershed. The above technical explanations supported by appropriate analyses substantiate that implementation of the existing and proposed basins and other stormwater management measures prevent and/or address potential adverse impacts with respect to flow rate, volume and stream stability. Another mitigation measure, MM 4.5-1(e), further requires re-evaluation in future project phases for measures to ameliorate further development impacts within the watershed(s).

<u>Financial Funding Long Term Hydrologic Mitigation</u>

Provisions have already been provided for the funding of the Stream Monitoring Program and there is also another financial mechanism for potential improvements in the event that smaller storm events cause streambed and stream bank damage, although current sediment transport/fluvial modeling tools indicates none should occur. *Appendix F* of the *San Juan Creek Watershed Stream Monitoring Program*, amended March 2008 and approved May 18, 2011 (initial document was dated October 2006), provides an overview of Monitoring Program Funding. This document clarifies that the monitoring program and adaptive response measures are funded by RMV, consistent with other mitigation measures for the Ranch Plan.

Streambank monitoring and adaptive management efforts will continue 10 years after the last dwelling unit is constructed in the Ranch Plan. As previously noted, RMV will continue to fund these efforts, consistent with other mitigation measures related to the Ranch Plan. To ensure adequate funds, RMV and the County will solicit the assistance of a Streambed Morphology Expert to study and make determinations regarding the locations and types of Adaptive Response Measures (ARM) that may require implementation during the term of RMV's obligation as they relate to development, This analysis will culminate in findings summarized within a document known as the ARM Study. The findings of the ARM Study will be used to forecast construction efforts and estimates and will be the basis of a pre-payment that RMV will provide to the County to ensure adequate funds are available. Discussions between RMV and the County are currently underway regarding the implementation of the ARM Study; the work associated with the study and associated pre-payment negotiation are expected to begin in mid-May 2017 and will be completed by the end of 2017.

<u>Summary / Conclusions</u>

The intent of the original mitigation measure (Ranch Plan Final Environmental Impact Report No. 589 (FEIR) Mitigation Measure 4-5.1(g)) has been achieved for all storm events with the proposed Ranch Plan stormwater facilities. For the smaller storm events, compliance is achieved since (1) regional "flood protection" is achieved downstream of the project, and (2) long term stream stability is maintained or erosion is not being increased. The objective of the mitigation measure is achieved by analyses which demonstrate that the development will "not produce adverse impacts" as well as the following narratives which support the same conclusion:

- Although the "regional" San Juan Creek watershed hydrology prepared for the RMV development does not demonstrate that the proposed development peak flowrates for the smaller storm events (2-, 5-, and 10- year storms) are attenuated to levels at or below the existing values, these smaller storm events do not influence "flood protection." The downstream channel has adequate capacity to convey the proposed development peak flowrates for these smaller storm events so there would not be an adverse impact to "flood protection." The proposed condition peak discharges for larger storm events, including 100-year, are reduced below the existing conditions with the proposed development mitigation detention basins so there is no "flood protection" impact.
- The proposed development **regional stormwater mitigation basins still provide a significant amount of peak flowrate attenuation for the smaller storm events.** In addition, the regional hydrology modeling does not account for the smaller local detention basins as well as the water quality/hydromodification basins in the model.
- Regional hydrology analyses prepared as part of the *RMV ROMP* (PACE, 2013) illustrated that runoff "volume" from the development was fully mitigated for all storm events (2- through 100-year) to below that existing conditions, which included accounting for the San Juan Creek "large river exemption" for hydromodification. This was achieved through retention and infiltration provided by the proposed stormwater management facilities.
- The hydrology quantities (peak flowrate and volume) associated with the "local" watershed for each storm drain outfall from the different development areas are **<u>fully mitigated for adverse conditions related to flooding and/or erosion for all storm events</u>** (2- through 100-year). A major reason that the local hydrology peak flowrates can be mitigated is that the hydrology

procedures used for the "local" watershed are different from the procedures applied to the regional watershed. Some of the differences include timing issues, low loss rate calculations, and depth-area reduction factors associated with the regional watershed.

- Smaller storm events potentially contribute to the instability and erosion of the alluvial streambed. However, detailed fluvial studies with long term modeling indicate that the changes from the development do not negatively impact the stability of San Juan Creek. These most recent fluvial studies include (1) *San Juan Creek Watershed Study* (PACE, July 2010), (2) *ROMP* (PACE, April 2013), and (3) the current San Juan Creek Stabilization Study being prepared by PACE under contract with the County of Orange. The reason that there is no adverse impact is because of the large amount of sediment being delivered from the upper San Juan Creek watershed as well as maintaining the natural creek floodplain conditions. Sensitivity analyses conducted as part of these fluvial studies illustrated that changes in sediment supply from the development area as well as changes in the hydrology did not produce any negative influences on the streambed stability.
- A comprehensive annual "Stream Monitoring Program," which includes detailed annual reporting, has been conducted by RMV since 2011. The objective of this program is to monitor potential negative erosion effects from the development which may adversely affect the streambed stability and implement corrective measures when needed. This extensive field monitoring effort is an additional level of confirmation to ensure that compliance with the mitigation measure is achieved. An adaptive management plan is included in the monitoring program to correct identified causes of erosion within the development watershed. The potential hydromodification effects from the smaller storm event peak flowrates are evaluated as part of this long-term monitoring program and adaptive management plan.

Technical Appendix

RMV Ranch Plan • Compliance with Development Hydrologic Mitigation Requirement

April 2017

Prepared For:

RANCHO MISSION VIEJO

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Dr. Chang Technical Review of Memo (Jan 15, 2017)

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January 15, 2017

Mr. Robert McLean
Public Works
County of Orange
300 N Flower Street
Santa Ana, CA 92703

Dear Mr. McLean:

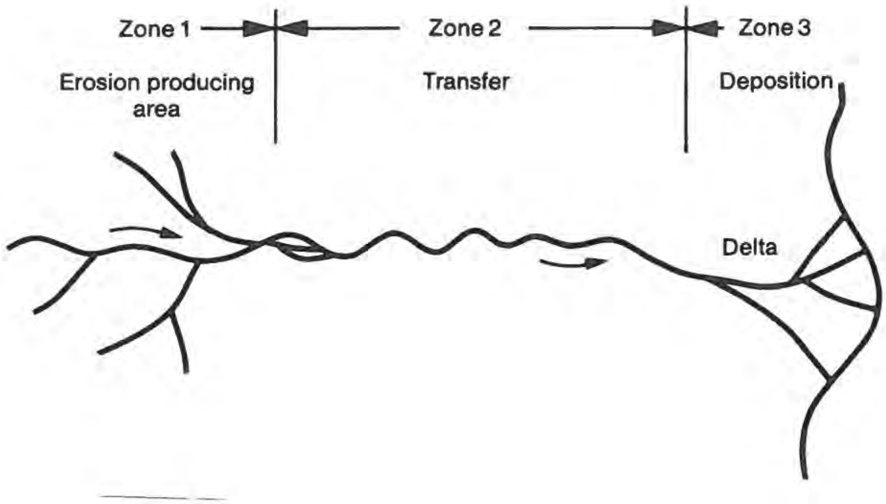
Subject: TECHNICAL REVIEW OF SAN JUAN CREEK STREAM MONITORING BY PACE

This letter is prepared in response to the comments from the County dated January 11, 2017 regarding the above-referenced matter. The County comments and my responses are given below. This letter is in supplement to my letter dated January 4, 2017.

Comment 1: During our conversation you discussed the stream morphology found within the SJC watershed and mentioned that the mid portions of SJC are not significant producer of sediment yield to the watershed. Instead, you stated that most of that yield comes from the upper portions of the watershed. Please discuss this within your response. Please make a determination and specifically identify that the middle portion of SJC includes the "Ranch Plan" area, if that is indeed the case.

In response, a stream is within the domain of the fluvial system, which also consists of the drainage basin (or watershed) and the downstream reservoir, lake, or ocean. Schumm (1977) divided the fluvial system into three parts as shown in the figure below. The upper part, or Zone 1, is the watershed, where most of the water and sediment for the stream originate. The middle part, or Zone 2, is the reach where the stream channel is the most stable and where its configuration is the best defined. Large rivers have long reaches of Zone 2, but this zone may be missing in small streams. This is the reach for which extensive river studies, modeling, and controls have been made. Despite the relative stability, a river channel, as a dynamic system, still undergoes changes that can be rapid and significant at times.

Zone 3 is near the river mouth, where the alluvial river is also under the influence of the tidal, or base level, variation. Because of continuous delta growth, it requires a rise in grade (aggradation) to maintain the channel slope and transport capacity. Rivers in this zone are often braided.



The fluvial system (after Schumm, 1977).

The fluvial system for San Juan Creek consists of the main channel together with the major tributaries of Chiquita Canyon and Gobernadora Canyon. Major development within the system is concentrated along the middle zone. The upper reach is within the Cleveland National Forest. Much of the upper reach may never be developed. This means that the sediment supply to the streams from the erosion producing area will be less affected by development. Development along the middle zones will decrease the sediment production and sediment supply to these streams. However, these areas have milder terrain and less sediment production by nature. In summary, development is expected to decrease sediment supply to the San Juan Creek stream system. This is primarily due to development along the middle reaches. The upper reaches along the major sediment producing areas are less affected by development. It may be concluded that the Ranch development in the fluvial system for San Juan Creek is not expected to have major effects on stream morphology in the foreseeable future.

Comment 2: You also mentioned that SCJ has reached an "equilibrium state" since sand and gravel mining activities within the creek have ceased. Please discuss this equilibrium state within your response and discuss how this determination relates to the future stability of SJC both with and without the Ranch Development.

In response, a steam channel is always undergoing changes because of the changing discharge and sediment supply. Each channel is constantly adjusting toward a state of dynamic equilibrium. Since San Juan Creek has not shown changes beyond what can be expected for the channel under natural conditions, it can therefore be considered to have reached an approximate state of equilibrium. Even for a stream in equilibrium, there are still changes but such changes can be expected under natural conditions, the channel is therefore considered to be in an equilibrium state.

Comment 3. You discussed how the channel forming discharges within the SJC watershed are the result of bankfull discharges and that the storm events that produce such discharges are far in excess of the 2, 5, & 10-year storm events. Please state and discuss the meaning of this determination within the written conclusions from your review.

In response: the HEC-RAS results by PACE for San Juan Creek show that the 2-, 5- and 10-yr storms are contained in the stream channel with the water surface below the bankline. For this reason, such storm discharges are lower than the bankfull discharge.

Comment 4: You mentioned that any stream alteration that results from the Ranch Development is expected to be deminimis and would not require mitigation. Please further discuss this conclusion within your letter and how the monitoring program will allow for confirmation of this conclusion with the additive benefit of the adaptive response measures to correct unforeseen impacts.

In response, the SJCSMP has provided field data for stream channel changes in recent years. The documented results from the monitoring program demonstrate that changes are limited and they are within what can be expected in the natural stream in the absence of the Ranch Plan. In other words, these changes would occur in the natural stream without the Ranch Plan The SJCSMP demonstrates that the stream channel changes for San Juan Creek during the 2-, 5-, and 10-yr events are very limited and they are within the changes for the channel in the absence of the Ranch Plan. The 2-, 5-, and 10-y storm events have limited effects on stream morphology. They are not expected to cause destabilization of the creek. In conclusion, the SJCSMP program demonstrates that development of the Ranch Plan will not produce adverse impacts from those storm events.

Comment 5: please discuss your example in comparing Serrano Creek vs SJC. Specifically discuss how the Ranch Plan is such a small percentage of the SJC watershed vs. how development within Serrano Creek consumed approximately 80% of the watershed. You mentioned that this small area and its location within the SJC watershed are not expected to contribute appreciable impacts to SJC. Please state and discuss this conclusion.

In response, Serano Creek was destabilized due to extensive urbanization covering over 80% of the watershed. in the Serano Creek drainage basin, housing development, pavements, landscaping, drainage facilities, etc. have greatly reduced soil loss and increased runoff from the watershed. The major reduction of sediment and increase in storm flow to San Juan Creek resulted in destabilization of the channel. On the other hand, the Ranch Plan covers less than 10% of the watershed area. The Ranch Plan area has a milder terrain within the San Juan Creek drainage basin; it has less sediment production under natural conditions.

Comment 6. Contained below is a summary table of the pre and post project discharges associated with the six recurrent storm events considered in this study; this information has been supplied by PACE. This summary table provides insight into the magnitude of the expected changed condition at the La Novia Bridge that result from the Ranch Plan. Please discuss the magnitude of these changes and how they relate to your conclusion that anticipated impacts attributable to the 2, 5, and 10-year storm events are deminimis in nature.

2013 Ranch Plan ROMP Existing and Proposed Condition (Planning Areas 1-5) Peak Discharge

Summary at La Novia Bridge (Hydrology Nod) Downstream of Ranch Boundary

Storm Event	2-Yr EV Discharge (CFS)	5-Yr EV Discharge (CFS)	10-Yr EV Discharg	25-Yr EV Discharge (CFS)	50-Yr EV Discharge (CFS)	100-Yr EV Discharg
Existing	635	2523	7034	16604	19922	22801
Proposed (with	748	2807	7415	16549	19803	22553
Delta	113	284	381	-55	-119	-248

In response, it is true that the Ranch development is found to increase the peak discharges for the frequent storms without hydromodification. The 2-, 5- and 10-yr storms for San Juan Creek are lower than the bankfull discharge. In river morphology, the bankfull discharge is used as the channel forming discharge because formation of the channel geometry and other morphologic features occurs primarily during the bankfull discharge. The increases in discharge due the Ranch Plan are still small. The increased discharges are still lower than the bankfull discharge. Such small discharge increases have insignificant effects on the formation of channel morphology.

Comment 7: Your letter states the site is subject to hydromodification requirements for water quality purposes. RMV is claiming to have a large river hydromodification requirement exemption along San Juan Creek. Would an exemption change the nature of your conclusion? Please discuss within your response.

In response, without hydromodification, the 2-, 5- and 10-yr storms for San Juan Creek are slightly higher; these higher discharges are still lower than the bankfull discharge. In river morphology, the bankfull discharge is used as the channel forming discharge because formation of the channel geometry and other morphologic features occur primarily during the bankfull discharge. The increases in discharge due the Ranch Plan are still small. The increased discharges are still lower than the bankfull discharge. Such small discharge increase has insignificant effects on the formation of channel morphology.

Comment 8: Please explain what is meant by "control facilities are sized for outfalls that drain to tributaries of San Juan Creek". There appears to be some confusion regarding the interpretation of this as it relates to achieving mitigation. Are you concluding that PACE has sized the basins and outfalls sufficient to achieve mitigation for the more frequent storm events? Are you concluding that mitigation is not required for the more frequent storm events and therefore the basins and outlets are appropriately sized for the less frequent storm events? Please clarify the intent of this statement.

In response, the control facilities are used for stream training and channel stabilization. Such structures have been studied and developed in a series of studies for San Juan Creek. These measures must meet the requirements of the County. Major control facilities consist of revetments and bank protection. Rock riprap is also used at outfalls for drainage into San Juan Creek. All the control facilities also provide protection of the 2-, 5- and 10-yr storms.

Comment 9: You make the statement "in view of the uncertainties for the analyses", please explain what is meant and implied by this statement. Are there uncertainties in your own analysis, that of PACE, or that of streambed morphology in general. Please provide examples of what is meant. This disclaimer should not be needed if the uncertainties are in the general sense and acceptably understood within the fluvial mechanics community?

In response, hydrology is based on physical analyses and statistical data. Any hydrology model has different degrees of uncertainty or confidence limit. I have deleted the disclaimer.

Comment 10. You mention the "countermeasures for channel stability" and provide two types (bank protection and grade control). Please discuss how you have reviewed the monitoring program and concluded that these types of countermeasures are included within the adaptive response measures listed within the program.

In response, the counter-measures for the Ranch project are used primarily for channel stabilization, consisting of revetments and bank protection. The PACE study has also identified erosion hazard zones, areas with bank erosion, and degradation. They have also provided the migration of the mender thalweg. These data were employed to develop the counter-measures.

Comment 11: Please discuss how you have made these conclusions regarding stream impacts associated with these more frequent storm events in full knowledge that the Ranch Plan and associated ROMP have shown an inability to achieve full mitigation for discharge and volume within the Regional Hydrology Model. This should be tied to your magnitude discussion mentioned elsewhere in these comments.

In response, the impacts of the Ranch plan on San Juan Creek are analyzed based on the changes in storm flow and sediment input into the stream channel. The Ranch plan increases the storm flow while decreases the sediment input to the stream channel. The net effect of the Ranch Plan on San Juan Creek is erosion, degradation and development of a more sinuous channel. These impacts are very small as the Ranch development covers a small portion (less than 10%) of the total watershed and it is in an area with mild terrain and less sediment production.

The stream monitoring program provides coverage of different aspects of stream channel changes. The monitoring program is adequate for moderate changes due to the more frequent events including the 2-, 5-, and 10-yr. storms. Such frequent storms and their accumulated effects include bank erosion, channel bed degradation below grade control structures. The monitoring results are useful for developing countermeasures for channel stabilization. Such counter-measures usually include bank protection and grade control structures, etc.

A stream channel in the natural environment undergoes changes. Such natural changes include those in climate, weather, flow rate, seismic event, forest fires, etc. Even in the absence of human activities, a natural channel may undergo aggradation/degradation, meander migration, bank erosion, etc. Such changes are limited in magnitude during the more frequent storms. A natural stream channel is not expected to be destabilized during the frequent storms.

The SJCSMP has provided field data for stream channel changes in recent years. The documented results from the monitoring program demonstrate that changes are limited and they are within what can be expected in the natural stream in the absence of the Ranch Plan. In other words, these changes would occur in the natural stream without the Ranch Plan The SJCSMP demonstrates that the stream channel changes for San Juan Creek during the 2-, 5-, and 10-yr events are very limited and they are within the changes for the channel in the absence of the Ranch Plan, In conclusion, the SJCSMP program demonstrates that development of the Ranch Plan will not produce adverse impacts from those storm events.

Please let me know if you have more comments or questions regard this matter.

Sincerely yours,

Howard H. Chang, Ph.D., P.E.

References

Schumm, S. A., *The Fluvial System*, John Wiley & Sons, New York, 338 pp., 1977.

Dr. Chang Technical Review of Memo (Jan 4, 2017)

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January 4, 2017

Mr. Robert McLean
Public Works
County of Orange
300 N Flower Street
Santa Ana, CA 92703

Dear Mr. McLean:

Subject: TECHNICAL REVIEW OF SAN JUAN CREEK STREAM MONITORING BY PACE

This letter is prepared in response to the comments from the County dated December 29, 2016 regarding the above-referenced matter

The Ranch Plan is subject to the requirement that the development may not cause an increase of the runoff discharge toward downstream. PACE has submitted a satisfactory Runoff Management Plan with verification of subsequent implementing actions.

The Ranch Plan Planned Community encompasses 75 percent permanent open space. The project site is subject to the requirements for hydromodification for the purpose of water quality control. Control facilities are sized for outfalls that drain to tributaries of San Juan Creek. PACE has provided important countermeasure for the potential instability of alluvial streams at the Ranch Plan Planned Community. The countermeasure is for the stream monitoring plan, which includes periodical inspection and survey of the alluvial streams and to provide necessary erosion protection measures when the need arises.

The net effect of the Ranch Plan on San Juan Creek is erosion, degradation and development of a more sinuous channel. The stream monitoring program provides coverage of these aspects of stream channel changes. The monitoring program is adequate for moderate changes due to the more frequent events including the 2-, 5-, and 10-yr. storms. Such frequent storms and their accumulated effects include bank erosion, channel bed degradation below grade control structures. The monitoring results are useful for developing countermeasures for channel stabilization. Such counter-measures usually include bank protection and grade control structures, etc.

A stream channel in the natural environment undergoes changes. Such natural changes include those in climate, weather, flow rate, seismic event, forest fires, etc. Even in the absence of human activities, a natural channel may undergo aggradation/degradation, meander migration, bank erosion, etc. Such changes are limited in magnitude during the more frequent storms. A natural stream channel is not expected to be destabilized during the frequent storms.

The SJCSMP has provided field data for stream channel changes in recent years. The documented results from the monitoring program demonstrate that changes are limited and they are within what can be expected in the natural stream in the absence of the Ranch Plan. In other words, these changes would occur in the natural stream without the Ranch Plan The SJCSMP demonstrates that the stream channel changes for San Juan Creek during the 2-, 5-, and 10-yr events are very limited and they are within the changes for the channel in the absence of the Ranch Plan, In conclusion, the SJCSMP program demonstrates that development of the Ranch Plan will not produce adverse impacts from those storm events.

Please let me know if you have more comments or questions regard this matter.

Sincerely yours,

Howard H. Chang, Ph.D., P.E.

Dr. Chang Technical Review of Memo (Nov 21, 2016)

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TECHNICAL REVIEW OF SAN JUAN CREEK STREAM MONITORING BY PACE

Prepared by
Howard H. Chang, Ph.D., P.E.

November 21, 2016

The Pacific Advanced Civil Engineering (PACE) undertook a monitoring plan to implement an Adaptive Management Program with respect to stream channel erosion and sedimentation within San Juan Creek. Howard Chang is a consultant to provide technical review of the monitoring plan submitted by PACE described in documents contained in the following packages:

- 2011 San Juan Creek Stream Monitoring Plan
- 2014 San Juan Creek Stream Monitoring Report – This report has 10 new channel cross sections included as part of the 2015 assessment.
- 2016 Additional Channel Cross Section Locations – This folder has HEC-RAS models, Proposed Reference Cross Section Analyses, etc.

Howard Chang has prepared this report presenting a technical review in order to determine if the PACE stream monitoring program and Adaptive Management Measures satisfy the mitigation requirements of Rancho Mission Viejo's FEIR 589 MM 4.5-1 for impacts associated with the 2-, 5-, & 10-year expected value storm events. If not, provide recommendations on how the Stream Monitoring Program and Adaptive Management Measures can be adapted to meet this objective. The technical review report is described below.

Steam Channel Formation and Response to Increases in the 2-, 5-, and 10-yr Storm Events Due to Development – It is generally acknowledged by river researchers that the sediment-laden flow imposed upon a river from its drainage basin is the cause from which river channel formation follows as an effect as illustrated in Figure 1. The discharge and load supplied to the river from the watershed constituting the cause for river channel formation are the independent variables. Channel characteristics, which consist of width, depth, bank slope, channel slope, meandering pattern, and so on, are dependent variables that represent the degrees of freedom that are not prescribed but need to be determined in the analysis. The number for the degrees of freedom varies with the type of alluvial river. Alluvial streams have four degrees of freedom in its width, depth, bank slope, and channel slope. The velocity is a dependent variable but is not an additional degree of freedom because it is determinable from the discharge and channel geometry. A natural stream has one more degree of freedom in its meandering pattern.

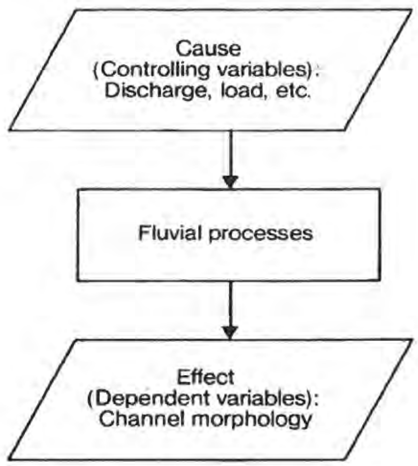

Figure 1. Major steps for hydraulic geometry determination

It is a general principle in hydrology that development results in an increase of the runoff discharge and it is usually accompanied by a decrease of sediment production. There may also be an increase of sediment production during the construction stage. Hydromodification, while lowers the downstream peak flow, usually decreases sediment supply toward downstream.

Development can destabilize a natural stream. Such cases can be found in many communities. In Orange County, destabilization of Serano Creek is primarily due to urbanization. Oso Creek has been destabilized resulting from sand and gravel mining.

The 2-, 5-, and 10-yr storms are not considered major events. Such storms occur more frequently. Development increases the discharge and decreases the sediment supply to the downstream stream channel. Such storms are expected to increase the downstream channel erosion. More discussions on steam channel response to development are described in the following sections.

Sediment Supply for the San Juan Stream System Affected by Development — A stream is within the domain of the fluvial system, which also consists of the drainage basin (or watershed) and the downstream reservoir, lake, or ocean. Schumm (l977) divided the fluvial system into three parts as shown in Figure 2. The upper part, or Zone 1, is the watershed, where most of the water and sediment for the stream originate. The middle part, or Zone 2, is the reach where the stream channel is the most stable and where its configuration is the best defined. Large rivers have long reaches of Zone 2, but this zone may be missing in small streams. This is the reach for which extensive river studies, modeling, and controls have been made. Despite the relative stability, a river channel, as a dynamic system, still undergoes changes that can be rapid and significant at times.

Zone 3 is near the river mouth, where the alluvial river is also under the influence of the tidal, or base level, variation. Because of continuous delta growth, it requires a rise in grade (aggradation) to maintain the channel slope and transport capacity. Rivers in this zone are often braided.

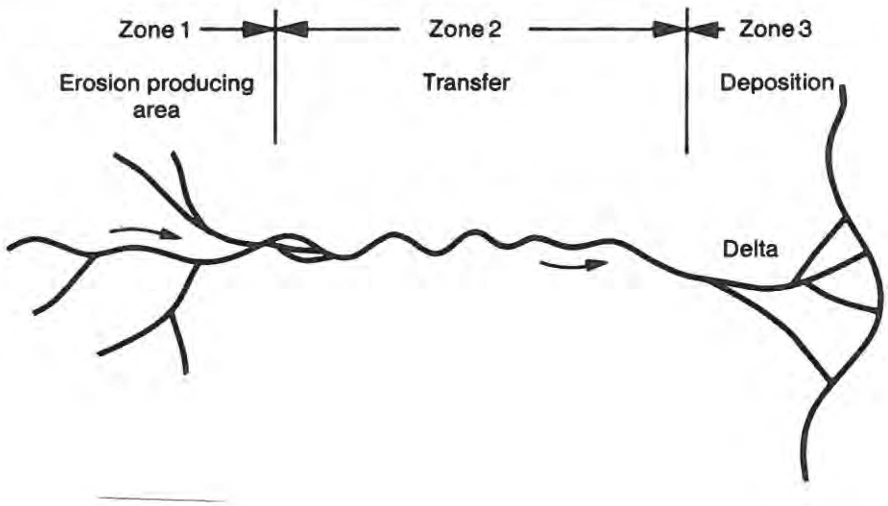

Figure 1.1 The fluvial system (after Schumm, 1977).

The fluvial system for San Juan Creek consists of the main channel together with the major tributaries of Chiquita Canyon and Gobernadora Canyon. Major development within the system is concentrated along the middle zone. The upper reach is within the Cleveland National Forest. Much of the upper reach may never be developed. This means that the sediment supply to the streams from the erosion producing area will be less affected by development. Development along the middle zones will decrease the sediment production and sediment supply to these streams. However, these areas have milder terrain and less sediment production by nature. In summary, development is expected to decrease sediment supply to the San Juan Creek stream system. This is primarily due to development along the middle reaches. The upper reaches along the major sediment producing areas are less affected by development. It may be concluded that development in the fluvial system for San Juan Creek is not expected to have major effects on stream morphology in the foreseeable future.

Potential Stream Channel Responses to Development — Geomorphic principles are useful for qualitative analysis of stream channel response without describing the transient behavior. Geomorphic approach is often employed at the conception and planning stage of a river project. The well-known geomorphic relationship by Lane (1955), depicting the concept of equilibrium, is

$$Q_s d \propto QS \qquad (1)$$

where Q_s is the sediment discharge and d is the sediment size. This principle is illustrated in

Figure 2 as a relationship of balance. If one or more variables are altered, adjustments in one or more of the others are necessary to restore equilibrium. This relationship, which is useful in predicting certain qualitative trends of adjustment, does not include the channel geometry nor does it provide thresholds between equilibrium states.

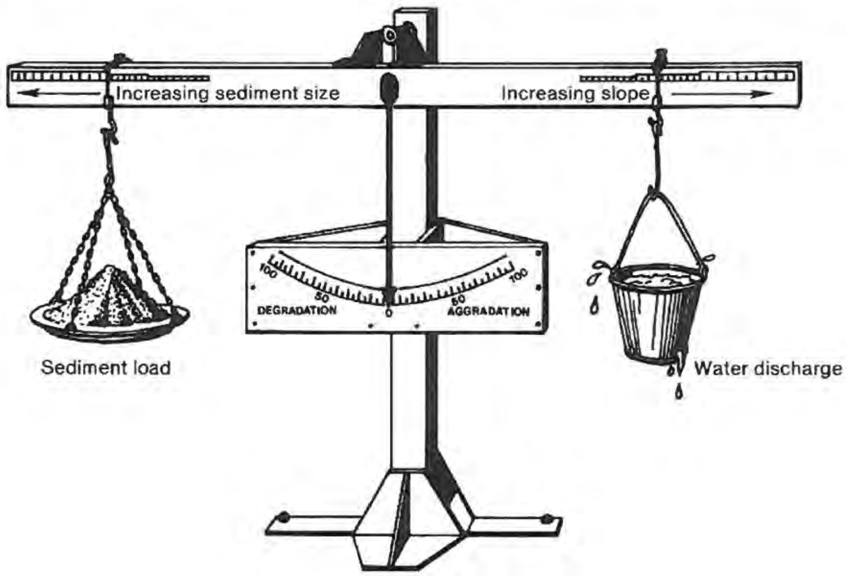

Figure 2. Stable channel balance (after Lane, 1955)

Lane's relationship suggests that the channel slope is controlled by the water discharge, sediment load, and its caliber. If the base level of a stream is raised by the construction of a dam, the slope of the upstream channel is reduced. Then upstream aggradation should occur in order to reestablish the original slope. On the other hand, the downstream river channel, in response to a deficit in sediment supply, usually undergoes degradation, development of a more sinuous course, and coarsening of the bed material through hydraulic sorting as exemplified in Figure 2. Aggradation and degradation, or short-term scour and fill, of the channel bed are usually accompanied by significant changes in channel width. Generally speaking, an aggrading channel tends to widen and a degrading channel tends to slide back into its banks.

Development can be expected to cause an increase of the stream flow discharge and a decrease the sediment supply to the stream channel. Such changes, according to Lane's relation in Figure 2, are expected to result in channel bed degradation. In response to decreased sediment inflow and increased discharge, the stream channel may respond by reducing its slope in addition to channel bed scour. This means the stream channel tends to become more sinuous in the process of reducing the slope. The development of a more sinuous plan form can be evidenced by erosion at the stream bank.

Development of a sinuous stream pattern caused by a deficit of sediment can be demonstrated by a case history shown in Figure 3. Here, the San Luis Rey River is located downstream of the check dam at Shearer Crossing near Escondido, California. Channel responses to sediment deficit include degradation, development of more sinuous course, and coarsening of bed material

The 2-, 5-, and 10-y storm events have limited effects on stream morphology. They are not expected to cause destabilization of the creek. Bank erosion and meandering development are evident from the observations by PACE.

Figure 3. San Luis Rey River downstream of check dam at Shearer Crossing near Escondido, California. Channel responses to sediment deficit include degradation, development of more sinuous course, and coarsening of bed material

Impacts of Frequent Storm Events on Stream Channel Morphology — Frequent storms in this case include the 2-, 5-, and 10-yr storm events. Flows during such events are contained in the stream channel and therefore they have direct effects on stream channel morphology. Stream channel formation is a result of the constantly changing discharge, and the bankfull discharge is usually used as the channel-forming discharge for downstream changes in channel geometry. This simplified approach is justified in view of the fact that lower discharges, which move less sediment, contribute less to the channel formation. Also, a discharge above the bankfull stage is largely absorbed by the broad flood plain and therefore it generally has less effect on the channel shape. From the 13 gaging stations in the eastern half of the United States, Leopold et al. (1964) found that the bankfull stage has a return period averaging 1.5 years. However, the bankfull discharge among the rivers studied by Williams (1978) does not have a common recurrence frequency. San Juan Creek and its tributaries have been affected by human activities associated changes in stream morphology in recent decades. The main channels within the system have undergone changes notably by sand and gravel mining. The channels have become incised and enlarged to different degrees. The bankfull discharge has also become greater. It can be seen from the HEC-RAS study results that the 10-yr flood is well contained in the channel with the water surface well below the top of bank elevation.

As the 2-, 5-, and 10-year events are contained in the channel, such flood events directly affects the stream morphology. Stream morphology formation and changes are directly related to sediment movement. Bed sediment moves along in the stream channel as long the as the flow velocity exceeds the critical velocity for incipient sediment motion. The bed materials consist of sand, gravel and cobble. There should be sediment motion during the 2-, 5- and 10-yr events. The rate of sediment transport is directly related to the discharge. The total sediment load is very sensitive the discharge and the relation may be expressed as:

$$Qs \infty Q^{2.5} \qquad (2)$$

In which, Qs is the sediment rate and Q is the discharge.

The effects of floods on sediment transport can be related to the flood discharges for San Juan Creek that are given below.

$Q10$ = 2023 cfs
$Q5$ = 684 cfs
$Q2$ = 152 cfs

The ratio of discharges for the 10- and 5-yr events is 2.95 but the ratio for sediment loads is 15 according to Equation 2. .

The sediment load increases more dramatically with the flood discharge, but the same ratio may not be applied to their effects on stream morphology. The changes in stream morphology reflect the steam channel adjustments toward equilibrium. Dynamic equilibrium is the condition toward which each stream channel evolves. The transient behavior of an alluvial stream undergoing changes must reflect its constant adjustment toward dynamic equilibrium, although the true equilibrium may never be attained. For a short stream reach of uniform discharge, the conditions for dynamic equilibrium are (1) equal sediment load along the channel and (2) uniformity in power expenditure QS. If the energy gradient is approximated by the water-surface slope, then a uniform energy gradient is equivalent to a linear (straight-line) water-surface profile along the channel. A stream channel undergoing changes usually does not have a linear water-surface profile or uniform sediment load and may have significant nonuniformities. However, river channel adjustments are such that the nonuniformities in water-surface profile and sediment load are effectively reduced. The rate of adjustment is limited by the rate of sediment movement and is subject to the rigid constraints such as grade-control structures, bank protection, abutments, bedrock, and so on.

Human activities due to sand mining and hydraulic structures such as grade controls, bridges, etc. in the stream system have ceased for many years. Erosion and deposition and the associated changes in stream morphology were more rapid in earlier years but they have slowed down gradually as the stream changes have also reached an approximate state of quasi-equilibrium. At this time, short-term changes are characterized by erosion along the channel bends associated with the channel curvature, as recorded in the field notes by PACE. Such changes are of long term nature and they can be expected to continue for many years to come. Long-term changes are also related to the gradual urbanization in the stream environment. The effects of urbanization on stream morphology are also of long-term nature and they can be expected to continue for a long time.

Efficacy and Thoroughness of the Existing Stream Monitoring Program – The existing PACE stream monitoring program includes data compilation, field monitoring, and analyses. They have compiled geologic data, rainfall and stream flow data, hydraulic data, historic erosion, aerial photographs, etc. They made periodic stream walks, and compiled field notes to record scattered gravel on the bed surface, scour or erosion signs, soil types, bed rock outcroppings, grade controls, bank erosion and sloughing, bed incision, field photographs. The field notes were made at many channel stations wherever erosion or other features were observed. PACE made visual monitoring of storm drain outlets, detention basin outlets. They also provided the input and output of the HEC-RAS modeling studies.

The efficacy of the monitoring stations relies on the adequate number of monitoring stations and the information obtained from these monitoring stations. The detailed information are recorded in the data and described in the written field notes.

A total of six monumented creek cross sections were installed initially along San Juan Creek. A total of eleven new monumented cross sections were added, with 4 in Gobernadora, 4 in Chiquita, and 3 in San Juan Creek. These monitoring stations were selected and used in the PACE monitoring study. In order to provide adequate information for stream monitoring, these stations must be located wherever there are significant changes in stream morphologic features. In reviewing the data and notes in the report, it can be seen that these changes from station to station are gradual. For this reason, the morphologic features are adequately described and recorded.

The original monitoring stations together with additional monitoring stations are considered adequate to identify the changes in stream channel changes for the 2-, 5- , and 10-yr floods. This is based on the observation that the stream channel changes have slowed down gradually after the sand and gravel mining activities in earlier years. The rate of changes has slowed down since the major changes due to sand and gravel mining had already occurred. The development in the drainage basin has induced changes in the stream system. The effects of development and urbanization are of long-term nature. The process is slow.

PACE should acknowledge if the monitored stream morphological changes also include the effects due to changes in nature. Natural factors, such as forest fires, erratic hydrologic phenomenon, bank settlement, fallen tree trunks, etc.

The PACE stream monitoring report provides field notes indicating observed erosion at numerous locations. Such locations with observed erosion are also shown on the map. It can be seen that most of these erosion locations are along the concave bank of the sinuous thalweg. Such an erosion pattern is expected as it is related to the flow in curved channels. Continued erosion along the concave bank will result in lateral migration of the stream channel.

Erosion in an alluvial stream, such as the San Juan Creek system, is under the physical constraints of bank protection, grade control, bedrock outcroppings, hydraulic structures, etc. This is evidenced from the field notes, channel bed profiles, etc.

Parameters and Selection Processes of the Monument Cross Sections and the Proposed Monitored Cross Sections — Monumented sections are also control sections. Markers are installed at the end points of each section to provide permanent control for field survey of the channel cross-sectional geometry. These sections are effective for identifying historical changes in channel dimension, thalweg migration, erosion process, etc. All sections were measured using the GPS methods. Seventeen such cross sections are used along San Juan Creek, Chiquita Canyon, and Gobernadora Canyon. These sections are selected such that they are representative of the channel reaches under study.

These monumented channel cross sections are limited in number; they do not provide the detailed variations in channel features within a channel reach. However, the more detailed variations in channel features are provided at the selected channel cross sections used in the HEC-RAS study.

In the PACE study, the channel geometry is also defined at selected channel cross sections. This finite difference scheme based on the channel cross sections assumes that the channel geometry varies linearly from one cross section to the next cross section. For this reason, the channel cross sections should be selected to cover the changes along the channel. In the PACE study, a large number of cross sections are selected at locations along the channel reaches under consideration. The PACE study has used a large number of cross sections. These cross sections provide adequate details to cover the variations in channel geometry and other features. The PACE study provides a comprehensive list of parameters for monitoring the stream channel characteristics and changes.

The PACE study presents the sinuous pattern of meandering thalweg along the stream channel and the changes with time. Such information cannot be provided by the monumented cross sections alone. The pattern needs to be obtained from the geometries at the large number of channel cross sections. The planform of the meandering thalweg is closely related to the scour pattern as bank erosion usually occurs at the apex of the meandering curve. The observed channel changes are characterized by erosion at the channel banks.

Comments and Recommendations on the Methods Utilized in Assessing Stream Response to the More Frequent Storm Events — Primary methods used in the PACE study for assessing stream response to more frequent storm events include data collection, monitoring of the stream channel geometry and changes over time. They have compiled data for the topography, geology, and hydrology of the stream system.

The existing Stream Monitoring Program by PACE is extensive and comprehensive; therefore, the program is effective in monitoring stream responses. Of course the monitoring program can still be improved by providing additional analyses of the fluvial system using geomorphic methods, hydraulic modeling, and sediment modeling. The impacts of development on stream morphology due to the more frequent storm events are a slow process. For this study, more hydraulic modeling or sediment modeling may not be justified at this time. However geomorphic analysis should improve our understanding the stream's response to development. .

The data compiled for the monitoring study provide the important basis that may be used to assess the stream channel stability and potential changes in the future. Changes of the stream morphology are directly related to the inflows of water and sediment that are supplied from the drainage basin. It is therefore important to develop a better understanding of the effects due to development on the water and sediment inflows to the stream channel system.

In order to assess the steam channel response to the more frequent storm events, one must consider the effects of development on the water and sediment supply to the stream channel. The RMV is located along the middle reach of San Juan Creek. For the stream system, the upper reach with a steeper slope is the sediment producing area. The area along the upper reach, however, is less affected by development and other human activities. The middle reach, where development occurs, also supplies water and sediment to the stream system. Development basically affects the water and sediment supply from the middle reach.

From the geomorphic perspective, potential changes of stream morphology are closely related to changes in nature and human activities. For this drainage basin of the San Juan Creek system, the primary human activity is development that affects the water and sediment flow to the stream channel. Improvement on the understanding of the steam morphological response can be achieved if additional data are obtained and presented by PACE. Improvement to the understanding on stream morphology and changes related to the more frequent storms can be accomplishment by the following tasks:

Recommendations — In addition to development, forest fires also affect the sediment and water inflow to the San Juan Creek system. As an example, the August 2016 Holy fire occurred on the steep hills of the Cleveland National Forest. The impacts due to this fire will gradually reach San Juan Creek. It is important to identify the impacts of all causes in addition to development on steam morphology. It is therefore recommend that the history of forest fires be compiled and included in the data basis for geomorphic analysis. The impacts of forest fires should be included in the discussions.

The sand and gravel mining has ceased in San Jan Creek for some time. Changes in stream morphology due to mining activities have gradually slowed down or even stopped. In order to develop a better understanding of the development impacts on stream morphology, it is recommended that the history of sand and gravel mining in the San Juan Creek system be reviewed and impacts be considered, at least qualitatively.

Suitability of the Adaptive Management Measures to Fully Address and Mitigate Stream Alteration Resulting from Increases in the 2-, 5-, and 10-yr Storm Events due to Development — Adaptive Management Measures for the fluvial system are for the purpose of assessing anticipated changes in stream morphology in the short term and in the long term. The 2-, 5- and 10-yr events will cause limited changes in the short term. The cumulative effects for long-term changes can be substantial. Changes in stream channel morphology consist of scour and fill of the channel bed (aggradation and degradation), width changes, and meandering development. Changes for San Juan Creek are characterized by channel bed scour, bank erosion and meandering development related to the decrease in sediment inflow together with the increase of the storm flow discharge. Erosion is wide spread notably along channel banks associated with the formation of a more sinuous channel planform.

Observers of the stream should notice the sinuous pattern of the thalweg. In fact, natural streams are hardly straight over a length longer than a few channel widths. Because of the close interrelationship between stream flow (the cause) and stream channel formation (the effect), many stream channel features and processes, such as meander planform, bed topography, bank erosion, and lateral migration, are very much related to the dynamics of flow in curved channels, which, in turn, provides the basis of analysis and modeling.

Spiral motion grows upon entering a bend. In a prismatic channel bend of sufficient length, the flow will eventually reach an equilibrium condition under which flow characteristics do not change from cross section to cross section. Such a flow is said to be fully developed. Because of the changing curvature of stream channels, the spiral motion undergoes constant growth and decay. In view of this morphological feature, it is useful to show the sinuous pattern by showing the thalweg in the stream channels. The sinuous pattern of the thalweg is useful to assess the effectiveness of the monitoring station. Those monitoring stations located near the apex of a sinuous curve provide the stream bank location vulnerable to stream bank erosion.

At this time, the changes in morphology are characterized by bank erosion due to continued meandering development. The monitoring has already identified erosion associated with the meandering development. To record such channel changes, the monitoring stations in adaptive management should continue to monitor the changes and make adjustment, whenever needed. The PACE Adaptive Measurement Measures has used adequate number of channel cross sections to capture the pattern of the sinuous thalweg. PACE has also used this information as the basis for developing countermeasures.

Summary and Conclusions — A technical review of the San Juan Creek Stream Monitoring program by PACE has been made. The stream monitoring program and Adaptive Management Measures are for the purpose of satisfying the mitigation requirements of Rancho Mission Viejo's FEIR 589 MM 4.5-1 for impacts associated with the 2-, 5-, & 10-year expected value storm events. Such storm events are contained in the stream channels to have direct impacts on stream morphology.

The primary objective for the monitoring program is to assess the impacts of development on stream morphology and to develop mitigation methods. The RMV development in the drainage basin of San Juan Creek contributes to an increase of the storm discharge together with a reduction of sediment supply to the stream system. Stream responses to these changes include general erosion, stream bed degradation, bank erosion, and development of a more sinuous stream course. PACE monitored the planform of the thalweg and its changes with time. This information is useful to identify the direction of changes and to develop countermeasure for stream channel stabilization.

The PACE stream monitoring program includes data compilation, field monitoring, and analyses. They have compiled geologic data, rainfall and stream flow data, hydraulic data, historic erosion, aerial photographs, etc. They made periodic stream walks, and compiled field notes to record physical features including channel bed materials, scour or erosion signs, bed rock outcroppings, grade controls, bank erosion and sloughing, bed incision, field photographs, etc. The field notes were made at many channel stations wherever erosion or other features were observed. PACE made visual monitoring of storm drain outlets, detention basin outlets. They also provided the input and output of the HEC-RAS modeling studies.

A total of six monumented creek cross sections were installed initially along San Juan Creek. A total of eleven new monumented cross sections were added, with 4 in Gobernadora, 4 in Chiquita, and 3 in San Juan Creek. These monitoring stations were selected and used in the PACE study. In order to provide adequate information for stream monitoring, these stations must be located wherever there are significant changes in stream morphologic features. In reviewing the data and notes in the report, it can be seen that these changes from station to station are gradual. For this reason, the morphologic features are adequately described and recorded.

The monumented channel sections together with the multiple channel sections provide adequate stream monitoring of the channel geometry and the meandering pattern shown by the sinuous thalweg. The planform of the sinuous thalweg is useful for identifying the locations of bank erosion and to develop countermeasures for stream channel training.

The original monitoring stations together with additional monitoring stations are considered adequate to identify the changes in stream channel changes for the 2-, 5- , and 10-yr. floods. This is based on the observation that the stream channel changes have slowed down gradually after the sand and gravel mining activities in earlier years. The rate of changes has slowed down since the major changes due to sand and gravel mining had already occurred. The development in the drainage basin has induced changes in the stream system. The effects of development and urbanization are of long-term nature. The process is slow.

Development can destabilize a natural stream. Such cases can be found in many communities. In Orange County, destabilization of Serano Creek is primarily due to urbanization. Oso Creek has been destabilized resulting from sand and gravel mining.

The fluvial system for San Juan Creek consists of the main channel together with the major tributaries of Chiquita Canyon and Gobernadora Canyon. Major development within the system is concentrated along the middle reaches. Much of the upper reaches are in the Cleveland National Forest and therefore they may never be developed. This means that the major sediment supply to the streams from the erosion producing upper reaches will be less affected by development. Development along the middle reaches will decrease the sediment supply to these streams. However, the development areas have milder terrain and less sediment production by nature. It may be concluded that development in the fluvial system for San Juan Creek is not expected to have major effects on stream morphology in the foreseeable future. The changes in steam morphology due to development are expected to develop continuously and the impacts will grow with time. Erosion should continue with time. Countermeasures for erosion mitigation have been identified and suggested by PACE. Such countermeasures should be implemented.

Recommendations — The sand and gravel mining activities have ceased in San Jan Creek for some time. Changes in stream morphology due to mining activities have gradually slowed down or even ceased. In order to develop a better understanding of the development impacts on stream morphology, it is recommended that the history of sand and gravel mining in the San Juan Creek system be reviewed and impacts be considered in the analysis.

The discharge and load supplied to the San Juan Creek stream system from the watershed constitute the cause for stream channel morphology. Development changes the water and sediment inflow to the stream channel. In addition to development, forest fires also affect sediment and water inflow to the San Juan Creek system. As an example, the August 2016 Holy fire occurred on the steep hills of the Cleveland National Forest. Impacts due to this fire will gradually reach San Juan Creek. It is important to identify and consider the impacts of all causes on stream morphology in addition to development on steam morphology.

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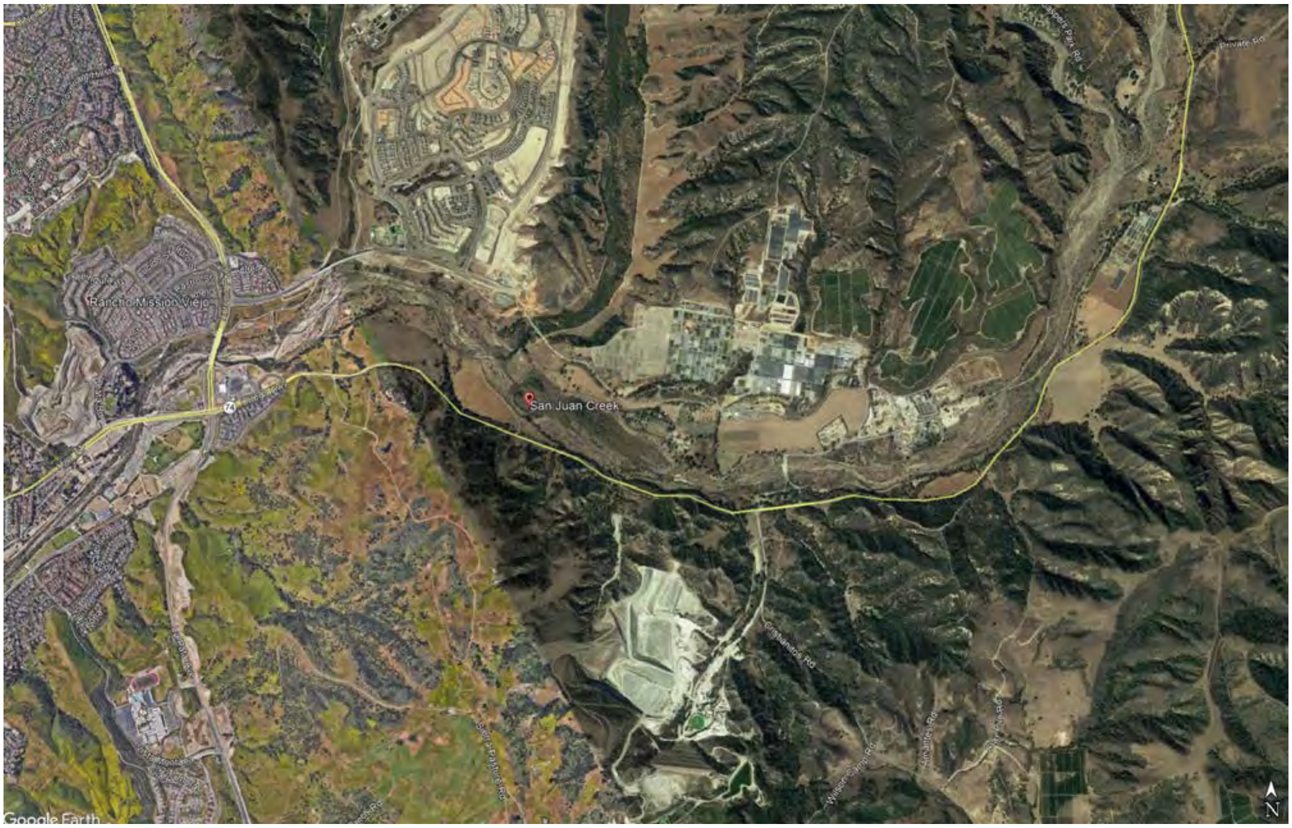
Sediment Study for San Juan Creek



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EXECUTIVE SUMMARY

This study is to provide technical assessment of San Juan Creek stream channel stability during the more frequent storm events and/or make recommendations regarding the appropriate use of adaptive response measures (ARM) as defined within Rancho Mission Viejo Stream Monitoring Program to insure channel stability during the more frequent storm events. In this case, the more frequent storm events refer to those events that are lower than the 25-yr event. In this study, the 25-yr flood was used together with a flood series representative of the post development long-term flood flow. The study covers the reach of San Juan Creek that is along the Rancho Mission Viejo property. One objective of the study is to generate a map identifying stream instability hotspots and the extents and types of ARM techniques for their stabilization.

The FLUVIAL-12 model (Chang, 1988) is employed for this study. For a given flood hydrograph, the FLUVIAL-12 model simulates spatial and temporal variations in water-surface elevation, sediment transport and channel geometry. Scour and fill of the streambed are coupled with width variation in the prediction of stream channel changes. Computations are based on finite difference approximations to energy and mass conservation that are representative of open channel flow.

Sediment delivery is the cumulative amount of sediment that has been delivered passing a certain channel section for a specified period of time. The spatial variation of sediment delivery depicts the erosion and deposition along a stream reach. A decreasing delivery in the downstream direction, i.e. negative gradient for the delivery-distance curve, signifies that sediment load is partially stored in the channel to result in a net deposition (aggradation). On the other hand, an increasing delivery in the downstream direction (positive gradient for the delivery-distance curve) indicates sediment removal from the channel boundary or net scour (degradation). A uniform sediment delivery along the channel (horizontal curve) indicates sediment balance, i.e., zero storage or depletion. Spatial variations in sediment delivery during different flood events for San Juan Creek show large increases and decreases in delivery along the channel, indicating major sediment erosion and deposition on the channel boundary. In other words, the natural equilibrium of San Juan Creek has been disturbed by human activities, including sand and gravel mining, hydraulic structures, etc.

The stream channel undergoes changes in channel bed profile, channel width and lateral migration during floods. The erosion hazard zone is the area along San Juan Creek that is subject to potential stream channel erosion during the selected flood series of frequent events. An important objective of the San Juan Creek study is to delineate the erosion hazard zone boundary, for which the change in channel width must be determined. It should also be clear that the changes in channel width and channel bed profile are closely inter-related. These changes must not be separated in studying river channel changes. The modeled results show that the changes in channel bed elevation are much smaller in magnitude than the changes in channel width. The bed elevation changes are generally less than a few feet at these channel stations. The channel width changes, however, are much greater; they can be as much as a few hundred feet. Such width changes are due to erosion of the channel boundary together with lateral migration of the channel

Lateral migration is a natural process; it develops along curved channel reaches for San Juan Creek. The natural stream channel changes due to lateral migration are augmented by sediment imbalance related to previous instream sand and gravel mining. This is particularly obvious for the short curved channel just downstream of the Antonio Parkway Bridge crossing. Lateral migration development along this curved channel reach is further enlarged by the deficit in sediment supply as large amounts of sediment are detained in the upstream sand and gravel mining site.

Delineation of the flood hazard zone is illustrated by graphical samples. The cross-sectional profile at the end of the flood series shows the maximum extent of erosion at the channel station. The flood hazard zone is the surface width of channel at maximum scour. The erosion hazard zone covers areas along San Juan Creek that are subject to stream channel erosion. The erosion hazard zone is also plotted on the map; it shows several places where large areas along the stream channel are subject to erosion hazard. Large changes in channel geometry due to erosion would demostrate the potential of adverse impacts due to both the pre and post Ranch Plan Development flows within San Juan Creek and the development entitled by the Rancho Plan.

The erosion hazard zone delineates areas along San Juan Creek that are subject to stream channel erosion. The boundaries of the erosion hazard zone are plotted on the maps shown in Figures 34 and 35. The maps have two sets of erosion hazard boundary lines. The yellow lines are determined based on 20-yr flood series. The red lines, based on the 100-yr flood, are provided by PACE. These two erosion hazard zones are established following different technical approaches.

An objective of the study is to determine the impacts of mitigated development flow on the potential erosion hazard for San Juan Creek. The flood series of frequent flood events for existing flow is plotted in Figure 7B together with the series for mitigated development flow. These flood series look closely similar in the figure. The mitigated development flood series has higher discharges for the more frequent events but lower discharges for less frequent events. The erosion hazard zone is delineated based on the flood series for the existing flow; it is also delineated using the flood series for the mitigated development flow. The erosion hazard zone is the surface width of the channel at the end of the flood series. The cross-sectional profile changes based on the existing flow and the mitigated development flow are closely similar. No significant differences in the erosion hazard zone can be discerned. It may therefore be concluded that the partially-mitigated development flow has no significant impacts on the potential erosion hazard for San Juan Creek.

However, the erosion hazard zone based on the 20-yr flood series of frequent storms is found to exceed the limit of erosion hazard zone established by PACE for the 100-yr flood at different locations. This erosion is attributable to natural processes within creek but must be accounted for in determining minimal safe distances from the erodible banks. One such location is along the channel reach downstream of the Antonio Parkway Bridge crossing. This erosion hazard may pose threat to the existing development along the channel bank; therefore, mitigation measure(s) for this potential threat is required. The potential erosion at this location is outside the erosion hazard zone delineated by PACE. In views of the potential erosion hazard, the mitigation in the form of ARMs appropriate to ensure the long term stability of San Juan Creek post development cannot be confirmed. The PACE study report needs to speak to how the use of the ARMs is appropriate for use in mitigated any unforeseen impacts associated with the 2, 5, 10 year storm events but that the larger issue related to lateral erosion for a 100 year event needs to be addressed and is a separate item of concern

PACE used the 100-yr flood to develop the lateral erosion. However, the technical method used is inadequate for several reasons. The method is not based on the post project (not fully mitigated) flood series. PACE used the HEC-6T model as the basis for the erosion hazard zone. The HEC-6T model, being an erodible bed model, lacks the ability to accurately predict lateral erosion and movement. This model does not account for the secondary flow inherent in curved channels. One cannot justify the application of a linear lateral erosion factor to account for the width change when the parameters are indeed not linear. PACE provided the erosion hazard zone map for the lower reach of the San Juan Creek recently. The map was not provided in any previous analyses that would have been based upon a previously determined lateral erosion extent.

In view of these considerations, it calls for more in depth study of potential erosion to ensure the long term stability for San Juan Creek. Any channel stabilization method for mitigation should be designed based on the 100-yr flood for long-term stability.

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Sediment Study for San Juan Creek

I. INTRODUCTION

San Juan Creek is subject to changes that may damage lives and properties in the stream environment. For the sake of protection, the engineering firm, PACE, has monitored stream channel erosion and has also developed an erosion hazard zone as a guide for development along the stream channel. This study has been made to reconfirm the study results by PACE and to recommend other measures, if needed.

This study is to provide technical assessment of San Juan Creek stream channel stability during the more frequent storm events and/or make recommendations regarding the appropriate use of adaptive response measures (ARM).as defined within the Rancho Mission Viejo Stream Monitoring Program to insure channel stability during the more frequent storm events. In this case, the more frequent storm events refer to those events that are lower than the 25-yr event. Rancho Mission Viejo (RMV) has proposed that mitigation is not needed for 2-, 5-, and 10-year storm events in relation to San Juan Creek and the development entitled by The Rancho Plan. This study shall validate that claim or suggest mitigation in the form of ARMs appropriate to ensure the long term stability of San Juan Creek post development.

Previous fluvial studies which include long term sediment transport modeling of the San Juan Creek (SJC) indicated that even if proposed condition peak discharges for the more frequent events (2-yr thru 10-yr storm events) are not mitigated to existing condition values, the Ranch Plan development will not produce adverse impacts on SJC's streambed stability. While the computer models are useful tools for predicting SJC's response to changing stream flows, the results may not be accurate. As required by FEIR 589 and as an additional level of confirmation, RMV has implemented a Stream Monitoring Program which includes annual reporting to address potential stream channel changes not predicted by the calculation procedures used in the fluvial studies for SJC. The annual monitoring effort by RMV includes implementation of corrective measures when needed and will continue up to 10 years after complete build out of the last Planning Area (PA) in the Ranch Plan.

The potential stream channel changes shall be analyzed using technical methods whenever possible. Recommendations shall be made in order to mitigate/stabilize the stream channel. To be specific, the study for San Juan Creek has the following objectives:

To confirm that the Stream Monitoring Program is an adequate mitigation measure for the unmitigated increase in peak discharges for the more frequent events due to the Ranch Plan development, and to determine potential stream channel changes beyond 10 years after complete build out of the last Planning Area in the Ranch Plan, recommend mitigation measures and provide cost estimates of needed improvements.

To assess the stream channel stability and to identify potential stream channel changes using available technical methods.

To determine the magnitude of potential stream channel changes in the time span of about 20 to 25 years.

To recommend mitigation or counter measures in order to maintain stream channel stability.

To generate a map identifying stream instability hotspots and the extents and types of ARM techniques for their stabilization.

The study covers the reach of San Juan Creek that is along the Rancho Mission Viejo property. A map of the stream channel is shown in Figure 1. Points of interest along the channel and their respective locations are listed below.

Points of interest	Channel station feet
La Novia Avenue	19936
Antonio Parkway	29539
Ortega Highway	32069
Chiquito confluence	35121-35233
Gobernadora Confluence	39524-39973
Bell confluence	58273-58874

Different storm events can be expected to occur in the future. In the time span of 20 years, one may expect one event exceeding the 20-year event, two events exceeding the 10-yr event, four events exceeding the 5-yr event, etc. Short term changes shall be evaluated using the 25 year storm. Long term effects shall be determined using a storm series that can be expected in a 20-yr time span.

Changes in stream channel morphology consist of scour and fill of the channel bed (aggradation and degradation), width changes, and meandering development. Changes for San Juan Creek are characterized by channel bed scour, bank erosion and meandering development related to the decrease in sediment inflow together with the increase of the storm flow discharge. Erosion is wide spread notably along channel banks associated with the formation of a more sinuous channel planform.

Observers of the stream should notice the sinuous pattern of the thalweg. In fact, natural streams are hardly straight over a length longer than a few channel widths. Because of the close interrelationship between stream flow (the cause) and stream channel formation (the effect), many stream channel features and processes, such as meander planform, bed topography, bank erosion, and lateral migration, are very much related to the dynamics of flow in curved channels, which, in turn, provides the basis of analysis and modeling.

Spiral motion grows upon entering a bend. In a prismatic channel bend of sufficient length, the flow will eventually reach an equilibrium condition under which flow characteristics do not change from cross section to cross section. Such a flow is said to be fully developed. Because of the changing curvature of stream channels, the spiral motion undergoes constant growth and decay. In view of this morphological feature, it is useful to show the sinuous pattern by showing the thalweg in the stream channels. The sinuous pattern of the thalweg is useful to assess the effectiveness of the monitoring station. Those monitoring stations located near the apex of a sinuous curve provide the stream bank location vulnerable to stream bank erosion.

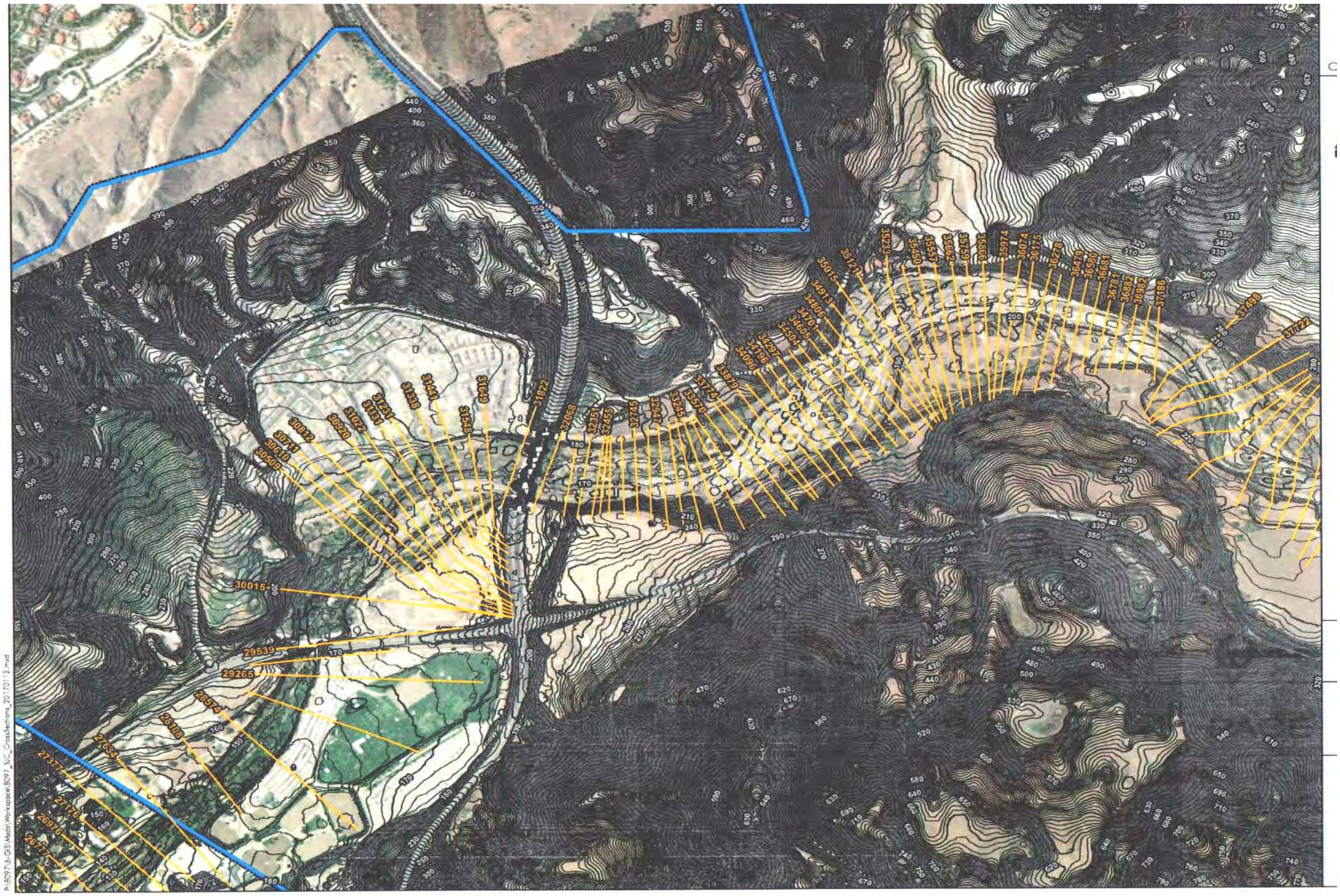


Figure 1. Map of San Juan Creek with channel cross sections

Figure 1(continued). Map of San Juan Creek with channel cross sections

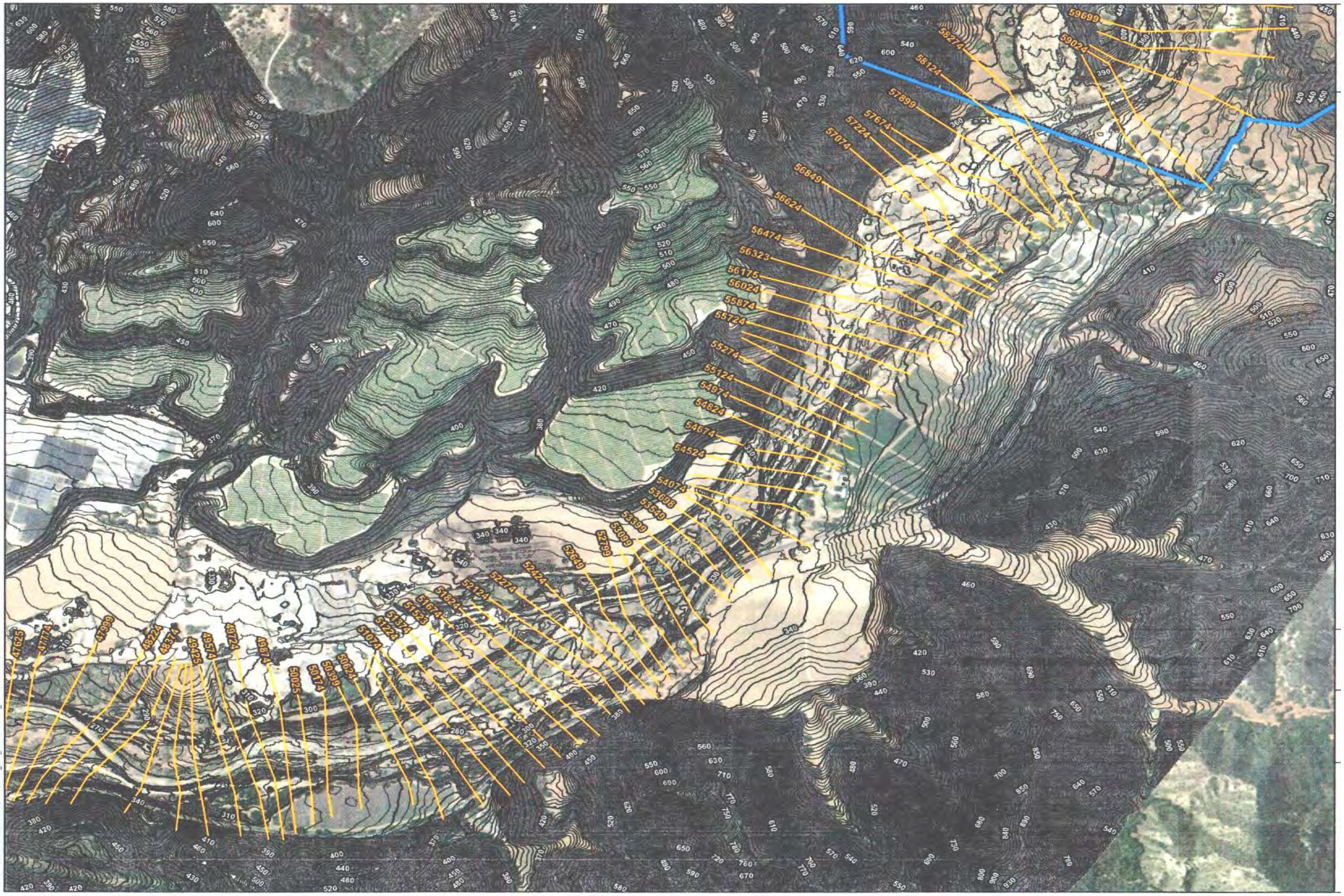


Figure 1(continued). Map of San Juan Creek with channel cross sections

II. MODELING STREAM CHANNEL CHANGES

The FLUVIAL-12 model (Chang, 1988) is employed for this study. For a given flood hydrograph, the FLUVIAL-12 model simulates spatial and temporal variations in water-surface elevation, sediment transport and channel geometry. Scour and fill of the streambed are coupled with width variation in the prediction of river channel changes. Computations are based on finite difference approximations to energy and mass conservation that are representative of open channel flow.

The model simulates the inter-related changes in channel-bed profile and channel width, based upon a stream's tendency to seek uniformities in sediment discharge and power expenditure. At each time step, scour and fill of the channel bed are computed based on the spatial variation in sediment discharge along the channel. Channel-bed corrections for scour and fill will reduce the non-uniformity in sediment discharge. Width changes are also made at each time step, resulting in a movement toward uniformity in power expenditure along the channel. Because the energy gradient is a measure of the power expenditure, uniformity in power expenditure also means a uniform energy gradient or linear water surface profile. A river channel may not have a uniform power expenditure or linear water-surface profile, but it is constantly adjusting itself toward that direction. The model was calibrated using 12 sets of field data. Such calibration studies are as listed in the User's Manual for FLUVIAL-12. Most of the calibration studies were peer-reviewed.

Selection of Engelund-Hansen Formula – A sediment transport formula is employed in the computer model. The Engelund-Hansen formula (1967) was selected for the study for the following reasons:

(1) The selection was based on the most extensive evaluation of formulas made by Brownlie (1981, see Figure 2); the Engelund-Hansen formula has the best correlation with field data.
(2) The Engelund-Hansen formula was used in many studies in the western U. S. The results of these studies were verified by field data. Sample studies applying the Engelund-Hansen formula are listed in the Users' Manual for FLUVIAL-12 (Chang, 2006).

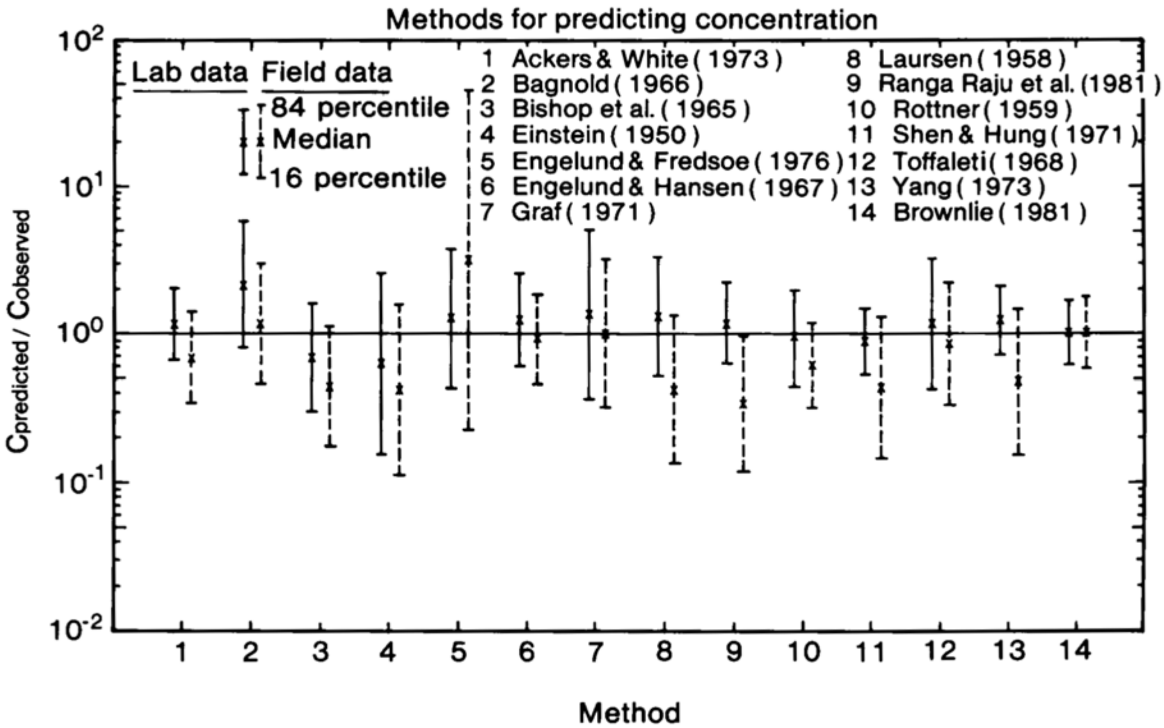


Figure 2. Evaluation of sediment transport formulas by Brownlie

Upstream Boundary Conditions for Sediment Inflow ─ The rate of sediment inflow into the study reach is provided by the upstream boundary condition for sediment. If this rate is known, it may be included as a part of the input and used in the simulation. Unfortunately, sediment rating data are rarely very reliable or simply not available. For such cases, it is assumed that the river channel remains unchanged above the study reach, and sediment inflow rate is computed at the upstream section at each time step, the same way they are computed at other cross sections.

River Channel Changes toward Dynamic Equilibrium ─ The dynamic equilibrium is the direction toward which each river channel evolves. The transient behavior of an alluvial river undergoing changes must reflect its constant adjustment toward dynamic equilibrium, although, under the changing discharge, the true equilibrium may never be attained. For a short river reach of uniform discharge, the conditions for dynamic equilibrium are: (1) Equal sediment discharge along the channel, and (2) uniformity in power expenditure γQS, where γ is the unit weight of the water-sediment mixture, Q is the discharge, and S is the energy gradient. If the energy gradient is approximated by the water-surface slope, then uniform power expenditure or energy gradient is equivalent to the linear (straight-line) water-surface profile along the channel. A river channel undergoing changes usually does not have a linear water-surface profile or uniform sediment discharge, but river channel adjustments are such that the non-uniformities in water-surface profile and sediment discharge are effectively reduced. The rate of adjustment is limited by the rate of sediment movement and subject to the rigid constraints such as grade-control structures, bank protection, abutments, bedrock, etc.

The energy gradient at a river cross section varies wildly. This variable is usually included in a hydraulic computation such as that of a HEC-RAS study. The output of any HEC-RAS study, even if it is for a fairly uniform river channel, usually exhibits non-uniformity in energy gradient along the channel. This variation is much more pronounced in disturbed rivers. A mathematical modeler realizes that a river channel will change in order to attain stream wise uniformity in sediment load. It is equally important to perceive that it will also adjust toward equal energy gradient along the channel. Because sediment discharge is a direct function of γQS, channel adjustment in the direction of equal power expenditure also favors the uniformity in sediment discharge. The sediment discharge in the reach will match the inflow rate when the equilibrium is reached. The FLUVIAL-12 simulated results on flow velocity and sediment transport along San Juan Creek will demonstrate the river channel's adjustments toward dynamic equilibrium.

Analytical Basis for Stream Channel Changes in Meandering and Lateral Migration ─ Since lateral migration usually occur along meandering streams, it is therefore important to review the dynamics of flow in curved channels programmed in FLUVIAL-12. The flow in curved channels as shown in Figure 3 has a longitudinal component as well as a transverse component. Because of the channel curvature, the flow is under the influence of the centrifugal acceleration, which induces (1) spiral motion in flow and (2) superelevation in water surface. Spiral motion, also known as helical motion, secondary currents, or transverse circulation, is in the direction normal to that of the primary (longitudinal) flow. Its occurrence is due to the difference in centrifugal acceleration u^2/r (u is the local longitudinal velocity, and r is the radius of curvature) along a vertical line in the flow because of the vertical profile of u in viscous fluid. For inviscid fluid without the velocity profile, spiral motion does not develop.

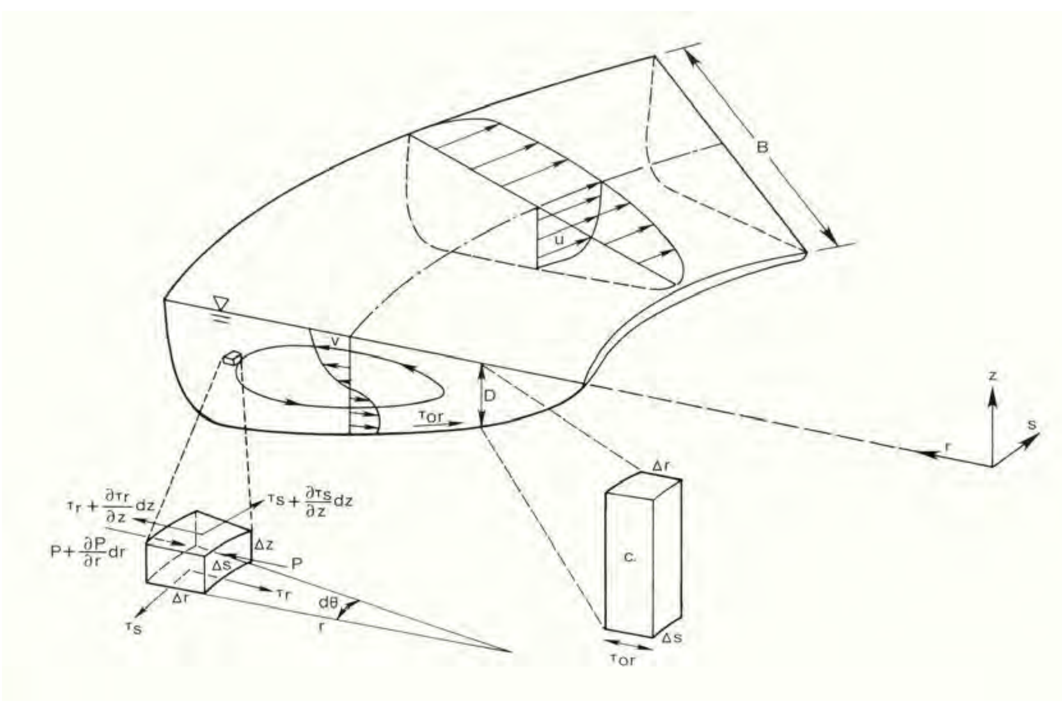


Figure 3. Components of flow through a curved channel

Spiral motion grows upon entering a bend. In a prismatic channel bend of sufficient length, the flow will eventually reach an equilibrium condition under which flow characteristics do not change from cross section to cross section. Such a flow is said to be fully developed. Because of the changing curvature of river channels, the spiral motion undergoes constant growth and decay.

Because of secondary currents, the surface current in a curved channel is skewed toward the concave bank and the bottom current is toward the convex bank as shown in Figure 4. At the channel bed, the angle of deviation δ for the bottom current is related to the channel curvature as follows

$$\tan \delta = 11 \frac{D}{r}$$

in which, D is the water depth and r is the radius of curvature.

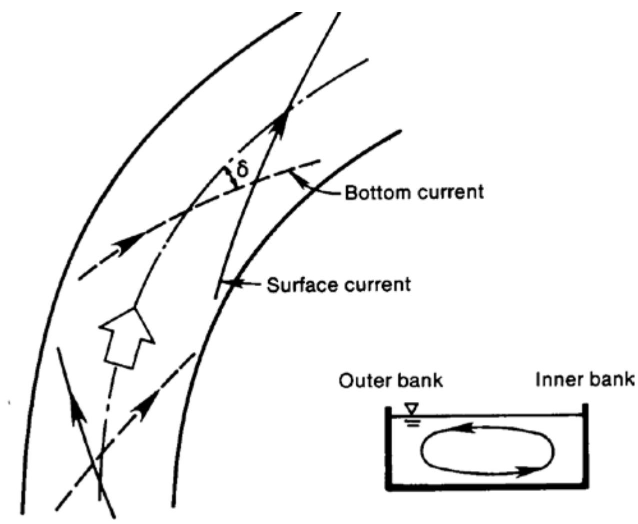


Figure 4. Surface and bottom currents in a curved channel

Sediment transport, in the presence of transverse flow, has a component in that direction. Sediment movement in the transverse direction contributes to the formation of transverse bed profile as exemplified by a sand bar formation along a river bend shown in Figure 5. In an unsteady flow, the transverse bed profile varies with time and is constantly adjusted toward equilibrium through scour and deposition.


Figure 5. Sand bar formation along a curved channel

Bank Failure by Mass Wasting – Lateral migration of a channel is due to retreat of the concave channel bank. There are two commons ways by which a bank retreats: (1) erosion of the bank material and (2) mass wasting. Erosion of the bank material is a gradual process, it occurs when bank material is detached and then carried away by the flowing water. Mass wasting, on the other hand, is a sudden process; it occurs when a chunk of the bank material sloughs and drops into the channel at the bank toe. Removal of such materials depends on fluvial entrainment. The material can be removed during the next flow episode.

The mechanics of failure depends on the size, geometry and properties of the bank material. In nature, no single process operates entirely alone to cause lateral migration. A comprehensive analysis of the processes and mechanics of river bank erosion has been made by Thorne (1982) and by Darby and Thorne (1996). Mass wasting is due to the processes of weakening and weathering that are directly associated with the soil moisture conditions. The processes fall into two groups: those which operate within the bank to reduce its strength, and those which act on the bank surface to loosen and detach particles of aggregates. Water is certainly an important factor that works with the bank to reduce its strength. The flow and its shear strength is the important factor which acts on the bank surface to loosen and detach the bank material. In a curved channel, the shear strength is contributed by the longitudinal flow as well as the secondary currents.

In order to account for the processes of mass wasting in FLUVIAL-12 model, the angle of repose and the bank erodibility factor are used. The angle of repose, PHI, is specified in field 9 of the G3 record; the bank erodibility factor, BEF, is specified in field 5 of the G1 record and in field 9 of the XF record. The selection of the angle of repose depends on the bank material. Normally, non-cohesive banks have a flatter angle and cohesive materials have a steeper angle of repose. The default value in the model for PHI is 36 degrees. The bank erodibility factor is selected in consideration of the strength against erosion. Normally, the non-cohesive banks have lower value for BEF and cohesive banks have a higher value. The default value for BEF in the model is 0.5.

The algorithm for lateral migration in the FLUVIAL-12 consists of the following processes. To start the process, flowing water erodes materials from the underwater part of the channel bank. The eroded material is carried away by the flowing water. Continued erosion steepens the bank slope. When the bank slope exceeds the angle of repose for the bank material, then the bank material drops down and deposits at the bank toe. The deposited material is gradually carried away by the flowing water. Such processes are closely related to the secondary currents, which flows downward at the concave channel bank and also flows from the concave bank toward the convex bank near the channel bed.

The 25-yr Flood and the Flood Series ─ In this study, the 25-yr flood was used together with a flood series representative of the long-term flood flow. The hydrology for San Juan Creek is provided by PACE. Figure 6 shows the hydrograph for the 25-yr flood under existing conditions. The flood discharges varies spatially. The peak 25-yr flood discharges for existing conditions at the concentration points are given below.

CONCENTRATION POINT 140, CHANNEL STATION 17402; Q25=16,698 CFS
CONCENTRATION POINT 138, CHANNEL STATION 22949; Q25=16,569 CFS
CONCENTRATION POINT 137, CHANNEL STATION 27634; Q25=16,395 CFS
CONCENTRATION POINT 134C, CHANNEL STATION 33353; Q25=16,352 CFS

PACE has also provided the hydrology of San Juan Creek for other conditions as listed in the Table below. They include the amount of difference between the two different conditions and their variations at different locations along the creek within the Ranch boundary.

Node 137 Summary Comparison Existing vs. Proposed Mitigated Flow					
Storm Return Period	Existing Peak Flow	Developed Peak Flow	Mitigated Development	Mitigated Delta	Percent
	(cfs)	(cfs)	(cfs)	(cfs)	
2-year	608	816	732	124	20.4%
5-year	2,496	2,846	2,796	300	12.0%
10-year	7,236	7,596	7,433	197	2.7%
25-year	16,865	16,894	16,415	-450	-2.7%
50-year	20,253	20,296	19,635	-618	-3.1%
100-year	23,098	23,185	22,352	-746	-3.2%

Peak Flowrates			
Node	2-Year Q (cfs)	5-Year Q (cfs)	10-Year Q (cfs)
119	524	2409	7216
126	534	2429	7178
127	559	2414	7159
133C	733	2758	7374
134C	718	2736	7373
137	732	2796	7433

In the future, one should expect various flood events. In the time span of 20 years, one may expect, statistically, one flood event exceeding the 20-year flood, two events exceeding the 10-year flood, four events exceeding the 5-year flood, ten events exceeding the 2-yr flood, etc. For this stream reach, most of the sediment transport occurs during major events. Those events less than the 2-yr flood have very limited discharge and hence sediment transport capacity; therefore, only those events equal to or greater than the 2-yr flood are included in the flood series for simulation. The series of flood events occur randomly. The sequence of occurrence of these floods is beyond human prediction, but the particular order of flood events does not affect the results pertaining to the long-term sediment delivery. The sequence of flood events as shown in Figure 7 is employed to represent the long-term flood flow.

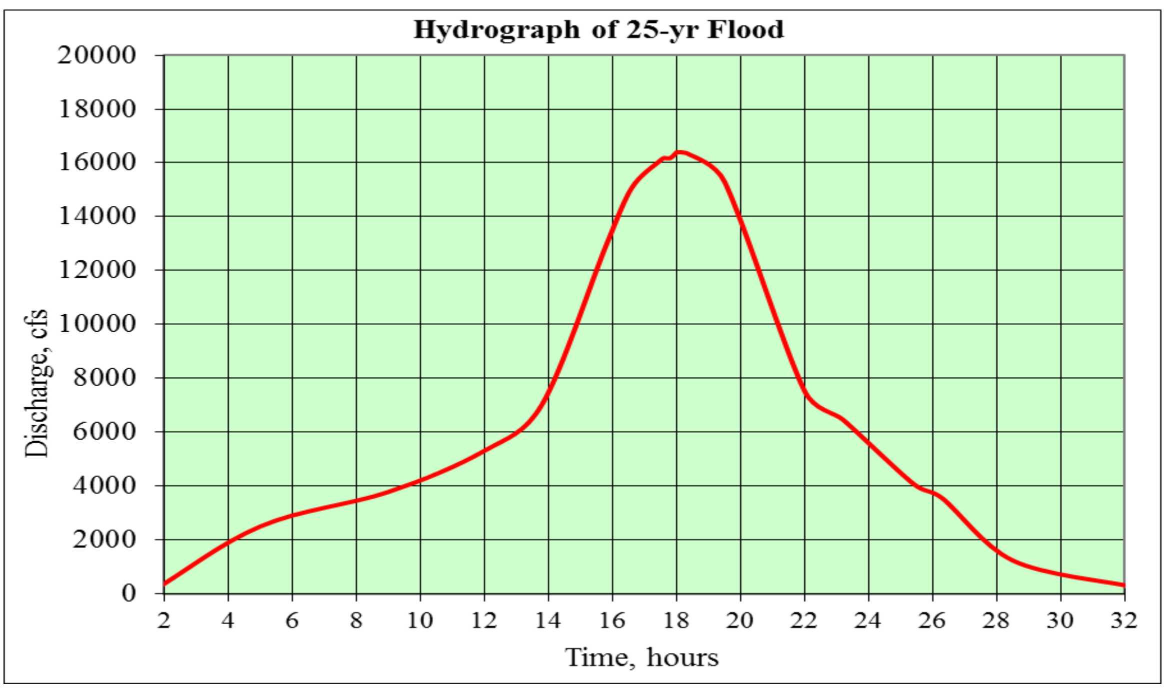


Figure 6. Hydrograph of the 25-yr flood

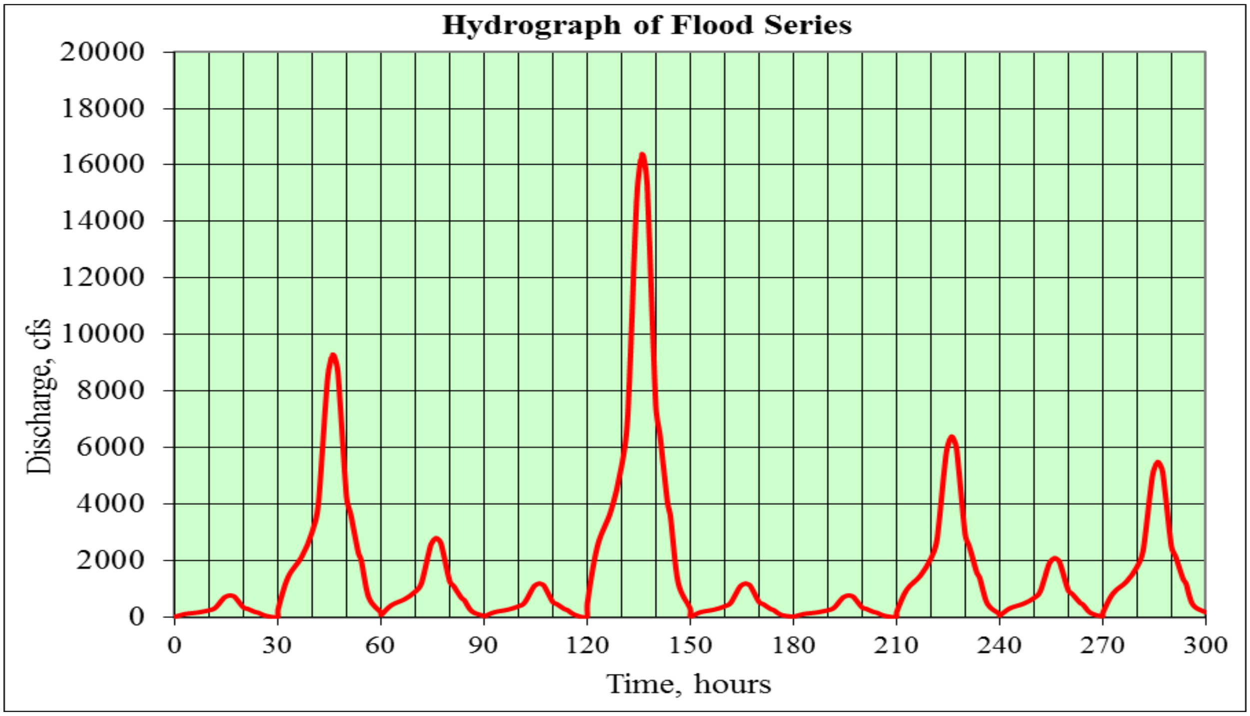


Figure 7A. Hydrograph of the flood series for existing conditions

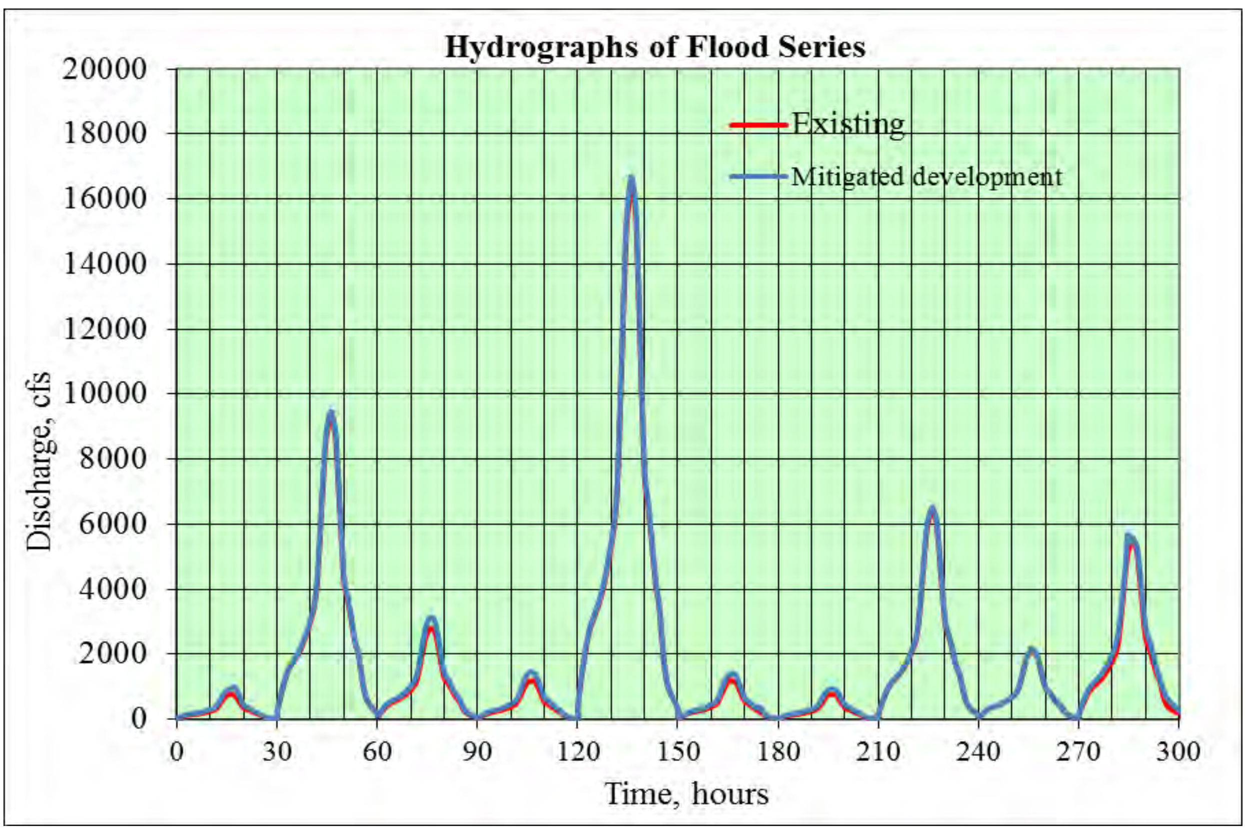


Figure 7B. Hydrograph of the flood series for existing and mitigated development conditions

III. TIME AND SPATIAL VARIATIONS OF HYDRAULIC AND SEDIMENT TRANSPORT PARAMETERS

The FLUVIAL-12 model was employed to simulate the hydraulics of flow, sediment transport and stream channel changes for San Juan Creek. The 25-yr flood and the flood series were used separately. Input/output parameters for the FLUVIAL-12 model are explained in Appendix A. Sample input/output listings are attached to the report. Results of the modeling study are described below.

The dynamics of stream flow and sediment transport is both unsteady and non-equilibrium Because of the changing discharge, the flood flow is unsteady. The sediment transport rate and channel geometry in the unsteady flow are non-equilibrium. The stream channel has gradually-varied channel geometry and it is constantly adjusting toward dynamic equilibrium but the true equilibrium may never be attained. Because of the changing features, the simulated results are used to address the time and spatial variations of the flow and sediment characteristics along the stream channel. Simulated results described below include the following items:

(1) Flow velocity,
(2) Sediment transport rate and sediment delivery, and
(3) Channel geometry.

Table 1 Summarizes the computer hydraulic parameters generated by the computer model.

Table 1. Summary of hydraulic parameters generated by the computer at the peak flow during the flood series

Ch. station Feet	W.S. Elev. feet	Width feet	Depth feet	Discharge CFS	Velocity FPS
17514	90.09	406.3	8.97	16698	6.76
17618	90.59	327	9.52	16698	7.84
17706	91.18	349.4	10.57	16698	8.16
18111	95.63	471.5	17.31	16698	6.16
18639	99.65	378.2	15.38	16698	5.59
19051	101.83	538.5	18.04	16698	4.97
19502	103.56	594.1	13.61	16698	3.67
19802	103.98	261.3	12.78	16698	6.87
19936	104.43	244.2	14.41	16698	6.98
20214	106.02	589	11.73	16698	3.99
20628	107.22	479.2	11.03	16698	4.49
20888	108.05	494.1	10.79	16698	4.09
21146	108.82	436.4	12.33	16698	5.12
21446	110.32	592.6	11.65	16698	4.77

21746	111.77	608.9	12.18	16698	5.63
22046	113.59	670.8	11.93	16698	4.83
22346	115	595	9.58	16698	4.89
22646	116.34	571.6	9.94	16698	5.19
22946	117.86	491.5	10.45	16569	5.85
23246	119.32	414	9.37	16569	5.83
23546	120.48	392.3	9.26	16569	6.18
23846	121.84	457.6	9.2	16569	5.91
24146	123.37	496.1	9.27	16569	6.17
24446	125.29	397.3	11.45	16569	6.3
24746	127.63	394.3	12.69	16569	5.9
25047	130.01	368.6	14.04	16569	6.16
25346	132.49	446.8	14.98	16569	5.44
25646	134.52	484.3	15.46	16569	4.9
25776	134.97	353.1	12.98	16569	6.18
25976	135.75	310.1	13.24	16569	6.54
26177	136.82	283.6	15.43	16569	5.84
26377	137.45	299.5	12.3	16569	6.97
26574	138.57	299.7	14.17	16569	5.52
26777	139.41	355.1	12.43	16569	5.46
26976	140.2	366.9	11.89	16569	5.59
27176	141.05	343.5	11.46	16569	5.78
27377	141.96	330.5	10.89	16569	6.26
27634	143.48	335.1	11.19	16394	5.97
28108	146.95	301.4	12.45	16394	7.31
28574	151.52	306.6	10.73	16394	6.78
28989	154.46	281	9.82	16394	8.45
29265	156.7	303.5	10.07	16394	7.6
29412	157.68	263.8	10.03	16394	8.2
29539	159.06	248	12.15	16394	7.04
30015	162.43	458.7	10.8	16394	4.63
30509	164.88	462.1	10.05	16394	6.41
30610	165.68	548.8	8.05	16394	5.96
30711	166.36	596.7	7.49	16394	5.98
30812	167.01	584.8	7.92	16394	6.27
30920	167.77	568.1	7.25	16394	6.24
31022	168.41	585.2	6.97	16394	6.5
31131	169.33	603.3	6.57	16394	5.86
31231	170.07	675.9	8.09	16394	5.85
31338	171.07	672.2	8.1	16394	5.39
31441	171.83	580.7	8.6	16394	6.08

31548	172.87	662.1	9.53	16394	5.11
31649	173.55	595.2	9.73	16394	5.27
31822	174.6	563.2	8.3	16394	5.09
32068	176.06	517.4	8.76	16394	5.49
32250	177.21	527.4	9.24	16394	5.42
32351	177.83	518.6	9.8	16394	5.34
32455	178.43	491.7	9.12	16394	5.53
32498	178.69	484.6	9.28	16394	5.53
32545	178.96	469.4	9.45	16394	5.58
32645	179.53	462.2	9.56	16394	5.54
32745	180.07	451	10.4	16394	5.58
32846	180.66	500.1	9.05	16394	5.21
32947	181.19	558.1	9.03	16394	5.04
33047	181.65	557.1	9.59	16394	5.33
33145	182.18	569.6	8.82	16394	5.37
33245	182.72	474.2	8.63	16394	5.37
33353	183.29	468.3	10.08	16391	5.43
33459	183.86	465.7	10.39	16391	5.49
33570	184.5	574.7	10.21	16391	5.17
33670	185.1	633.5	9.84	16391	4.88
33774	185.65	671	8.63	16391	4.6
33879	186.09	699.3	7.61	16391	4.53
33993	186.56	706.4	7.78	16391	4.57
34096	186.99	704.4	8.51	16391	4.72
34196	187.45	705.2	7.44	16391	4.82
34297	187.97	759.2	7.42	16391	4.58
34400	188.51	817.4	6.51	16391	4.43
34504	189.08	791.6	6.77	16391	4.48
34605	189.63	780.7	7.09	16391	4.54
34701	190.13	702.7	7.75	16391	4.9
34806	190.76	722.4	6.54	16391	4.88
34913	191.39	750	7.16	16391	5.11
35015	192.06	755.2	5.8	16391	5.14
35121	192.77	721.6	6.39	16391	5.45
35233	193.68	743.8	9.02	16391	5.58
35352	194.77	681.6	7.68	16391	5.59
35450	195.59	547	8.86	16391	5.94
35557	196.55	580.2	8.95	16391	5.79
35662	197.42	472.8	10.44	16391	6.1
35759	198.26	462.2	10.15	16391	6.03
35866	199.19	473.2	8.96	16391	5.79

35974	200.15	605.4	9.24	16391	5.48
36074	201.08	688.8	9.29	16391	5.16
36175	201.88	606.2	9.91	16391	5.71
36278	202.68	571.6	10.59	16391	5.92
36376	203.48	478.8	9.96	16391	6
36479	204.44	605.3	11.17	16391	5.62
36580	205.22	492.8	9.4	16391	5.85
36681	205.87	477.3	7.96	16391	6.13
36781	206.64	492	10.86	16391	5.62
36882	207.21	461	11.21	16391	5.65
36982	207.72	437.3	11.42	16391	5.59
37082	208.18	424.5	10.05	16391	5.35
37186	208.6	442.7	9.99	16391	5.08
37498	209.83	495.6	9.95	16391	5.25
37722	210.92	453	11.17	16391	5.79
37873	211.79	462.8	11.99	16391	5.6
38023	212.62	545.6	11.04	16391	5.38
38173	213.43	597.4	11.48	16391	5.05
38398	214.51	731.2	10.13	16391	4.42
38665	215.67	688	11.53	16391	4.43
38848	216.63	831.3	9.99	16391	4.2
38998	217.43	602.9	9.35	16391	5.23
39147	218.46	455	11.07	16391	6.13
39298	219.61	436.3	12.03	16391	6.24
39524	221.35	609.3	11.11	16391	5.25
39973	223.93	372.5	12.09	16391	6.61
40123	224.93	428.3	12.61	16391	6.38
40273	226.38	805.9	16.53	16391	5.37
40423	227.23	806.1	15.26	16391	1.74
40573	227.28	827.5	15.76	16391	1.52
40723	227.31	847	15.66	16391	1.49
40873	227.33	786.4	14.96	16391	1.64
41024	227.37	720.1	13.32	16391	1.99
41173	227.43	682.7	13.23	16391	2.66
41323	227.62	731.5	11.62	16391	2.75
41473	227.84	809.1	10.76	16391	2.84
41623	228.09	858.6	9.94	16391	3.02
41773	228.4	704.3	9.95	16391	3.42
41923	228.81	742.2	9.41	16391	3.73
42073	229.36	758.9	9.18	16391	3.86
42223	229.96	776.9	9.56	16391	4.02

42373	230.63	759.8	8.19	16391	4.02
42523	231.35	706.8	8.15	16391	4.35
42673	232.16	640.1	9.32	16391	4.66
42823	233.11	624.9	8.87	16391	4.69
42973	234.13	638.4	9.28	16391	4.95
43123	235.25	587.3	9.96	16391	5.37
43273	236.49	548.4	10.68	16391	5.67
43423	237.82	536	9.13	16391	5.71
43573	239.21	551	8.06	16391	6.41
43798	241.65	495.2	6.56	16391	6.89
43948	243.08	446.9	8.52	16391	6.19
44098	244.12	338	7.37	16391	9.46
44248	245.87	159.9	10.02	16391	11.79
44398	248.27	189.5	13.67	16391	10.43
44548	250.45	183.4	17.51	16391	9.2
44698	252.09	157.4	18.73	16391	9.1
44848	253.59	160.7	19.46	16391	8.67
44998	255.1	224.8	15.78	16391	7.62
45147	256.15	244	12.16	16391	7.63
45298	256.95	192.7	14.39	16391	8.3
45373	257.26	159.8	14.81	16391	8.87
45523	258.04	131.3	17.04	16391	8.97
45598	258.44	154.3	18.2	16391	8.95
45748	259.81	240.1	16.46	16391	6.86
45898	260.47	274.7	14.3	16391	6.58
46048	261.04	256.4	15.2	16391	6.4
46198	261.76	303	14.36	16391	5.56
46348	262.45	430	12.98	16391	4.73
46499	262.9	397.5	11.64	16391	5.79
46738	263.92	360.3	11.17	16391	6.25
46887	267.02	248.5	9.47	16391	12.81
47024	271.76	488.2	14.16	16391	6.03
47174	272.82	415.7	14.78	16391	5.91
47324	273.81	422.7	14.74	16391	5.81
47474	274.84	485.4	12.38	16391	5.39
47625	275.81	551.5	12.43	16391	4.99
47774	276.66	480.6	12.57	16391	5.35
47999	278	475.7	11.94	16391	5.59
48224	279.37	350.1	15.22	16391	6.01
48374	280.31	370.7	15.18	16391	5.54
48524	281.07	384.9	14.13	16391	4.71

48824	282.05	472.2	13.4	16391	3.77
49049	282.53	459.8	11.79	16391	4.32
49199	282.87	402.7	12.87	16391	5.29
49425	283.6	236.7	14.52	16391	6.48
49574	284.22	265.2	14.45	16391	6.16
49724	284.96	390.6	13.22	16391	4.89
49874	285.4	399.3	12.1	16391	4.72
50025	285.8	413.7	11.26	16391	5.02
50174	286.27	386.1	10.51	16391	5.08
50399	287.08	435.5	11.19	16391	4.42
50624	287.7	365.2	12.4	16391	5.5
50774	288.27	352.2	13.1	16391	5.56
50923	289.11	617.7	13.17	16391	3.76
51074	289.51	501.7	12.25	16391	3.62
51224	289.84	557.3	10.79	16391	3.62
51374	290.19	580.3	9.59	16391	3.84
51523	290.65	608.6	9.48	16391	4.13
51674	291.27	606.5	9.07	16391	4.47
51824	292.06	590	9.07	16391	4.79
51974	293.06	648.5	9.26	16391	4.76
52124	294.13	649.3	10.21	16391	4.85
52274	295.14	679.2	8.69	16391	4.73
52424	296.18	719.8	9.41	16391	4.33
52649	297.68	563.4	8.46	16391	5.35
52799	299.19	447.4	6.37	16391	7.29
52949	301.82	303.5	8.6	16391	9.01
53099	304	108.7	16.32	16391	16.5
53249	310.1	145.5	16.8	16391	11.91
53399	311.64	95.4	18.1	16391	13.17
53549	312.4	66.5	22.39	16391	18.65
53698	320.03	123.9	25.27	16391	10.3
53849	321.23	91.3	25.04	16391	11.43
54074	325.37	373.6	26.99	16391	7.45
54223	327.26	453	24.31	16391	4.7
54374	327.96	487.8	22.44	16391	3.94
54524	328.32	382.8	20.47	16391	3.87
54674	328.65	454.7	19.17	16391	3.45
54824	328.88	444	16.85	16391	3.41
54974	329.11	467.4	16.01	16391	3.42
55124	329.35	446.4	15.24	16391	3.55
55274	329.62	458.4	14.48	16391	3.62

55424	329.9	444.1	13.81	16391	3.92
55574	330.27	464.7	13.34	16391	3.91
55724	330.7	599.7	11.77	16391	3.5
55874	331.07	688.5	10.74	16391	3.31
56024	331.43	729.1	9.25	16391	3.47
56175	331.86	694.1	8.76	16391	3.79
56323	332.4	633.5	8.26	16391	4.45
56474	333.23	677.5	9.27	16391	4.41
56624	334.1	741.2	8.89	16391	4.23
56849	335.36	804.6	9.12	16391	4.23
57074	336.82	832.3	8.66	16391	4.69
57224	337.97	805.9	7.8	16391	4.65
57525	340.41	827.5	6.16	16391	4.84
57674	341.86	782	6.13	16391	5.27
57899	344.27	800.4	6.81	16391	5.37
58124	346.35	742	6.49	16391	5.71
58274	347.76	607.7	7.19	16391	6.88
58874	356.44	258	11.31	16391	7.76
59024	359.04	280.7	11.44	16391	7.2
59325	363.33	294.8	12.3	16391	6.81
59550	366.2	261.3	13.16	16391	7.06
59699	368.08	253.3	14.67	16391	7.24
59999	372.1	242.3	10.8	16391	7.56
60149	374.29	238.5	10.94	16391	7.88
60374	379.13	666.5	11.91	16391	5.8
60599	383.18	1353.5	11.81	16391	3.58
60750	384.82	1153.7	12.54	16391	3.73
60921	386.31	1091.6	10.09	16391	3.3
61123	387.67	977.3	11.36	16391	3.53
61295	389.07	780.1	11.91	16391	4.34

Time and Spatial Variations of Flow Velocity ─ The velocity of stream flow is a part of the computer output. For a stream channel undergoing dynamic changes, the flow velocity also changes during the flow and it also varies along the channel. Time and spatial variations of the flow velocity for San Juan Creek are exemplified by the simulated results shown in Figure 8. The figure shows that the flow velocity varies along the channel during the peak flow as well as toward the end of the flood. The flood discharge is 16,392 cfs at the peak and it is 218 cfs toward the end of the simulation period.

At the peak flow, the flow velocity shows wide variations along the channel; it is between 1 and 20 feet per second. Such a spatial variation is related to the gradually-varied channel geometry, with the lowest velocity occurring near channel station 40,000 in the borrow pit. The spatial variation of flow velocity also means varied sediment transport along the stream channel. As the stream channel undergoes changes; it is adjusting toward dynamic equilibrium with the flow velocity and sediment transport also adjusting toward uniformity along the channel.

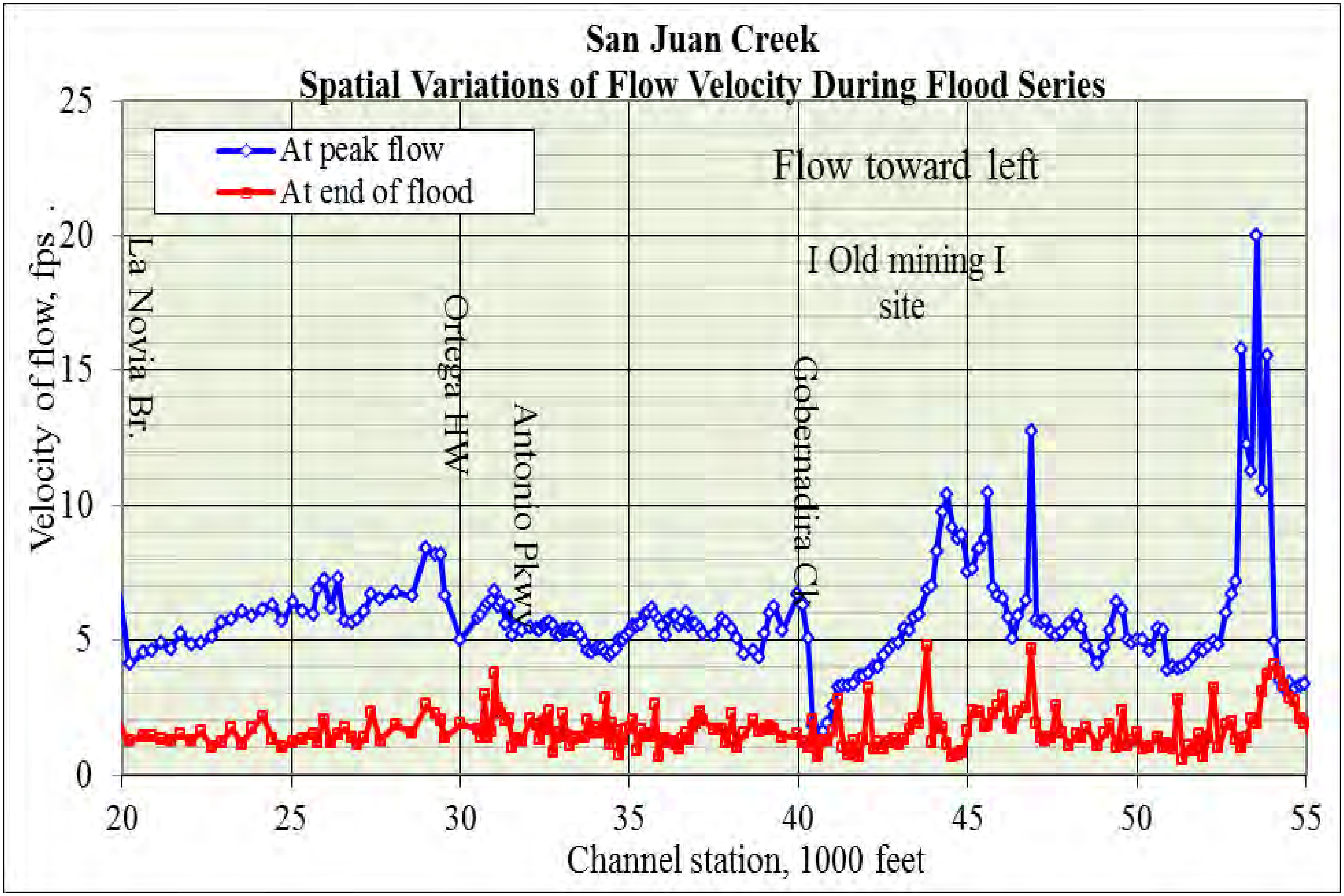


Figure 8. Time and spatial variations of flow velocity during 25-yr flood along river channel

Sediment Delivery ─ Sediment delivery is defined as the cumulative amount of sediment that has been delivered passing a certain channel section for a specified period of time, that is,

$$Y = \int_T Q_s dt \tag{1}$$

where Y is sediment delivery (yield); Q_s is sediment discharge; t is time; and T is the duration. The sediment discharge Q_s pertains only to bed-material load of sand, gravel and cobble. Fine sediments of clay and silt constituting the wash load may not be computed by a sediment transport formula. Sediment delivery is widely employed by hydrologists for watershed management; it is used herein to keep track of sediment supply and removal along the channel reach.

Changes in stream channel geometry are due to the differences between sediment inflow and outflow for a channel reach. In other words, spatial variations in sediment delivery are related to sediment storage in channel or sediment removal from the channel boundary. The spatial variation of sediment delivery depicts the erosion and deposition along a stream reach. A decreasing delivery in the downstream direction, i.e. negative gradient for the delivery-distance curve, signifies that sediment load is partially stored in the channel to result in a net deposition (aggradation). On the other hand, an increasing delivery in the downstream direction (positive gradient for the delivery-distance curve) indicates sediment removal from the channel boundary or net scour (degradation). A uniform sediment delivery along the channel (horizontal curve) indicates sediment balance, i.e., zero storage or depletion. Channel reaches with net sediment storage or depletion may be designated in each figure on the basis of the gradient. From the engineering viewpoint, it is best to achieve a uniform delivery, the non-silt and non-scour condition, for dynamic equilibrium.

Spatial variations in sediment delivery during the 25-yr flood are shown in Figure 9, those for the flood series are shown in Figure 10. These variations indicate the potential for erosion and deposition along the stream channel. The following general trends are depicted in the figures:

(1) There are more sediment delivery and greater spatial variations in sediment delivery during the flood series than during the 25-yr flood. This means more sediment movement and greater stream channel changes due to erosion and deposition during the flood series than during the single 25-yr flood.

(2) The largest sand and gravel mining site is located from channel station 40,000 to channel station 46,000. The borrow site has not been totally refilled. The spatial variations in sediment delivery near the site show a large drop in sediment delivery, indicating major sediment deposition in the borrow pit.

(3) The uneven spatial variations in sediment delivery along the stream channel upstream from the borrow site reflect the effects of previous instream sand and gravel mining. The stream channel is still adjusting toward dynamic equilibrium while it undergoes erosion and deposition during storm events.

(4) The spatial variations in sediment delivery show a general increasing trend downstream of channel station 40,000. The channel reach is downstream of the large mining site that detains a large amount of sediment. The increasing sediment delivery downstream of the mining site indicates erosion of the channel boundary in response to the deficit in sediment supply from upstream. .

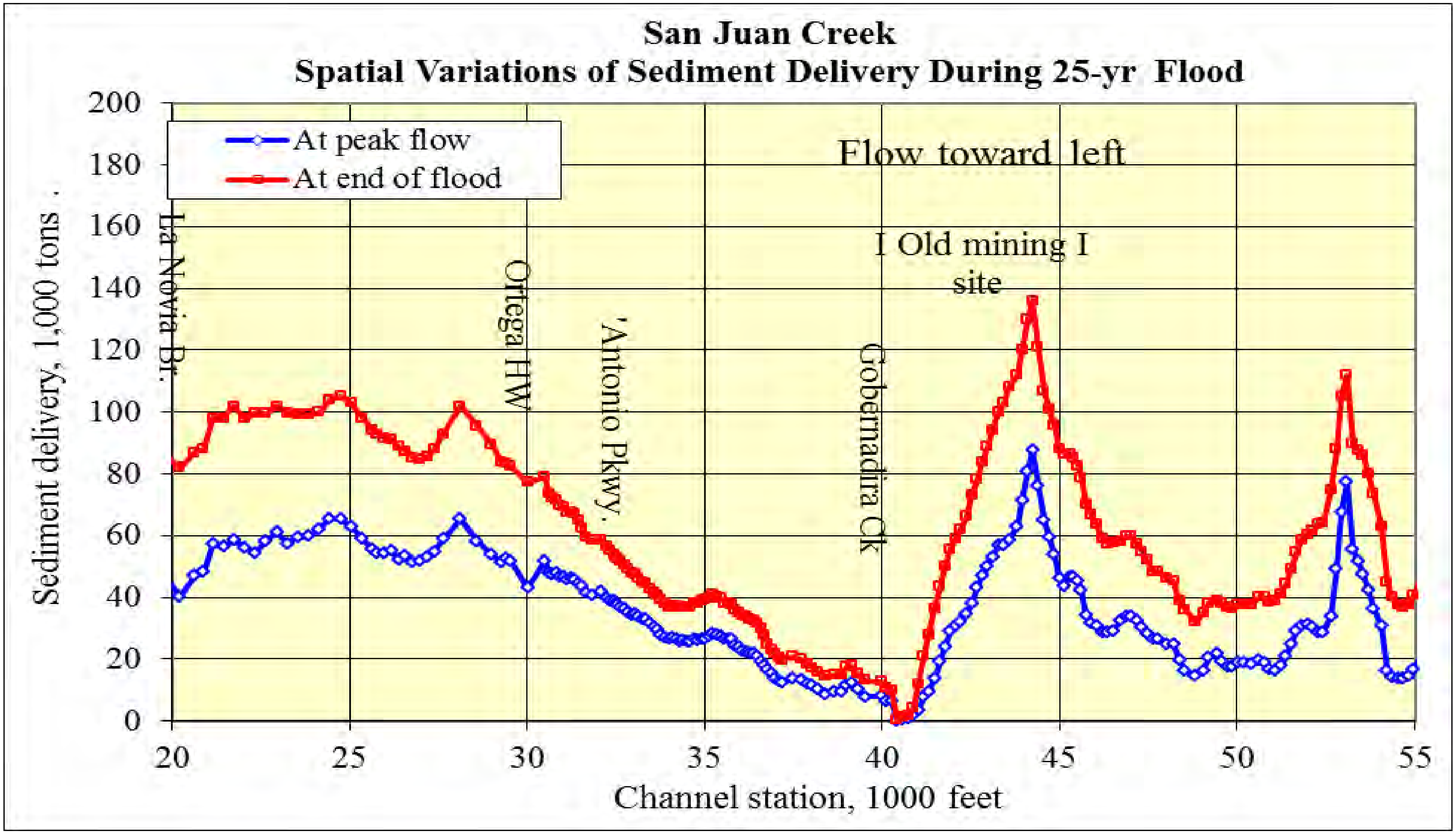


Figure 9. Time and spatial variations of sediment delivery during the 25-yr flood

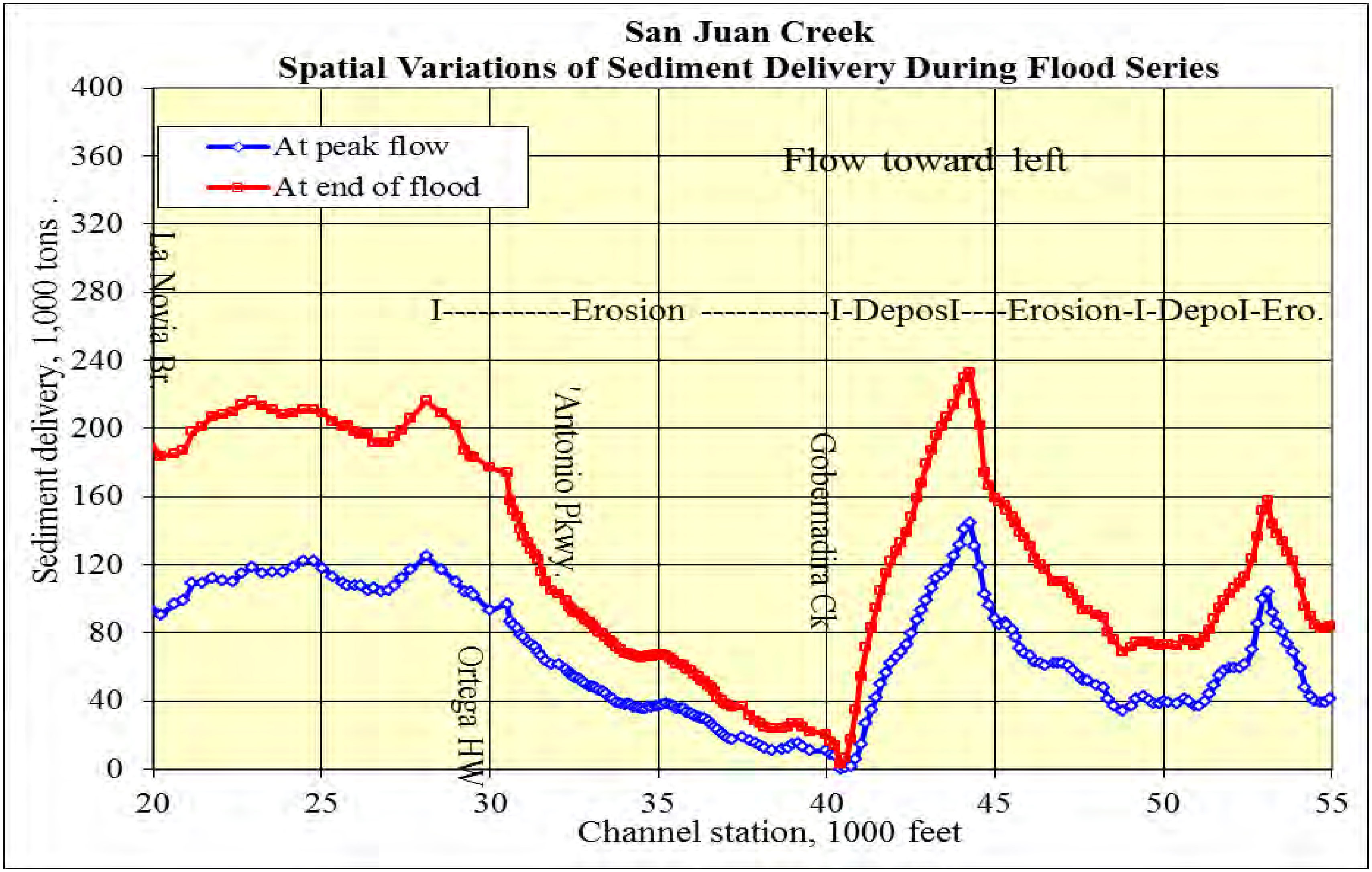


Figure 10. Time and spatial variations of sediment delivery during the flood series

IV. WATER-SURFACE AND CHANEL-BED PROFILE CHANGES DURING FLOOD SERIES

Water-surface and channel-bed profile changes along the stream channel are simulated by the FLUVIAL-12 model. Sample results are presented in this section. Figure 11 shows the simulated water-surface profile together with channel-bed profile changes during the flood series.

Simulated changes in water-surface and cross-sectional profiles at the channel stations along a short channel reach are presented. The short channel reach is between the Ortega Highway Bridge and the Antonio Parkway Bridge; it is selected to illustrate the dynamic changes in channel geometric features simulated using the FLUVIAL-12 model. This short channel reach is selected because it is a curved channel reach along which lateral migration of the channel can be expected.

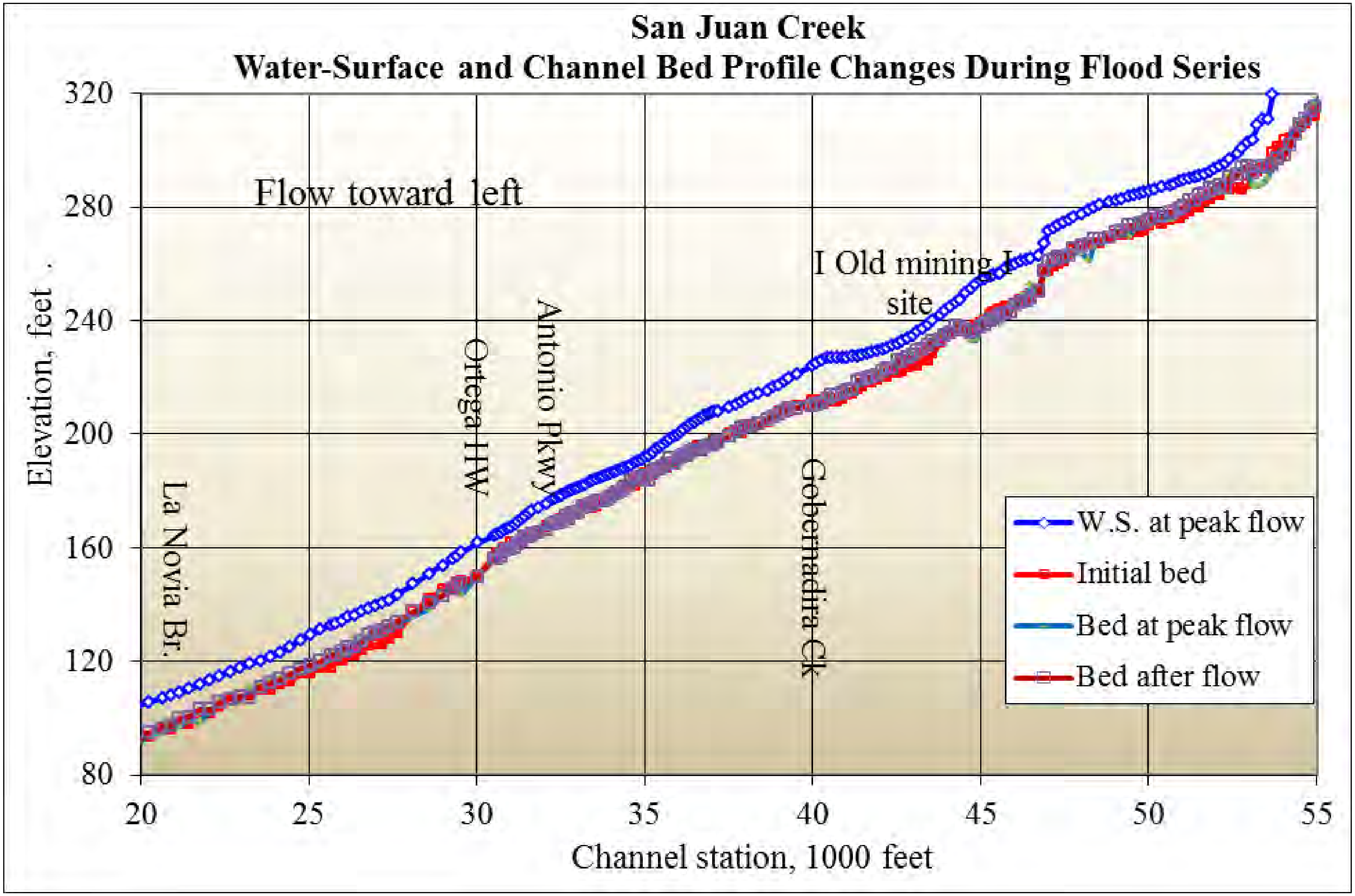


Figure 11. Water-surface and channel bed profile changes during flood series

Modeled Channel Geometry Changes along Curved Channel Reach ─ The curved channel reach along San Juan Creek between the Ortega Highway Bridge and Antonio Parkway Bridge is selected to illustrate the effects of lateral migration on stream channel changes. The channel reach is selected because it is a curved channel reach where lateral migration often occurs, The erosion hazard zone is determined based on the potential stream channel changes in boundary affected by lateral migration.

Figure 12. Curved channel reach between the Ortega Highway Bridge and the Antonio Parkway Bridge

In the following, the modeled cross-sectional geometry changes are presented for the stations from the Ortega Highway Bridge crossing toward the Antonio Parkway Bridge crossing. Peak flow velocities along this reach, as shown in Figure 8, are in the range of 5 to 7 feet per second, capable of eroding channel boundary materials

The spatial variation in sediment delivery along this channel reach as shown in Figure 10 has an increasing trend toward downstream. For the flood series, the sediment inflow at the upstream channel station 32068 is 103,000 tons and the sediment outflow passing the downstream channel station 29412 is 184,000 tons. The increase in sediment delivery from 103,000 tons to 184,000 tons is 81,000 tons.

The weight of bed material can be converted into volume using the factor that one cubic yard of bed material has the average weight of 1.35 tons. The weight of 81,000 tons has the volume of 60,000 cubic yards. This is the volume of sediment removed by flow from the boundary of this channel reach during the flood series. Since there is more sediment removal than sediment supply, the sediment deficit is reflected by erosional changes of the channel geometry. The amount of erosion occurs in the channel bed or channel width, or both. The changes in bed profile and channel width will be shown by the changes in channel cross-sectional profiles in the next section.

From the downstream end, channel sections 29412 and 29539 are located at the Ortega Highway Bridge crossing. The channel width at this location is constrained by the bridge abutments so that flood flow through the bridge opening has a higher flow velocity. The higher flow velocity means greater sediment transport through the bridge crossing and channel bed scour. The simulated changes in cross sectional geometry during the flood series are shown below. These cross sectional profile changes are characterized by greater channel bed scour during the high flow followed by some refill of the channel bed toward the end of the flow period.

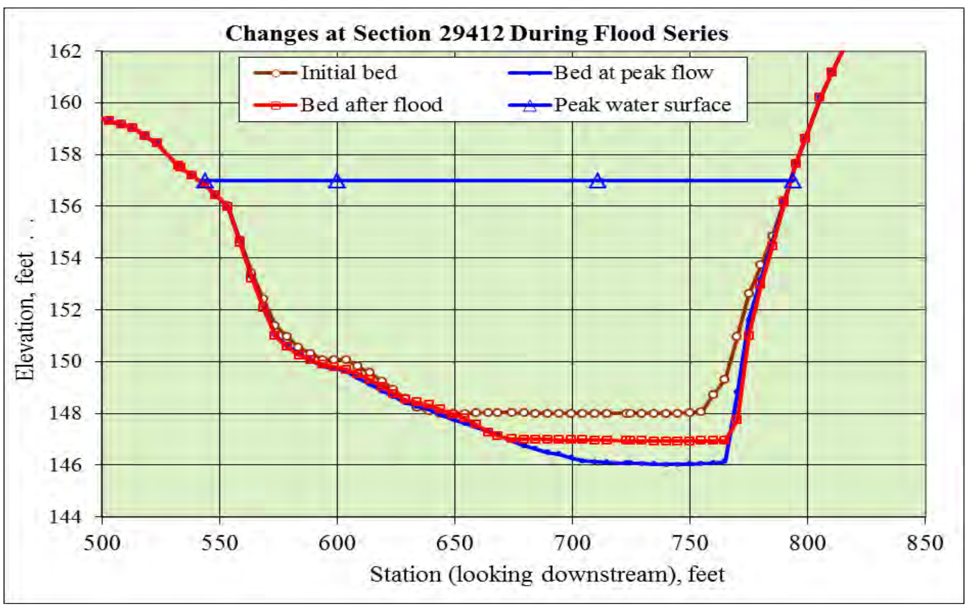


Figure 13. Simulated cross-sectional changes during flood series at channel station 29412

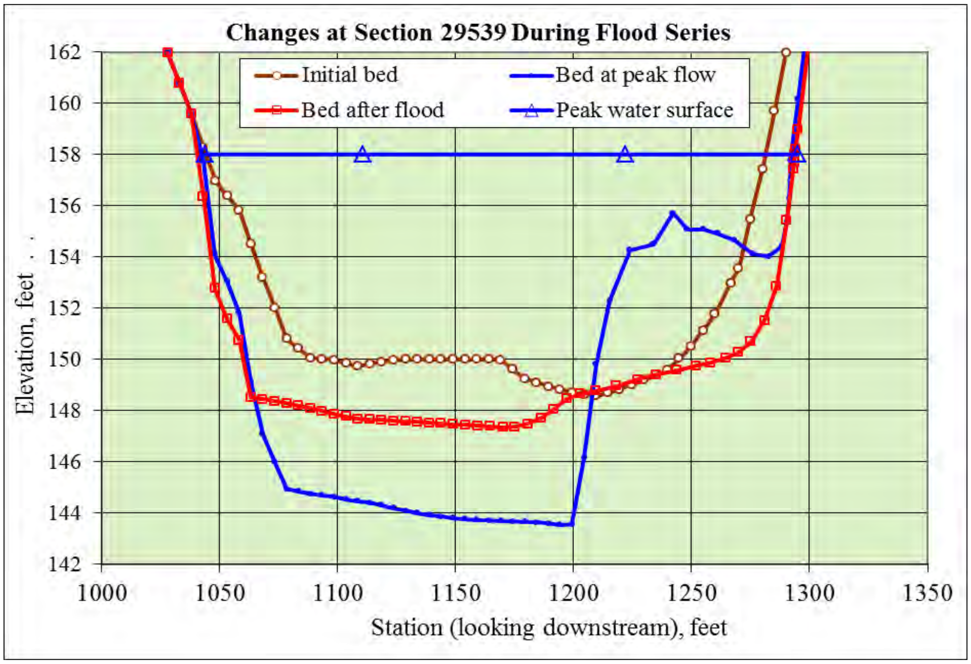


Figure 14. Simulated cross-sectional changes during flood series at channel station 29539

The next channel reach is from channel station 30015 to 31231. This channel reach has a mild curvature with the northwest bank (right bank) being the concave bank and the southeast bank (left bank) as the convex bank. Modeled results for the channel reach are shown in the figures below, including those at channel stations 30015, 30509, 30711, 30920, 31022, 31131, and 31231. These graphical results show the following general trends:

(1) Net erosion with more bed material removal from the channel boundary than deposition on the channel boundary. Cross-sectional areas of channel will be enlarged by flood flow due to net erosion.
(2) Changes on the channel banks as well as in the channel bed. The figures are plotted with a distorted scale with exaggerated vertical scale. Changes on the channel banks are much greater in magnitude than the changes in channel bed elevation. Bank eroion increases the erosion hazard area.
(3) With a mild channel curvature, there is slighty more scour of the right (concave) bank than the left (convex) bank. This means some lateral migration of the channel.
(4) The increase in erosion hazard area is attributed to erosion of the channel boundary and lateral migration of the channel .

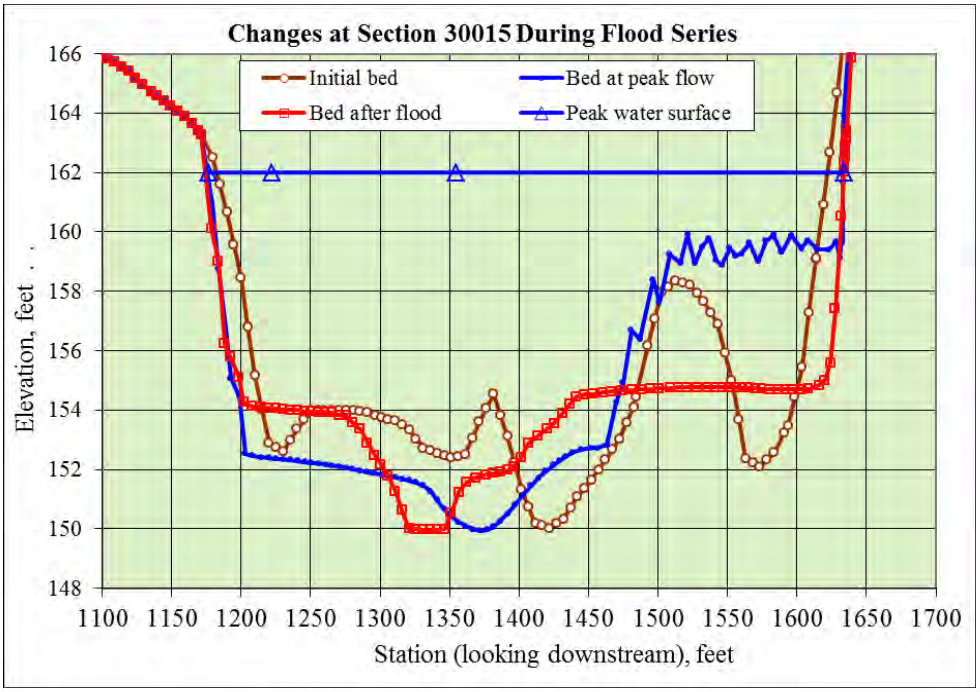


Figure 15. Simulated cross-sectional changes during flood series at channel station 30015

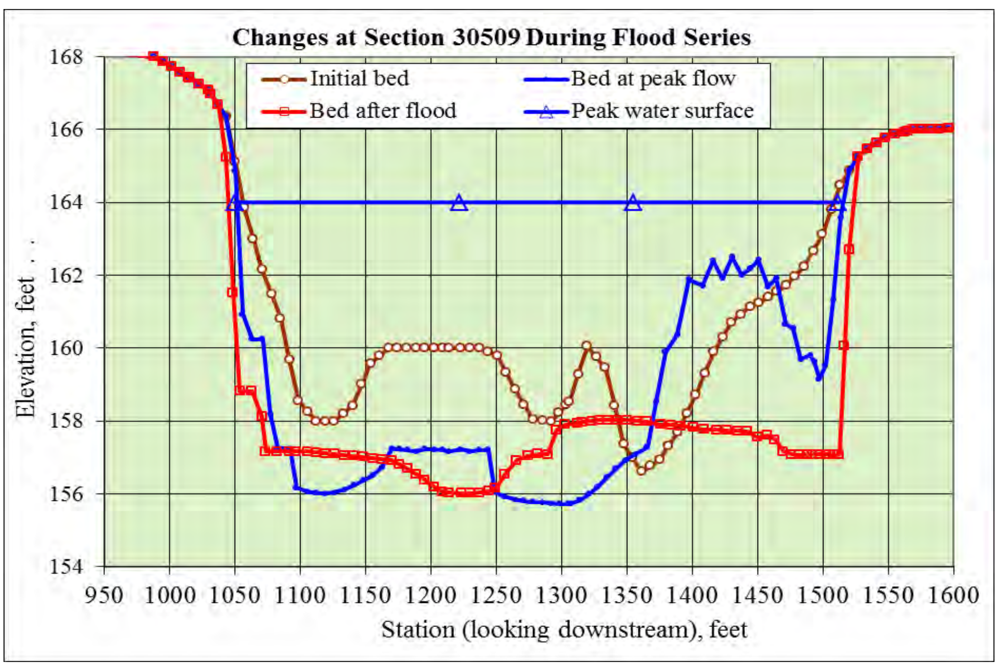


Figure 16. Simulated cross-sectional changes during flood series at channel station 30509

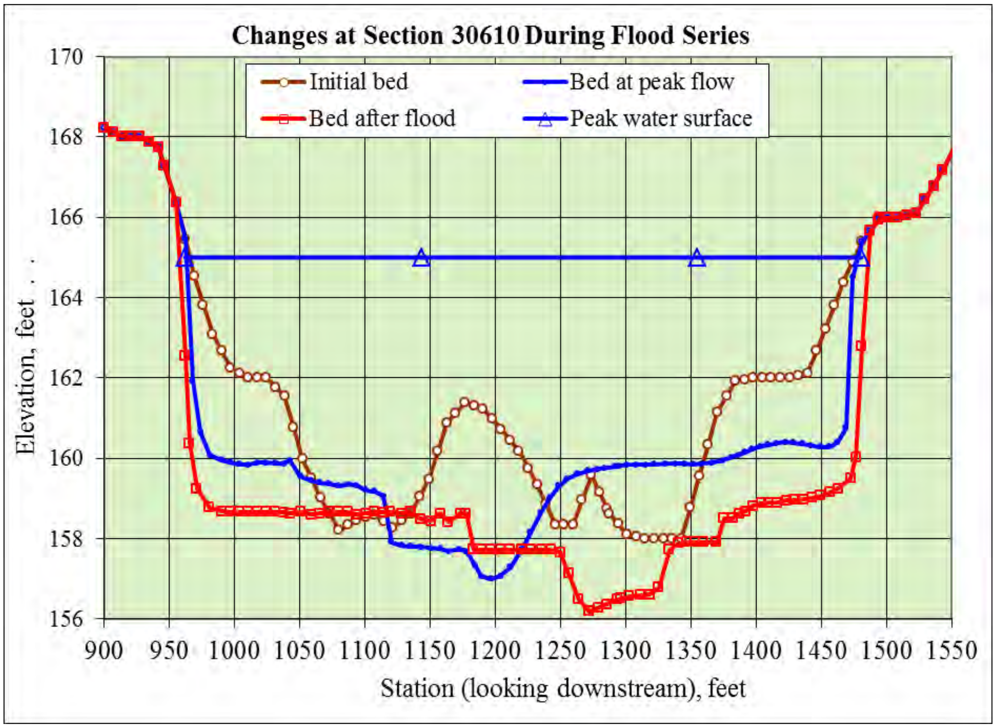


Figure 17. Simulated cross-sectional changes during flood series at channel station 30610

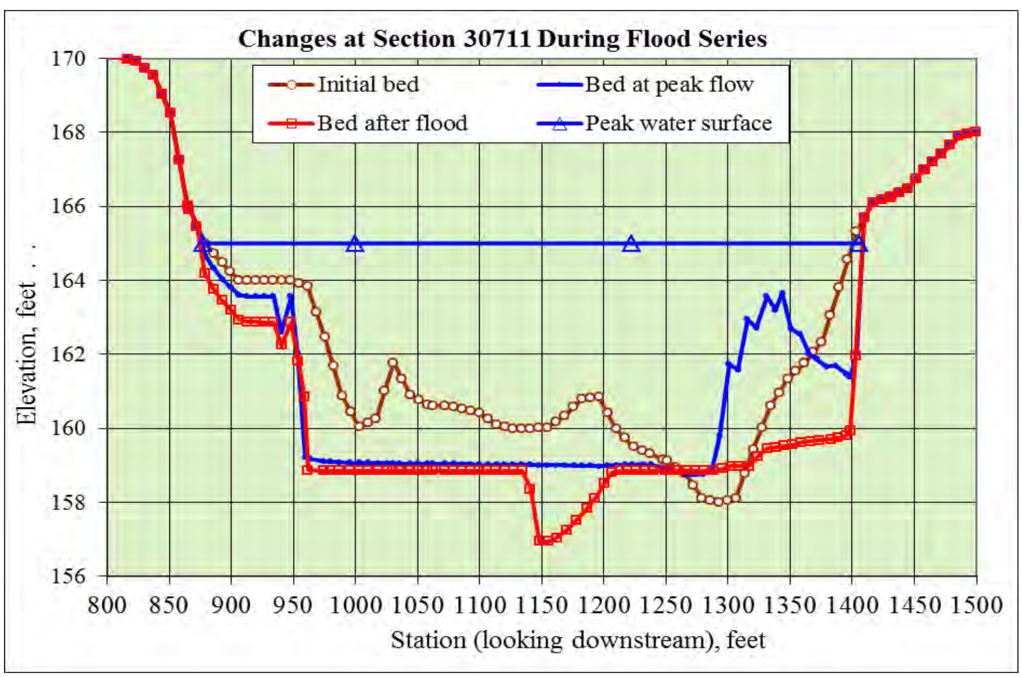


Figure 18. Simulated cross-sectional changes during flood series at channel station 30711

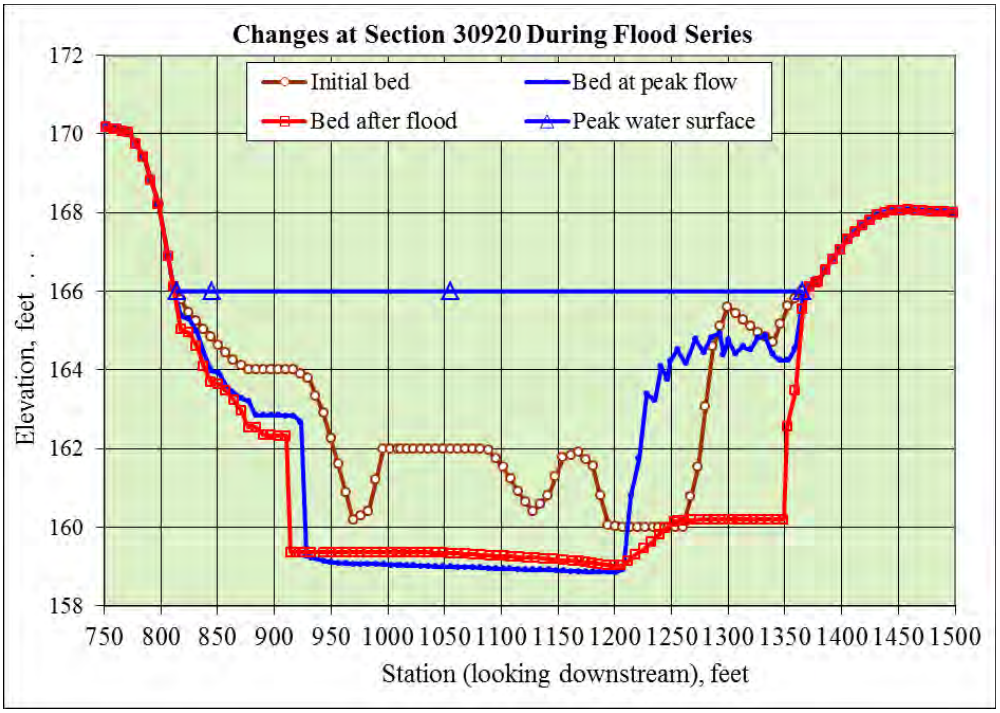


Figure 19. Simulated cross-sectional changes during flood series at channel station 30920

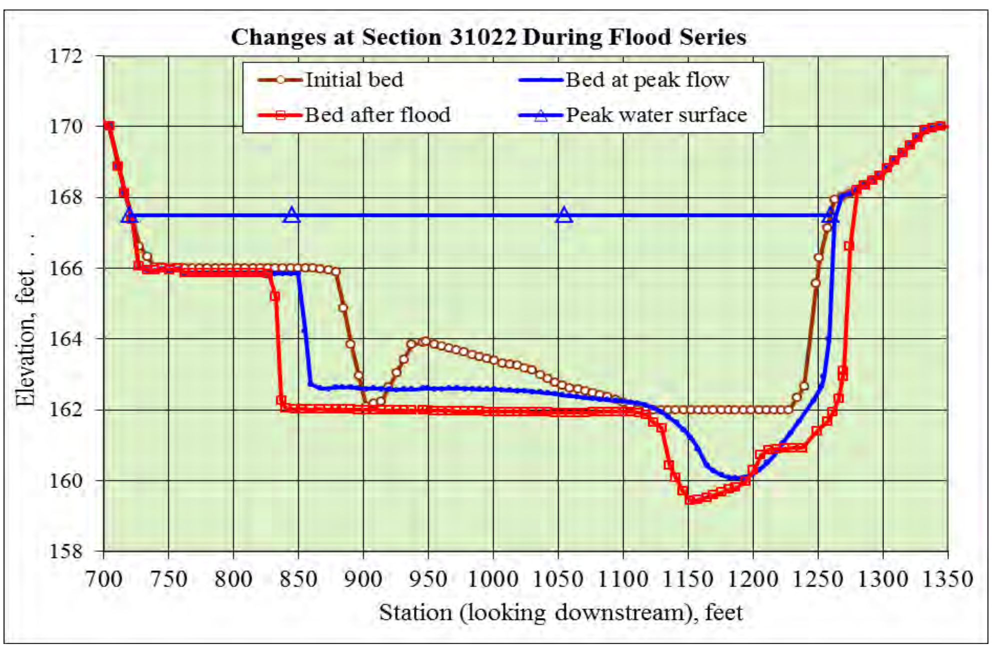


Figure 20. Simulated cross-sectional changes during flood series at channel station 31022

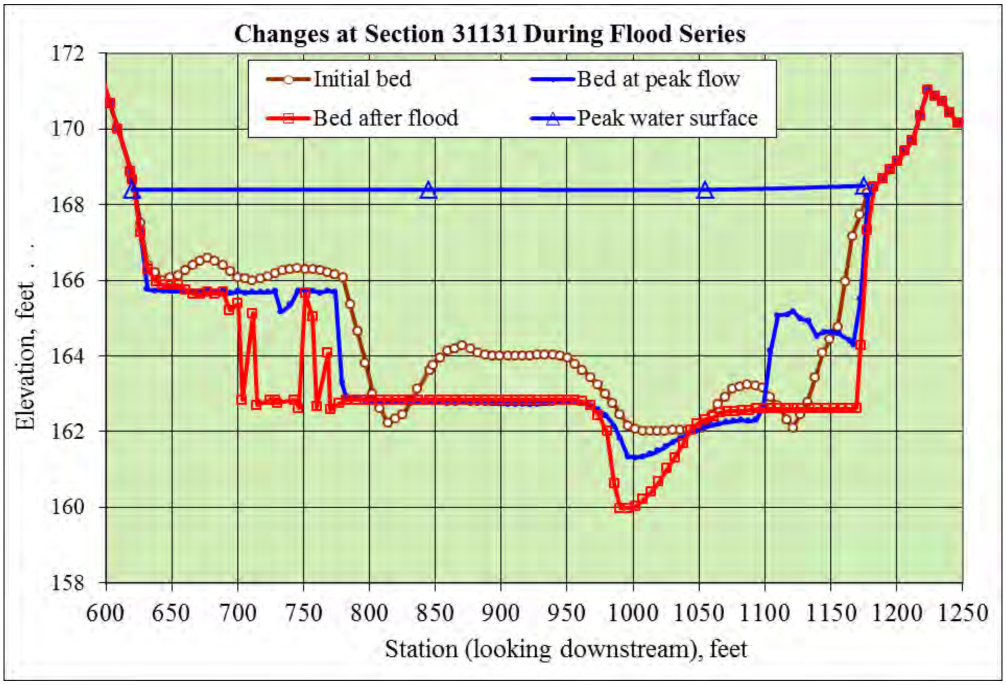


Figure 21. Simulated cross-sectional changes during flood series at channel station 31131

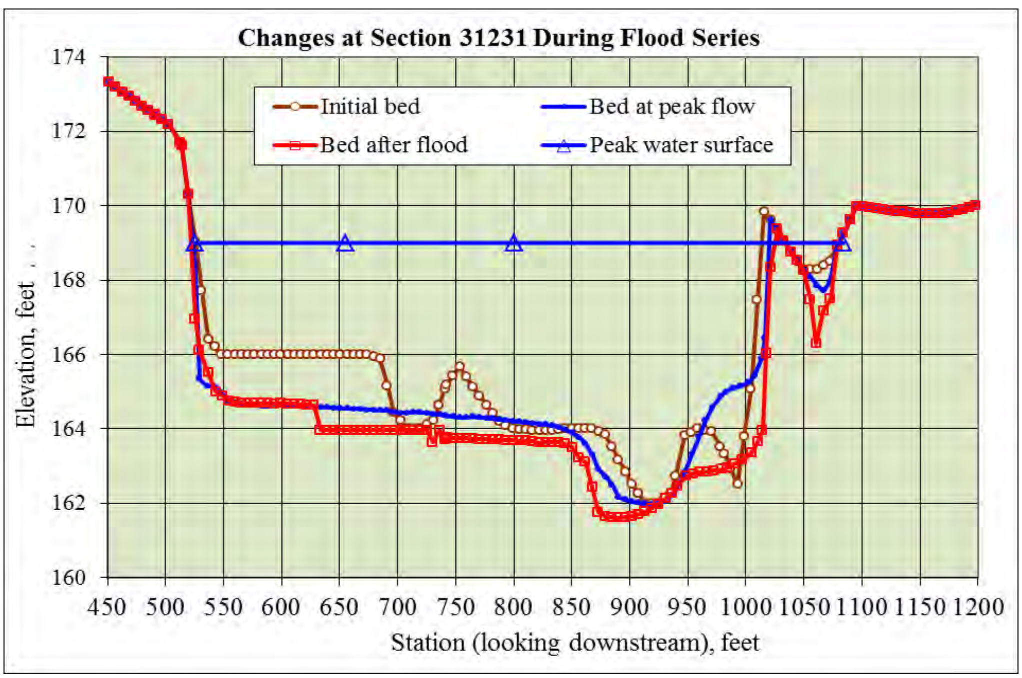


Figure 22. Simulated cross-sectional changes during flood series at channel station 31231

The next channel reach is from channel station 31338 to 31649. This channel reach has a sharp curvature with the northwest bank (right bank) being the concave bank and the southeast bank (left bank) as the convex bank. Modeled results for the channel reach are shown in the figures below for channel stations 31338, 31441, 31548, and 31649.

This channel reach is predicted to have general erosion since sediment delivery increases toward downstream indicating more sediment removal from the channel boundary than sediment deposition on the channel boundary. General erosion is reflected by changes in channel bed profile as well as incereses in channel width. The changes in channel bed profles are much smaller in magnitude than the changes in channel width. The channel bed elevation changes are generally less than 5 feet at these channel stations. The channel width changes, however, are much geater in magnitude. Such width changes are due primarily to lateral migration of the channel toward the right bank. The amount of lateral migration at these channel stations are listed below:

Channel station	Lateral migration
31338	110 feet
31441	120 feet
31548	240 feet
31649	250 feet

The amount of lateral migration is the shifting of right top-of-bank from the initial bed profile to the bed profile after the flood. The lateral migration is much greater in magnitude than channel bed scour and fill. These figures are plotted with a distorted scale as the vertical scale is exaggerated. In reality, the lateral changes in channel boundary are an order of magnitude greater than the changes due to bed scour and fill. Since an important objective of the San Juan Creek study is to delineate the erosion hazard zone, the change in channel width must be determined in the study. It should also be clear that the changes in channel width and channel bed profile are inter-related. These changes must not be separated in studying river channel changes.

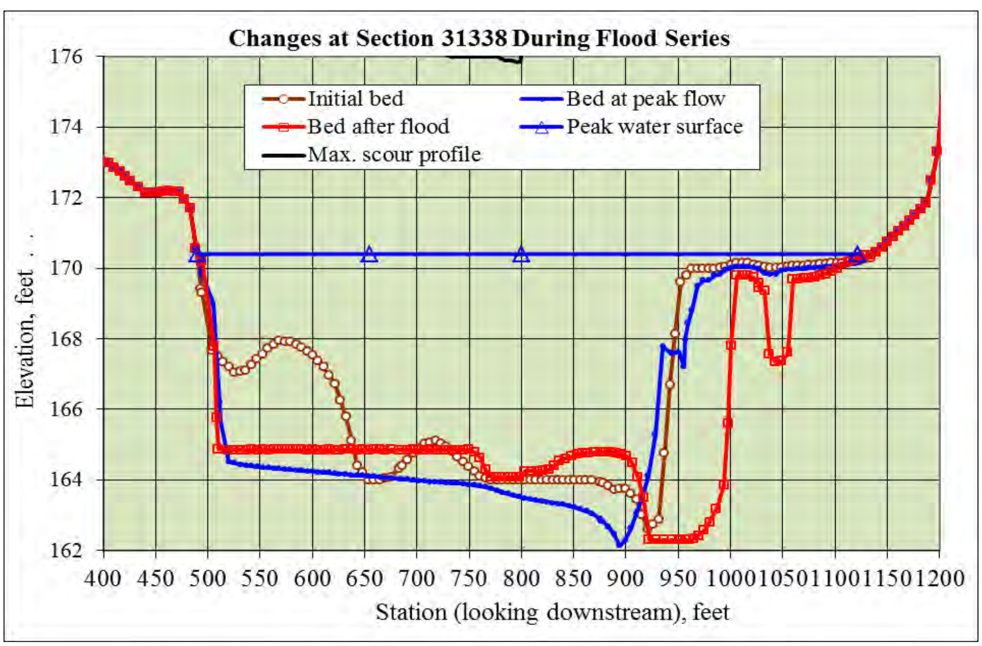


Figure 23. Simulated cross-sectional changes during flood series at channel station 31338

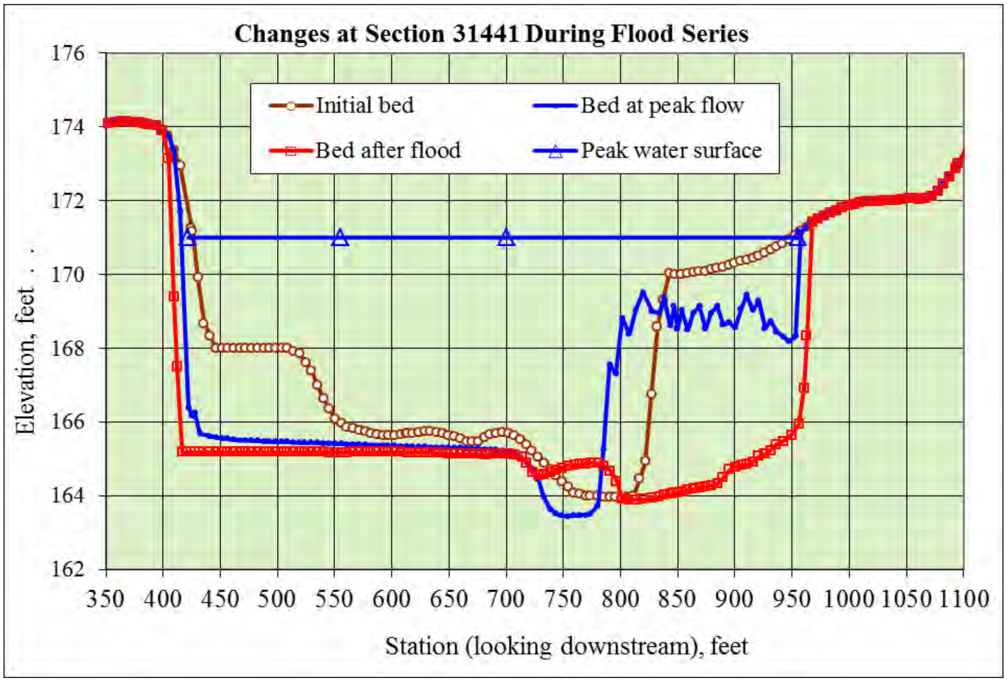


Figure 24. Simulated cross-sectional changes during flood series at channel station 31441

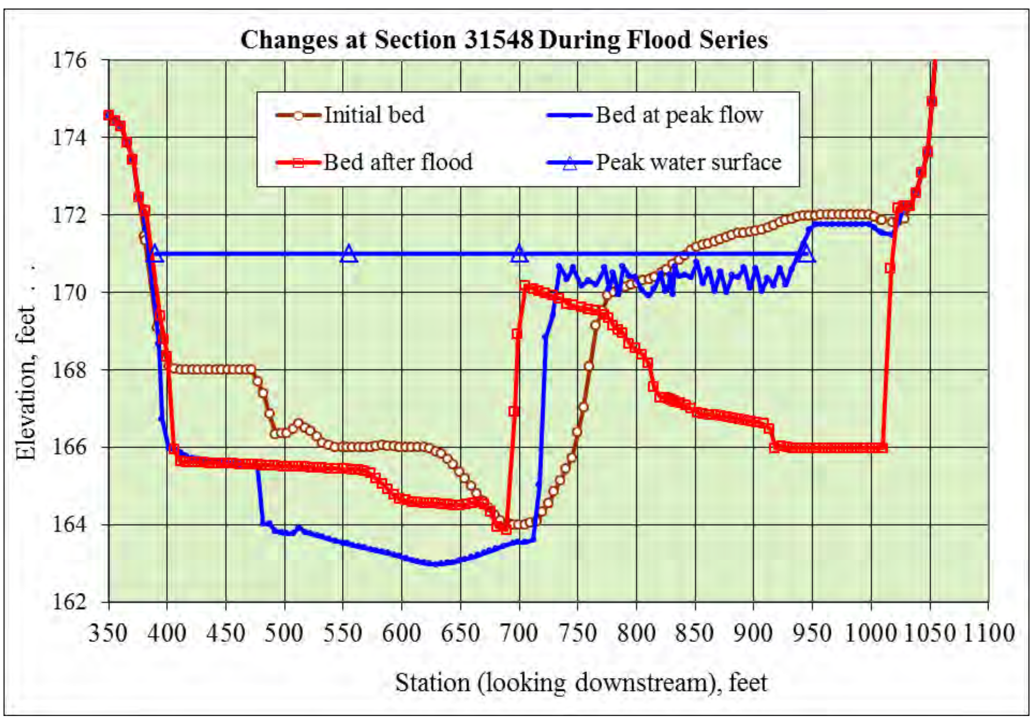


Figure 25. Simulated cross-sectional changes during flood series at channel station 31548

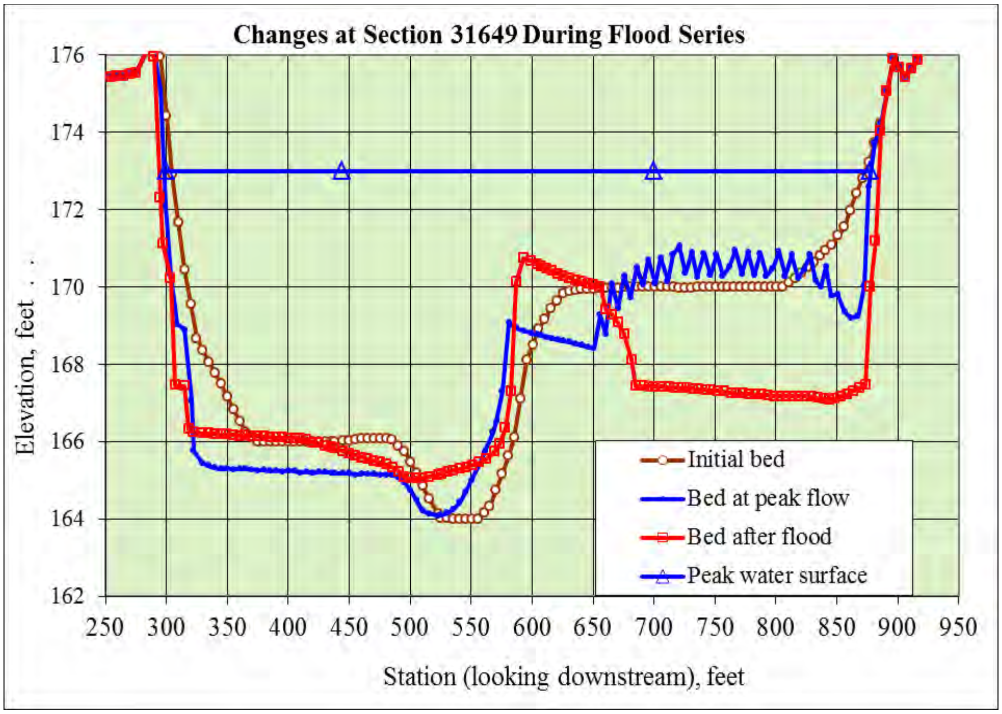


Figure 26. Simulated cross-sectional changes during flood series at channel station 31649

Channel sections 31822 and 32068 are located at the Antonio Parkway Bridge crossing. The channel width is constrained by the bridge abutments so that the storm flow through the bridge opening has a narrower width and higher flow velocity. The higher flow velocity causes greater sediment transport and channel bed scour through the bridge opening. The graphical results in the figures below show modeled channel changes during the flood series. Greater channel bed scour occurs during the high flow followed by some refill of the channel bed toward the end of the flow period.

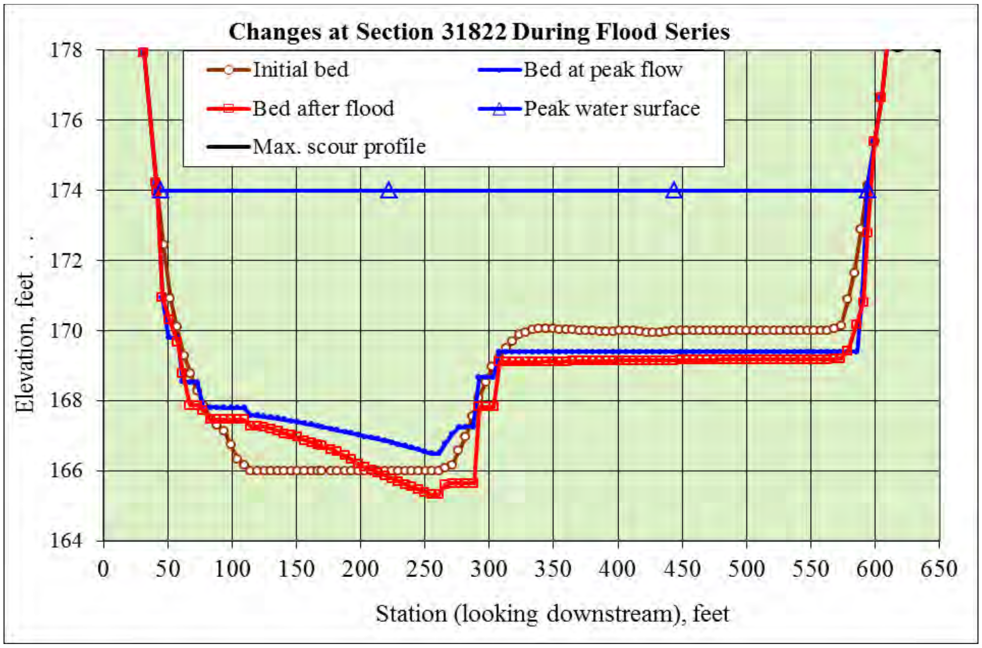


Figure 27. Simulated cross-sectional changes during flood series at channel station 31822

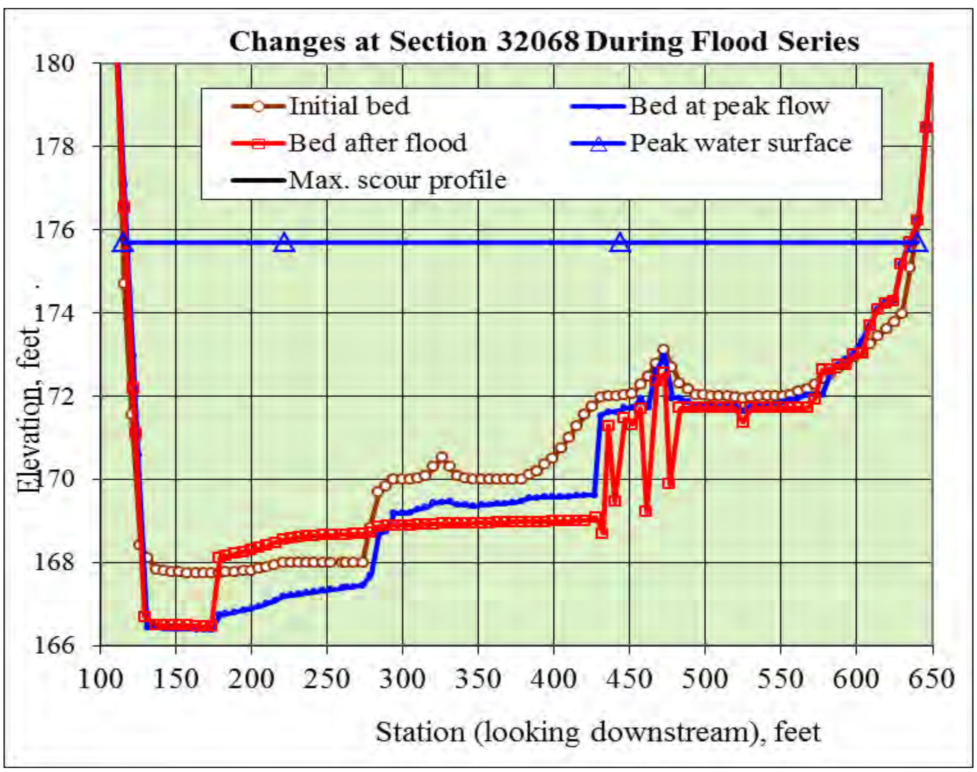


Figure 28. Simulated cross-sectional changes during flood series at channel station 32068

Summary of Results ─ The short channel reach from the Ortega Highway Bridge crossing to the Antonio Parkway Bridge crossing is used to illustrate the modeled stream channel changes. Major findings are itemized below:

(1) The study shows that sediment delivery increases toward downstream along this channel reach, indicating more sediment removal from the channel reach than sediment suppy to the reach. General erosion of the channel boundary is predicted. The volume of bed material removed from this short channel reach is 60,000 cubic yards. Such large change in channel geometry demonstrates the potential of adverse impacts of unmitigated flow on San Juan Creek

(2) General erosion is reflected by changes in channel bed profile as well as increases in channel width. The modeled changes in channel bed elevation are much smaller in magnitude than the changes in channel width. The bed elevation changes are generally less than 5 feet at these channel stations. The channel width changes, however, are much greater in magnitude. Such width changes are due to erosion of the channel boundary and lateral migration of the channel toward the right (concave) bank.

(3) The cross-sectional profile changes are plotted with a distorted scale as the vertical scale is exaggerated. In reality, the lateral changes in channel boundary are an order of magnitude greater than the changes due to channel bed scour and fill.

(4) The predicted lateral migrations at selected channel stations are listed below:

Channel station	Lateral migration
31338	110 feet
31441	120 feet
31548	240 feet
31649	250 feet

The amount of lateral migration is measured by the shifting of the right top-of-bank from the initial bed profile to the bed profile after the flood. It should be noted that channel width changes due to lateral migration are much greater in magnitude than channel bed scour and fill. In order to delineate the erosion hazard boundary, the changes in channel width must be considered.

(5) An increase of the erosion hazard zone is predicted for ths channel reach, attributed to the deficit in sediment supply as some of the inflow sediment is detained in the upstream borrow pit. The increase in erosion hazard area is also due to lateral migration of the stream channel. The change in erosion hazard zone will be analyzed in a later section

(6) It should be clear that the changes in channel width and channel bed profile are inter-related. These changes must not be separated in determing river channnel changes.

V. EROSION HAZARD ZONE

Erosion hazard zone is the area along San Juan Creek that is subject to potential stream channel erosion during the selected flood series of frequent events. Areas within the erosion hazard zone may be below or above the peak water surface elevation during the flood series.

Delineation of the flood hazard zone is illustrated by graphical samples. The cross-sectional profiles at selected channel stations are shown below. Each figure shows the existing cross-sectional profile together with those at the peak flow and at the end of flood series. The cross-sectional profile at the end of flood series shows the maximum extent of erosion at the channel station. The flood hazard zone is the surface width of channel for maximum scour. The illustrative samples are given below.

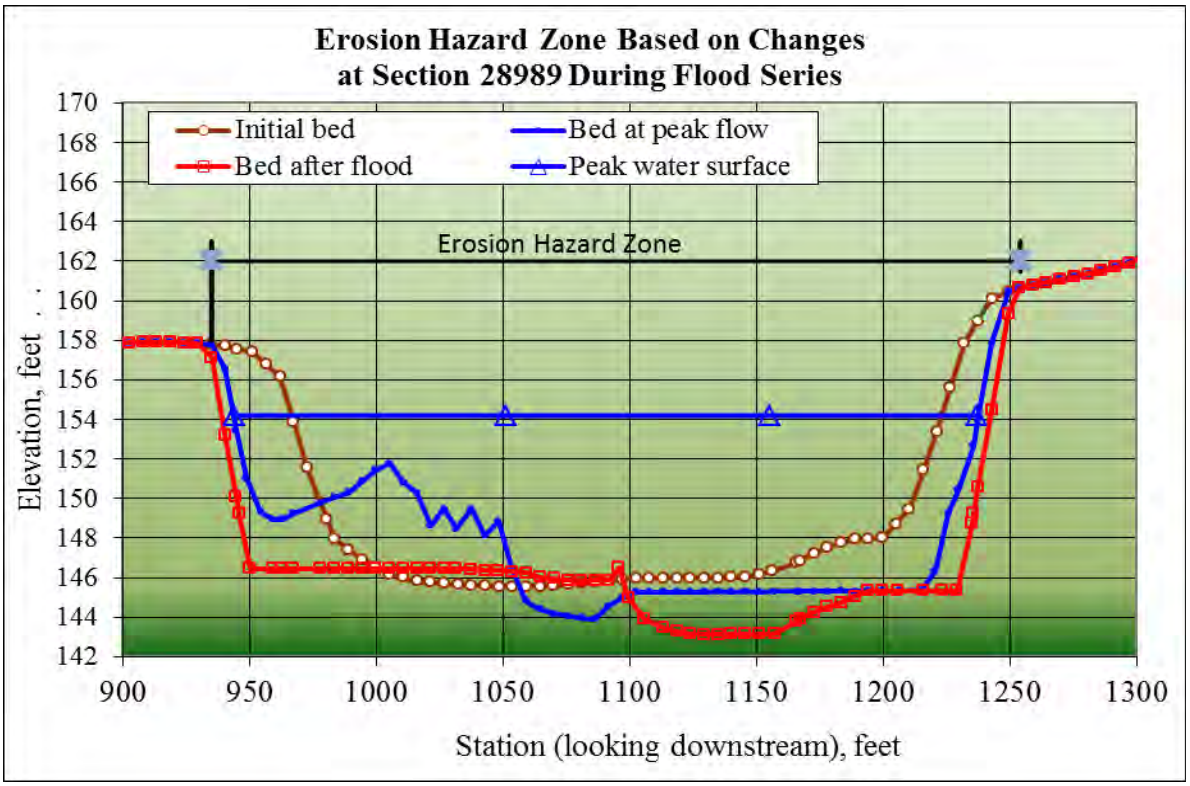


Figure 29. Erosion hazard boundary based on simulated cross-sectional changes during flood series at channel station 28989. The erosion hazard zone at this channel station is wider than the exisitng channel width. This section is predicted to widen as both banks retreat during the flood series.

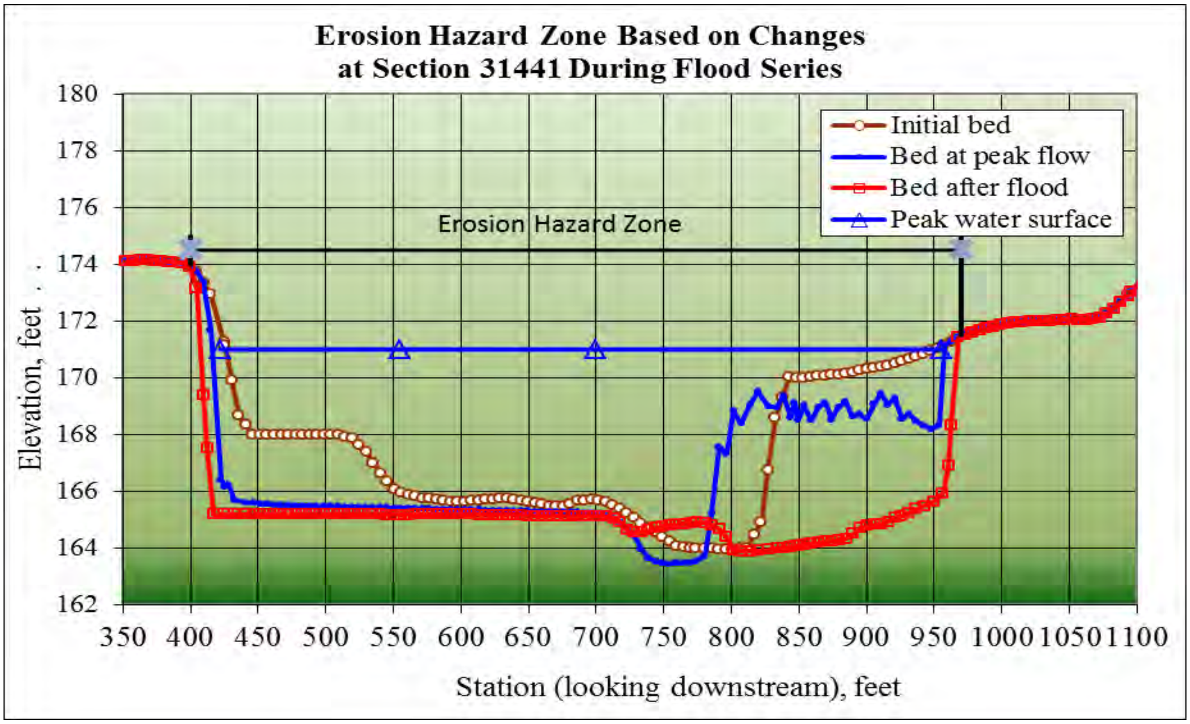


Figure 30. Erosion hazard boundary based on simulated cross-sectional changes during flood series at channel station 31441. The eroion hazard zone at this channel station is wider than the exisitng channel. This section is predicted to undergo major lateral migration toward the right bank. *

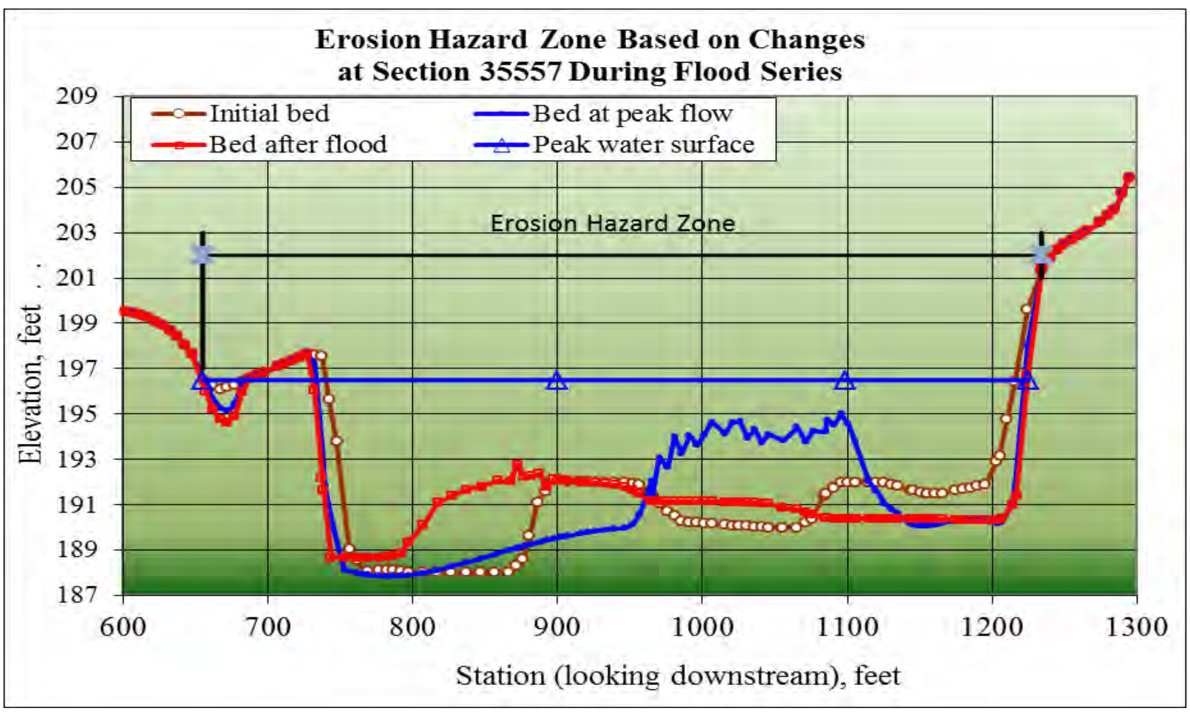


Figure 31. Erosion hazard boundary based on simulated cross-sectional changes during flood series at channel station 35557. The erosion hazard zone at this channel station is the same as the existing channel width.

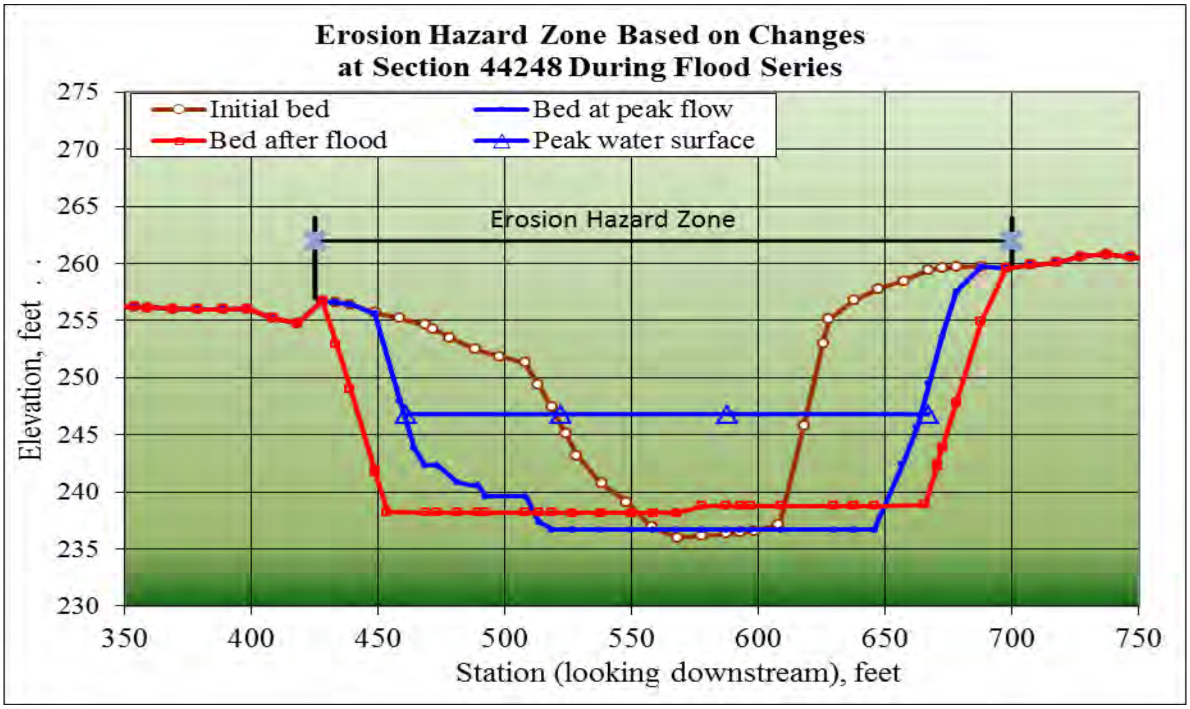


Figure 32. Erosion hazard boundary based on simulated cross-sectional changes during flood series at channel station 44248. This channel station is located at the upsteam entrance to the old mining site. It is predcited to undergo major increase in width. The erosion hazard zone is much wider than the existing channel width..

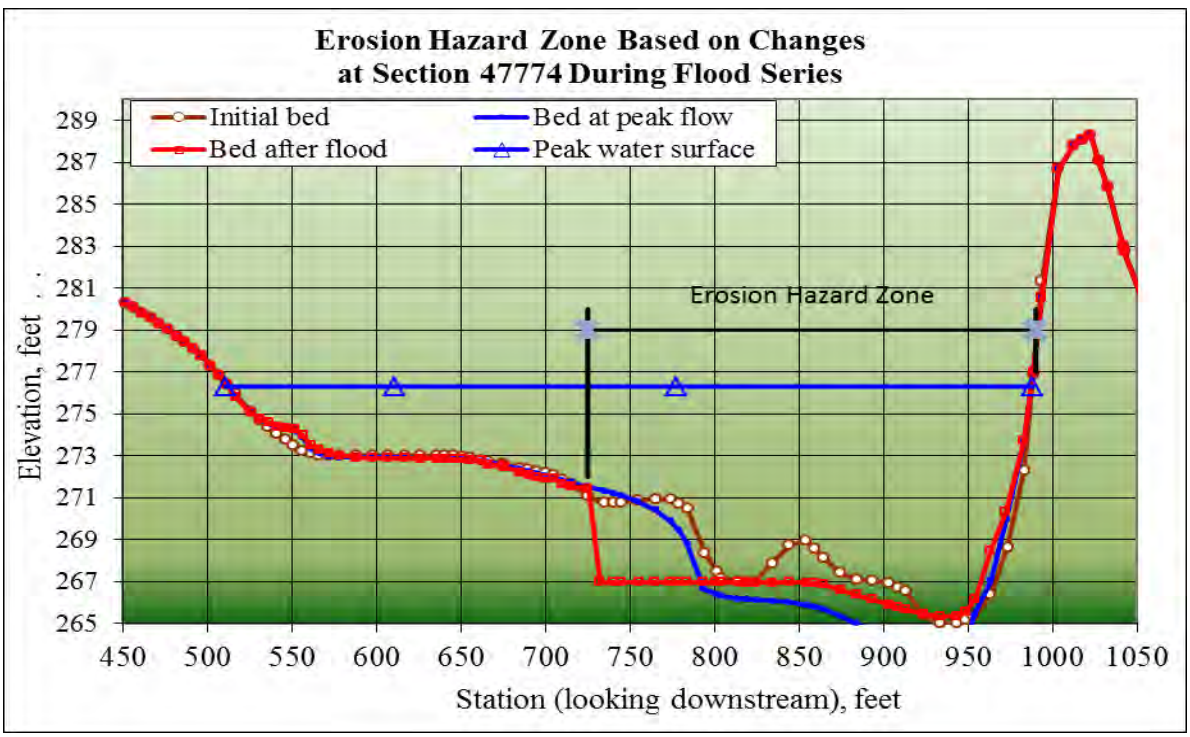


Figure 33. Erosion hazard boundary based on simulated cross-sectional changes during flood series at channel station 47774. At this wide channel section, the erosion hazard zone is smaller than the channel width.

Table 2. Erosion Hazard Zone

Channel Station feet	W.S. at Peak Flow feet	Sequential No.	Left Bank Station feet	Right Bank Station feet
26777	138.73	34	320	705
26976	139.60	35	340	740
27176	140.53	36	400	770
27377	141.52	37	320	650
27634	143.26	38	530	860
28108	147.02	39	130	430
28574	151.21	40	880	1,185
28989	154.21	41	935	1,254
29265	156.44	42	1,220	1,500
29412	157.52	43	555	790
29539	158.84	44	1,040	1,310
30015	162.18	45	1,170	1,650
30509	164.93	46	1,040	1,520
30610	165.61	47	950	1,485
30711	166.25	48	870	1,410
30812	166.92	49	810	1,370
30920	167.62	50	790	1,325
31022	168.26	51	720	1,280
31131	169.19	52	640	1,180
31231	169.97	53	515	1,075
31338	171.02	54	480	1,100
31441	171.74	55	400	870
31548	172.75	56	380	1,020
31649	173.40	57	290	880
31822	174.49	58	40	600
32068	175.98	59	80	580
32250	177.11	60	100	640
32351	177.73	61	105	610

32455	178.33	62	95	515
32498	178.59	63	70	520
32545	178.85	64	120	520
32645	179.40	65	140	630
32745	179.96	66	180	640
32846	180.54	67	170	675
32947	181.07	68	230	790
33047	181.57	69	320	830
33145	182.10	70	310	820
33245	182.63	71	230	680
33353	183.22	72	210	680
33459	183.75	73	190	670
33570	184.37	74	290	850
33670	184.94	75	280	835
33774	185.46	76	320	1,000
33879	185.89	77	270	970
33993	186.33	78	240	960
34096	186.75	79	250	1,000
34196	187.20	80	250	940
34297	187.70	81	200	970
34400	188.24	82	180	1,000
34504	188.80	83	180	1,060
34605	189.33	84	190	1,020
34701	189.85	85	300	1,040
34806	190.50	86	355	1,100
34913	191.17	87	450	1,240
35015	191.89	88	545	1,270
35121	192.67	89	610	1,350
35233	193.65	90	700	1,425
35352	194.75	91	680	1,340
35450	195.57	92	770	1,280
35557	196.51	93	655	1,234
35662	197.38	94	720	1,170

35759	198.22	95	685	1,140
35866	199.12	96	670	1,140
35974	200.04	97	600	1,130
36074	200.99	98	500	1,045
36175	201.81	99	500	1,030
36278	202.69	100	570	1,000
36376	203.50	101	420	920
36479	204.42	102	280	760
36580	205.15	103	145	630
36681	205.76	104	100	615
36781	206.47	105	300	575
36882	207.01	106	60	510
36982	207.49	107	70	500
37082	207.93	108	70	490
37186	208.33	109	80	540
37498	209.67	110	380	860
37722	210.77	111	400	850
37873	211.64	112	380	860
38023	212.48	113	380	900
38173	213.28	114	250	850
38398	214.35	115	230	1,020
38665	215.53	116	220	920
38848	216.55	117	230	1,120
38998	217.42	118	260	880
39147	218.45	119	360	840
39298	219.52	120	370	870
39524	221.22	121	560	900
39973	223.99	122	550	960
40123	225.00	123	650	840
40273	226.37	124	180	1,120
40423	227.07	125	380	1,000
40573	227.12	126	360	1,060
40723	227.15	127	350	1,200

40873	227.17	128	350	1,150
41024	227.21	129	440	1,160
41173	227.30	130	450	1,140
41323	227.53	131	420	1,150
41473	227.84	132	350	1,230
41623	228.21	133	350	1,220
41773	228.62	134	520	1,230
41923	229.09	135	500	1,250
42073	229.62	136	480	1,250
42223	230.18	137	480	1,280
42373	230.81	138	500	1,250
42523	231.49	139	480	1,180
42673	232.28	140	480	1,150
42823	233.23	141	500	1,130
42973	234.27	142	480	1,150
43123	235.40	143	530	1,140
43273	236.62	144	570	1,150
43423	237.92	145	575	1,150
43573	239.31	146	550	1,125
43798	241.72	147	580	1,180
43948	243.49	148	540	1,010
44098	245.45	149	540	900
44248	246.80	150	425	700
44398	248.65	151	380	610
44548	250.50	152	380	570
44698	251.73	153	350	530
44848	253.00	154	335	525
44998	254.25	155	330	495
45147	255.23	156	275	535
45298	256.06	157	400	550
45373	256.46	158	430	640
45523	257.24	159	490	660
45598	257.61	160	685	820

45748	259.14	161	700	965
45898	259.80	162	710	1,020
46048	260.41	163	700	1,005
46198	261.15	164	700	1,030
46348	261.92	165	700	1,080
46499	262.43	166	720	1,130
46738	263.50	167	---	--
46887	267.10	168	--	--
47024	271.70	169	820	1,140
47174	272.72	170	820	1,190
47324	273.68	171	750	1,145
47474	274.68	172	635	1,105
47625	275.63	173	-	-
47774	276.47	174	720	1,000
47999	277.79	175	665	910
48224	279.16	176	655	925
48374	280.04	177	465	850
48524	280.78	178	420	850
48824	281.84	179	180	750
49049	282.42	180	340	820
49199	282.85	181	435	840
49425	283.56	182	465	715
49574	284.15	183	550	865
49724	284.88	184	595	1,005
49874	285.34	185	515	950
50025	285.79	186	445	815
50174	286.26	187	380	770
50399	287.07	188	315	760
50624	287.69	189	430	815
50774	288.24	190	620	1,000
50923	289.04	191	400	1,020
51074	289.48	192	520	1,055
51224	289.90	193	435	1,030

51374	290.34	194	385	1,010
51523	290.83	195	365	1,020
51674	291.41	196	480	990
51824	292.12	197	420	1,010
51974	293.03	198	320	960
52124	294.00	199	280	955
52274	294.98	200	255	980
52424	296.18	201	310	1,010
52649	298.57	202	180	950
52799	300.89	203	220	860
52949	303.46	204	200	780
53099	305.26	205	430	700
53249	307.71	206	445	565
53399	311.42	207	310	430
53549	312.02	208	290	390
53698	321.30	209	255	375
53849	322.04	210	365	465
54074	327.18	211	355	845
54223	328.17	212	210	725
54374	328.65	213	230	760
54524	328.93	214	235	780
54674	329.24	215	230	620
54824	329.45	216	230	750
54974	329.68	217	250	720
55124	329.93	218	270	700
55274	330.21	219	270	730
55424	330.50	220	310	730
55574	330.85	221	330	800
55724	331.25	222	290	910
55874	331.64	223	350	1,050
56024	332.08	224	280	1,110
56175	332.59	225	430	1,140
56323	333.16	226	460	1,270

56474	333.84	227	400	1,220
56624	334.56	228	400	1,175
56849	335.76	229	370	1,280
57074	337.11	230	440	1,300
57224	338.19	231	460	1,240
57525	340.67	232	340	1,200
57674	342.08	233	300	1,170
57899	344.34	234	370	1,170
58124	346.59	235	400	1,220
58274	348.17	236	700	1,320
58874	356.53	237	1,000	1,320
59024	358.86	238	960	1,320
59325	363.27	239	755	1,140
59550	366.43	240	630	1,045
59699	368.42	241	740	1,045
59999	372.47	242	880	1,180
60149	374.61	243	940	1,240
60374	378.04	244	960	1,320
60599	381.83	245	580	1,280
60750	383.85	246	240	1,150
60921	385.81	247	330	1,330
61123	387.80	248	380	1,600

The boundaries of the erosion hazard zone are plotted on the maps shown in Figures 34 and 35. These figures cover the downstream and upstream parts of San Juan Creek within the Rancho Mission Viejo property. The maps have two sets of erosion hazard boundary lines: The yellow lines are based on the current study. Areas within the boundaries of the yellow lines are subject to erosion hazard as determined based on the 20-yr flood series. The red lines are provided by PACE. The basis for the erosion hazard zone bounded by the redlines are given by Bruce Phillips as follows:

> One of the criteria that we had applied, since we had applied several and used the maximum at each cross section used the following: Probability weighted bank erosion distance equivalent to the calculated HEC-6T sediment deficit volume applied to streambanks over a 60-year planning period, plus the 100-year HEC-6T sediment deficit volume (So we had a 60-year horizon period).

The PACE erosion hazard zone is based on the 100-yr flood and the current study is based on the 20-yr flood series with the 25-yr flood as the largest event; therefore, these two sets of results are not on the same basis and therefore may not compared. The 100-yr flood should cause more erosion than the 20-yr flood series.

It is also important to point out that different technical methods were used to produce these two sets of results. The PACE study is based on the HEC-6T model while this study is based on the FLUVIAL-12 model. The HEC-6T model is an erodible bed model and the FLUVIAL-12 model is an erodible boundary model. The erodible bed model only considers channel bed aggradation and degradation by keeping the channel width constant. The erodible boundary model considers the inter-related changes in channel width and bed profile and these changes are coupled at each time step. The erodible bed model does not account for the curvature effect on bed topography. Natural streams are seldom straight over a length longer than a few channel widths. The channel curvature, with its inherent secondary currents, has important effects on channel morphology. The HEC-6T model is not substantiated by test and calibration studies using field data of this region.

The erosion hazard zone is used to cover areas along San Juan Creek that are subject to stream channel erosion. For the sake of property protection, the erosion hazard zone is useful for regulating future development along San Juan Creek at Rancho Mission Viejo. Improvements along San Juan Creek can also be protected by channel improvements and/or flood control structures. However, the use of the erosion hazard zone is a natural technique for erosion protection.

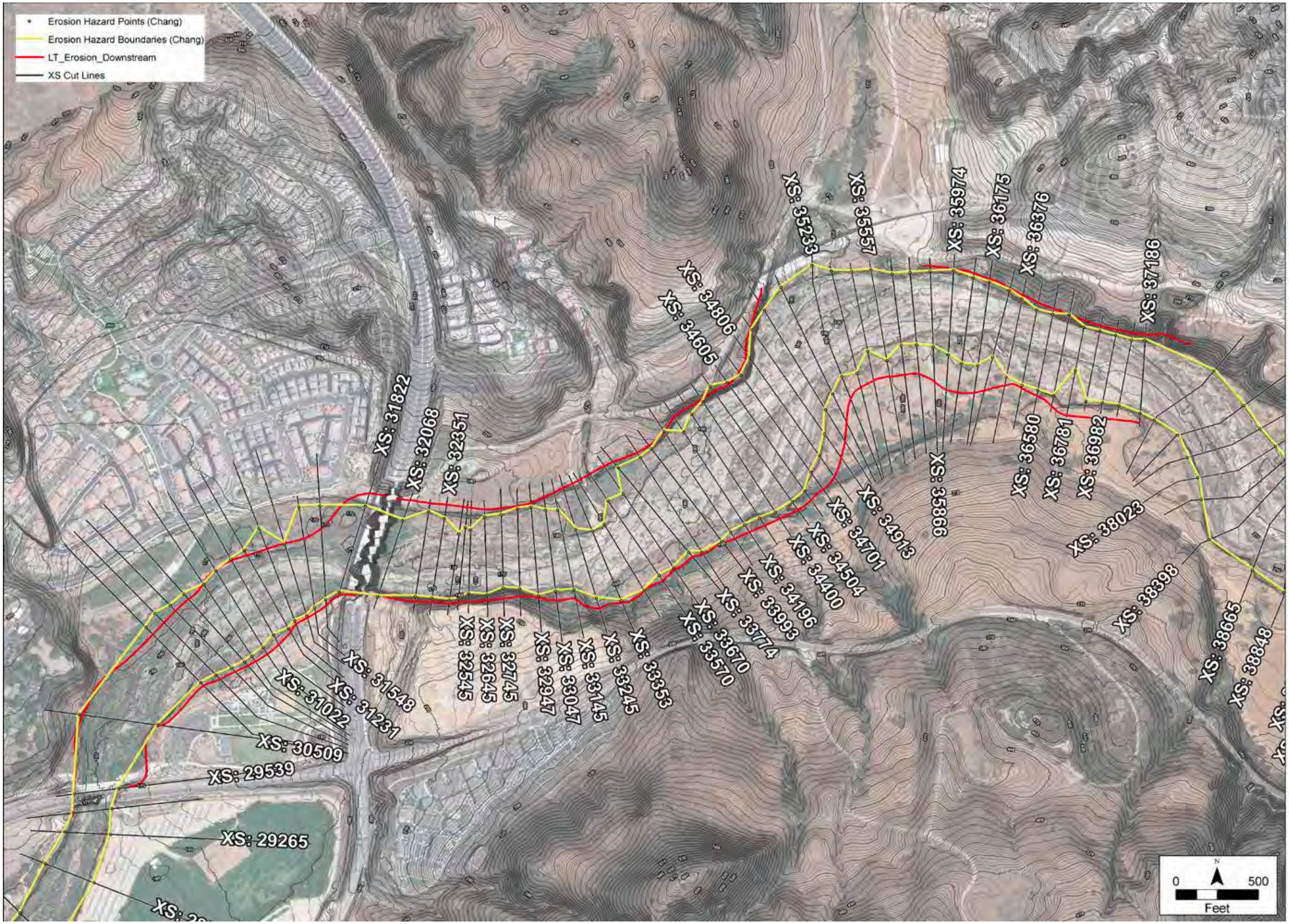


Figure 34. Erosion hazard zone for downstream area

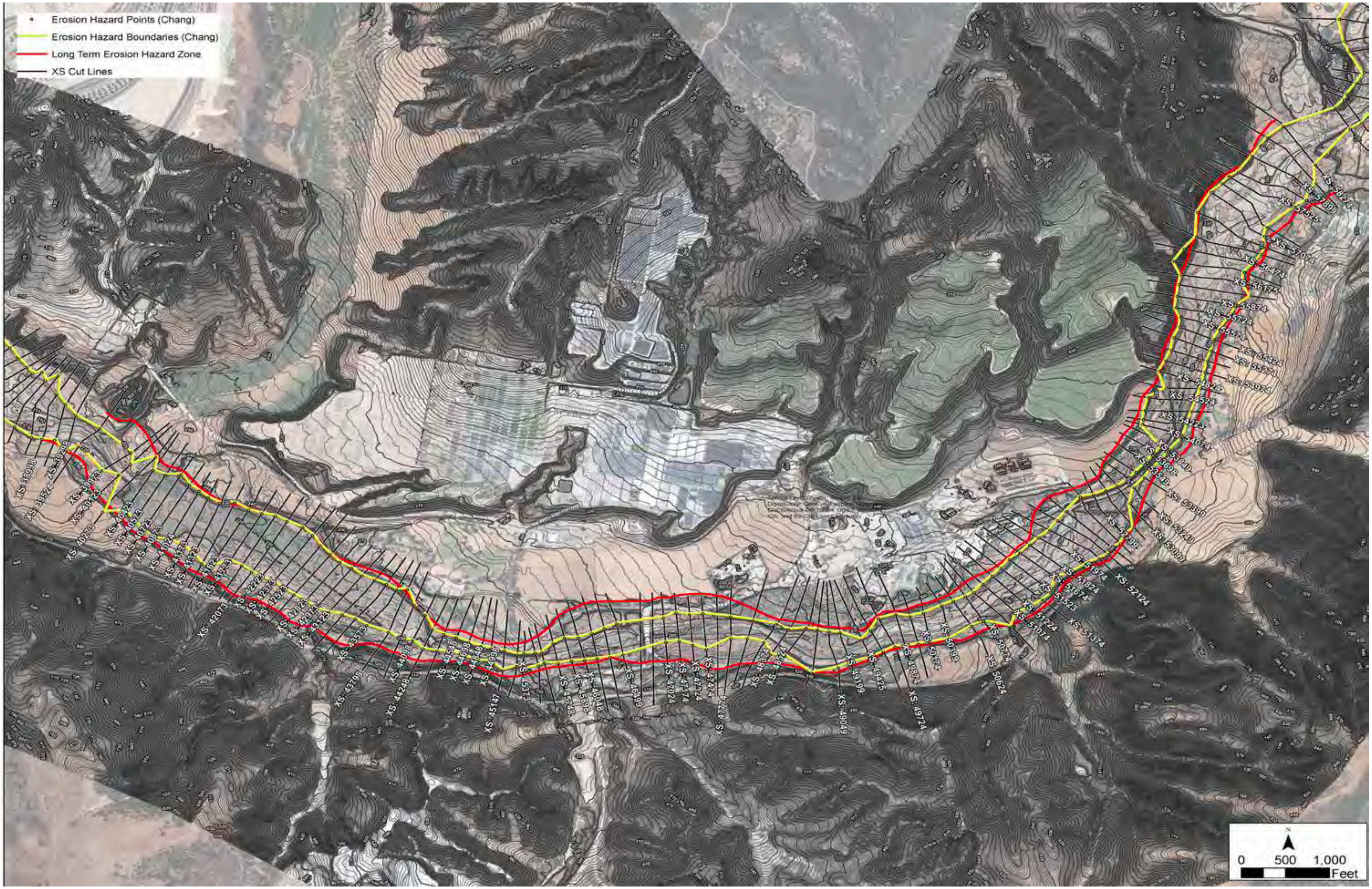


Figure 35. Erosion hazard zone for upstream area

Impacts of Mitigated Development Flow on Erosion Hazard Zone ─ The erosion hazard zone is delineated based on the flood series for the existing flow. One of the objectives of the study is to determine the impacts of mitigated development flow on the potential erosion hazard for San Juan Creek. The flood series of frequent flood events for existing flow is plotted in Figure 7B together with the series for mitigated development flow. These flood series look closely similar in the figure. The mitigated development flood series has higher discharges for the more frequent events but lower discharges for less frequent events.

The simulated changes in channel cross-sectional profiles at sample locations are shown in Figures 36, 37, 38, 39 and 40. Each figure shows the simulated cross-sectional profiles at the end of the flood series for the existing flow and the mitigated development flow. The erosion hazard zone is the surface width of the channel at the end of the flood series. These cross-sectional profiles based on the existing flow and the mitigated development flow are closely similar. No significant differences in the erosion hazard zone can be discerned. It may therefore be concluded that the mitigated development flow has no significant impacts on the potential erosion hazard for San Juan Creek.

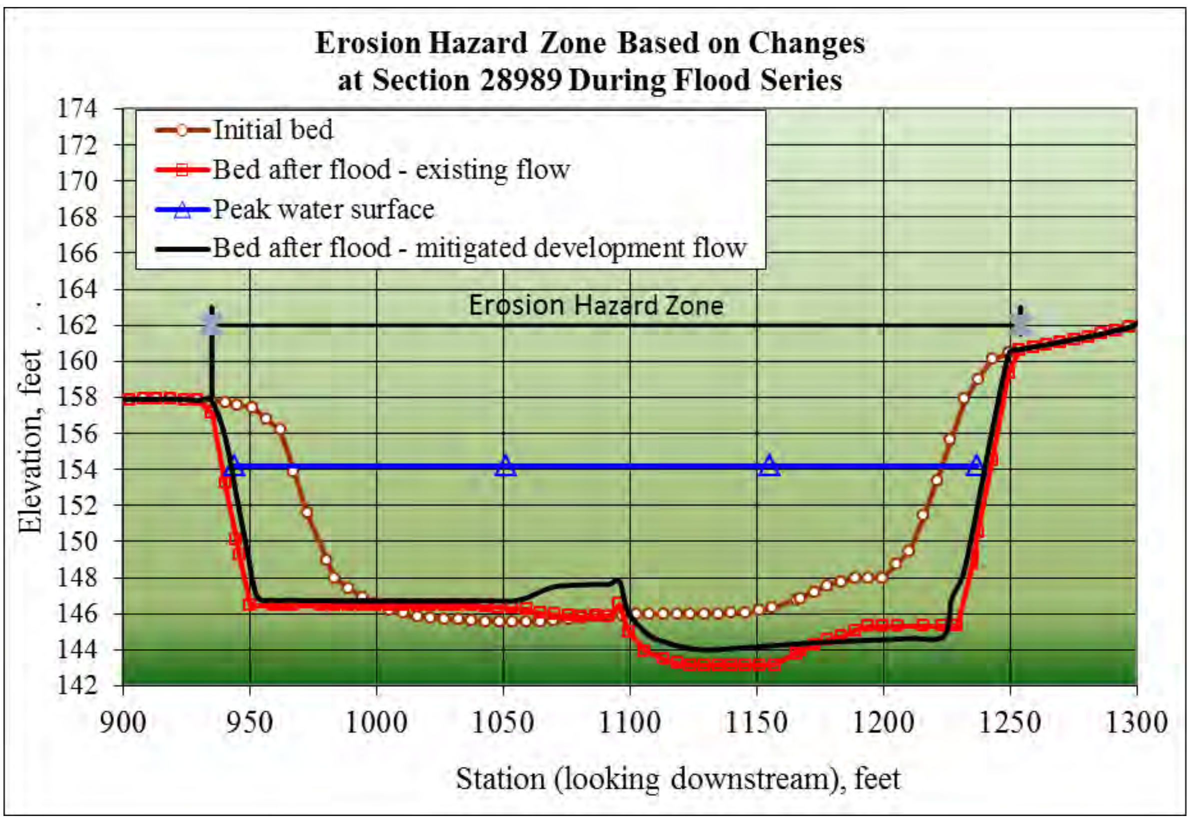


Figure 36. Erosion hazard zone based on the final cross-section profiles simulated using the existing flow and the mitigated development flow at channel station 28989

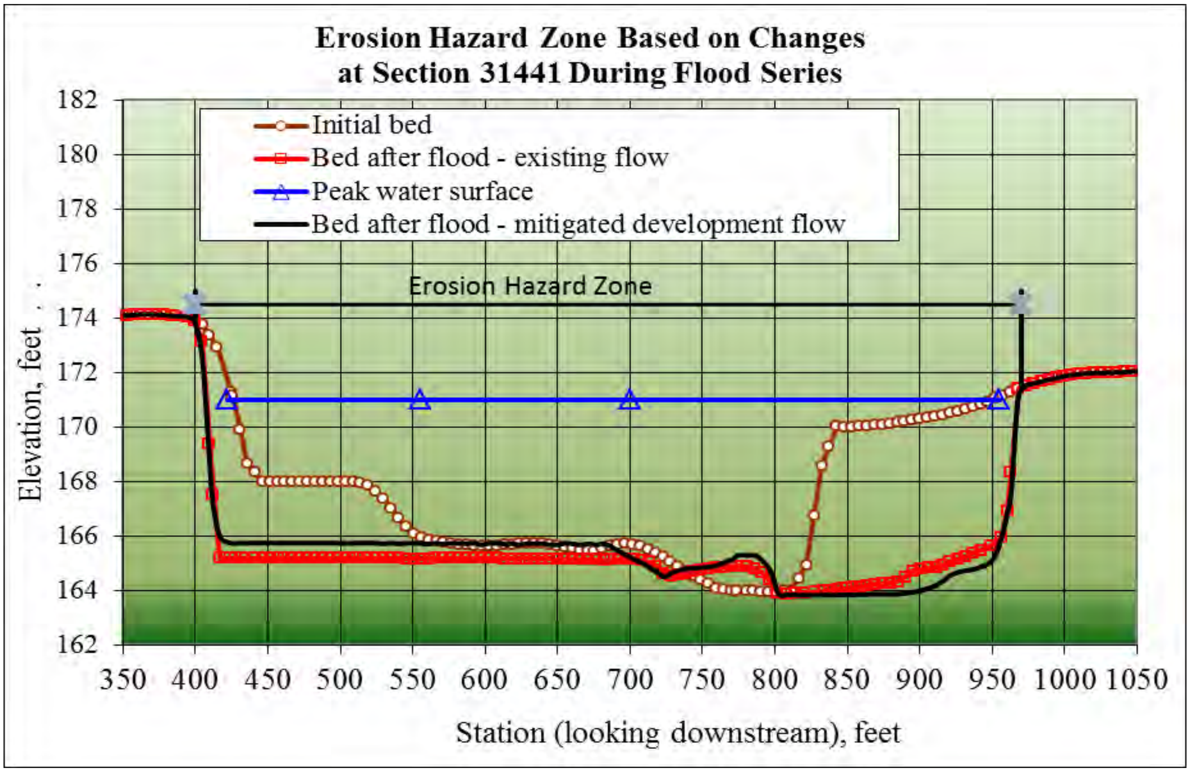


Figure 37. Erosion hazard zone based on the final cross-section profiles simulated using the existing flow and the mitigated development flow at channel station 31441

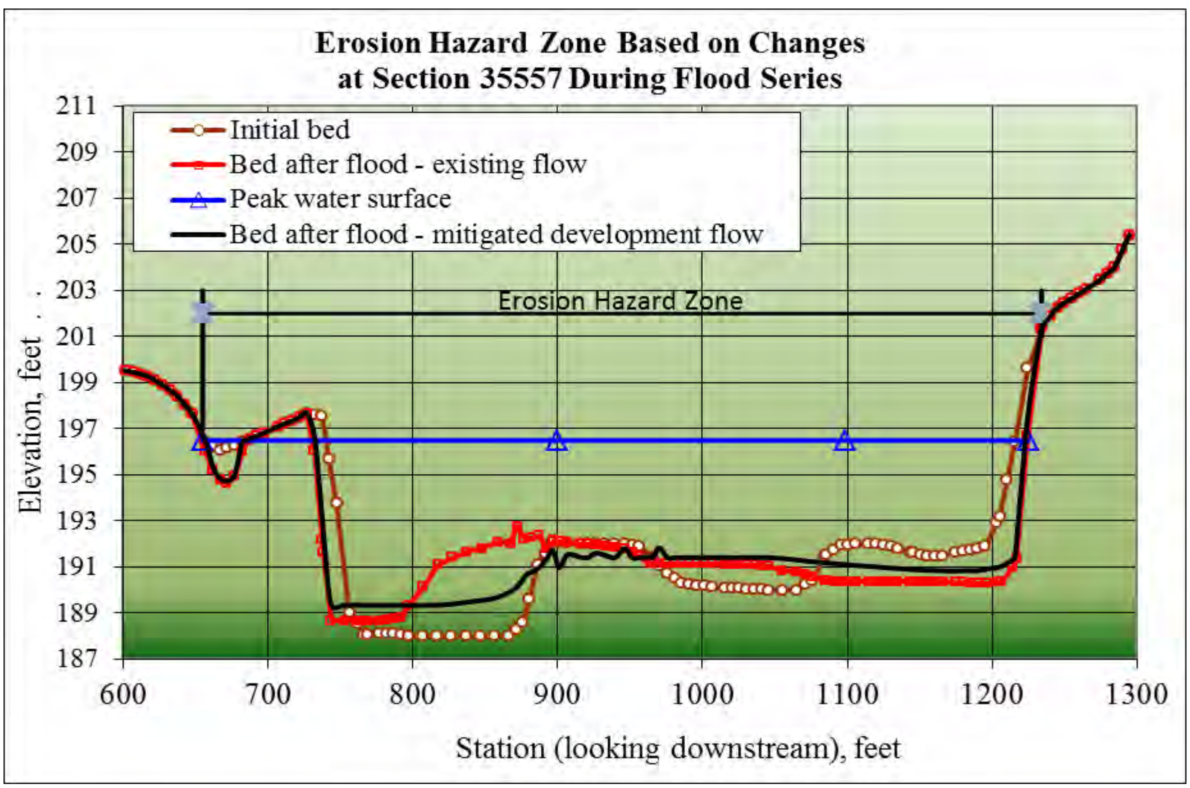


Figure 38. Erosion hazard zone based on the final cross-section profiles simulated using the existing flow and the mitigated development flow at channel station 35557

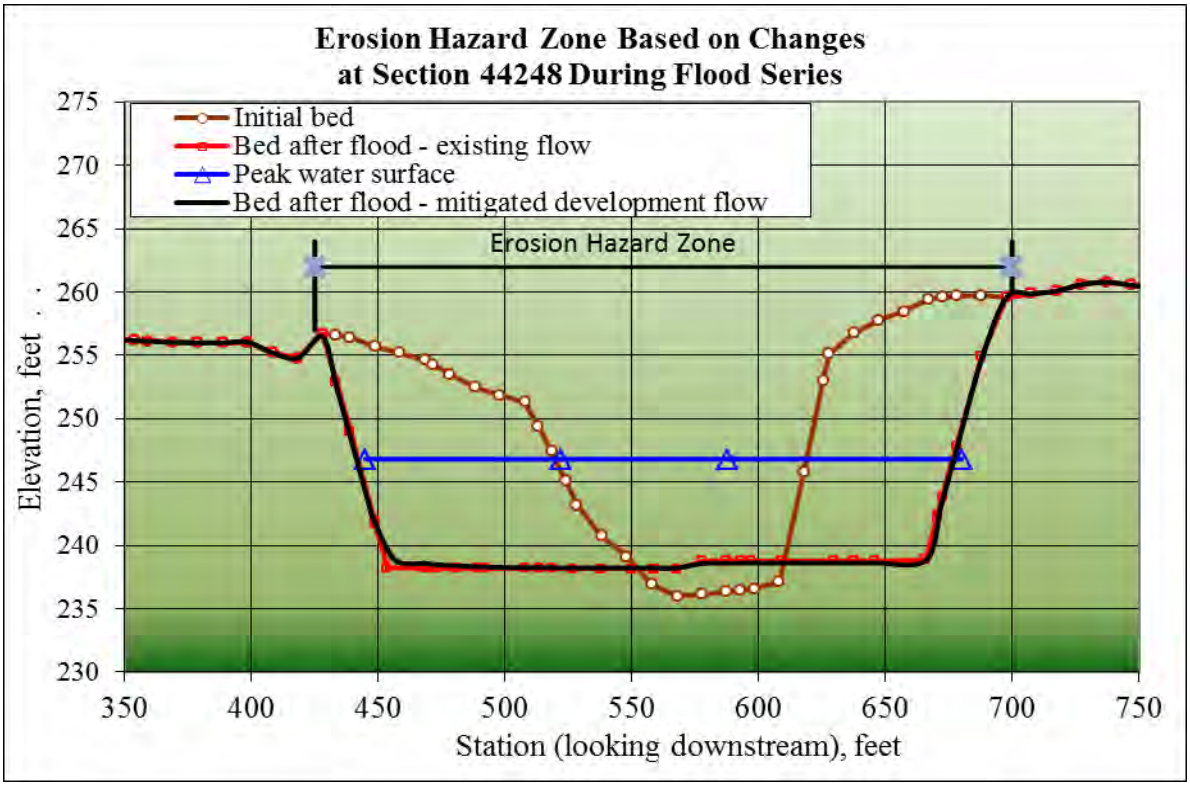


Figure 39. Erosion hazard zone based on the final cross-section profiles simulated using the existing flow and the mitigated development flow at channel station 44248

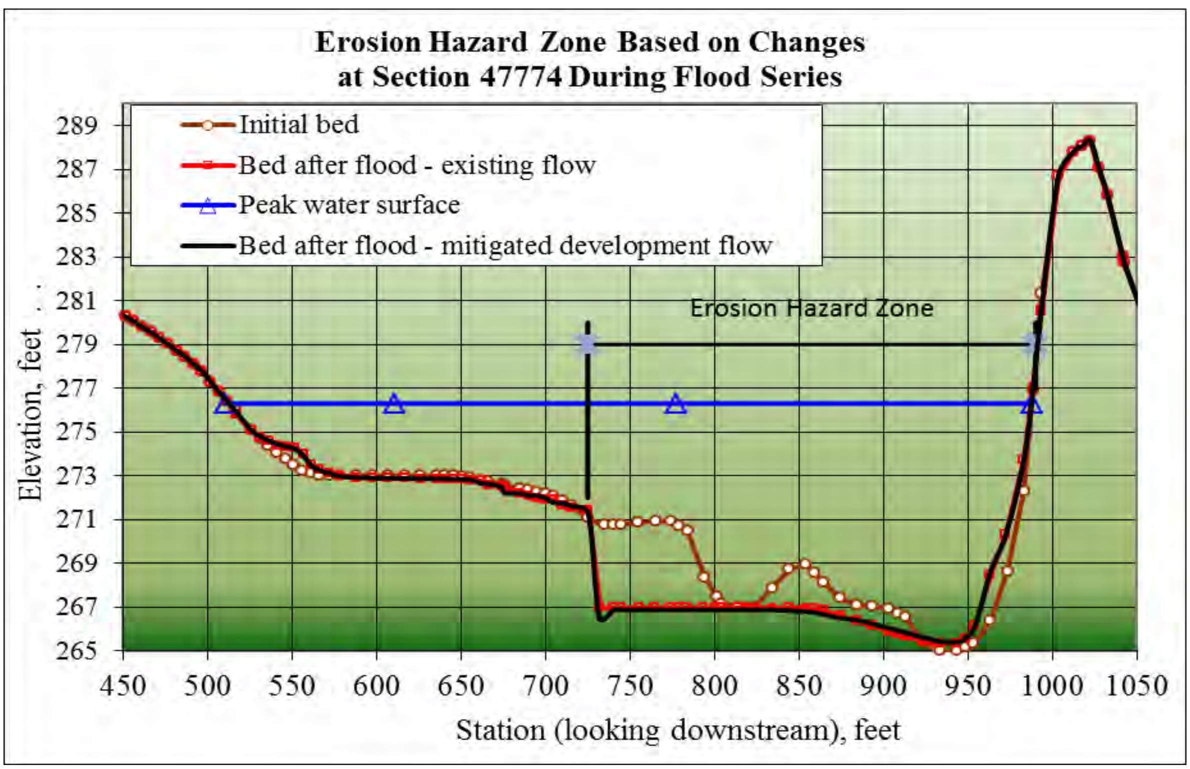


Figure 40. Erosion hazard zone based on the final cross-section profiles simulated using the existing flow and the mitigated development flow at channel station 47774

Identifying Potential Stream Instability Hotspots ─ The erosion hazard zone is useful to identify potential erosion problems along San Juan Creek In addition, potential erosion problems can be identified in consideration of the following factors: (1) channel curvature, (2) bank materials, (3) bank height, (4) erosion potential related to spatial variations in sediment delivery, (5) flow velocity, (6) adjacent developments or improvements, (7) physical constraints, and (8) other factors. These factors and their effects on erosion hazard are described below.

(1) Channel curvature has direct effects on lateral migration of the channel; therefore, potential erosion problems can be identified by channel curvature. Greater lateral migration is associated with sharper curvature.
(2) Different bank materials have different degrees of erodibility and erosion potential.
(3) Bank height directly affects bank erodibility. Low banks are more easily eroded since less bank material needs to be removed. On the other hand, channel reaches in deep canyons (and tall banks) have lower erosion potential. Tall channel bank inhibits erosion.
(4) The amount of erosion and deposition is related to the spatial variation in sediment delivery. Large spatial variation in sediment delivery indicates high potential erosion and deposition hazard.
(5) Higher flow velocity is associated with greater erosion potential.
(6) The protection of adjacent developments or improvements must be considered.
(7) Physical constraints, such as bank protection and other structures, are used to control erosion.

In consideration of these factors, one channel reach is identified to pose erosion hazard on adjacent properties. This channel reach as shown in Figure 37 is located just downstream of the Antonio Parkway Bridge crossing. This reach has a sharp curve, low channel bank, high flow velocity, high erosion potential, and existing housing development along the north channel bank. The north channel bank has existing bank protection, for which the stability should be evaluated in consideration of potential erosion.

The potential erosion hazard of this channel reach has already been identified in the modeling study based on the 20-yr flood series. The study shows that sediment delivery increases toward downstream along this channel reach, indicating general erosion of the channel boundary. The modeled lateral migration can exceed 200 feet at certain channel stations. The north boundary of the erosion hazard zone, the yellow line, as shown Figure 34 shows that erosion hazard has the tendency to approach the channel bank adjacent to the housing development.

The north channel bank of San Juan Creek is along the curved channel reach for San Juan Creek. This reach is subject to major lateral migration during the 20-yr flood series. For the sake of long-term stability, the existing bank protection should be evaluated based on the 100-yr flood. PACE has previously analyzed this portion of the creek for lateral erosion based upon 100-year storm events. However, the analysis is based on the HEC-6T model and the pre-project hydrology. The HEC-6T model, being an erodible bed model, does not account for the secondary flow inherent in the curved channel and it therefore has no mechanism for lateral migration. The PACE erosion hazard zone in Figure 34 shows that the bank is outside the erosion hazard zone marked by the red line. The channel bank is also outside the erosion hazard zone marked by the yellow line from this study. However, the yellow line is based on the 20-yr flood series. Since major lateral migration of the channel has been identified based on the 20-yr flood series, it is logical to believe that the lateral migration may pose threat to the bank protection during the 100-yr flood.

If channel bed scour reaches the toe of bank protection, the non-erodible bank actually increases the local scour at the bank toe. Any bank protection should have toe-down reaching beyond the potential channel bed scour.

Figure 36. View of San Juan Creek toward downstream from Antonio Parkway Bridge

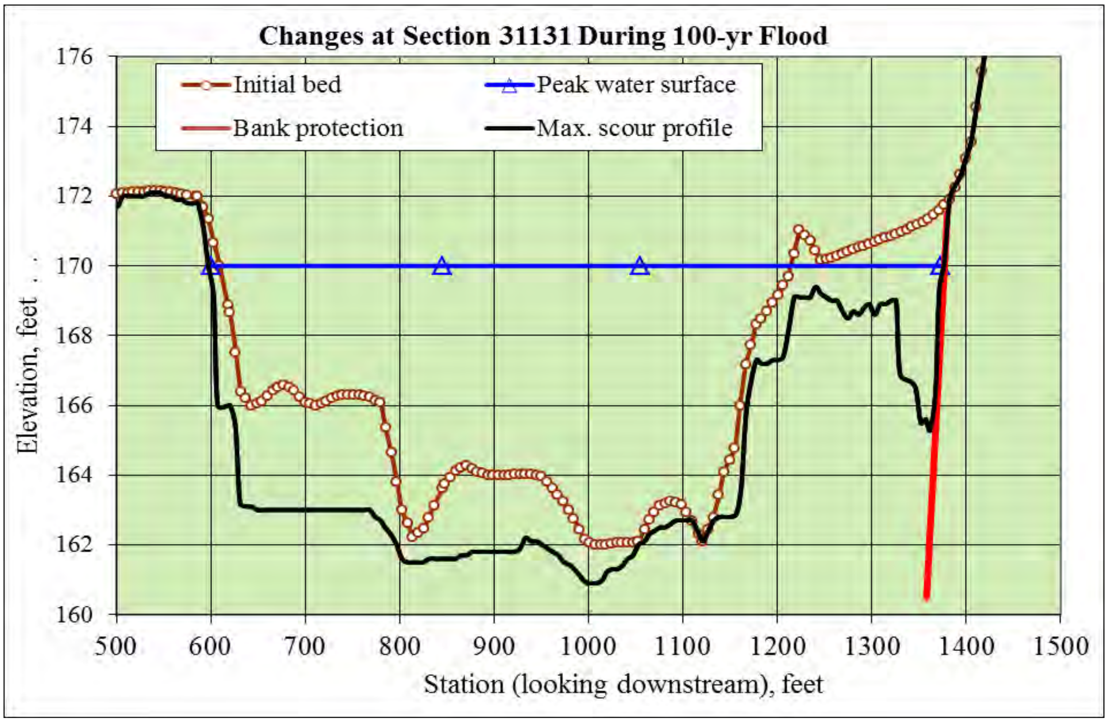
Evaluation of ARM Techniques for Channel Stabilization ─ Channel stabilization will be required at locations where erosion hazard poses threat to existing and planned improvements. Types of structures used for channel stabilization are numerous. For San Juan Creek, bank protection is a choice for bank protection along curved channel reaches. The use of bank protection is illustrated by a sample case. This study does not provide complete design information for San Juan Creek; it simply illustrates a technical approach for channel stabilization design.

Bank protection can be used to provide protection of areas along San Juan Creek where potential hazard exists. The bank protection must meet the following conditions:

(1) It must be strong enough to withstand the force of flow.
(2) The top of bank protection should stay above the design flood water surface elevation.
(3) The bank toe should entrench beyond the potential channel bed scour. The scour at bank toe should include the effects of channel curvature.

Since the bank toe must entrench beyond the potential channel bed scour, it is therefore necessary to determine the potential channel bed scour. Normally, channel bed scour during the 100-yr flood is used as for design standard. The scour depth must include the effects of channel curvature since scour depth can be greater in channel bend.

Potential channel-bed scour depth for San Juan Creek has been simulated by the FLUVIAL-12 model using the 100-yr flood. The simulated maximum channel bed scour depth at the bank toe as shown in Figure 37 is about 6 feet, reaching the minimum bed elevation of 165.5 feet at the bank toe. The recommended toe elevation for the bank protection is five feet below the maximum scour depth. The five-foot margin is a safety factor used to account for unexpected factors, such as erratic hydrologic phenomenon, bed settlement, bed forms, fallen tree trunks, etc. It is important to point out that the channel bed scour, in this case, includes the effects of channel curvature since this channel section is along a channel bend.



Figuire 37. Design of bank protection in consideration of potential channel bed scour at bank toe

This example illustrates the potential erosion hazard for San Juan Creek. Ths study shows that the potential for channel bed scour at the bank toe can cause deep scour holes posing threat to bank stability. This channel reach is along San Juan Creek downstream of the Antonio Parkway Bridge crossing. The existing development is along the channel bank outside the erosion hazard zone provided in the PACE study (see Figure 34). The erosion potential is not predicted and therefore not included in the ARM techniques for channel stabilization. Because of the potential erosion hazard, the stability of the existing bank protection should be re-evaluated.

In consderaion of the potential erosion hazard posed to the adjacent dvelopment, the claim or suggested mitigation in the form of ARMs appropriate to ensure the long term stability of San Juan Creek post development cannot be confirmed. This also calls for more in depth study of the potential erosion hazard.

Summary and Conclusions ─ Erosion hazard zone delineates areas along San Juan Creek that are subject to stream channel erosion. The boundaries of the erosion hazard zone are plotted on the maps shown in Figures 34 and 35. The maps have two sets of erosion hazard boundary lines. The yellow lines are determined based on 20-yr flood series. The red lines, based on the 100-yr flood, are provided by PACE. These two erosion hazard zones are established following different technical methods.

The erosion hazard zone based on the 20-yr flood series of frequent storms as determined in this study exceeds the limit of erosion hazard zone established by PACE for the 100-yr flood at different locations. One such location is along the channel reach downstream of the Antonio Parkway Bridge crossing. This erosion hazard poses threat to the existing development along the channel bank; therefore, mitigation measure for this potential threat is required. Any channel stabilization method for mitigation should be designed based on the 100-yr flood for long-term stability.

In views of the potential erosion hazard, the mitigation in the form of ARMs appropriate to ensure the long term stability of San Juan Creek post development cannot be confirmed. It calls for more in depth study of potential erosion to ensure the long term stability of San Juan Creek.

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APPENDIX A. COMMENTS ON THE PACE STUDY REPORTS

San Juan Creek is subject to changes. Stream monitoring, studies and analyses for San Juan Creek are for the purpose of developing methods for protecting lives and properties in the stream environment. For this purpose, PACE has made extensive efforts to monitor and to analyze the potential stream channel changes in order to define the erosion hazard zone along the stream channel. The PACE analyses applied geomorphic, hydrologic, hydraulic and sediment modeling methods for assessing potential stream channel changes.

The geomorphic, hydrologic and hydraulic studies are necessary and standard approaches for stream channels. Such studies provide the basic knowledge of the stream channel but they do not provide the analytical basis essential for the delineation of the erosion hazard zone. In order to define the erosion hazard zone analytically, it requires the analytical basis to address the changes in channel width that occur concurrently with channel bed scour and fill as well as lateral migration of the stream channel.

PACE recommends the erosion hazard zone as a management tool for protecting the health, safety and welfare of landowners and users of the river corridors in the study area. Erosion hazard zones were defined adjacent to the main stream channel of San Juan Creek along the focused study reach. PACE has provided two primary erosion hazard zones; they were defined based on channel stability assessment methodologies described below.

> **1. Severe Erosion Hazard Zone** - The Severe Erosion Hazard Zone encompasses the active channel, and the area next to the active channel that could reasonably be expected to erode during a single large flood year floodplain.
>
> 2. **Lateral Erosion Migration Hazard Zone** - The Lateral Migration Erosion Hazard Zone includes the portion of the floodplain that could reasonably be expected to erode during a series of floods. This is the minimum area required to maintain the processes of natural channel movement. The Lateral Migration Erosion Hazard Zone is also the minimum area required for preservation of the natural form and function of the stream.

It can be seen from the above PACE statements that the methods used in defining these two zones rely on the geologic, hydraulic and sediment study results. The expected mechanism of lateral erosion for the study reach was defined based on interpretation of historical aerial photographs, field data, the geologic history of the study area, the relative age of stream terraces adjacent to the active channel, and general geomorphic principles. The Severe Erosion Hazard Boundary is comprised of the active floodplain channel and channel margin areas likely to be eroded during a single 100-year flood event, or the area likely to be removed if the bank angle were to be reduced to the natural angle of response (stable channel side slope 3(horizontal.):1(vert.). The key point in this case is the channel boundary that may be affected by erosion, which is from the modeling results using the sediment model HEC-6T. The development of the "final" resulting boundary line required interpretation of the information and applying judgement

The HEC-RAS, HEC-6T, and FLUVIAL-12 sediment models were employed to determine sediment transport and stream channel changes for San Juan Creek. The channel boundary erosion was modeled using the HEC-6T together with the Yang formula for sediment transport for the 100-yr flood. Since boundary erosion directly affects the erosion hazard zone; it is therefore important to comment on the accuracy of this approach.

Lateral migration is a major factor to be included for the erosion hazard zone delineation. Geomorphic methods and hydrologic/hydraulic analyses can only be considered as qualitative analyses of channel boundary changes and lateral migration. Such methods do not address the channel boundary changes. There exist two kinds of computer models for river sedimentation: the erodible bed model and the erodible boundary model. Among the models used by PACE, the HEC-RAs and HEC-6T models are erodible bed models; the FLUVIAL-12 is an erodible boundary model. An erodible boundary model must simulate inter-related changes in channel-bed profile, channel width and bed topography induced by the channel curvature. The erodible-boundary model is different from an erodible-bed model in the following ways.

(1) An erodible-bed model does not simulate changes in channel width. Since changes in channel-bed profile is closely related to changes in width, these changes may not be separated.
(2) The change in bed profile in an erodible-bed model is assumed to be uniform in the erodible zone. All points adjust up and down by an equal amount during aggradation and degradation. Actual bed changes are by no means uniform and therefore they may not be simulated by an erodible-bed model.
(3) An erodible-bed model does not consider the channel curvature. In reality, the bed topography is highly non-uniform in a curved channel, especially during a high flow. Lateral migration occurs along curved channels; it directly affects the erosion hazard zone.

The accuracy of modeling results from a computer model depends not only on the capability of the model but also on the accuracy of the sediment transport formula. A sediment transport formula may either under-predict or over-predict the sediment transport rate. Of course the transport rate affects the boundary erosion. Any justification that can be provided for using the Yang formula should improve the confidence of the computer simulated results. The validity of a model relies upon the accuracy of the sediment transport formula as well as field calibration of the model. No calibration of the HEC-6T model is provided. While the final erosion hazard zone was not determined solely based on the model simulation, but the modeled results were used as a basis in setting the final erosion hazard zone.

In the PACE approach, bank retreat or boundary erosion is calculated using the sediment transport modeling results from the HEC-6T model. The sediment deficit determined by the model at a section or reach is applied to the channel banks. This method assumes that bank erosion is directly related to the sediment deficit at the cross section or reach. In reality, erosion due to sediment deficit can occur along the banks, or on the bed, or both. It cannot be attributed to the bank erosion alone. In fact, channel widening often accompanies channel bed aggradation. In river morphology, it is well known that an aggrading channel tends to widen itself to flood adjoining areas while a degrading channel tends to slide back into the banks.. Such geomorphic features signal that bank retreat often accompanies sediment deposition at the channel bed and vice versa. The changes in channel bank and channel bed are inter-related; they cannot be separated. In conclusion, the HEC-6T model was not developed for the purpose of boundary erosion and lateral migration that are essential for erosion hazard zone delineation. The HEC-6T model is an *erodible-bed model* but not an *erodible boundary model*;

In addition to channel widening and boundary erosion, a very important factor for lateral migration is the secondary flow inherent in curved channels. In a straight channel, the flow velocity is in the longitudinal direction along the channel. However, the flow velocity, in a curved channel, has a component in the transverse direction. The transverse flow component is responsible in moving sediment from the outside bank (concave bank) toward the convex bank. The net result of the transverse flow is erosion of the concave bank and lateral migration of the stream channel. The effects of secondary flow are not included in the PACE approach.

Erosion Monitoring Using Erosion Pins

Erosion pins have been used by PACE to keep track of stream channel changes due to erosion. These pins are scattered along the low flow channel but within the flood plain boundary. Installation of the pines stated in 2014.

The erosion pins are 0.375 inch in diameter and three feet in length. The lower part of the pin is inserted into the ground but the upper part is exposed. During storms, these pins are submerged in the stream flow. The erosion pin in the stream flow is like a small bridge pier; it causes flow disturbance and local scour around the pin. Such local scour is well known in bridge hydraulics and scour. Because of the small size, the local scour induced by a pin should also be small.

The erosion pins are installed for the primary purpose of tracking the general scour related to sediment imbalance along the stream channel; they are not intended for the local scour. Because of mixed local scour and general scour at the pins, the monitored changes by the pins must be carefully interpreted. In addition, vandalism should be carefully monitored.

Field Inspections: Howard Chang visited San Juan Creek twice during the first month.

APPENDIX B. CONFIRMATION OF MODEL VALIDITY USING OBSERVED DATA FROM SAN JUAN CREEK

Stream channel changes for San Juan Creek are dynamic in nature, characterized by channel bed scour and fill, changes in channel width and lateral migration. These changes are dynamic and inter-related as the stream channel is constantly adjusting toward a dynamic equilibrium in sediment transport and energy experience. Before applying a computer model to the stream channel, the computer model must show that it has the capability for simulating the dynamic changes in channel geometry. The validity of the model needs to be confirmed before it is applied to simulate the potential channel changes,

The accuracy of a mathematical model depends on the physical foundation, numerical techniques, and physical relations for momentum, flow resistance and sediment transport. Testing and calibration are important steps to be taken for more effective use of a model. Because of the difference in sensitivity of simulated results to each relation or empirical coefficient, more attention needs to be paid to those that generate sensitive results. Major items that require calibration include the roughness coefficient, sediment transport equation, bank erodibility factor, bed erodibility factor, and so on.

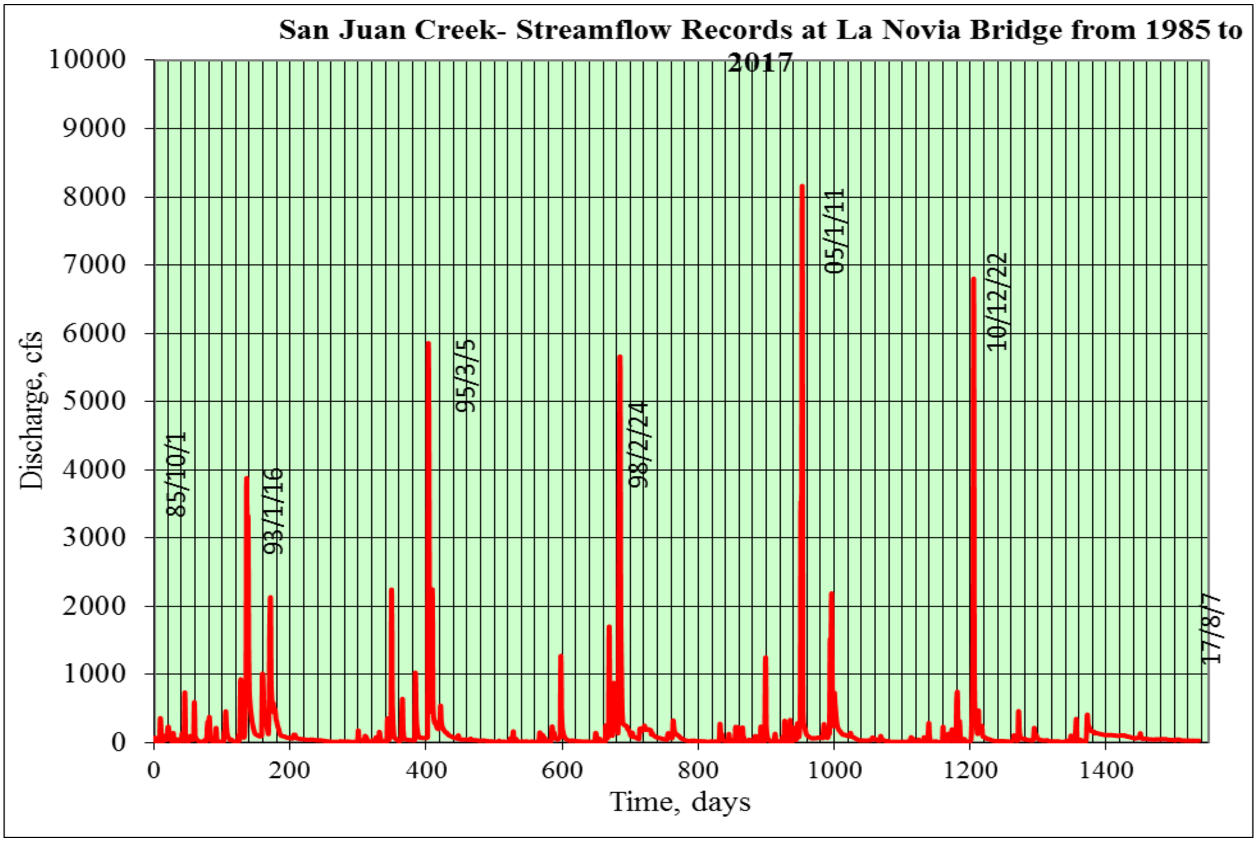
Field data are generally used for test and calibration of a model. The required information includes channel configuration before and after the changes, a flow record, and sediment characteristics. Data sets with more complete information are also more useful. The FLUVIAL-12 has undergone test and calibration using many data sets. Such studies together with their respective references are given in the users' manual. Many such data sets are also useful for the test and calibration of other models

The model validity as applied to San Juan Creek shall be confirmed using data from San Juan Creek. The PACE monitoring study provides observed channel changes in recent years at many locations along the stream channel. The observed data together with the hydrology for the period are employed to test and to confirm the validity of the model as applied to San Juan Creek.

The stream flow records for San Juan Creek at the La Novia Bridge are shown in Figure 5 below. In recent years, the most important storm event occurred on December 22, 2010. The monitored stream channel changes for recent years are provided in PACE's annual reports of 2014, 2015 and 2016. The storms that occurred after the December 2010 event were much smaller in magnitude; therefore, the stream channel changes were primarily caused by the December 2010 storm event.

For the sake of evaluating the validity of the modeling, the observations made by PACE given in the 2016 report are used to compare with the modeled channel changes. The observations given in the report "2016 SJC Watershed Stream Monitoring Annual Report". The monitored channel changes listed in Table 4-1 Summary of San Juan Creek Erosion Locations and Observations are compared with the modeled results covering the storms from December 2010 to 2016. Most observed changes occurred during the December 2010 storm.

The modeled stream channel changes at those channel locations are compared with reported observations at the same locations are described in the following. These locations are within the channel reach for Rancho Mission Viejo. The channel cross sections are shown in the work maps by PACE.



Stream flow records at the La Novia Bridge from 1985 to 2017

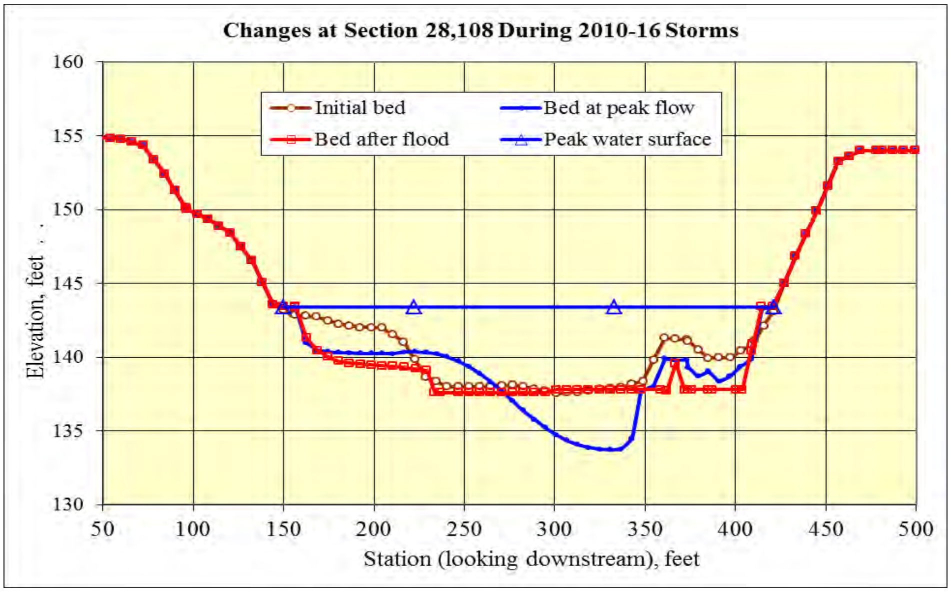
Channel Section 28108(20A) and 28574(20B) located 9,100-ft upstream of La Novia Bridge

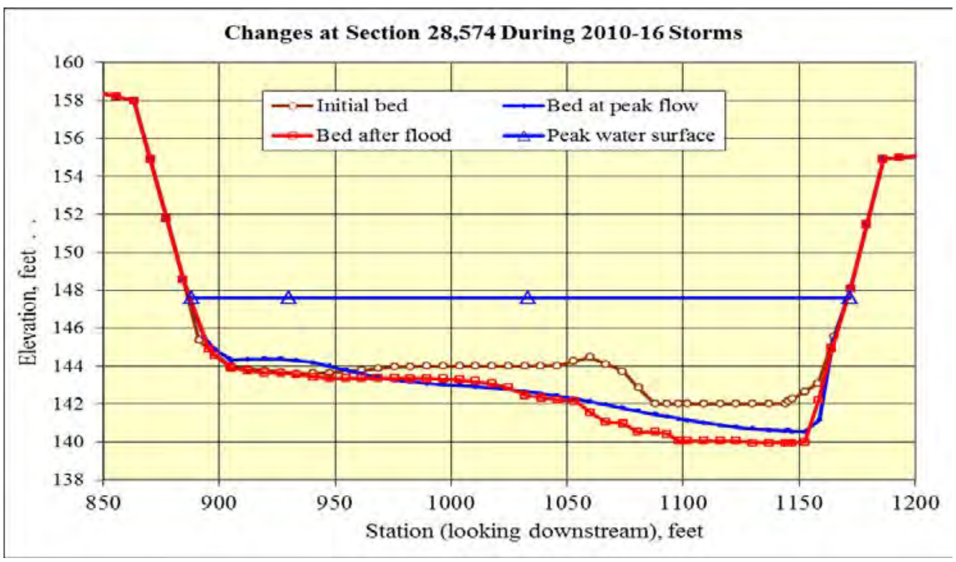
The monitoring report has: Moderate erosion; cut bank; riparian belt thickness ~20ft; located at left main channel bank; medium brush and grasses with small trees and one large tree on bank; moderately dense vegetation (~65% cover) with heavy vegetation at toe; age of vegetation: greater than 5 years (trees up to 20 years); tipped vegetation at 10 degree angle; natural runoff from site forms. hard clay layer on surface of soil.

The modeled results are presented in the figures below; Section 28108 is for 20A; Section 28574 is for 20B. The results for 20A show channel bed scour during the high flow followed by refill to the original level near the channel center. Stream channel changes are characterized by scour along the banks; that is, cut banks.

Section 28574 is located at 20B. The figure for this section shows channel bed scours during the high flow and refill toward the end of storm flow.

It should be noted that that the graphical presentation has distorted scales because the vertical scale is exaggerated. As an example, the maximum change in bed elevation in these figures is less than 5 feet but the changes in the horizontal direction exceed 50 feet. In other words, the bank cut far exceeds the bed erosion.





Section 29539 located 9,800-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; vertical bank (~5%) and undercut bank (~95%); riparian belt thickness ~15ft; located at left main channel bank; very highly vegetated with large trees at toe; very high density canopy: (greater than 75% cover); age of vegetation: greater than 5 years; tightly packed, silty sand (~30% gravel and ~10% cobbles); bank material is resistant with large rocks at toe; massive growth of vegetation since previous year.

The modeled results presented in the figure below show limited erosion at the channel bank. Erosion tends to steepen the channel bank

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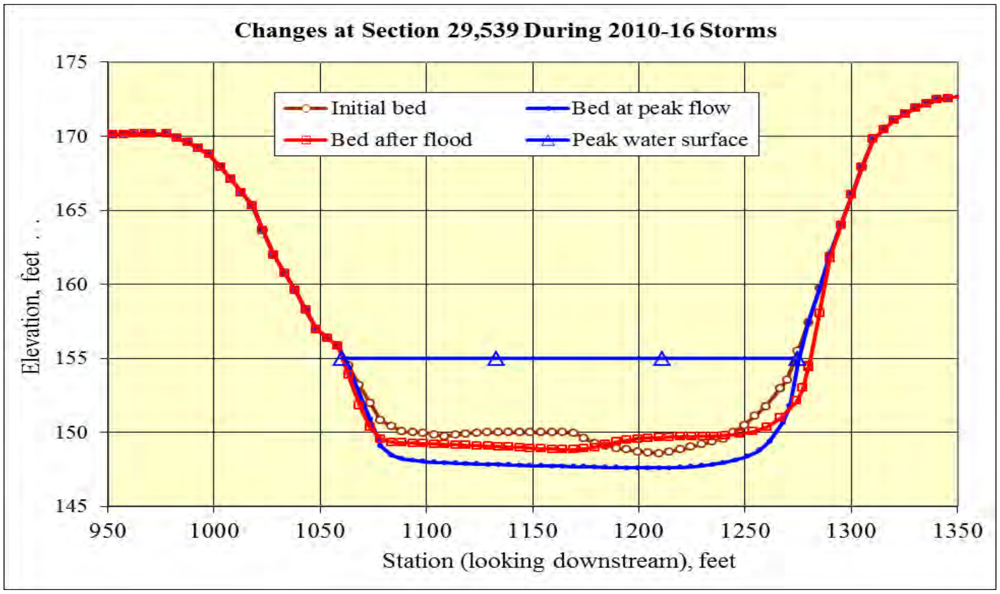
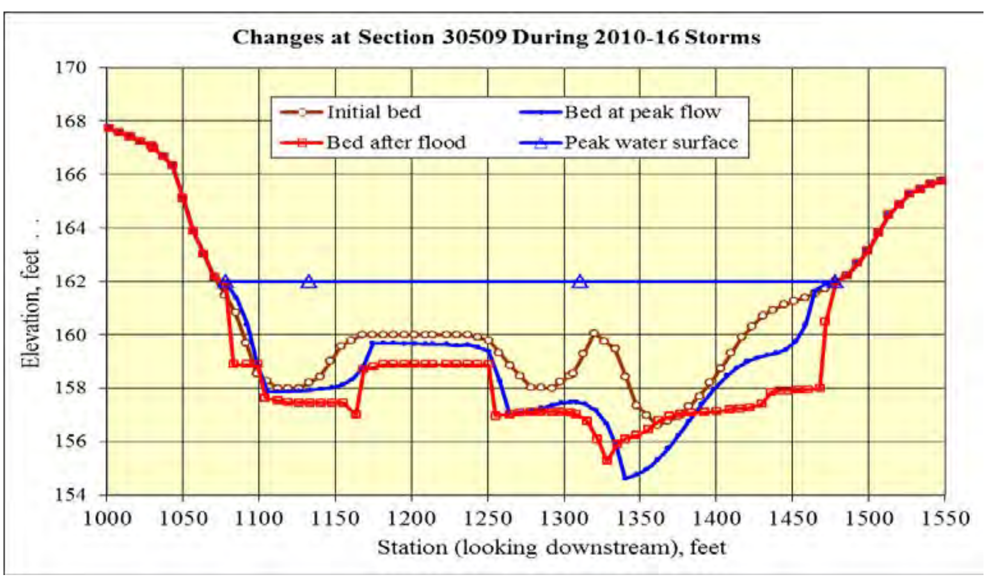


Section 30509 located 10,400-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; cut banks (~50%), vertical banks (~50%), and minor undercutting in some areas; riparian belt thickness ~15ft; left bank; short grass, brush, poison oak, and mulefat; moderately dense canopy (~40% cover); root mat (~15% cover); substantial protrusion of large tree roots; age of vegetation: greater than 2 years; loose, silty sand (~15% gravel and 10% cobbles around toe); bank material is layered; evidence of small landslide: tension cracks around vertical bank and very loose sand below.

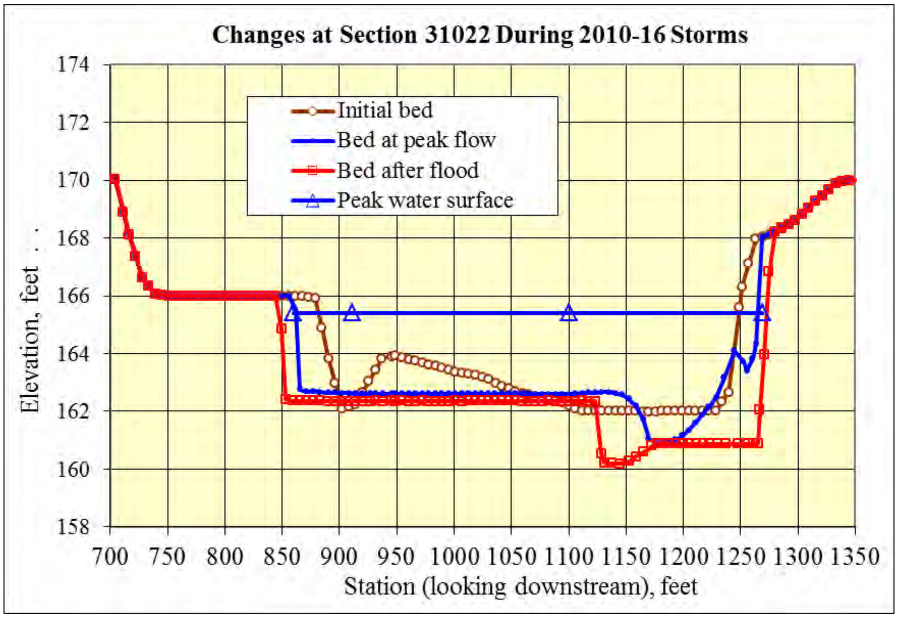
The modeled results presented in the figure below show distinct signs of bank cutting along both banks. It shows moderate bed erosion at this location. The right bankline moved back for over 70 feet; the average bed erosion is about 2 feet.



Section 31022, located 11,100-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank (~95%) and vertical bank (~5%); riparian belt thickness ~15ft; located within low flow channel near left main channel bank; short brush with a large tree and cactus; low density canopy (less than 20% cover); age of vegetation: greater than 5 years; sandy clay (~15% gravel and ~2% cobbles); bank material is generally weak and uniform; minor amounts of alluvium at toe; creek bed is rocky; minimal change from previous year beyond minor vegetation growth.

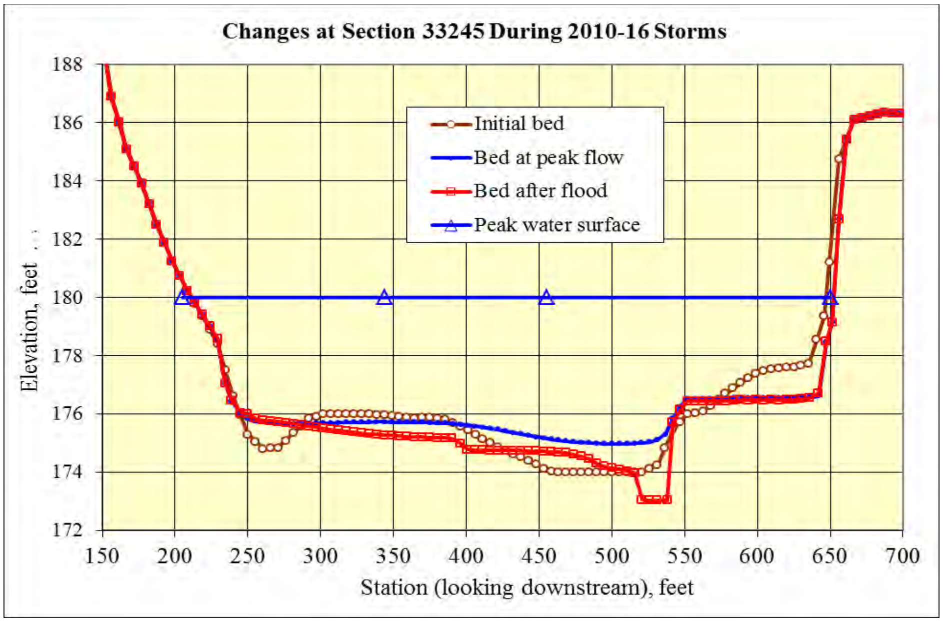
The modeled results presented in the figure below show distinct signs of bank cutting along both banks. The right bankline moved back for about 20 feet; the left bank retreated by about 40 feet. The average bed erosion is about 1 foot.



Section 33245 located 13,300-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; vertical bank (~97%) and undercut bank (~3%); riparian belt thickness ~10ft; located at left main channel bank; large trees, grass, mulefat at toe; ~70% of bank covered by vegetation; age of vegetation: greater than 5 years (trees greater than 20 years); substantial root protrusion; material is layered: top layers are very fine, loose sand, possibly held together by vegetation's root system; bottom layers are very rocky and highly resistant.

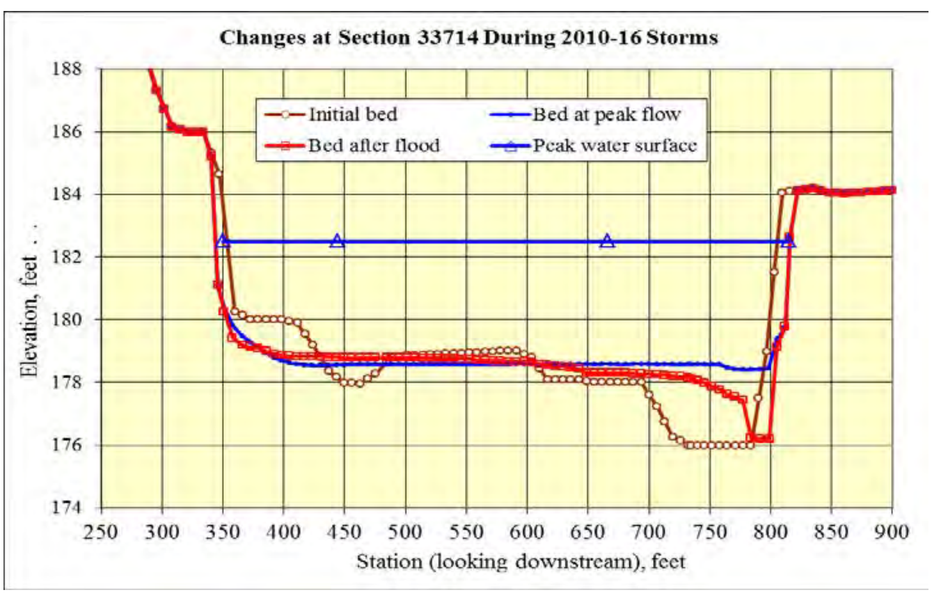
The modeled results presented in the figure below show mild erosion that has the average of less than 1 foot. The steep right bank shows sign of cutting.

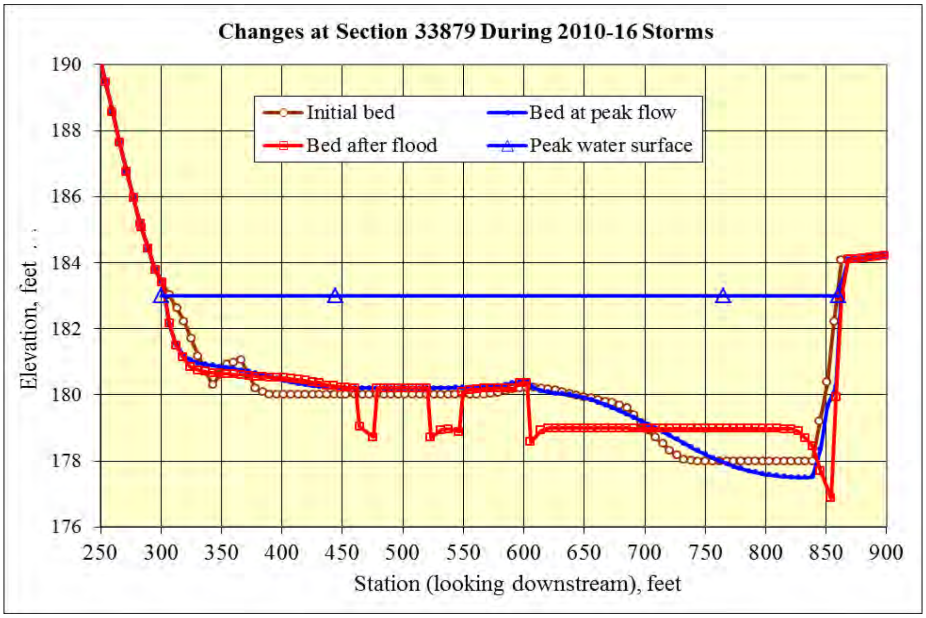


Section 33714(27A) is at the downstream southwest bank. Section 33879(27B) is at upstream northeast bank;

The monitoring report for this location has: Severe erosion, especially at 27A; solely cut banks; riparian belt thickness approx. 25ft; located at right main channel bank; short bushes, weeds, mulefat and cacti; moderately dense canopy (~50 to 75% cover); age of vegetation: greater than 2 years; loose silty sand (~20% gravel); large section of site is a man-made stream velocity diffuser consisting of large rocks along slope; storm drain on site with stone below to diffuse; erosion detected could be from construction or from outflow.

The modeled results presented in the figures below show distinct signs of bank cutting of about 10 feet along both banks. The average bed erosion is less than 1 foot.

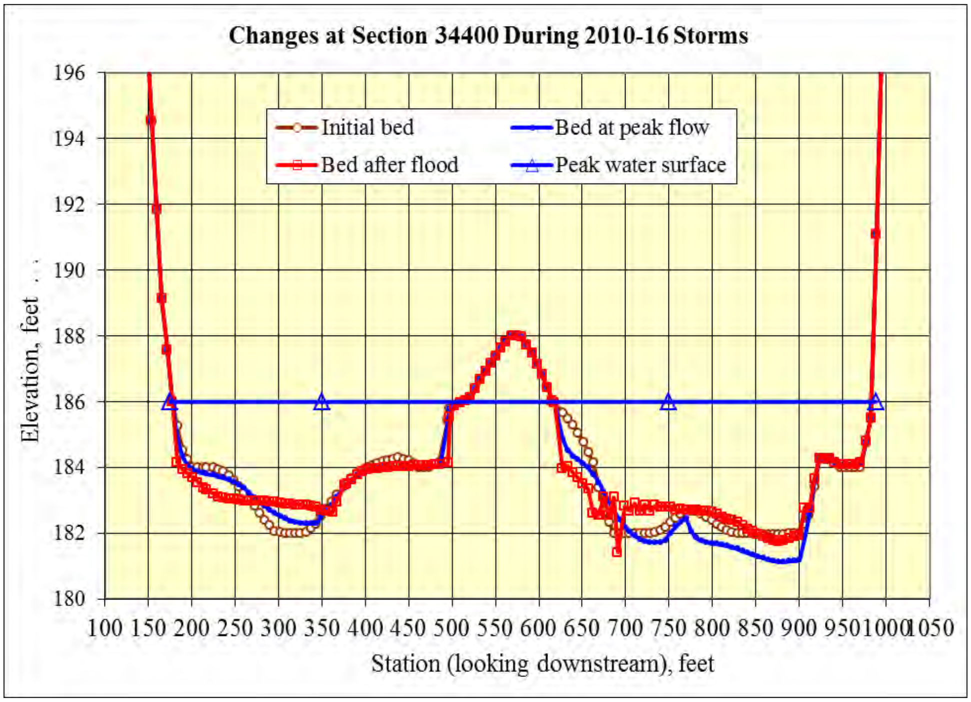




Section 34400 located 14,500-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank (~50%) and vertical bank (~50%) with minor undercutting in some areas; riparian belt thickness~15ft; located at right low flow bank; short grasses, medium bushes and mulefat; moderately dense canopy (~55 to 65% cover); age of vegetation: greater than 5 years; loosely packed, silty sand on cut bank; some clay content in vertical bank; ~30% gravel; material is generally weak and layered.

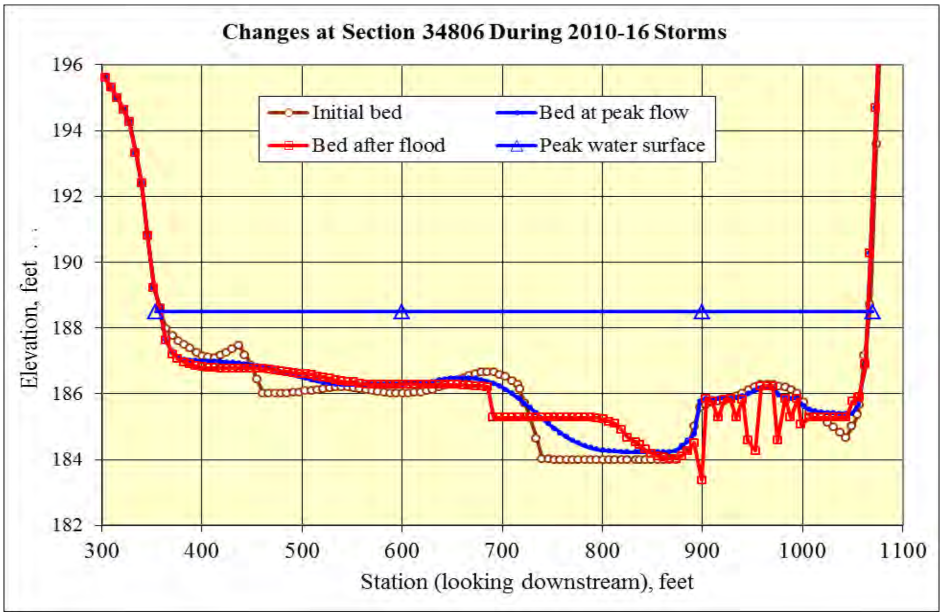
The modeled results presented in the figure below show mild erosion and steep banks.



Section 34806 located 14,900-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank (~90%), vertical bank (~10%);riparian belt thickness ~10ft; located at low flow left bank; short grasses, small brush, cacti and mulefat; moderately dense canopy (up to 80% cover); age of vegetation: less than 5 years; ~25% gravel; ~25% cobbles; bank material is layered and generally weak.

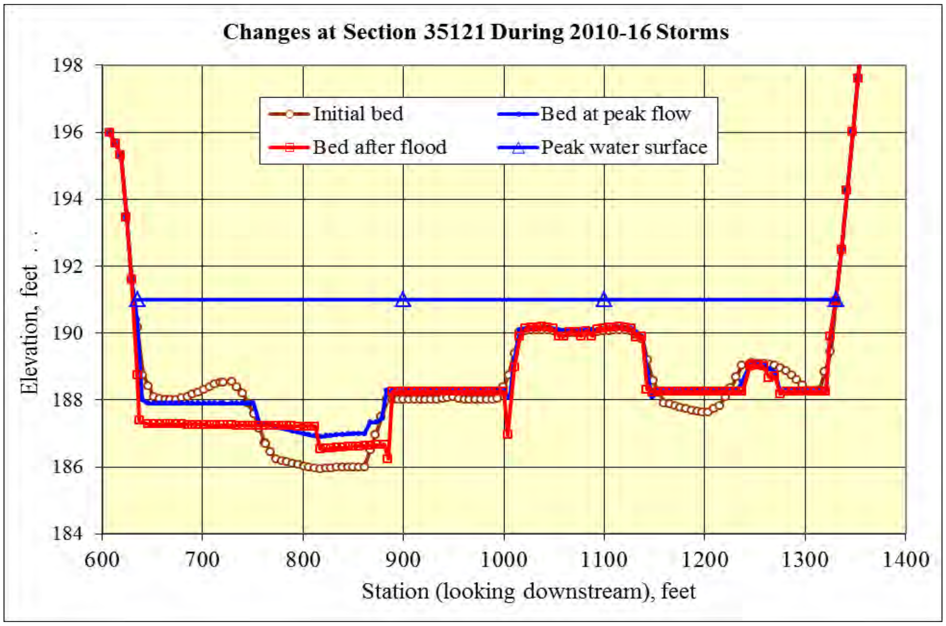
The modeled results presented in the figure below show mild bed erosion and steep banks.



Section 35121 located 15,200-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; cut bank (~24 to 36' height), vertical bank (~6 to 10' height), and local undercut bank (approx. 10" height); located at right main channel bank; large trees and large shrubs; high density canopy (greater than 75%); age of vegetation: greater than 7 years; substantial root protrusion along vertical face; approx. 50% sand; approx. 50% gravel; medium cobbles (less than 25% of bank cover); bank material is resistant and layered.

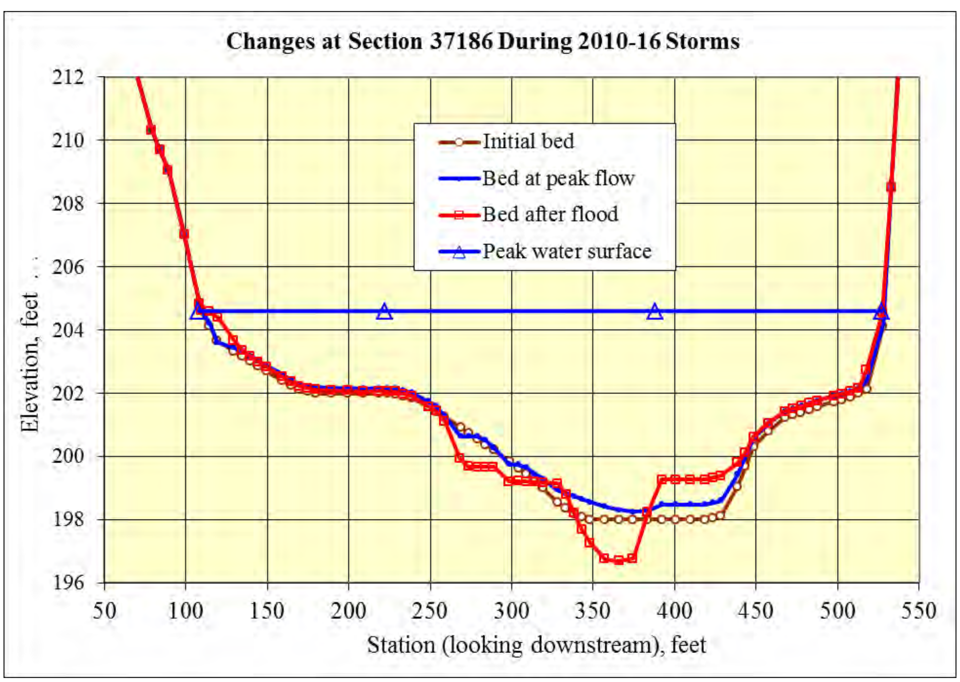
The modeled results presented in the figure below show mild erosion and steep banks.



Section 37186 located 17,300-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; cut bank (~80%); vertical bank (~20%); riparian belt thickness ~10ft; located at low flow left bank; medium shrubs, bamboo, medium grasses; trees located at downstream end; age of vegetation: moderately dense canopy (~50 to 75% cover); ~5 years; loosely packed, silty sand (~25% gravel and ~10% cobbles); bank material is layered and weak; minor exposed roots around reeds.

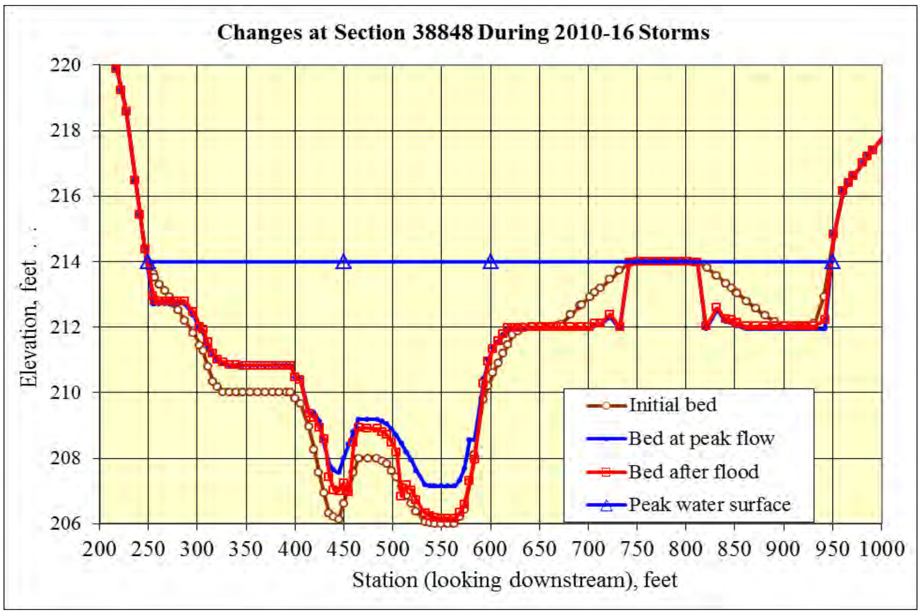
The modeled results presented in the figure below show mild erosion that has the average of less than 1 foot. The steep right bank shows sign of cutting.



Section 38848 located 18,400-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; cut bank (~90%), vertical bank (~10%), and undercut banks (minimal); left bank, riparian belt thickness ~15ft; large plants at toe and some trees at top; substantial root protrusion from trees; moderately high density canopy (~75% cover); age of vegetation: up to 20 years; loose silty sand; ~15% gravel; medium cobbles (less than 25% cover); bank material is weak; cobbles near toe of bank; low flow bar present.

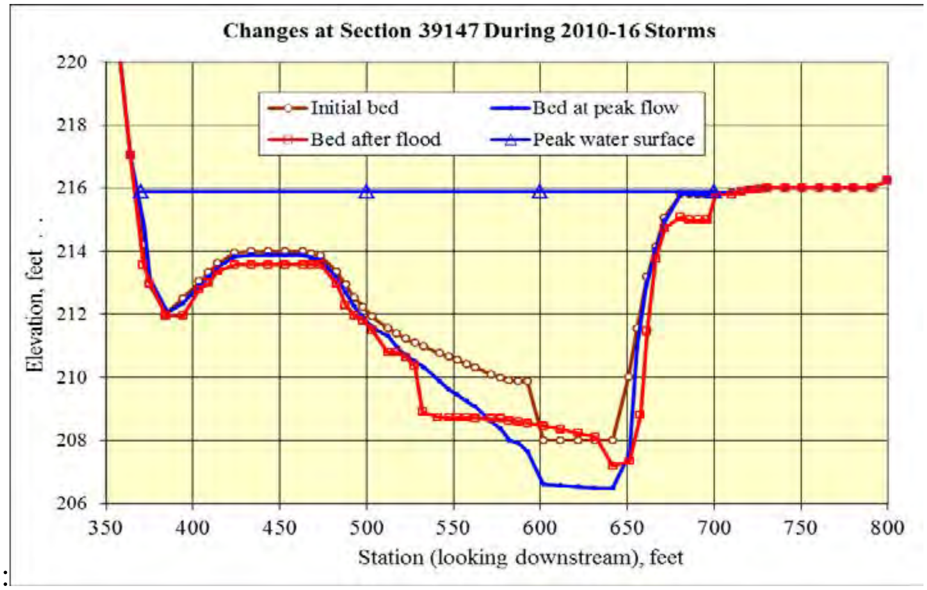
The modeled results presented in the figure below show mild bed erosion that has the average of less than 1 foot. The steep right bank shows sign of cutting at the toe.



Section 39147 located 15,600-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank; riparian belt thickness ~15ft; located at right main channel bank; small grasses, shrubs, and mulefat; moderately dense canopy (~80% cover); age of vegetation: between 5 to 7 years; loose, fine, silty sand with no notable percentage of gravel or cobbles; creek bed has large amount of cobbles; bank material is uniform and weak.

The modeled results presented in the figure below show mild erosion and steep right bank with clear sign of cutting.



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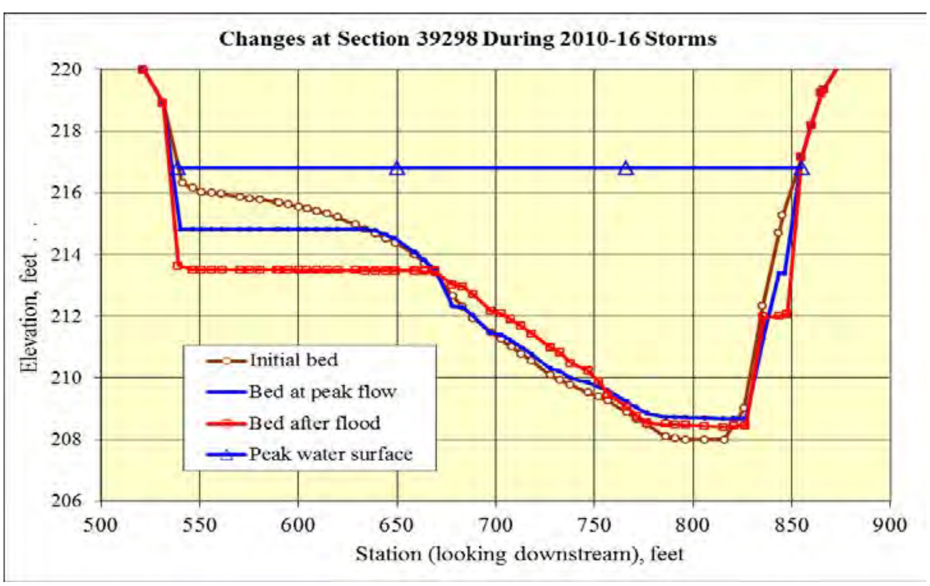
Section 39298 located 15,800-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank (~90%) and vertical bank (~10%); riparian belt thickness ~10ft; located at left main channel bank; small grasses with occasional mulefat; 85% of bank covered by vegetation; age of vegetation: ~5 years; some exposed roots along vertical bank; collapsed dead trees along bank; ~95% sand; ~5% gravel; bank material is uniform, loose, and weak.

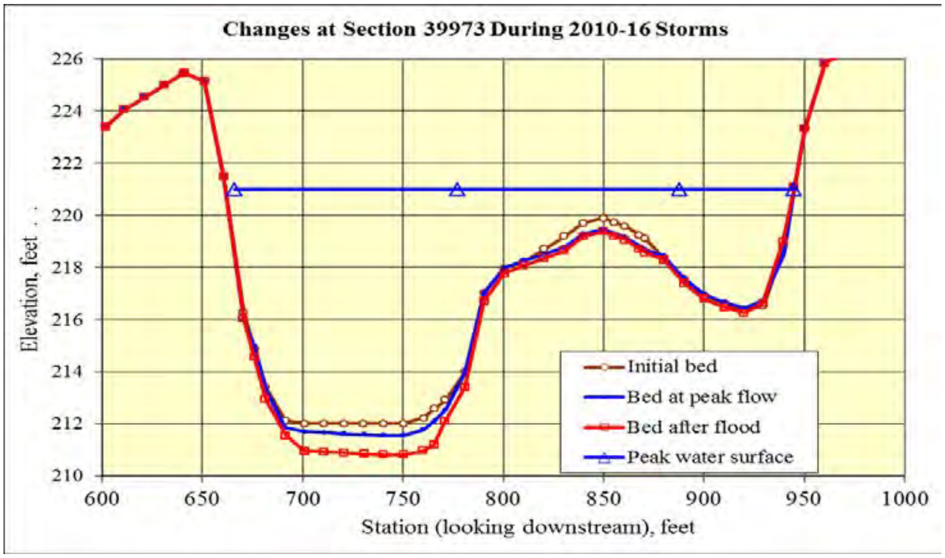
The modeled results presented in the figure below show mild erosion and steep banks with clear sign of cutting.



Section (39973) located 20,900-ft upstream of La Novia Bridge (39973)

The monitoring report for this location has: Moderate erosion; cut bank (~10%) and tiered vertical bank (~90%); riparian belt thickness ~20ft; located at right main channel bank; short grass and large trees; ~55% loose sand and less than 45% gravel; generally weak bank material; two CMP outlets and a 12" RCP pipe present; minimal piles of alluvium at toe of bank.

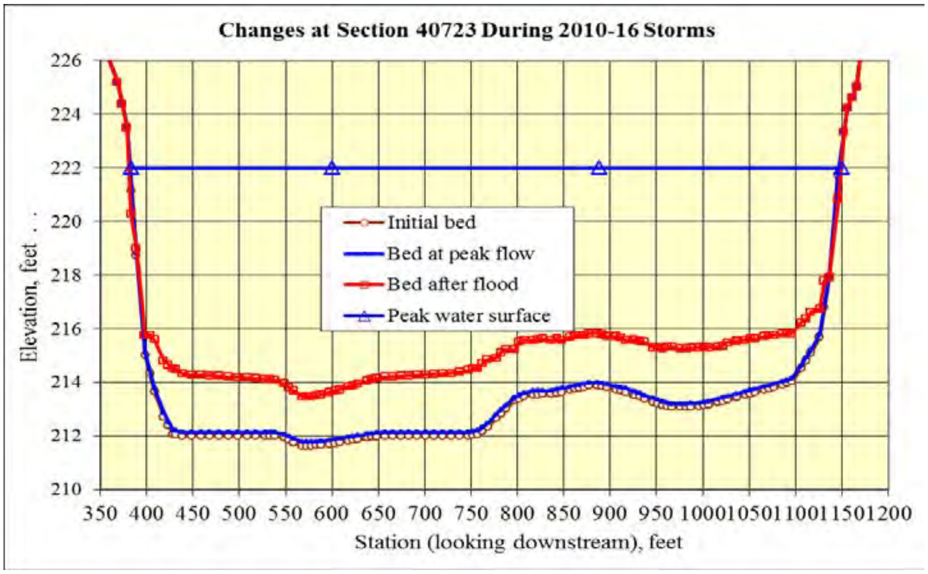
The modeled results presented in the figure below show sign of bank cutting below the water surface. Mild erosion of channel bed...



Section 40723 located 20,800-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; cut bank (~50%) and vertical bank on east side (~50%); riparian belt thickness ~25ft; located at left main channel bank; small shrubs and small brush; moderately dense canopy (~25 to 50% cover); age of vegetation: ~5 years; loose sand and silt; less than 30% gravel; minimal tension cracks, vegetation removed above vertical bank, large cobbles at toe.

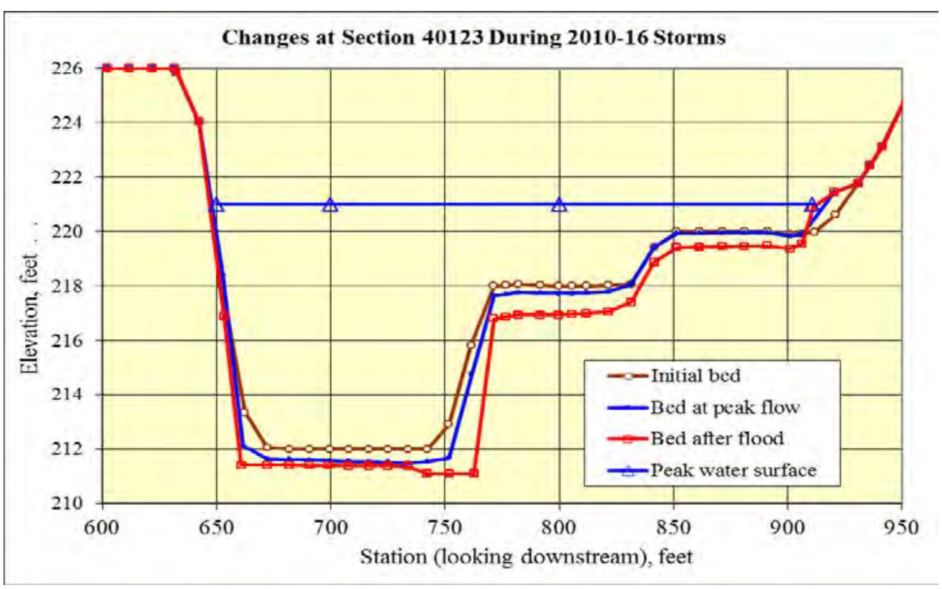
The modeled results presented in the figure below show sign of bank cutting below the water surface. The figure also shows mild erosion of channel bed...



Section 40123 located 20,200-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank (~50%) and vertical bank (~50%); riparian belt thickness ~10ft; left main channel bank; small shrubs and small brush; very low density canopy (~25% cover); mostly packed sand; ~25% gravel; bank material is layered and generally resistant; one 12" PVC pipe and one 24" CMP pipe emerging from bank; low vegetative cover.

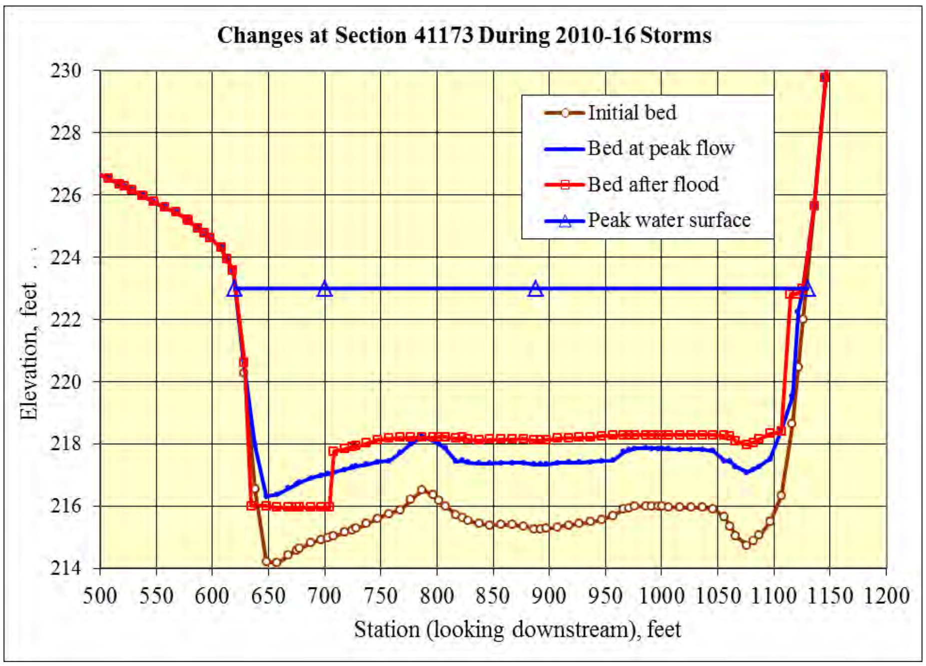
The modeled results presented in the figure below show sign of bank cutting below the water surface. The figure also shows mild erosion of channel bed...



Section 41173 located 21,200-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; riparian belt thickness ~15ft; 8 ft high cut banks (~80%), 3 ft high vertical banks (~20%); located at right main channel bank; medium brush, thin reeds, and small cacti; high density canopy (~80% cover); age of vegetation: between 2 to 5 years; ~50% sand; ~40% gravel; medium cobbles (less than 10% of bank cover); bank material is uniform and resistant; vertical bank mostly consists of compacted sand; steep cut banks show weaker soil.

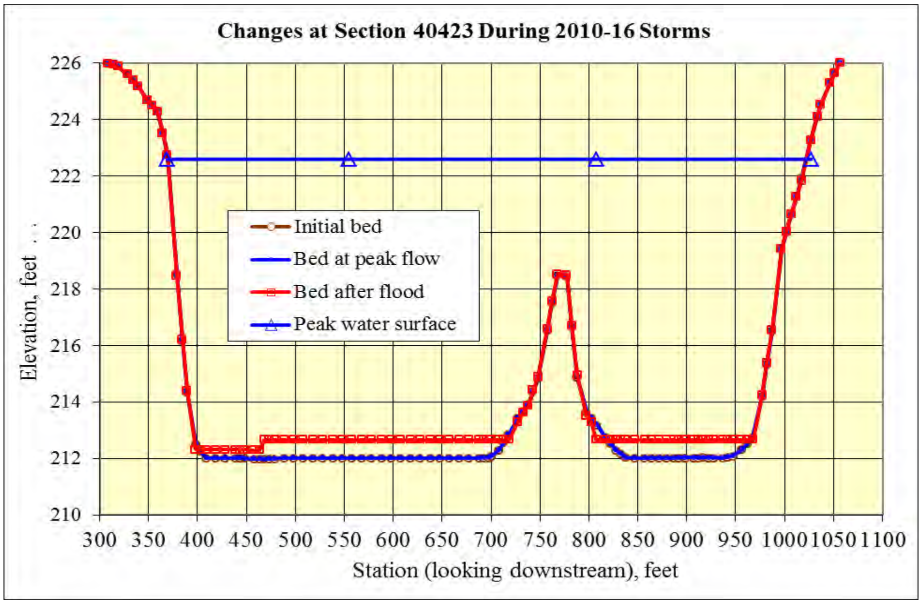
The modeled results presented in the figure below show sign of bank cutting below the water surface to cause 8 ft high cut bank. The average change in bed elevation is about 2 feet...



Section 40423 located 20,500-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank (~75%), vertical bank (~25%); middle bank, riparian belt thickness ~10ft; 6-ft tall grasses; minimal root mat; moderately dense canopy (~70% cover); age of vegetation: up to 5 years; minimal root protrusion; collapsed tall grass stalks; packed silty sand and 15% gravel; bank material generally resistant, layered bank material; gravel layer continues beneath cut bank.

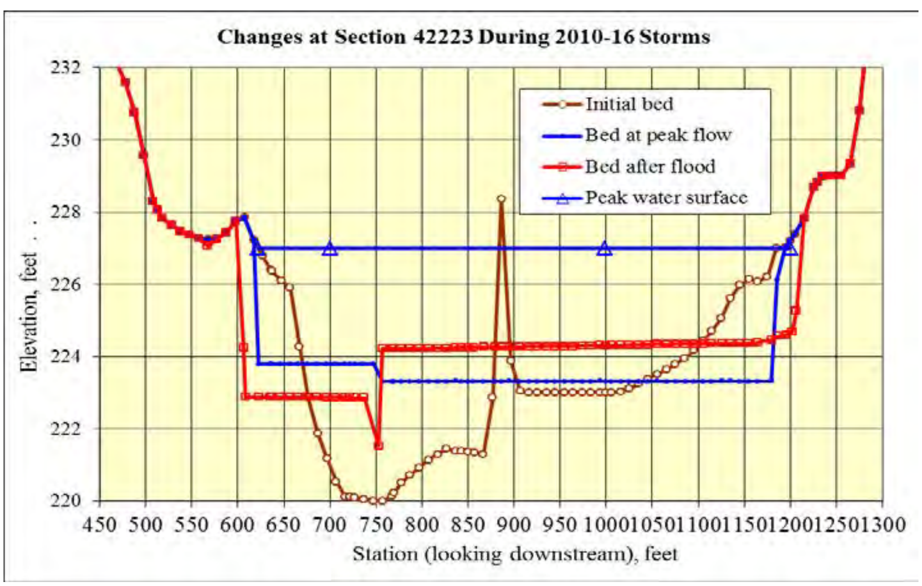
The modeled results presented in the figure below show mild bed erosion that has the average of less than 1 foot. The channel bank shows sign of cutting.



Section 42223 located 22,300-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank (~85%) and vertical bank (~15%); left bank; riparian belt thickness ~10ft; small brush with 20-ft trees in the middle; highly dense canopy (~100% cover); age of vegetation: greater than 10 years; substantial root protrusion; tightly-packed silty sand and 10% gravel; bank material is generally resistant, piles of alluvium at banks (~10%).

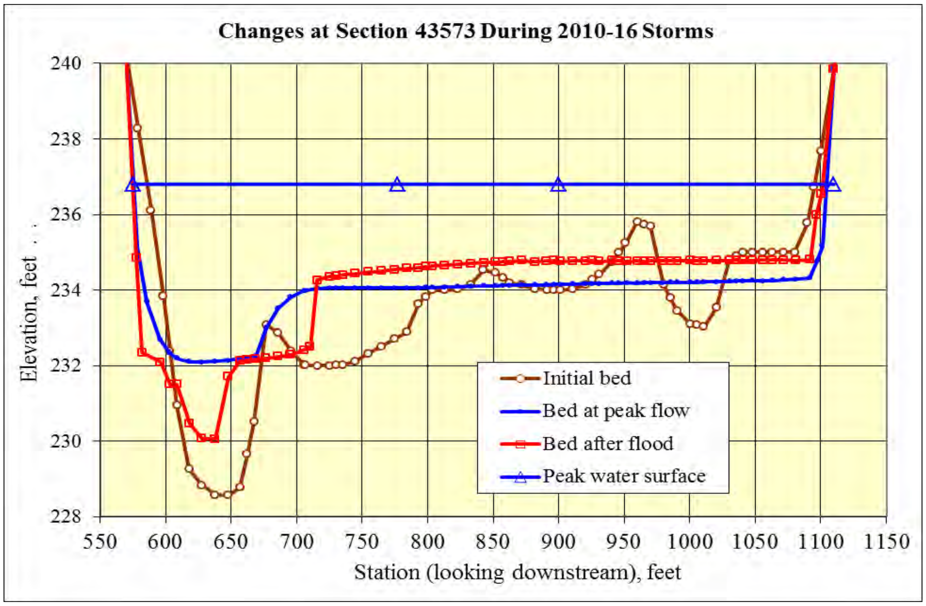
The modeled results presented in the figures below show distinct signs of bank cutting at the bank toe. The maximum change in bed elevation bed is 4 feet.



Section 43273 located 23,600-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; cut bank (~90%), vertical bank (~10%); located at left main channel bank; riparian belt thickness ~10ft; short grasses, 10-ft small shrubs, and small trees; low density canopy (~25% cover); age of vegetation: up to 10 years; silty sand, ~10% gravel; bank material is uniform and weak; storm drain outlet located at end of canyon; minimal vegetation removed from bank.

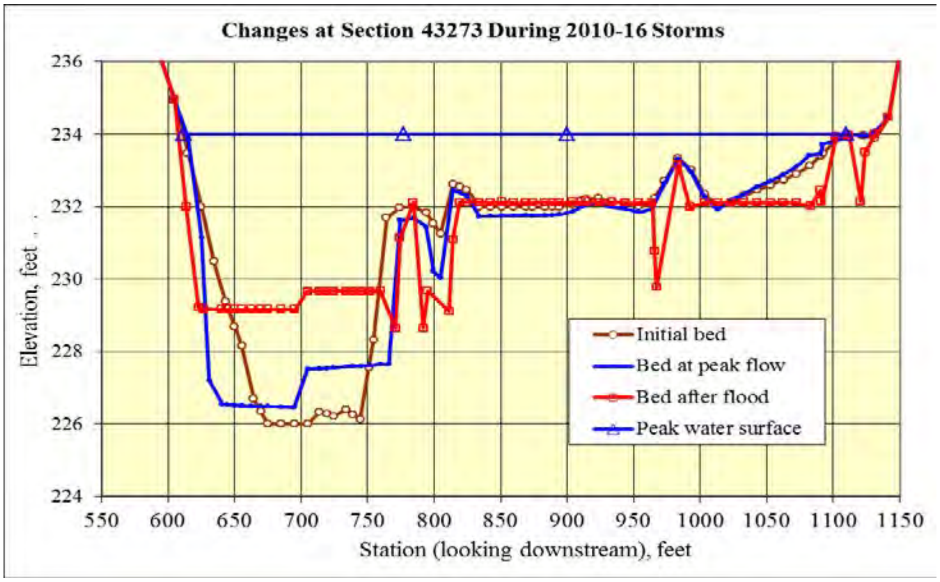
The modeled results presented in the figure below show distinct signs of bank cutting. The maximum change in bed elevation bed is 2 feet.



Section 43273 located 24,300-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; cut bank (~80%) and vertical bank (~20%);riparian belt thickness ~15ft; left bank; large stalks of bamboo at toe and a medium tree; low density canopy (20% cover); age of vegetation: ~5 years; removed vegetation along toe; medium cobbles (less than 10% bank cover); bank material is weak.

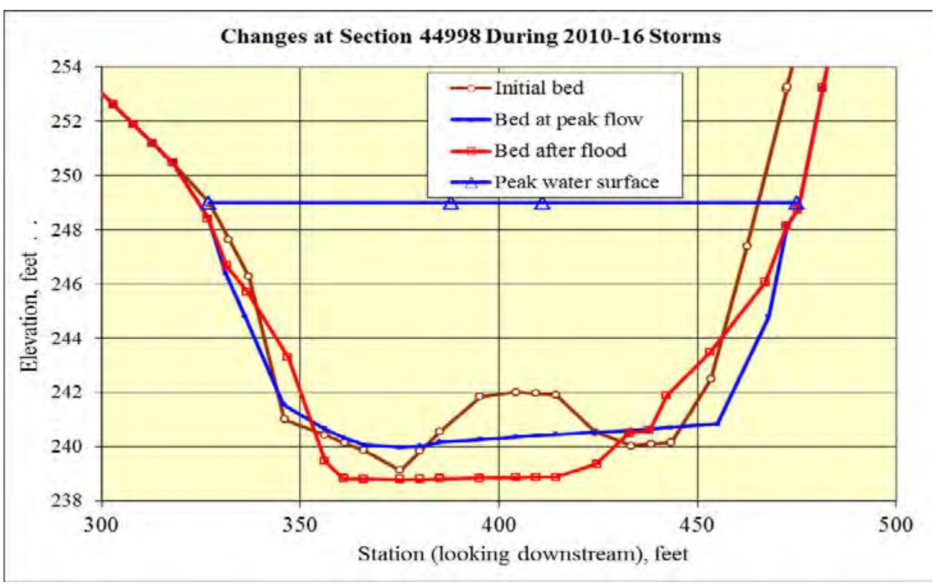
The modeled results presented in the figure below show distinct signs of bank cutting. The maximum change in bed elevation is 4 feet.



Section 44998 located 25,000-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; cut bank (~20%) below vertical bank (~80%); intermediate right bank; riparian belt thickness ~10ft; small shrubs, medium cacti, and large trees; low density canopy (~20 cover); age of vegetation: greater than 5 years; silty sand; ~25% gravel; bank material is layered; minimal vegetation removed from banks; most cobbles located at toe; exposed bedrock.

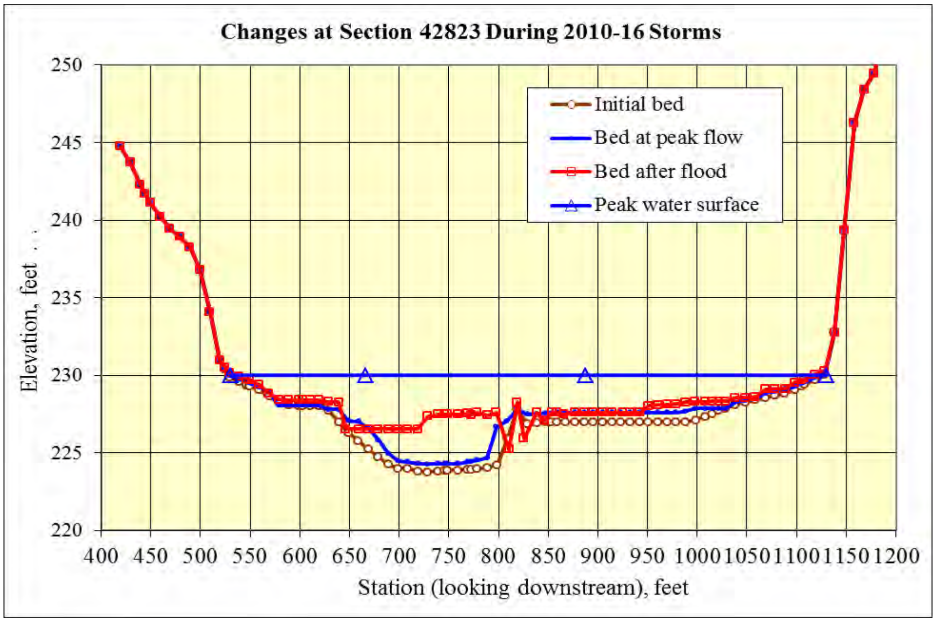
The modeled results presented in the figure below show distinct signs of bank cutting. The average change in bed elevation is about 2 feet.



Section 42823 located 22,900-ft upstream of La Novia Bridge

The monitoring report for this location has: Mild erosion; 20ft high cut bank (~50%), 10ft high vertical bank (~50%); riparian belt thickness ~10ft; right bank; tall brush, reeds, and cacti; highly dense canopy (~90% cover); age of vegetation: greater than 5 years; ~90% sand; ~5% gravel; 5% cobbles; vegetation tipped at 10 degree angle; deep, narrow channel with fallen trees at top of bank.

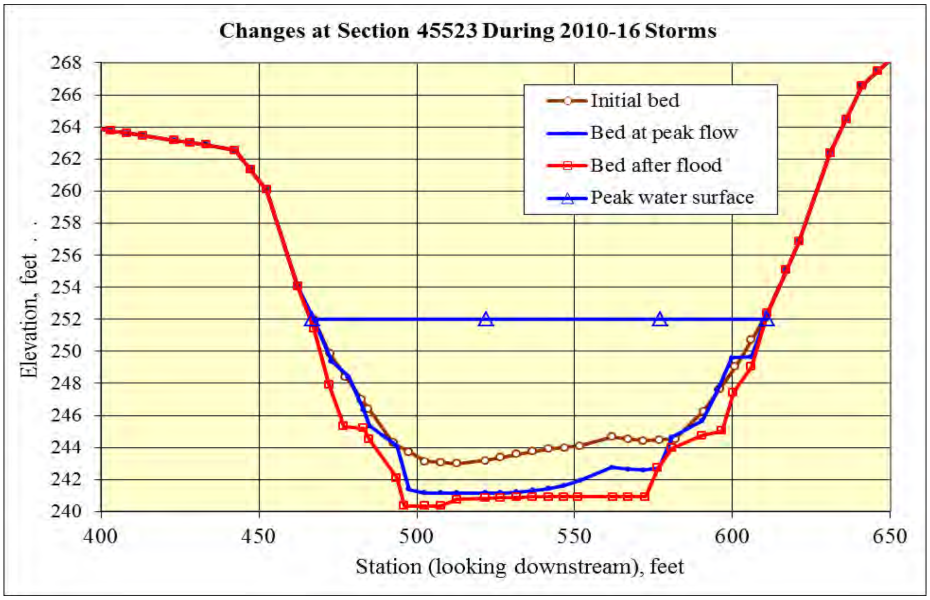
The modeled results presented in the figure below show high steep cut right bank. The bed changes are small.



Section 45223 located 23,800-ft upstream of La Novia Bridge

The monitoring report for this location has: Moderate erosion; elevated mound near right bank, 5 ft high cut bank (~100%); riparian belt thickness ~10ft; located at right main channel bank; small brush, sage; moderately dense canopy (~70% cover); removed vegetation at toe; sloping down towards bed at 10˚; ~50% sand, ~40% gravel; bank material is uniform and weak; medium cobbles (less than 10% of bank cover); no vertical cut banks.

The modeled results presented in the figure below show moderate erosion; elevated mound near right bank, 5 ft high cut bank, distinct signs of bank cutting. The average change in bed elevation is about 2 feet.



Summary — In order to apply the FLUVIAL-12 model to San Juan Creek, the model validity needs to be confirmed using the data for channel changes from the same stream channel. San Juan Creek has undergone relatively limited changes in recent years. Most of the changes occurred during the December 2010 storm. PACE has provided detailed observed channel changes during this time period.

The FLUVIAL-12 model was used to simulate the stream channel changes for the time covering the 2010 storm and other subsequent small events. The modeled results were compared with the observations at numerous locations along the channel reach for Rancho Mission Viejo.

The modeled channel changes are compared with the observations for the same time period. The modeled changes are generally small in magnitude. The modeled and observed changes are in general agreement. It is recognized that the stream channel changes are not based on measurement but based on observation. The modeled results are consistent with field observations. There are no exceptions to the agreements based on observations at all locations along the channel reach.

The available data for stream channel changes along San Juan Creek do not permit a calibration study of the FLUVIAL-12 model. However, this model has been calibrated using many sets of field data. Such calibrated studies are available from published literature listed in the FLUVIAL-12 User's Manual.

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APPENDIX C. INPUT/OUTPUT DESCRIPTIONS FOR FLUVIAL-12

I. INPUT DESCRIPTION

The basic data requirements for a modeling study include (1) topographic maps of the river reach from the downstream end to the upstream end of study, (2) digitized data for cross sections in the HEC-2 format with cross-sectional locations shown on the accompanying topographic maps, (3) flow records or flood hydrographs and their variations along the study stream reach, it any, and (4) size distributions of sediment samples along the study reach. Additional data are required for special features of a study river reach.

The HEC-2 format for input data is used in all versions of the FLUVIAL model. Data records for HEC-2 pertaining to cross-sectional geometry (X1 and GR), job title (T1, T2, and T3), and end of job (EJ), are used in the FLUVIAL model. If a HEC-2 data file is available, it is not necessary to delete the unused records except that the information they contain are not used in the computation. For the purpose of water- and sediment-routing, additional data pertaining to sediment characteristics, flood hydrograph, etc., are required and supplied by other data records. Sequential arrangement of data records are given in the following.

Records	Description of Record Type
T1,T2,T3	Title Records
G1	General Use Record
G2	General Use Records for Hydrographs
G3	General Use Record
G4	General Use Record for Selected Cross-Sectional Output
G5	General Use Record
G6	General Use Record for Selecting Times for Summary Output
G7	General Use Record for Specifying Erosion Resistant Bed Layer
GS	General Use Records for Initial Sediment Compositions
GB	General Use Records for Time Variation of Base-Level
GQ	General Use Records for Stage-Discharge Relation of Downstream Section
GI	General Use Records for Time Variation of Sediment Inflow
X1	Cross-Sectional Record
XF	Record for Specifying Special Features of a Cross Section
GR	Record for Ground Profile of a Cross Section
SB	Record for Special Bridge Routine
BT	Record for Bridge Deck Definition
EJ	End of Job Record

Variable locations for each input record are shown by the field number. Each record has an input format of (A2, F6.0, 9F8.0). Field 0 occupying columns 1 and 2 is reserved for the required record identification characters. Field 1 occupies columns 3 to 8; Fields 2 to 10 occupy 8 columns each. The data records are tabulated and described in the following.

T1, T2, T3 Records - These three records are title records that are required for each job.

Field	Variable	Value	Description
0	IA	T1	Record identification characters
1-10	None		Numbers and alphameric characters for title

G1 Record - This record is required for each job, used to enter the general parameters listed below. This record is placed right after the T1, T2, and T3 records.

Field	Variable	Value	Description
0	IA	G1	Record identification characters
1	TYME	+	Starting time of computation on the hydrograph, in hours
2	ETIME	+	Ending time of computation on the hydrograph, in hours
3	DTMAX	+	Maximum time increment Δt allowed, in seconds
4	ISED	1	Select Graf's sediment transport equation.
		2	Select Yang's unit stream power equation. The sediment size is between 0.063 and 10 mm.
		3	Select Engelund-Hansen sediment equation.
		4	Select Parker gravel equation.
		5	Select Ackers-White sediment equation.
		6	Select Meyer-Peter Muller equation for bed load.
5	BEF	+	Bank erodibility factor for the study reach. This value is used value between 0 and 1 may be used.
6	IUC	0	English units are used in input and output.
		1	Metric units are used in input and output.
7	CNN	+	Manning's *n* value for the study reach. This value is used for a section unless otherwise specified in Field 4 of the XF record. If bed roughness is computed based upon alluvial bedforms as specified in Field 5 of the G3 record, only an approximate *n* value needs to be entered here.
8	PTM1	+	First time point in hours on the hydrograph at which summary output and complete cross-sectional output are requested. It is usually the peak time, but it may be left blank if no output is requested.
9	PTM2	+	Second time point on the hydrograph in hours at which summary usually the time just before the end of the simulation. This field

			may be left blank if no output is needed.
10	KPF	+	Frequency of printing summary output, in number of time steps.

G2 Records - These records are required for each job, used to define the flow hydrograph(s) in the channel reach. The first one (or two) G2 records are used to define the spatial variation in water discharge along the reach; the succeeding ones are employed to define the time variation(s) of the discharge. Up to 10 hydrographs, with a maximum of 120 points for each, are currently dimensioned. See section II for tributaries. These records are placed after the G1 record.

Field	Variable	Value	Description
First G2			
0	IA	G2	Record identification characters
1	IHP1	+	Number of last cross section using the first (downstream most) hydrograph. The number of section is counted from downstream to upstream with the downstream section number being one. See also section II.
2	NP1	+	Number of points connected by straight segments used to define
3	IHP2	+	Number of last section using the second hydrograph if any. Otherwise leave it blank.
4	NP2	+	Number of points used to define the second hydrograph if any. Otherwise leave it blank.
5	IHP3	+	Number of last section using the third hydrograph if any. Otherwise leave it blank.
6	NP3	+	Number of points used to define the third hydrograph if any. Otherwise leave it blank.
7	IHP4	+	Number of last section using the fourth hydrograph if any. Otherwise leave it blank.
8	NP4	+	Number of points used to define the fourth hydrograph if any. Otherwise leave it blank.
9	IHP5	+	Number of last section using the fifth hydrograph if any. Otherwise leave it blank.
10	NP5	+	Number of points used to define the fifth hydrograph if any. Otherwise leave it blank.

Second G2: Note that this record is used only if more than 5 hydrographs are used for the job. It is necessary to place a negative sign in front of NP5 located in the 10th field of the first G2 record as a means to specify that more than 5 hydrographs are used.

0	IA	G2	Record identification characters
1	IHP6	+	Number of last cross section using the sixth hydrograph if any. Otherwise leave it blank.
2	NP6	+	Number of points connected by straight segments used to define
3	IHP7	+	Number of last section using the seventh hydrograph if any. Otherwise leave it blank.
4	NP7	+	Number of points used to define the seventh hydrograph
5	IHP8	+	Number of last section using the eighth hydrograph if any. Otherwise leave it blank.
6	NP8	+	Number of points used to define the eighth hydrograph
7	IHP9	+	Number of last section using the ninth hydrograph if any. Otherwise leave it blank.
8	NP9	+	Number of points used to define the ninth hydrograph
9	IHP10	+	Number of last section using the tenth hydrograph if any. Otherwise leave it blank.
10	NP10	+	Number of points used to define the tenth hydrograph

Succeeding G2 Record(s)

1	Q11, Q21 Q31	+	Discharge coordinate of point 1 for each hydrograph, in ft^3/sec or m^3/sec
2	TM11,TM21 TM31	+	Time coordinate of point 1 for each hydrograph, in hours
3	Q12, Q22 Q32	+	Discharge coordinate of point 2 for each hydrograph, in cfs or cms
4	TM12,TM22 TM32	+	Time coordinate of point 2 for each hydrograph, in hours

Continue with additional discharge and time coordinates. Note that time coordinates must be in increasing order.

G3 Record - This record is used to define required and optional river channel features for a job as listed below. This record is placed after the G2 records.

Field	Variable	Value	Description
0	IA	G3	Record identification characters
1	S11	+	Slope of the downstream section, required for a job
2	BSP	0	One-on-one slope for rigid bank or bank protection
		+	Slope of bank protection in BSP horizontal units on 1 vertical unit. for all cross sections unless otherwise specified in Field 8 of the XF record for a section.
3	DSOP	0	Downstream slope is allowed to vary during simulation.
		1	Downstream slope is fixed at S11 given in Field 1.
4	TEMP	0	Water temperature is 15°C.
		+	Water temperature in degrees Celsius
5	ICNN	0	Manning's n defined in Field 7 of the G1 record or those in Field 4 of the XF records are used.
		1	Brownlie's formula for alluvial bed roughness is used to calculate Manning's n in the simulation.
6	TDZAMA	0	Thickness of erodible bed layer is 100 ft (30.5 m).
		+	Thickness of erodible bed layer in ft or m. This value is applied to
7	SPGV	0	Specific gravity of sediment is 2.65.
		+	Specific gravity of sediment
8	KGS	0	The number of size fractions for bed material is 5.
		+	The number of size fractions for bed material. It maximum value is 8.
9	PHI	0	The angle of repose for bed material is 36°.
		+	Angle of repose for bed material

G4 Record - This is an optional record used to select cross sections (up to 4) to be included at each summary output. Each cross section is identified by its number which is counted from the downstream section. This record also contains other options; it is placed after the G3 record.

Field	Variable	Value	Description
0	IA	G4	Record identification characters
1	IPLT1	+	Number of cross section
2	IPLT2	+	Number of cross section
3	IPLT3	+	Number of cross section
4	IPLT4	+	Number of cross section
5	IEXCAV	+	A positive integer indicates number of cross section where sand/gravel excavation occurs.
6	GIFAC	+	A non-zero constant is used to modify sediment inflow at the upstream section.
7	PZMIN	0	Minimum bed profile during simulation run is not requested.
		1	Output file entitled TZMIN for minimum bed profile is requested.
10	REXCAV	+	A non-zero value specifies rate of sand/gravel excavation at Section IEXCAV.

G5 Record - This is an optional record used to specify miscellaneous options, including unsteady-flow routing for the job based upon the dynamic wave, bend flow characteristics. If the unsteady flow option is not used, the water-surface profile for each time step is computed using the standard-step method. When the unsteady flow option is used, the downstream water-surface elevation must be specified using the GB records.

Field	Variable	Value	Description
0	IA	G5	Record identification characters
1	DT	0	The first time step is 100 seconds.
		+	Size of the first time step in seconds.
2	IROUT	0	Unsteady water routing is not used; water-surface profiles are computed using standard-step method.
		1	Unsteady water-routing based upon the dynamic wave is used to

			compute stages and water discharges at all cross sections for each
3	PQSS	0	No output of gradation of sediment load
		3	Gradation of sediment load is included in output in 1,000 ppm by weight.
5	TSED	0	Rate of tributary sediment inflow is 1 times the discharge ratio.
		+	Rate of tributary sediment inflow is TSED times the discharge ratio.
6	PTV	0	No output of transverse distribution of depth-averaged velocity
		1	Transverse distribution of depth-averaged velocity is printed. The velocity distribution is for bends with fully developed transverse flow.
10	DYMAX	0	No GR points are inserted for cross sections.
		+	Maximum value of spacing between adjacent points at a cross

G6 Record - This is an optional record used to select time points for summary output. Up to 30 time points may be specified. The printing frequency (KPF) in Field 10 of the G1 Record may be suppressed by using a large number such as 9999.

Field	Variable	Value	Description
First G6 Record			
0	IA	G6	Record identification characters
1	NKPS	+	Number of time points
Succeeding G6 Record(s)			
0	IA	G6	Record identification characters
1	SPTM(1)	+	First time point, in hours
2	SPTM(2)	+	Second time point, in hours

Continue with additional time points.

G7 Record - This is an optional record used to specify erosion resistant bed layer, such as a caliche layer, that has a lower rate of erosion.

Field	Variable	Value	Description

First G7 Record

0	IA	G7	Record identification characters
1	KG7	+	Number of time points used to define the known erosion rate in relation to flow velocity
2	THICK	+	Thickness of erosion resistant layer, in feet

Succeeding G7 Record(s)

0	IA	G7	Record identification characters
1	ERATE(1)	+	Erosion rate, in feet per hour
2	G7V(2)	+	Velocity, in feet per second

Continue with additional time points.

GS Record - At least two GS records are required for each job, used to specify initial bed-material compositions in the channel at the downstream and upstream cross sections. The first GS record is for the downstream section; it should be placed before the first X1 record and after the G4 record, if any. The second GS record is for the upstream section; it should be placed after all cross-sectional data and just before the EJ record. Additional GS records may be inserted between two cross sections within the stream reach, with the total number of GS records not to exceed 15. Each GS record specifies the sediment composition at the cross section located before the record. From upstream to downstream, exponential decay in sediment size is assumed for the initial distribution. Sediment composition at each section is represented by five size fractions.

Field	Variable	Value	Description
0	IA	GS	Record identification characters
1	DFF	+	Geometric mean diameter of the smallest size fraction in mm
2	PC	+	Fraction of bed material in this size range

Continue with other DFF's and PC's.

GB Records - These optional records are used to define time variation of stage (water-surface elevation) at a cross section. The first set of GB records is placed before all cross section records (X1); it specifies the downstream stage. When the GB option is used, it supersedes other methods for determining the downstream stage. Other sets of GB records may be placed in other parts of the data set; each specifies the time variation of stage for the cross section immediately following the GB records.

Field	Variable	Value	Description

First GB Record

Field	Variable	Value	Description
0	IA	GB	Record identification characters
1	KBL	+	Number of points used to define base-level changes

Succeeding GB Record(s)

Field	Variable	Value	Description
0	IA	GB	Record identification characters
1	BSLL(1)	+	Base level of point 1, in ft or m
2	TMBL(1)	+	Time coordinate of point 1, in hours
3	BSLL(2)	+	Base level of point 2, in ft or m
4	TMBL(2)	+	Time coordinate of point 2, in hours

Continue with additional elevations and time coordinates, in the increasing order of time.

GQ Records - These optional records are used to define stage-discharge relation at the downstream section. The GQ input data may not used together with the GB records.

First GQ Record

Field	Variable	Value	Description
0	IA	GQ	Record identification characters
1	KQL	+	Number of points used to define base-level changes

Succeeding GQ Record(s)

Field	Variable	Value	Description
0	IA	GQ	Record identification characters
1	BSLL(1)	+	Base level of point 1, in ft or m
2	TMQ(1)	+	Discharge of point 1, in cfs or cms
3	BSLL(2)	+	Base level of point 2, in ft or m
4	TMQ(2)	+	Discharge of point 2, in cfs or cms

Continue with additional elevations and discharges, in the increasing order of discharge.

GI Records - These optional records are used to define time variation of sediment discharge entering the study reach through the upstream cross section. The GI input data, if included, will supersede other methods for determining sediment inflow. The sediment inflow is classified into the two following cases: (1) specified inflow at the upstream section, such as by a rating curve; and (2) sediment feeding, such as from a dambreach or a sediment feeder. These two cases are distinguished by DXU in Field 2 of this record. For the first case, sediment discharge at the upstream section is computed using size fractions of bed-material at the section, but for the second case, the size fractions of feeding material need to be specified using the PCU values in this record. The upstream section does not change in geometry for the first case but it may undergo scour or fill for the second case.

Field	Variable	Value	Description
First GI Record			
0	IA	GI	Record identification characters
1	KGI	+	Number of points used to define time variation of sediment inflow.
2	DXU	+ or 0	Channel distance measured from the upstream section to the and KGI signify case 2, for which PCU values are required.
3-10	PCU	+	Size fractions of inflow material. The number of size fractions is given in Field 8 of the G3 record and the sizes for the fractions are given in the second GS record.
Succeeding GI Record(s)			
0	IA	GI	Record identification characters
1	QSU(1)	+	Sediment discharge of point 1, in cubic ft or m (net volume) per second
2	TMGI(1)	+	Time coordinate of point 1, in hours
3	QSO(2)	+	Sediment discharge of point 2
4	TMGI(2)	+	Time coordinate of point 2.

Continue with additional sediment discharges and time coordinates, in the increasing order of time coordinates.

X1 Record - This record is required for each cross section (175 cross sections can be used for the study reach); it is used to specify the cross-sectional geometry and program options applicable to that cross-section. Cross sections are arranged in sequential order starting from downstream.

Field	Variable	Value	Description
0	IA	X1	Record identification characters

1	SECNO	+	Original section number from the map
2	NP	+	Total number of stations or points on the next GR records for
7	DX	+	Length of reach between current cross section and the next down-stream section along the thalweg, in feet or meters
8	YFAC	0	Cross-section stations are not modified by the factor YFAC.
		+	Factor by which all cross-section stations are multiplied to increase or decrease area. It also multiplies YC1, YC2 and CPC in the XF record, and applies to the CI record.
9	PXSECE	0	Vertical or Z coordinate of GR points are not modified.
		±	Constant by which all cross-section elevations are raised or lowered
10	NODA	0	Cross section is subject to change.
		1	Cross section is not subject to change.

XF Record - This is an optional record used to specify special features of a cross section.

Field	Variable	Value	Description
0	IA	XF	Record identification characters
1	YC1	0	Regular erodible left bank
		+	Station of rigid left bank in ft or m, to the left of which channel dinates in GR records but not the first Y coordinate.
2	YC2	0	Regular erodible right bank
	+		Station of rigid right bank, to the right of which channel is non-erodible. Note: This station is located at toe of rigid bank; its value must be equal to one of the Y coordinates in GR records but not the last Y coordinate.
3	RAD	0	Straight channel with zero curvature
		+	Radius of curvature at channel centerline in ft or m. Center of radius is on same side of channel where the station (Y-coordinate) starts.
		-	Radius of curvature at channel centerline in ft or m. Center of radius is on opposite side of zero station. Note: RAD is used only if concave bank is rigid and so specified using the XF record. RAD produces a transverse bed scour due to curvature.
4	CN	0	Roughness of this section is the same as that given in Field 7 of the

			G1 record.
		+	Manning's *n* value for this section
5	CPC	0	Center of thalweg coincides with channel invert at this section.
		+	Station (Y-coordinate) of the thalweg in ft or m
6	IRC	0	Regular erodible cross section
		1	Rigid or nonerodible cross section such as drop structure or road crossing. There is no limit on the total number of such cross sections.
8	BSP	0	Slope of bank protection is the same as that given in Field 2 of the G3 record.
		+	Slope of bank protection at this section in BSP horizontal units
		5	Slope of rigid bank is defined by the GR coordinates.
9	BEFX	0	Bank erodibility factor is defined in Field 5 of the G1 record.
		+	A value between 0.1 and 1.0 for BEFX specifies the bank erodibility factor at this section.
	RWD	+	RWD is the width of bank protection of a small channel in the specified by a value greater than 1 (ft or m) in this field. When RWD is used, BEFX is not specified.
10	TDZAM	0	Erodible bed layer at this section is defined by TDZAMA in Field
		+	Thickness of erodible bed layer in ft or m. Only one decimal place is allowed for this number.
	ENEB	±	Elevation of non-erodible bed, used to define the crest elevation of a grade-control structure which may be above or below the existing channel bed. In order to distinguish it from TDZAM, ENEB must have the value of 1 at the second decimal place. For example, the ENEB value of 365 should be inputted as 365.01 and the ENEB value of -5.2 should be inputted as -5.21. When ENEB is specified, it supersedes TDZAM and TDZAMA

CI Record - This is an optional record used to specify channel improvement options due to excavation or fill. The excavation option modifies the cross-sectional geometry by trapezoidal excavation. Those points lower than the excavation level are not filled. The fill option modifies the cross-sectional geometry by raising the bed elevations to a prescribed level. Those points higher than the fill level are not lowered. Excavation and fill can not be used at the same time. This record should be placed after the X1 and XF records but before the GR records. The variable ADDVOL in Field 10 of this record is used to keep track of the total volume of excavation or fill along a channel reach. ADDVOL specifies the initial volume of fill or excavation. A value greater or less than 0.1 needs to be entered in this field to keep track of the total volume of fill or excavation until another ADDVOL is defined.

Field	Variable	Value	Description
0	IA	G5	Record identification characters
1	CLSTA	+	Station of the centerline of the trapezoidal excavation, expressed according to the stations in the GR records, in feet or meter.
2	CELCH	+	Elevation of channel invert for trapezoidal channel, in feet or meters.
4	XLSS	+	Side slope of trapezoidal excavation, in XLSS horizontal units for 1 vertical unit.
5	ELFIL	+	Fill elevation on channel bed, in feet or meters.
6	BW	+	Bed width of trapezoidal channel, in feet or meters. This width is measured along the cross section line; therefore, a larger value should be used if a section is skewed.
10	ADDVOL	0	Volume of excavation or fill, if any, is added to the total volume already defined.
		+	Initial volume of fill on channel bed, in cubic feet or cubic meters.
		-	Initial volume of excavation from channel bed, in cubic feet or meters.

GR Record - This record specifies the elevation and station of each point for a digitized cross section; it is required for each X1 record.

Field	Variable	Value	Description
0	IA	GR	Record identification characters
1	Z1	"	Elevation of point 1, in ft or m. It may be positive or negative.
2	Y1	"	Station of point 1, in ft or m
3	Z2	"	Elevation of point 2, in ft or m
4	Y2	"	Station of point 2, in ft or m

Continue with additional GR records using up to 79 points to describe the cross section. Stations should be in increasing order.

SB Record - This special bridge record is used to specify data in the special bridge routine. This record is used together with the BT and GR records for bridge hydraulics. This record is placed between cross sections that are upstream and downstream of the bridge.

Field	Variable	Value	Description
0	IA	SB	Record identification characters
1	XK	+	Pier shape coefficient for pier loss
2	XKOR	+	Total loss coefficient for orifice flow through bridge opening
3	COFQ	+	Discharge coefficient for weir flow overtopping bridge roadway
4	IB	+	Bridge index, starting with 1 from downstream toward upstream
5	BWC	+	Bottom width of bridge opening including any obstruction
6	BWP	0	No obstruction (pier) in the bridge
		i	Total width of obstruction (piers)
7	BAREA	+	Net area of bridge opening below the low chord in square feet
9	ELLC	+	Elevation of horizontal low chord for the bridge
10	ELTRD	+	Elevation of horizontal top-of-roadway for the bridge

BT Record - This record is used to compute conveyance in the bridge section. The BT data defines the top-of -roadway and the low chord profiles of bridge. The program uses the BT, SB and GR data to distinguish and to compute low flow, orifice flow and weir flow.

Field	Variable	Value	Description
0	IA	BT	Record identification characters
1	NRD	+	Number of points defining the bridge roadway and bridge low Chord to be read on the BT records
2	RDST(1)	+	Roadway station corresponding to RDEL(1) and XLCEL(1)
3	RDEL(1)	+	Top of roadway elevation at station RDST(1)
4	XLCEL(1)	+	Low chord elevation at station RDST(1)
5	RDST(2)	+	Roadway station corresponding to RDEL(2) and XLCEL(2)
6	RDEL(2)	+	Top of roadway elevation at station RDST(2)
7	XLCEL(2)	+	Low chord elevation at station RDST(2)

Continue with additional sets of RDST, RDEL, and XLCEL.

EJ Record - This record is required following the last cross section for each job. Each group of records beginning with the T1 record is considered as a job.

Field	Variable	Value	Description
0	IA	EJ	Record identification characters
1-10			Not used

II. OUTPUT DESCRIPTION

Output of the model include initial bed-material compositions, time and spatial variations of the water-surface profile, channel width, flow depth, water discharge, velocity, energy gradient, median sediment size, and bed-material discharge. In addition, cross-sectional profiles are printed at different time intervals.

Symbols used in the output are generally descriptive, some of them are defined below:

SECTION	Cross section
TIME	Time on the hydrograph
DT	Size of the time step or Δt in sec
W.S.ELEV	Water-surface elevation in ft or m
WIDTH	Surface width of channel flow in ft or m
DEPTH	Depth of flow measured from channel invert to water surface in ft or m
Q	Discharge of flow in cfs or cms
V	Mean velocity of a cross-section in fps or mps
SLOPE	Energy gradient
D50	Median size or d_{50} of sediment load in mm
QS	Bed-material discharge for all size fractions in cfs or cms
FR	Froude number at a cross section
N	Manning's roughness coefficient
SED.YIELD	Bulk volume or weight of sediment having passed a cross section since beginning of simulation, in cubic yards or tons.
WSEL	Water-surface elevation, in ft or m
Z	Vertical coordinate (elevation) of a point on channel boundary at a cross-section, in ft or m
Y	Horizontal coordinate (station) of a point on channel boundary at a cross-section, in ft or m
DZ	Change in elevation during the current time step, in ft or m
TDZ	Total or accumulated change in elevation, in ft or m

PACE
Advanced Water Engineering

Technical Memorandum

Bruce M. Phillips
REGISTERED PROFESSIONAL ENGINEER
BRUCE M. PHILLIPS
No. C38635
Exp. 03-31-19
CIVIL
STATE OF CALIFORNIA

Date: February 9, 2018 (revised)

From: Bruce M. Phillips, PE

Re: **RMV Ranch Plan Updated Assessment for Lateral Streambank Erosion Analyses for PA1 / PA2** B097

Introduction / Background

This memorandum provides updated lateral streambank erosion analyses along a portion of the mainstem San Juan Creek within the Rancho Mission Viejo (RMV) property addressing hydrologic impacts from urbanization and technical peer review comments from previous fluvial studies. These updated analyses specifically address adjustments to the lateral erosion limits adjacent to PA1/PA2 through the application of technical scientific approaches recently used for studies along PA3/PA4/PA5 as well as update the analyses for these planning areas also. The updated analyses include the application of revised hydrology (development mitigated condition) for all the different development Planning Areas (PA). The proposed RMV development, The Ranch Plan, within the San Juan Creek (SJC) watershed was developed through a comprehensive watershed planning program that incorporated various strategies to provide appropriate levels of mitigation that will ensure the long-term protection of the watershed resources by addressing development impacts. Part of this program provides the control measures to adequately setback from natural river systems to account for future lateral streambank migration as an important land management tool. Defining the anticipated long term lateral erosion limits adjacent to active creek corridors also limits the need for the construction of engineered "structural" streambank protection measures since this role is fulfilled instead with development building setbacks.

Two separate engineering studies, *San Juan Creek – PA1 RMV Development Area – Lateral Stream Bank Erosion Analysis* (PACE, September 2006) and *San Juan Creek Lateral Erosion Analysis – Gobernadora Creek to Upstream RMV Boundary – PA3/PA4 RMV Development Areas* (PACE, July 2017), involving detailed fluvial analyses and geomorphic assessments were performed to predict the potential future lateral streambank migration / erosion limits (see *Figure No.1- Typical Channel Section Lateral Erosion Limits*) along the different portions of the mainstem San Juan Creek within the RMV property. The comprehensive assessment used rigorous scientific procedures from a variety of different analyses/assessments that were combined together to predict the future lateral erosion boundaries and define a maximum envelope of the erosion hazard limits. The combination of the different maximum erosion limits generated from the multiple scientific engineering techniques applied and review of various data sources (including historical aerial photos, historical topography, and multiple field investigations) were used at each creek cross-section location to establish the maximum envelope in order to define the erosion hazard boundary. Where minor localized adjustments were made based on engineering interpretation.

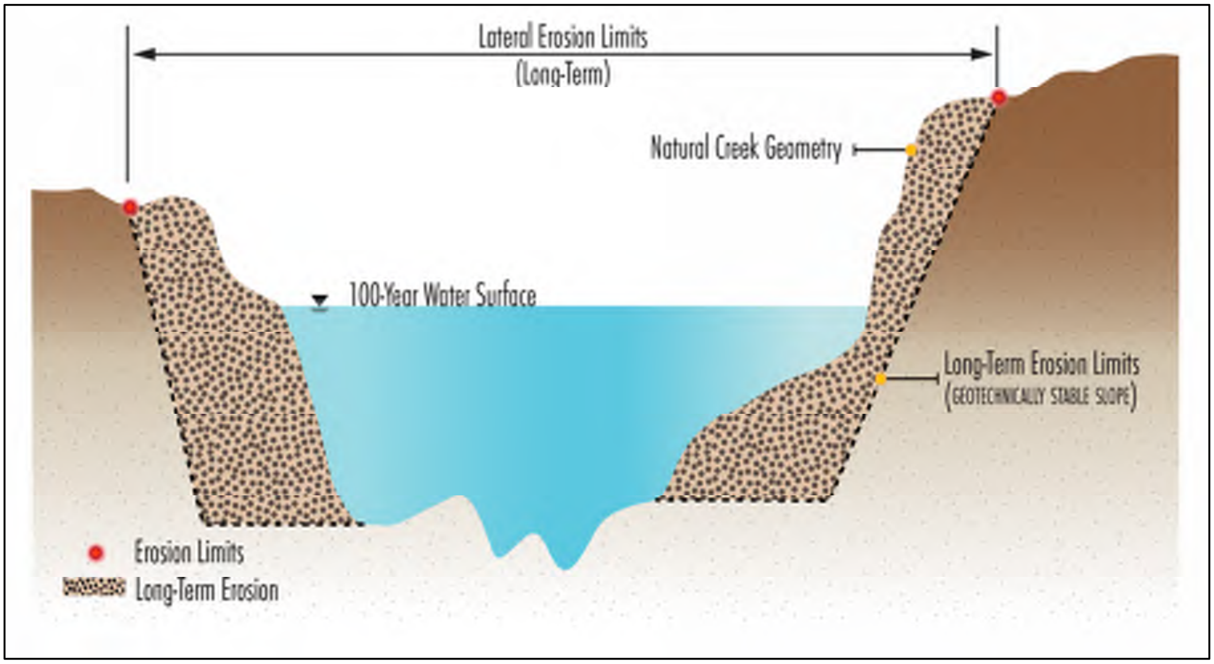

Figure 1 - Typical Channel Section Lateral Erosion Limits

The County review process for the different previous lateral erosion studies had used independent peer review as well as their own internal staff review. The peer review had included the application of a separate sediment transport computer program, FLUVIAL-12, to model the long term lateral erosion along the study limits and compare the results with the two different PACE studies. The long-term time simulation in PACE modeling was different than the peer review modeling. PACE has computed from the HEC-6T modeling an annualized sediment erosion deficit at each cross section and multiplied this value by 60 in order to compute 60-years of erosion, plus adding a single 100-year storm erosion amount to compute the total lateral erosion. This is the procedure adopted from Maricopa County Flood Control District studies. The peer review modeling had used a sequence of storms over a 20-year period The primary findings from the comparison with peer review computed erosion limits indicated that (1) the July 2017 PACE lateral erosion limits/hazard zones along the PA3/PA4 development areas were the same or provided larger erosion boundary limit than peer review FLUIAL-12 model results (see *Figure No.3 – Comparison 2017 PACE Lateral Erosion Limits and Peer Review FLUVIAL-12 Model*), and (2) along the northern San Juan Creek bank adjacent to the PA1 development area there was a significant deviation between the PACE (September 2006) and the peer review model had computed much greater lateral erosion in this area (see *Figure No. 2 Comparison of Long Term Lateral Erosion Estimates PA1 Development Area)*.

An updated series of analyses was prepared for the PA1 zone using the improved scientific procedures adopted for the July 2017 erosion study in order to evaluate the effects of the developed condition hydrology on the estimated lateral erosion limits as well as address the differences identified in the peer review for the PA1 area. The specific items addressed in this updated fluvial analysis include the following:

1. **Lateral Erosion Applying Revised Hydrology** - An important technical foundation for the analyses associated with the previous lateral erosion fluvial studies (PACE, September 2006 and July 2017) was the hydrology which has assumed that the development runoff would be mitigated to the "existing" conditions. The revised "mitigated developed condition" hydrology was incorporated into the sediment transport HEC-6T models, which was used as one of the procedures to quantify the lateral erosion. The updated HEC-6T models with the revised

hydrology input was used to compute the "total eroded sediment volume" at each channel cross section and compared to the original analysis to determine if there were any significant differences that would influence the previous computed lateral erosion estimates.

2. **PA1 Development Area Revised Lateral Erosion Analysis** – The previous 2006 PACE study which focused on the lateral erosion in the PA1 development area had used slightly different procedures than the July 2017 study. The July 2017 study used a more rigorous and detailed procedure related to the modeling effort to quantify the amount of lateral erosion. The previous 2006 PACE study had used a slightly modified procedure by evaluating longer "reaches" rather than "individual" cross sections in the sediment transport modeling along the PA1. A revised lateral erosion analysis using HEC-6T modeling was prepared by PACE for the north bank of San Juan Creek adjacent to PA1 specifically addressing those areas where the peer review FLUIVAL-12 models had indicated greater amounts of lateral erosion than the original PACE estimates.

Updated PA1 Streambank Lateral Erosion Analysis

The previous initial lateral erosion analysis (PACE, September 2006) along San Juan Creek adjacent to the PA1 development area had used slightly different procedures than the July 2017 study. The July 2017 study utilized a more rigorous and detailed procedure than the 2006 study related to the modeling effort to quantify the amount of lateral erosion. HEC-6T was the sediment transport model used by PACE in both studies, however, HEC-6T does not directly compute lateral erosion was developed by PACE. A specialized procedure that used HEC-6T computed results to determine the amount of lateral erosion. This procedure involved using the HEC-6T computed total sediment deficit (scour) or surplus (deposition) for the computation of total eroded sediment volume for each channel cross section during the entire storm hydrograph. This total eroded sediment volume was used to adjust the horizontal erosion boundary of the streambank cross section either on the right or left bank. The total volume was divided by the average distance between next adjacent cross section, assuming all the bank erosion occurred on only one side of the channel, which determined the bank erosion area. Although this procedure does not directly analyze the additional erosion forces on the streambank for bends or curves, it does however provide a very conservative estimate of the lateral streambank erosion distance since the total eroded volume of the entire streambed is applied to only one bank at a time. In addition, this procedure for defining lateral erosion hazard boundaries has been adopted and used on multiple large watershed masterplans by other agencies in the Southwest, including Maricopa County Flood Control District (Arizona).

The previous 2006 PACE study had used a slightly modified procedure by evaluating longer "reaches" rather than "individual" cross sections in the sediment transport modeling along the PA1. This procedure resulted in "averaging" the total eroded sediment volume over several cross sections and reducing the total estimated eroded volume at this particular location. The reduced estimated eroded sediment volume then also reduced the estimated lateral erosion distance for that area. The "averaging" procedure is the reason why the narrower lateral erosion limits are reflected in the comparison of PACE's results with the peer review FLUIVAL-12 results.

A revised lateral erosion analysis using HEC-6T modeling was prepared by PACE for San Juan Creek adjacent to PA1 specifically addressing those areas where the peer review FLUIVAL-12 models had indicated greater amounts of lateral erosion than the original PACE estimates. The revised lateral erosion analysis involved preparing an updated HEC6-T model and using the more rigorous procedure, applying the estimated total eroded volume at each cross section to compute the eroded streambank migration distance. The basic steps of this procedure included the following:

1. HEC6-T model was developed to analyze separately the 100-year and 10-year storm hydrographs.
2. The computed total eroded sediment volume at each cross section for the entire storm hydrograph was extracted from HEC-6T. The two values were used to compute the "annualized" sediment transport volume and then this value was multiplied by 60 to determine the 60-year long

term eroded volume. However, the maximum long-term sediment volume used was the 60-year plus the single 100-year storm event.

3. The maximum computed sediment deficit for each cross section was applied to the cross-section geometry graphically to estimate an eroded area that was equivalent to the volume computed divided by the average distance between adjacent cross sections. The eroded limits were adjusted in a trial-and-error process until the correct eroded geometry matched the computed eroded volume. The eroded bank slope used in generating this geometry matched the existing bank slope. (This procedure follows the standard process used in Maricopa County studies for lateral stability assessment)
4. The deficit for that cross section was applied to either the left or right bank individually, as if none of the deficit was satisfied from the opposite bank or the streambed.

PA1/PA2 Revised Lateral Erosion Results / Recommendations

The results of this revised lateral erosion for the PA1 area are summarized on *Figure No. 2 – Comparison of Long Term Lateral Erosion Estimates PA1 Development Area* which compares the different analyses by PACE and Dr. Chang. The figure only illustrates the portion of the PA1 area where there was difference identified or additional erosion from the peer review modeling. The remainder of the erosion boundaries in the PA1/ PA2 area are adequate. The figure illustrates that **the revised PACE analysis generates lateral erosion distances that exceed the Dr. Chang model estimates, but does not extend into the development area** since the development was actually setback further using the floodplain limits. The detailed calculations that were performed for each individual cross section are provided in the *Technical Appendix*. Although improvements continue to be outside of the conservative limits of the erosion setback line, the County should continue to require evaluation and survey of the special monitoring monuments for this area. Site-specific erosion monitoring program and mitigation program was developed to specifically address lateral migration along a large river meander bend in this area. The monitoring composed of several different monitoring features/processes which also serve to identify level of risk. The results of the active monitoring program would potentially trigger different levels of corrective/preventative erosion mitigation measures depending on the severity of the measured erosion. This involves using three monuments which are four-inch buried steel pipes filled with concrete differentiated by either a (1) green – closest monument to the bank, (2) yellow – intermediate monument to bank and development, or (3) red – monument closest to the development edge. Each of the monuments have the colored metal tag identifier. The horizontal distance from the closest remaining monument to the active streambank edge is measured after each rainfall event of significance. The severity of lateral erosion associated with a storm event would be defined by the location of the erosion relative to the type of monument (green, yellow, or red). This specialized monitoring effort for this area provides an additional layer of safety to ensure the long protection of the development.

Upstream San Juan Creek Sediment Transport Model – Updated Revised Hydrology

A revised HEC-6T sediment transport modeling effort was prepared for the entire study each of San Juan Creek within the RMV boundary. This revised modeling involved using different storm hydrographs to reflect the “mitigated development” conditions. The revised “mitigated developed condition” hydrology was incorporated into the sediment transport HEC-6T models. The computed “total eroded sediment volume” at each cross section for the entire storm hydrograph was extracted from HEC-6T for both the 10- and 100-year storm events. The two values were used to compute the “annualized” sediment transport volume and then this value was multiplied by 60 to determine the 60-year long term eroded volume. However, the maximum long-term sediment volume used was the 60-year plus the single 100-year storm event. Tables in the *Technical Appendix* provides a summary of the revised computed cross section eroded volume as well as the “long-term” value. The revised or updated eroded sediment volumes are compared to the previous 2017 modeling results.

The results of the revised HEC6-T modeling shown in the tables (*Technical Appendix*) indicated that the change in hydrology did not significantly influence the previous results and almost half of the cross sections were in deposition (positive volume) rather than erosion (negative volumes). In addition, as will be shown below from the analysis, in most of the areas where there was increased eroded volume (1) the amount was generally small; and (2) at locations where it appears to be larger, the HEC-6T procedure did not govern the lateral erosion limits, but either the "erosion template" procedure (see *Figure No.4 – Erosion Template*) used in the PACE 2017 study or the historical geomorphology streambank limits controlled. This ultimately resulted in no change to the previously published erosion limits except in the PA1 as shown in the *Figure No.2*. The results of the HEC-6T analysis are provided in a spreadsheet (see the *Technical Appendix*) that was used to perform all the calculations at each cross section and estimate the long term eroded volumes.

Upstream San Juan Creek Long Term Lateral Erosion

An updated lateral erosion analysis was performed for the PACE 2017 study in order to incorporate the developed condition hydrology used in the HEC-6T analyses. A specialized procedure was developed that used HEC-6T computed results to determine the amount of lateral erosion in the PACE studies. This procedure involved using the HEC-6T computed total sediment deficit (scour) or surplus (deposition) for the computation of total eroded sediment volume for each channel cross section during entire storm hydrograph as discussed in the previous section (Updated PA1 Streambank Erosion Analysis). This total eroded sediment volume was used to adjust the horizontal erosion boundary of either the right or left bank of the channel cross section. The total volume was divided by the average distance between next adjacent cross section, assuming all the bank erosion occurred on only one side of the channel, which determined the bank erosion area. Although this procedure does not directly analyze the additional erosion forces on the streambank for bends or curves, it does however provide a conservative and reasonable estimate of the lateral streambank erosion distance since the total eroded volume of the entire streambed is applied to only one bank at a time. This is a conservative estimate because other models such as FLUIVAL-12 calculate the amount of total erosion through a similar "sediment transport continuity analysis" and the results are applied to both the streambed and streambank. FLUVIAL-12 has an additional feature to compute additional lateral erosion using stream power, but that amount does not exceed the total eroded volume from the sediment continuity procedure. The PACE procedure, adopted from Maricopa County Flood Control District studies, applies the total eroded volume for the cross section to just one side of the streambank and converts streambed erosion to lateral streambank erosion. However, since multiple procedures were used in the PACE 2017 study, the HEC-6T analysis was not necessarily the method which provided the maximum or controlling erosion boundary limits.

PA3/PA4 Updated Lateral Erosion Results / Discussion

The results indicated that there was not a significant deviation in the lateral distances as shown on the original comparison of the lateral erosion limits on *Figure No. 3.* From the results of the updated study that is provided in the *Technical Appendix*, lateral erosion migration is predicted to vary from -10 feet to +20 feet from the 2017 PACE HEC-6T analysis. The revised analysis illustrating the long-term erosion distance in comparison to the 2017 results is summarized in the *Technical Appendix* for the study portion of San Juan Creek extending from the downstream Gobernadora Canyon confluence to the upstream RMV boundary. The lower reach of San Juan Creek was modeled in the updated analyses for the PA1 development area and the only changes were in the small area of discrepancy identified by peer review performed by Dr. Chang. Although there were only minor changes in the HEC-6T results, the HEC-6T model generally did not control the ultimate erosion boundary limits. A detailed description of the assumptions and selection of the final boundary line at different locations along the San Juan Creek study reach is discussed below beginning at the downstream confluence with Gobernadora Canyon and extending to the upstream RMV boundary. This discussion is provided as a guidance to indicate the controlling input in each location along the creek for the erosion boundary, since the HEC-6T modeling results did not necessarily govern and one of the other procedures provided a larger erosion limit value which was generally the "erosion template" adopted by other agencies for these analyses including the City of Austin, TX (see *Figure No.4 – Erosion Template*).

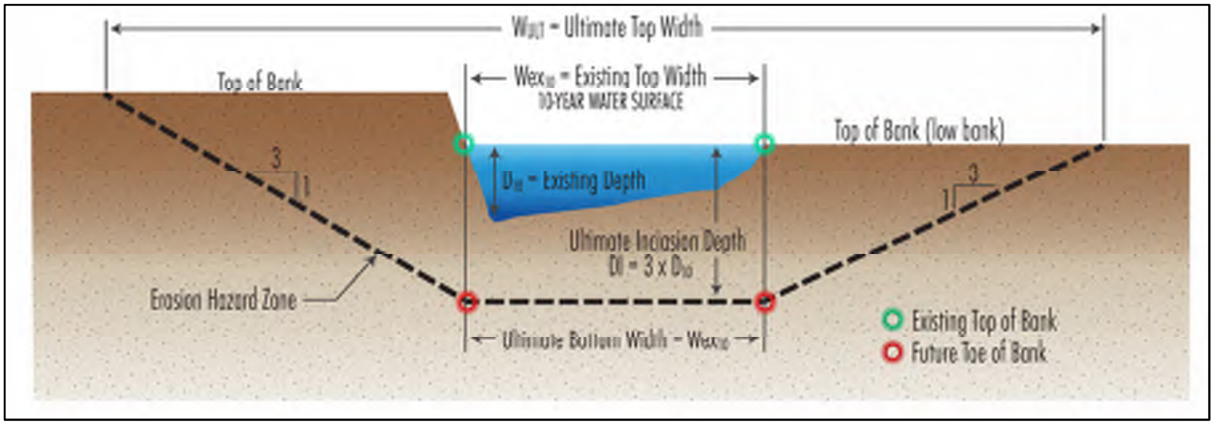

Figure 4: Defining limits of maximum eroded channel based on conceptual erosion limits geometry template

Sta. 395+24 to 402+73 - Maximum lateral erosion limits defined on both the left and right banks by large historical flood bank lines from **1967 and the current100-year floodplain delineation** on the south bank.

Sta. 402+73 to 408+73 - The erosion limits, both on the left and right bank, are located along the limits **"lateral erosion template"** which was the controlling boundary line.

Sta. 408+73 to 426+73 - The northerly bank line limits were controlled by the **"lateral erosion template" and the 100-year floodplain limits**, but adjusted to conform to topographic influences.

Sta. 426+73 to 435+73 - The northerly bank erosion limits were defined by the **1980 floodplain bank line limits** and the top of slope for the adjacent bluff/terrace.

Sta. 435+73 to 443+98 - The northerly bank erosion limits use **1980 historical bank limits**, since the 1938 and 1967 were ignored because of the channel breakout elimination.

Sta. 443+98 to 451+47 - This reach is within the central portion of the exposed bedrock area of the channel which defines the narrow channel section. The erosion limits for both the north and south banks were defined by the limits **"lateral erosion template"** geometry which is very conservative since it discounts the bed rock influence, although the bedrock is erodible.

Sta. 451+47 to 461+98 - This reach limits correspond to the transition from the exposed bedrock limits with the narrow channel to the upstream expanded channel width. The northerly bank erosion limits were defined by **1980 floodplain bank line** which corresponds well to the top of bank.

Sta. 461+98 to 468+87 - The northerly limits corresponded to the **1938 and 1967 historical bank line** limits which encompassed all the other lines.

Sta. 468+87 to 471+74 - This reach corresponds to the widened channel section immediately upstream of the existing Gibby Road low-water culvert crossing. The maximum **lateral erosion template** was used for both the north and south bank erosion limits which was close to the 100-year floodplain limits.

Sta. 471+74 to 477+74 - This reach is the widened channel area further upstream of the Gibby Road low-water culvert crossing, but still under the hydraulic influence of the culvert. The northerly bank erosion limits reflect the maximum "lateral erosion template" geometry which is above the 100-year floodplain.

Sta. 477+74 to 488+24 - This reach is a widened floodplain with the northern bank more pronounced steepened banks, but with large overbank area contained outside the active channel. The northern erosion limits were defined **combining both the maximum of either the HEC-6T calculated limits or the "erosion template"** whichever was larger.

Sta. 488+24 to 495+74 - The erosion limits were defined along this reach based on the **"erosion template"** on both the north and south bank.

Sta. 495+74 to 524+24 - This reach corresponds to the widened floodplain area up to the bedrock constricted channel at the upstream limits of this reach. The erosion limits were defined along this reach based on the **"erosion template"** on both the north and south bank.

Sta. 524+24 to 535+49 – This reach corresponds to the contracted channel section within the exposed bedrock and the majority of the historical active streambank lines are contained within the smaller active channel width. The erosion limits were defined along this reach based on the **"erosion template"** on both the north and south bank.

Sta. 535+49 to 545+24 – This reach corresponds to the narrow-incised channel within bedrock and the transition to the widened floodplain upstream. The **"erosion template"** contained the majority of the historical bank limits and the HEC-6T calculated long term erosion.

Sta. 545+24 to 582+74 – This reach corresponds to the widened floodplain upstream of the contracted section that extends to the upstream Ranch boundary. The erosion limits were defined along this reach based on the **"erosion template"** on both the north and south bank. The northern bank erosion limits were adjusted to corresponded more closely with actual topography of the top of bank limits.

Conclusion / Discussion of Lateral Erosion Analyses Results

Additional updated analyses were performed to updated both the 2006 and 2017 Lateral Erosion Studies prepared by PACE for the portion of San Juan Creek within the RMV boundary. The updated analysis was prepared to address several comments generated during the County review process for the most recent lateral erosion study. Technical peer review of these studies had indicated that along the northern San Juan Creek bank adjacent to the PA1 development area that there was a significant deviation between the PACE (September 2006) and identified more lateral erosion in a portion of PA1. The updated fluvial analysis was prepared to evaluate the effects of the changed hydrology from urbanization influencing the estimated lateral erosion limits as well as addressing the computed differences in the amount of lateral erosion identified in the peer review for the PA1 area. The results of these revised analyses indicated the following:

1. The lateral erosion hazard zones provided in the June 2017 PACE study do not need to be modified since the revised HEC-6T modeling using the updated hydrology indicated that the changes in lateral erosion distance was small or nonexistent, and generally the "erosion template" governed the limits of defined lateral erosion. The most conservative erosion boundary was used in developing the erosion hazard boundary.

2. The lateral erosion limit near the PA1 development did change with the more detailed modeling procedure and the revised limits are shown for comparison on *Figure No.2*. This figure illustrates that **the revised PACE analysis generates lateral erosion distances that exceed the Dr. Chang model estimates, but does not extend into the development area** since the development was actually setback further using the floodplain limits. However, in this area a site-specific erosion monitoring program and mitigation program was developed to specifically address lateral migration along a large river meander bend. The monitoring composed of several different monitoring features/processes which also serve to identify level of risk. This specialized monitoring effort for this area provides an additional layer of safety to ensure the long protection of the development.

SAN JUAN CREEK
LATERAL EROSION HAZARD
BOUNDARIES STUDY

ORANGE CO. CA

Legend

- Erosion Hazard Boundary (PACE New)
- Erosion Hazard Boundary (PACE Old)
- Erosion Hazard Boundary (Chang)
- XS Cut Lines

0 100 200 400 Feet

PACE Advanced Water Engineering

Date: 1/25/2018

Job Number B097

Drawn By sfifield

Figure No. 2

COMPARISON OF LONG TERM LATERAL EROSION ESTIMATES PA1 DEVELOPMENT AREA

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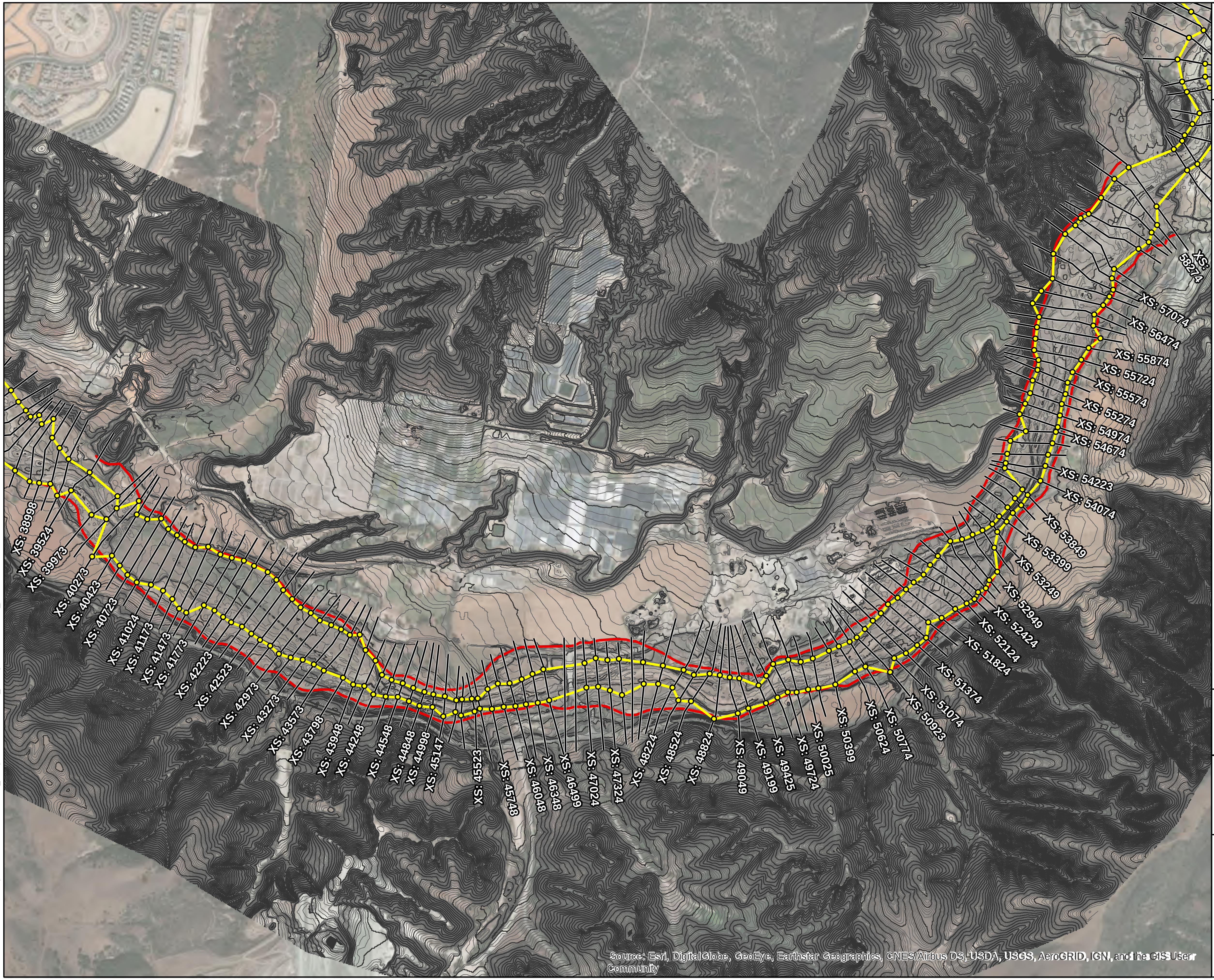

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SAN JUAN CREEK LATERAL EROSION HAZARD BOUNDARIES STUDY

ORANGE CO. CA

Legend

- Erosion Hazard Points (Chang)
- XS Cut Lines
- Erosion Hazard Boundaries (Chang)
- Long Term Erosion Hazard Zone

0 600 1,200 2,400 Feet

PACE Advanced Water Engineering

Date: 1/25/2018

Job Number B097

Drawn By sfifield

Figure No. 3

COMPARISON 2017 PACE LATERAL EROSION LIMITS AND DR. CHANG FLUVIAL-12 MODEL