South Orange County Wastewater Authority

Lower Aliso Creek Erosion Assessment

County of Orange, California

April 2012

Prepared by:

TETRA TECH

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Prepared for:

South Orange County Wastewater Authority

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Executive Summary

As part of the ongoing preparation of an environmental impact report (EIR) the South Orange County Wastewater Authority (SOCWA) is currently considering alternatives for the Coastal Treatment Plant (CTP) Export Sludge Force Main Replacement Project. The potential for erosion along lower Aliso Creek between the CTP Bridge crossing and the AWMA Road Bridge crossing has been identified as a key consideration relative to the Export Sludge Force Main Replacement planning process. This report documents the erosion assessment conducted to categorize the vulnerability of the proposed infrastructure in/along both the east bank and west bank of the creek over a 50-year planning period. This assessment was specifically conducted to aid SOCWA in the evaluation of alternatives for the replacement of the existing Export Sludge force mains. These alternatives include two options for the installation of a new force main (Alternatives FM 1 and FM 2) and for the trucking of liquid sludge over the existing paved access road (Alternative TR 1). The erosion assessment documented in this report focuses only on the two alternatives for the installation of a new force main.

The assessment began with field reconnaissance to document recent and historical erosion areas, including modes of failure and conditions which promote failure, as well as conditions that have promoted stable banks. Hydraulic modeling was performed to quantify and categorize hydraulic conditions that control fluvial processes most likely to initiate or maintain bank erosion. A bank energy index (BEI) was calculated, and quartiles were used to rank bank energy as a basis for identifying specific locations along the channel where erosion potential is greatest. To better interpret the BEI, factors affecting resistance to erosion were considered (i.e., bank materials, clay in the toe of the bank, woody vegetation along the toe of the bank, and depositional berms along the banks). Bank materials were categorized based on available boring log profiles, because available geologic and soils mapping do not differentiate the composition of the soils throughout the valley bottom in which lower Aliso Creek is contained. Slope stability modeling was carried out to evaluate the influences of various types of soils and stratification, slope geometry, and groundwater conditions on stable slope geometry using limit equilibrium for desired factors of safety.

The vulnerability of the infrastructure along the channel to bank erosion was rated considering: 1) fluvial erosion potential (*High, Moderate,* or *Low*), 2) geotechnical erosion risk (*High, Moderate,* or *Low*), and 3) the erosion risk associated with bend migration (*High, Moderate* or *Low*). The *High*-rated combined erosion risk, based on the analyses conducted for this assessment, indicates that the proposed pipeline alignment will likely be impacted by bank erosion over the 50-year planning period, so pipeline realignment or bank protection measures are recommended. A *Moderate*-rated erosion risk indicates, based on the analyses conducted, that the pipeline alignment could be impacted over the planning period, so bank erosion should be monitored on a regular basis (i.e., after all floods) and bank protection measures installed if necessary. A *Low*-rated erosion risk indicates, based on the analyses conducted, that the pipeline alignment is unlikely to be impacted by bank erosion over the planning period, so occasional monitoring is recommended (i.e., every few years, or after major floods, whichever occurs first).

The proposed FM 1 alignment along the east (left) bank is potentially subject to approximately 3,300 feet of *High* erosion risk and approximately 1,250 feet of *Moderate* erosion risk; the remaining 12,050 feet of the proposed alignment is along banks with erosion risk rated *Low*.

The proposed FM 2 alignment along the west (right) bank is potentially subject to approximately 1,200 feet of *High*-rated erosion risk and approximately 850 feet of *Moderate*-rated erosion risk; the remaining 17,350 feet of the existing and proposed alignment is along banks with erosion risk rated *Low*.

Additional factors related to erosion along lower Aliso Creek that may affect the erosion risk ratings (and thus the stability of the proposed pipelines) were considered. These factors include: 1) locations where concentrated surface runoff and tributary channels cross the proposed alignments, 2) the reliability of existing bank protection measures that may not have been designed because they were installed as emergency protection, 3) the potential for seepage induced bank failures associated with abandoned pipelines in the banks, 4) the potential for localized vertical degradation of the channel bottom, and 5) the reliability of the CTP and AWMA Bridges.

This erosion assessment was undertaken to evaluate the impacts of potential channel erosion on proposed alternatives for the replacement of the Export Sludge system. However, this assessment also has implications for existing infrastructure. The proposed route of the FM 1 pipeline is roughly the same alignment as the existing Export Sludge force mains and the Effluent Transmission Main (ETM). The ETM is buried below the existing force mains and the proposed FM 1 pipeline, so it is likely less vulnerable to channel erosion. However, the erosion risk to the ETM can be roughly equated to the erosion risk posed to the proposed FM 1 pipeline. The AWMA Road (upon which the TR 1 alternative is dependent) is roughly the same alignment as the proposed FM 2 pipeline, but the road is at greater elevations than the proposed pipeline. Therefore, the erosion risk to the AWMA Road is likely to be greater than the erosion risk to the proposed FM 2 pipeline.

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1 Introduction

This report presents the methods used and results from an erosion assessment along lower Aliso Creek in support of the assessment of proposed alternatives associated with ongoing preparation of an environmental impact report (EIR) for the South Orange County Wastewater Authority (SOCWA) Coastal Treatment Plant (CTP) Export Sludge Force Main Replacement Project.

1.1 Study Area

The Aliso Creek watershed is located in the County of Orange in southern California, approximately 40 miles southeast of the City of Los Angeles. As shown in **Figure 1-1**, the creek drains a long, narrow coastal watershed, with its headwaters in the Cleveland National Forest and its mouth at the Pacific Ocean. The drainage area is 34.6 square miles, and the mainstem of the creek is approximately 19.5 miles in length.

Except for a small portion of the Cleveland National Forest in the upper watershed, and the Aliso and Wood Canyons Wilderness Park in the lower watershed, the Aliso Creek watershed is nearly fully developed. Portions of the following municipalities are located in the watershed: Lake Forest, Aliso Viejo, Mission Viejo, Laguna Niguel, Laguna Hills, and Laguna Beach. The drainage systems associated with this development are typically more efficient hydraulically, and in places, the creek channel has been realigned and or modified.

The mainstem of Aliso Creek originates in the Santiago Hills and flows south for a distance of 1.5 miles within the Cleveland National Forest. It flows from the National Forest under the Foothills Transportation Corridor and through highly developed areas in Mission Viejo and Lake Forest. Further southwest, the creek flows through a fully urbanized area along the I-5 corridor and the City of Laguna Hills. Upstream of Pacific Park Drive, Aliso Creek enters a floodwater retarding basin; downstream of Pacific Park Drive the creek flows through an engineered channel toward the confluence of Sulphur Creek and the upstream end of the Aliso and Wood Canyons Wilderness Park. Sulphur Creek conveys runoff from an 8.9-square-mile watershed, nearly half of which first flows into Sulphur Creek Reservoir (also called Laguna Niguel Lake) before draining into Aliso Creek. Downstream of the Sulphur Creek confluence (approximately 14.5 miles downstream from the origin and 5 miles upstream from the mouth), the Park opens into a coastal canyon that is nearly undeveloped. Aliso Creek continues approximately 1.5 miles to the diversion structure for the Aliso Creek Wildlife Habitat Enhancement Project (ACWHEP). Roughly 0.3 miles downstream of the ACWHEP structure is the confluence of Wood Canyon Creek, a right bank (west) tributary draining nearly 4 square miles largely within the park. The combined flows continue to the southwest through the narrow canyon. Approximately 1 mile upstream from the Pacific Ocean, Aliso Creek flows out of the Wilderness Park and enters the private Aliso Creek Golf Course located in the confined valley. Just upstream of the ocean, the creek passes through a narrow strip of development along the Pacific Coast Highway in the City of Laguna Beach.

The study area (**Figure 1-2**) focuses on lower Aliso Creek (a distance of approximately 4 river miles), specifically the reach from the CTP to the Aliso Water Management Agency (AWMA) Road Bridge over Aliso Creek and the reach on Sulphur Creek from the Alicia Parkway culvert crossing to the confluence with Aliso Creek.

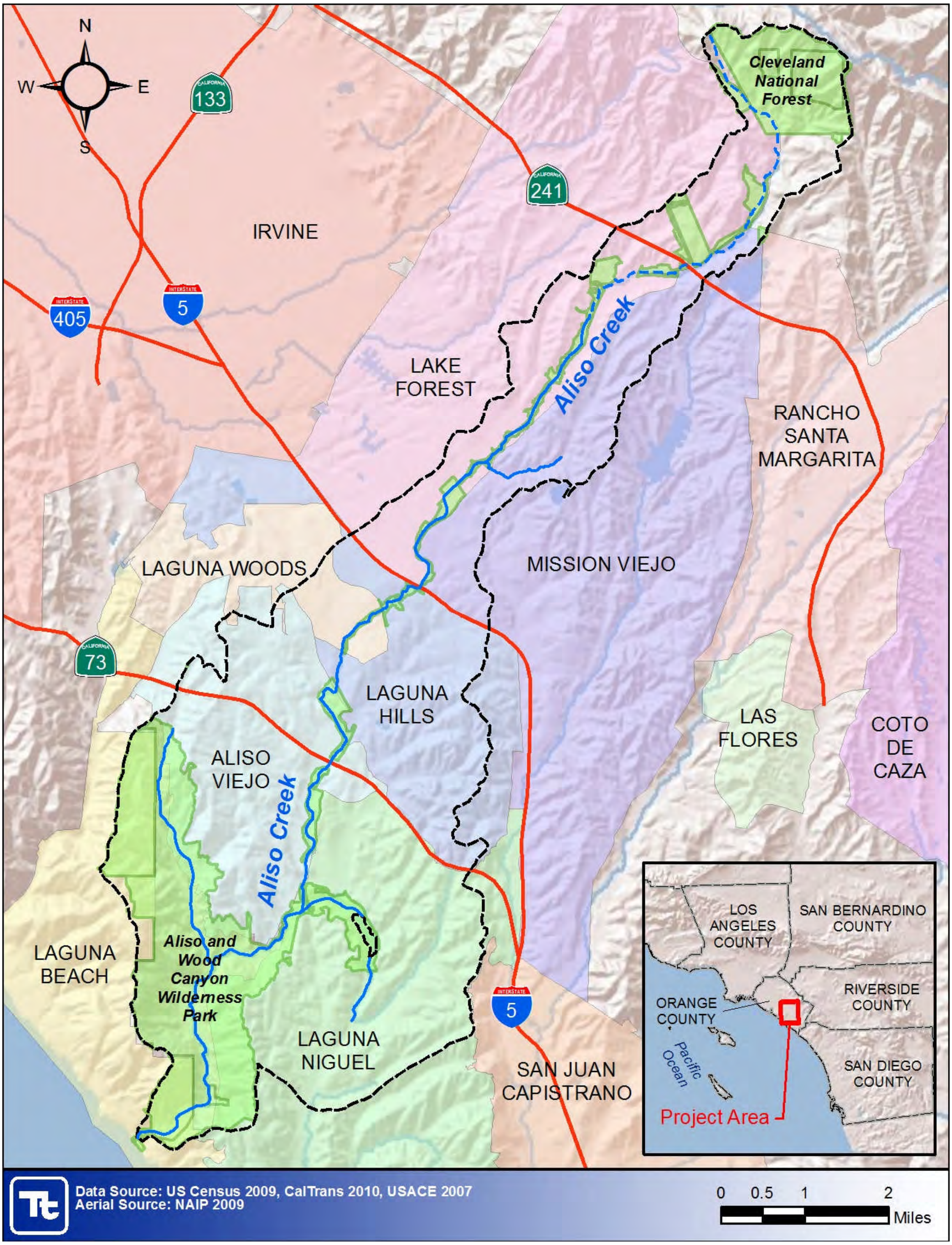

Figure 1-1. Aliso Creek Watershed

Figure 1-2. Study Area – Lower Aliso Creek

1.2 Project Background

SOCWA pumps sludge generated at the CTP (approximately RM 1.2) to their Regional Treatment Plant (RTP) for digestion and dewatering. The sludge is pumped approximately 4.5 miles through two parallel 4-inch diameter ductile-iron pipelines from the CTP, north along the eastern side of Aliso Creek to the RTP located upstream of Sulphur Creek Reservoir (Dudek 2011). The dual Export Sludge force mains were placed into service more than 30 years ago; at that time they were designed to be constructed as far from the eastern bank of Aliso Creek as reasonably possible (Dudek 2011). The pipelines have deteriorated through corrosion and internal deposition to the point they need to be replaced, or risk future sewage spills in the environmentally sensitive Aliso and Wood Canyons Wilderness Park. The ongoing erosion of the Aliso Creek channel poses a threat to proposed alternatives for the replacement of the Export Sludge system as well as to existing infrastructure. Past storms have resulted in erosion that has caused the failure of the Moulton Niguel Water District (MNWD) 18-inch sewer line in Aliso Canyon (**Figure 1-3**). Erosion from storm events has not caused past failures of either the SOCWA 4-inch diameter Export Sludge force mains or the Effluent Transmission Main (ETM). However, past storm events have caused SOCWA to install riprap along threatened embankments. Various historical floods have washed out portions of the west bank of Aliso Creek and AWMA Road (**Figure 1-4**), the only paved access road connecting the CTP to Alicia Parkway. Due to the risk of undermining proposed Export Sludge force main or the existing AWMA Road (for trucking of liquid sludge), SOCWA is evaluating the potential for the further erosion of Aliso Creek as part of the analysis of alternatives for the replacement of the Export Sludge system.

Figure 1-3. East (left) Bank Erosion along Aliso Creek Showing Undermined MNWD Pipeline (photo courtesy of SOCWA, appears to be near RM 1.60)

Figure 1-4. Emergency Repair of West (right) Bank of Aliso Creek (photo courtesy of SOCWA, appears to be near RM 1.85)

In a 2006 study for SOCWA, Dudek identified five alternative Export Sludge force main alignments, including two along the eastern side of Aliso Creek, two along the western side, and one that crossed from west to east. The recommended alignment was along the west side of Aliso Creek.

A Pre-Design Report is currently being prepared for SOCWA that evaluates two alternatives for a new Export Sludge force main (Alternatives FM 1 and FM 2) and an option involving the hauling of liquid sludge (Alternative TR 1). Alternative FM 1 follows the existing SOCWA easement along the east side of Aliso Creek (**Figure 1-5**). Alternative FM 2 will follow a new alignment located west of Aliso Creek primarily following the AWMA Road (**Figure 1-5**). Alternative TR 1 involves trucking of liquid sludge to the Regional Treatment Plant using the AWMA Road. Due to the location of the AWMA Road at greater elevations along the banks of Aliso Creek than the proposed elevations of the FM 2 pipeline, the erosion risk posed to the AWMA Road is likely greater than the erosion risk posed to the FM 2 pipeline. This report documents only the erosion risk to the proposed FM 1 and FM 2 alignment.

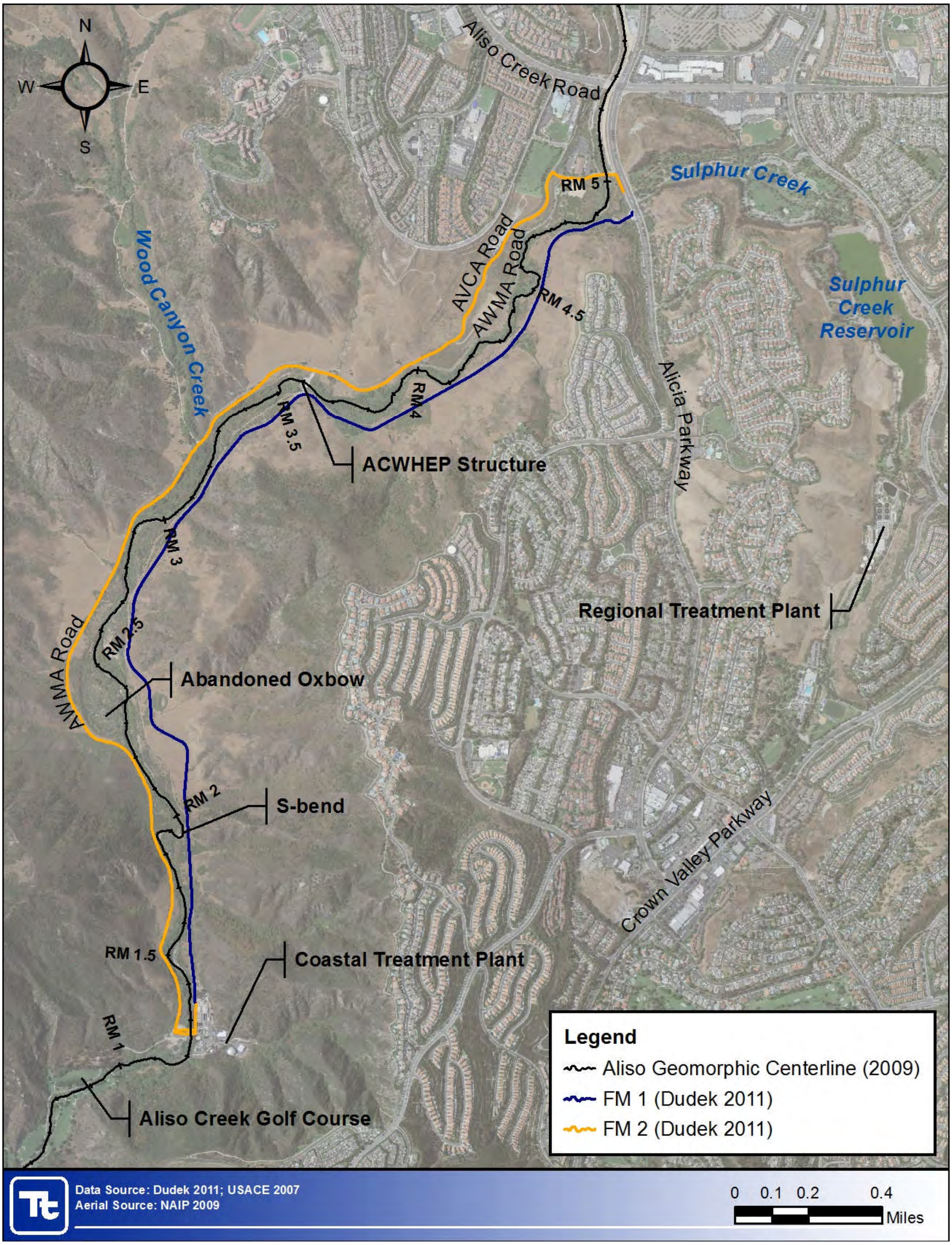

Figure 1-5. Proposed Force Main Alignments between the CTP and Alicia Parkway

1.3 Study Objective

The potential for erosion along Aliso Creek has been identified as a key consideration relative to the Export Sludge force main replacement planning process (Dudek 2011). The objective of this study was to conduct an erosion assessment of lower Aliso Creek to categorize the vulnerability of the proposed FM 1 and FM 2 alignments along the east (left) bank and west (right) bank, respectively. The assessment includes the identification and evaluation of locations where erosion of the channel, floodplain, banks, and hillslopes along lower Aliso Creek and Sulphur Creek could lead to exposure/undermining of the proposed pipelines. The purpose of this study is to aid SOCWA in the evaluation of preliminary alignments of proposed alternatives for the replacement of the Export Sludge force mains.

1.4 Study Approach

The following framework was established to achieve the study objective:

- Characterize the geomorphic conditions of Aliso Creek and Sulphur Creek within the study area.
- Compile available geotechnical data to provide a basis for evaluating the potential for bed and bank resistance to erosion.
- Conduct field reconnaissance to: observe and document recent and historical erosion areas, assess identified erosion areas (e.g., failure mode, physical properties of the bank, and bank materials and stratification), observe conditions that have promoted stable banks, and consider any factors that may minimize/exacerbate impacts of erosion on the stability of proposed force main alignments.
- Simulate flood event hydraulics to quantify the potential for flows to exert erosive energy on the banks, and to remove mass wasted bank materials along the toes of the banks. Specifically, the channel hydraulics and the radii of curvature for bends in the channel were used to calculate a Bank Energy Index (BEI) (Harvey and Mussetter 1993).
- Perform preliminary slope stability calculations to determine stable angles for banks identified during the field reconnaissance as geotechnically unstable. The stable bank angles establish a means for comparing risk of future bank instabilities to the location of proposed pipeline alignments.
- Calculate erosion risk associated with bend migration using the BEI values and the offset between calculated stable bank slopes and the proposed pipeline alignments.
- Combine results to categorize the vulnerability of the proposed pipeline alignments to erosion of the Aliso Creek and Sulphur Creek channels.

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2 GEOMORPHOLOGY

The stability of the easements associated with the proposed FM 1 and FM 2 pipeline alignments for the Export Sludge Force Main Replacement Project is dependent upon to geomorphic condition of lower Aliso Creek. Previous studies were reviewed to provide a general characterization of recent historical, existing, and likely future geomorphic conditions.

2.1 Previous Studies

Previous studies have focused on the geologic setting of lower Aliso Creek, as well as the aspects of fluvial geomorphology that affect the existing physical character, and likely future characteristics, of lower Aliso Creek. A few studies have specifically focused on fluvial geomorphology as it pertains to the infrastructure (i.e., pipelines and access roads) along lower Aliso Creek. The results/conclusions of these studies are summarized briefly to provide context for the efforts undertaken in this study; citations for the studies are provided if further details are of interest.

Jack G. Raub Company. 1980. *Aliso Viejo Refined Runoff Management Plan.* Prepared for Aliso Viejo Company. Costa Mesa, California.

In January 1980, the County of Orange Board of Supervisors conditionally approved the Aliso Viejo Plan (i.e., the construction of 20,000 dwelling units and an 800-acre industrial/commercial center on the upland portions of a 6,619-acre parcel of land between Laguna Beach and the Saddleback Valley). One of the concerns raised during the review process was the impact of Aliso Viejo runoff on erosion and sedimentation problems in Wood Canyon and Aliso Creek, including existing flood levels in Laguna Canyon. To address this issue, the Board of Supervisors conditioned approval of the Aliso Viejo Plan on the submission of a concept plan for diverting urban runoff away from sensitive environmental areas and for assuring the runoff would not contribute unacceptably to the Laguna Canyon flood problem. The *Aliso Viejo Refined Runoff Management Plan* (AVRRMP) outlined a runoff management program including diversions, desilting basins, retention basins, channel stabilization, landscaping, and erosion control.

Camp Dresser & McKee, Inc. 1982. *Sediment Discharge and Mechanics of Aliso Creek.* Prepared for Jack G. Raub Company. Newport Beach, California.

This report is a supplement to the *AVRRMP* (Jack G. Raub Company 1980). It was conducted to evaluate the channel stabilization measures recommended for Aliso Creek in the *AVRRMP*; results showed that fewer structures were required. Construction of the structures recommended in this report was expected to aggravate the existing bank erosion problems along Aliso Creek because the reduction of the bed slope due to construction of grade control structures was noted as having the tendency to alter the stream's meandering pattern and to cause attacks on the bank. Thus, selection of appropriate corrective and preventative measures was recommended (i.e., piling revetment with wire fence, tree revetment, jetted willow poles, jacks, brush mats, and riprap); the selection of the exact measure would depend on the severity of the problem and the risk involved. The cause of the bank erosion was attributed to the storms of 1978, 1979, and 1980, which produced the greatest three-year storm volume of record in most Southern California watersheds. The problem of bank erosion was particularly noticeable at the outer bank of stream bends. The report includes predicted limits of vertical degradation of the Aliso Creek channel, corresponding to ultimate watershed development conditions. The impact of vertical degradation and bank instabilities is referenced throughout the report.

Rivertech, Inc. 1999. *Aliso Creek Stream Instability Countermeasures, For the Protection of: AWMA's Effluent Transmission Main / Land Outfall.* Prepared for Aliso Water Management Agency (AWMA). Laguna Hills, California.

In the years subsequent to the publication of *Sediment Discharge and Mechanics of Aliso Creek* (CDM 1982), bank erosion and channel degradation continued along Aliso Creek. [NOTE: although not included in this report, it was during this period (i.e., the early 1990s) that the Mission Viejo Company constructed a riprap drop structure along Aliso Creek, upstream of the confluence with Wood Canyon, as part of a mitigation banking project.] While channel degradation and bank erosion continued, the AWMA (predecessor to SOCWA) had to maintain and operate its facilities along Aliso Creek, requiring emergency measures to avoid damage to pipelines and spillage of wastewater into the creek (e.g., addition of riprap to the east embankment of Aliso Creek at the confluence with Sulphur Creek during the El Nino storms of 1998). This mode of operation was excessively costly and imposed a significant financial burden on the AWMA. To minimize the cost of operating and maintaining its facilities, the AWMA retained Rivertech, Inc. to analyze future improvements that might need to be implemented to protect infrastructure along Aliso Creek. It was not feasible for the AWMA to construct and maintain the recommended counter measures without the participation of other agencies (Rivertech, Inc. 2003), so the AWMA awaited the completion of the U.S. Army Corps of Engineers *Aliso Creek Watershed Management Study / Plan*.

U.S. Army Corps of Engineers, 2002. *Aliso Creek Watershed Management Study / Plan*. Los Angeles, California.

This study performed a general review of existing conditions, and identified problems and opportunities within the watershed as a whole. Identified problems included instability of Aliso Creek channel and associated erosion damage, poor water and environmental quality, and flooding damages. A range of structural and non-structural solutions (measures) were identified as potential means to address the identified problems, followed by an evaluation and screening process to arrive at recommendations. The study also included an assessment of a potential restoration effort for the mainstem Aliso Creek utilizing a hydrology, hydraulics and sediment transport model, and a habitat assessment numerical classification.

Ninyo & Moore. 2003. *Preliminary Geotechnical Evaluation, Rehabilitation of the East Aliso Creek Emergency Sewer (REACES).* Prepared for Moulton Niguel Water District. Irvine, California.

This report was not available for review; the following information attributed to the report is provided in Rivertech, Inc. (2004). Ninyo & Moore performed a preliminary geotechnical evaluation of the creek alignment to assess the geological conditions and potential slope stability hazards to the existing pipelines (i.e., along the east (left) bank only). The report presents the results of the geotechnical evaluation (which did not include subsurface exploration). The figures in Rivertech, Inc. (2004) are not to scale (due to the oblique nature of the background aerial photographs), and tabular lengths of results of the ranked slope stability hazards by evaluated subreach are not available. However, Ninyo & Moore did provide categorical risk rankings as presented in Rivertech, Inc. (2004); these ratings are summarized below:

- Condition 4: Generally safe against slope stability hazards provided that future severe undermining of the creek bank does not occur (4 of 14 subreaches, approximately 25 percent of the evaluated subreach length).

- Condition 3: Relatively stable if further erosion does not occur (8 of 14 subreaches, approximately 60 percent of the evaluated subreach length).
- Condition 2: Marginally stable (1 of 14 subreaches, approximately 10 percent of the evaluated subreach length).
- Condition 1: Unstable (1 of 14 subreaches, approximately 5 percent of the evaluated subreach length).

Rivertech, Inc. 2003. *Aliso Creek Feasibility Analysis of Stabilizing the East Bank during Interim Period.* Prepared for Moulton Niguel Water District. Laguna Hills, California.

The Moulton Niguel Water District (MNWD) was evaluating the feasibility of rehabilitating the East Aliso Creek Emergency Sewer (EACES) – a series of pipelines situated along the east floodplain of Aliso Creek between Alicia Parkway and the CTP. Due to persistent channel degradation and instability of Aliso Creek, it was noted that the channel had widened and banks had the tendency to slump into the channel such that continuation of these geomorphic processes would cause failure of the EACES. MNWD retained Rivertech, Inc. to identify cost-effective solutions to protect the pipelines against bank failures caused by channel degradation. The report describes four alternative plans and their conceptual-level estimated costs.

Rivertech, Inc. 2004. *Prioritizing Stabilization of the East Bank during Interim Period.* Prepared for Moulton Niguel Water District. Laguna Hills, California.

The purpose of this study was to prioritize the recommendations for the alternatives presented in Ninyo & Moore (2003) and Rivertech, Inc. (2003). The prioritization considered evaluations of instability based on river mechanics (Rivertech, Inc. 2003) and evaluations of geotechnical processes (Ninyo & Moore 2003). These evaluations were combined with considerations of bend effects, bank slopes, vegetative cover, and availability of riprap (i.e., presence of existing riprap) to generate an integrated grade for prioritizing the stabilization measures. The tabular summary of the integrated grades does not include subreach lengths, and the figures on which the subreaches are shown is not to scale (due to the oblique nature of the background aerial photographs). However, as estimated from the not-to-scale figures, the integrated grades for the evaluated subreach are summarized below (using a scale of 0 to 10, with 0 indicating least stable conditions and 10 indicating most stable conditions):

- Grade 5: 1 of 14 subreaches, approximately 5 percent of the evaluated subreach length.
- Grade 4: 6 of 14 subreaches, approximately 35 percent of the evaluated subreach length.
- Grade 3: 4 of 14 subreaches, approximately 40 percent of the evaluated subreach length.
- Grade 2: 2 of 14 subreaches, approximately 15 percent of the evaluated subreach length.
- Grade 1: 1 of 14 subreaches, approximately 5 percent of the evaluated subreach length.

The report notes the prioritization is based on qualitative analyses, and straight averaging of the river mechanics rankings and the geotechnical rankings produced the integrated grades.

Tetra Tech, Inc. 2006. *DRAFT Aliso Creek Concept Plan Report.* Submitted to County of Orange Resources & Development Management Department. Irvine, California.

The County of Orange Resources and Development Management Department (RDMD) contracted with Tetra Tech, Inc. to perform an analysis of alternatives for restoration of stream stability. The study focuses on stream stability as a priority project goal. The project is identified as the Aliso SUPER (i.e.,

Stabilization, **U**tility **P**rotection, and **E**nvironmental **R**estoration). Three stream stability alternatives were considered, and each is evaluated in part based on protection provided to the utilities located along the maintenance road east of the main channel. Due to the conceptual level of the restoration alternative designs, it was recommended that proximity to utility pipelines and potential for channel migration into the utility corridor should be considered during more advanced design efforts.

Collison, A. and N. Garrity. 2009. *Memorandum: Aliso Creek Stabilization Project Review.* Submitted to Kenneth Frank, City of Laguna Beach. Prepared by Philip Williams & Associates (PWA). San Francisco, California.

The memorandum documents, in part, a one-day field geomorphic reconnaissance of Aliso Creek and a review of Orange County's *DRAFT Aliso Creek Concept Plan Report.* The report concludes that the high degree of channel incision and widening has resulted from urbanization in the watershed and that future widening threatens infrastructure that runs alongside the creek (i.e., the AWMA Road and the utility pipelines) if they are left in the current locations and no action is taken. Field observations made suggest that for the last ten years at least (as evidenced by the age of the trees on the inset floodplain) the channel has been vertically stable or slightly aggradational (progressive raising/increasing in elevation through alluvial deposition). This is consistent with the actively eroding banks: aggrading systems tend to exhibit more rapid rates of lateral migration and bank erosion as sedimentation and vegetation establishment on point bars promotes meander migration.

Tetra Tech, Inc. 2010. DRAFT *Aliso Creek F4 Geomorphic Assessment.* Prepared for the U.S. Army Corps of Engineers, Los Angeles District. Irvine, California.

Tetra Tech, Inc. conducted a geomorphic assessment of Aliso Creek to provide a basis for interpreting the hydraulic engineering work associated with the comparison of alternative environmental restoration plans, and specifically to provide a rational basis for prediction of future geomorphic conditions associated with the no-action plan. The assessment builds on numerous earlier hydrologic, hydraulic, geotechnical, and geologic studies and investigations conducted in the Aliso Creek watershed.

Key findings relative to bank erosion/bank stability are as follows:

- The nature and distribution of bed material in lower Aliso Creek are a function of historical colluvial inputs (e.g., landslides) that led to blockages of the creek and subsequent upstream deposition of clay materials. The clay layers are influential in controlling streambank strength and the resistance to channel widening.
- Colluvial inputs and outcrops of coarse materials (e.g., San Onofre Breccia) are being concentrated into natural grade controls that limit the potential for future degradation of the channel bed.
- Hydraulic modeling analyses confirmed existing hydraulic conditions are incapable of mobilizing the cobble-sized materials that are concentrated in natural grade controls.
- Due to nearly built-out development conditions, there is low potential for future land cover-induced changes to the flood regime (i.e., future flood hydrology will be similar to existing flood hydrology).
- A geomorphic model was developed and tested to explain the potential for future changes in channel morphology. Results confirmed that future vertical adjustments of the bed profile will be limited because: 1) the widened channel and decreased channel bed slope have decreased

unit discharge and bed material transport capacity, and 2) the concentrations of coarse sediments have increased the critical flows required to mobilize these materials.

- An Incised Channel Evolution Model (ICEM) was applied on a reach-by-reach basis to both categorize existing geomorphic conditions and provide a means for predicting future geomorphic conditions, particularly with regarding to bed degradation and channel widening.
- System-wide continuation of upper bank failures is likely along much of lower Aliso Creek, particularly where banks are nearly vertical, composed of non-cohesive alluvium, and contain tension cracks. However, field observations suggest that mass-failed bank materials are not consistently being removed from the toe of the bank by fluvial entrainment. Retention of the failed material is enhanced by the high density of the riparian vegetation that is supported by greater base flows in the channel. In contrast, at locations where failed materials are removed from the toe of the bank by fluvial entrainment, or at locations where the channel locally impinges against the base of the terrace, continuing erosion and retreat of that bank is likely.
- Continuation of both localized (colluvial) and more widespread (fluvial) deposition of sediment on the inset floodplain will reduce the effective heights of the banks to the point where they no longer exceed the critical height for geotechnical stability. This, combined with reduced bank angles, will ultimately lead to bank stabilization.
- Despite the natural progression toward stable banks, stabilization measures may be required for those locations where infrastructure (e.g., AWMA Road, buried pipelines) is at risk from continuing bank erosion.

The results of this analysis provide the foundation for the continued analyses presented in this current study.

2.2 Geomorphic Characterization of Lower Aliso Creek

The previous studies of the geomorphology of lower Aliso Creek illustrate the following common themes:

- Development of the Aliso Creek watershed has led to changes in runoff hydrology such that the morphology of the channel has adjusted to accommodate greater peaks rates of runoff and runoff volumes. Space for future watershed development is now so limited, that there is minimal potential for future changes to flood hydrology.
- Degradation of the bed of the channel and subsequent bank erosion/channel widening are the two primary manifestations of the channel response to the altered hydrology.
- Continuation of systemic bed degradation does not appear likely; however, localized incision and degradation may occur.
- Channel width appears to have reached a point where unit discharges have decreased enough to allow bed material deposition to form berms and inset floodplains.
- Due to excessive bank height, non-cohesive bank materials, tension cracking in the upper banks, and the absence of mature woody vegetation on the banks, bank erosion is expected to continue at some locations.
- Bank erosion is driven by two types of processes: 1) flow impingement on bank materials and fluvial entrainment of eroded bank materials along the toe, and 2) bank slumping and slab/block failures of upper bank materials due to geotechnically unstable conditions.

- Geomorphic instabilities of the channel poses risks to the infrastructure (e.g., AWMA Road and sewer pipelines) located along both banks of Aliso Creek.

3 Erosion Assessment

An erosion assessment along lower Aliso Creek was conducted to provide a technical basis for evaluating the potential erosion risk posed to the proposed FM 1 and FM 2 pipeline alignments, assuming no new erosion protection measures are implemented over a 50-year planning period.

3.1 Erosion Assessment Approach

Various approaches for conducting an erosion assessment were considered and the following was selected.

Tetra Tech, Inc. staff conducted field reconnaissance along both banks of lower Aliso Creek. The reconnaissance was performed to observe and document conditions and factors present at erosional areas as well as conditions and factors that promote bank stability. Observations indicated bank erosion is primarily gravity driven (e.g., mass failures of bank materials), but the stability of the banks was linked to whether failed materials at the toe of the bank were being removed by fluvial processes. Thus, technical analyses focused on the erosion potential/erosion resistance. Hydraulic analyses were carried out to quantify the potential for fluvial erosion to contribute to destabilizion of banks and contribute to the undermining of proposed infrastructure. These analyses were conducted at individual sites along the creek. Geotechnical erosion resistance was characterized by compiling and categorizing subsurface boring logs recorded along both banks of Aliso Creek. Geotechnical erosion processes were evaluated using slope stability analyses. These analyses quantified the stable bank slope depending on bank materials and bank height. The risk of erosion associated with bend migration was categorized using the hydraulic erosion potential and the offsets between calculated stable bank slopes and the proposed pipeline alignments. The various indices of erosion risk were considered together to generate a combined erosion risk for the proposed FM 1 and FM 2 alignments.

3.2 Field Reconnaissance

In December 2011 and January 2012 field reconnaissance was conducted along both banks of lower Aliso Creek as well as along the left bank of Sulphur Creek below Alicia Parkway. On December 26, 2011, the fluvial geomorphologist and hydraulic engineer started at Alicia Parkway and walked downstream along the south (left) bank of Sulphur Creek. The day's efforts continued downstream along the east (left) bank of Aliso Creek, to approximately river mile 3.21 – about 2,100 feet downstream from the ACWHEP diversion structure. The remainder of the east (left) bank was surveyed on December 27th. Hasan Nouri of FluvialTech (previously of Rivertech, Inc.) provided a briefing the morning of December 27th of work he performed related to stabilization studies along Aliso Creek. The morning of December 28, the inspection team worked upstream along the west (right) bank of Aliso Creek, from the downstream limit at the CTP to the ACWHEP diversion structure. The remainder of the west (right) bank was surveyed on January 25, 2012.

The objectives of the field reconnaissance included:

- Observe and document recent and historical erosion areas that have the potential to destabilize/expose infrastructure.
- Assess the identified erosion areas (e.g., failure mode, physical properties of the bank, and bank materials and stratification).
- Observe and quantify conditions that have promoted stable banks, including the development of depositional berms along the toe, the presence of cohesive clay materials in the toe of the bank, graded upper banks without tension features (i.e., near vertical cracks along the top of

bank parallel to the bank face), the influence of woody vegetation, and the presence and condition of existing protection measures.

- Consider any factors that may minimize/exacerbate impacts of erosion on the stability of proposed pipeline alignments.

Features of interest that were observed during the reconnaissance were located with hand-held mapping grade GPS units, and digital photographs were taken. Field notes were subsequently compiled with the location information and photographs to spatially relate the information. Appendix A includes figures and photographs documenting the field reconnaissance. The figures illustrate the spatial relationships between the Aliso Creek centerline, the extents of existing bank protection measures, the proposed FM 1 and FM 2 alignments, as well as locations preliminarily rated *High* or *Moderate* in regard to erosion risk to infrastructure (a de facto preliminary rating of *Low* was assumed for all locations not preliminarily rated *High* or *Moderate*). Locations where conditions were observed that promote stable banks are noted as *Stable.* These preliminary ratings were based only on the field reconnaissance, prior to the initiation of all technical analyses. Selected photographs representative of these various areas follow the figures in Appendix A.

To illustrate some of the observed/inferred fluvial and geotechnical processes affecting bank stability and risk to proposed infrastructure, a series of eight cross section schematics has been prepared (Appendix B). Each figure contains notes that describe the processes illustrated in the schematic.

- Bank Slumping due to Geotechnically Unstable Slope – **Figure B-1**
- Over-steep Existing Riprap Revetment – **Figure B-2**
- Stable Bank Angle – **Figure B-3**
- Establishment of Inset Floodplain – **Figure B-4**
- Bank Instability due to Flow Impingement and Potential Bend Migration – **Figure B-5**
- Bank Erosion due to Concentrated Runoff along AWMA Road – **Figure B-6**
- Existing Exposure of East (Left) Bank Infrastructure – **Figure B-7**
- Bank Erosion Exacerbated by Concentrated Upland Runoff – **Figure B-8**

Table 3-2 and **Table 3-3** note the presence/absence of geomorphic features observed to have controlling influences on limiting the potential for bank erosion. The features include:

- Clay-bearing materials or bedrock in the toe of the bank
- A depositional berm along the toe of the bank
- Substantial woody vegetation established along the toe of the bank
- Existing bank protection measures

3.3 Fluvial Erosion Potential

As documented in Section 2.1, previous studies consistently make reference to the destabilizing effects of flood flows on the morphology of the lower Aliso Creek channel, and the impacts on the stability of the valley bottom. The lateral stability of the channel banks is of particular interest in this erosion assessment due to the potential for destabilizing/undermining the proposed pipeline alignments. This section presents: 1) the methodology used to quantify the potential for fluvial erosion to destabilize stream banks, and 2) the categorization of fluvial erosion potential.

3.3.1 Methodology for Quantifying Fluvial Erosion Potential

The potential for bank erosion and removal of mass-failed bank material driven by fluvial processes needs to consider both the magnitude of hydraulic stresses applied on the banks during a flood event as well as the duration of the flood event. To incorporate the effects of both magnitude and duration, the potential for fluvial processes to contribute to erosion of the banks along lower Aliso Creek was quantified using the Bank Energy Index (BEI) (Harvey and Mussetter 1993). The BEI is based on the concept of total energy (*E*) applied to the banks. Energy is defined as the product of the stream power expended on the banks and the incremental time over which it is applied (**Equation 1**). Bank stream power is the product of the average main channel velocity (V_{ch}) and the shear stress applied on the bank (τ_b) (**Equation 2**).

$$E = \int_0^t (V_{ch} * \tau_b)\ dt$$ **Equation (1)**

where

E	=	total energy applied at a specific bank location
V_{ch}	=	average main channel velocity
τ_b	=	shear stress applied on the bank
dt	=	incremental time for discretizing the flood event hydrograph

$$\tau_b = K_b * \gamma * d_h * S_f$$ **Equation (2)**

where

τ_b	=	shear stress applied on the bank at a specific location
K_b	=	factor that accounts for the effect of channel curvature on the shear stress acting on the outside of a channel bend (**Figure 3-1**)
γ	=	unit weight of the water-sediment mixture flowing in the channel (62.4 lbs/ft^3)
d_h	=	hydraulic depth in the channel
S_f	=	slope of the energy grade line

Equation (1) and **Equation (2)** were solved for a given flood event by discretizing flood hydrographs into a series of five-minute times-steps, calculating hydraulics for each time-step, and integrating the resulting energies at each time step over the duration of the flood hydrograph. The BEI was calculated for a flood event by normalizing the total energy applied at specific bank locations by the median energy applied at all cross sections.

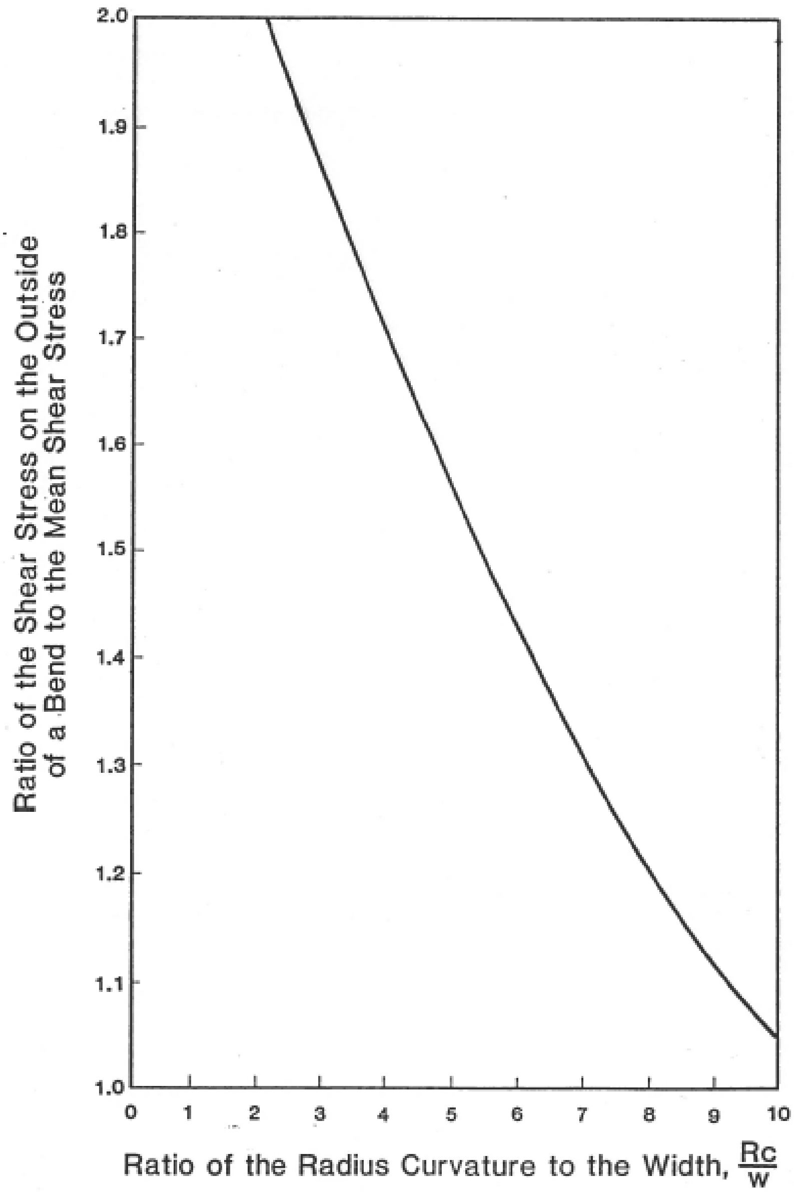

Figure 3-1. SCS (1977) Relation for Calculating the Increase in Shear Stress on the Outside of a Bend

Flood event hydrographs have been previously simulated at various locations along lower Aliso Creek (USACE 2000). The hydrographs were generated using the U.S. Army Corps of Engineers HEC-1 computer software (USACE 1998). Details regarding the setup, testing, and calibration of the HEC-1 models are available in USACE (2000). Hydrographs were simulated for the following average annual recurrence interval floods: 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year.

Channel hydraulics (i.e., velocity (V_{ch}), top width (W_{ch}), hydraulic depth (d_h), and slope of the energy grade line (S_f)) were simulated using the HEC-RAS model developed for Aliso Creek (USACE 2009). The refined and calibrated version of this model (Tetra Tech, Inc. 2010) was applied for this study; however only the portion of the model between the Pacific Ocean and the AWMA Road Bridge crossing of Aliso

Creek was used. Additional cross sections were added for the portion of Sulphur Creek between the Alicia Parkway culvert and the confluence with Aliso Creek. **Figure A-1** to **Figure A-4** in Appendix A show the locations of the cross sections included in the model. The hydraulics were calculated for a range of flows, up to the peak discharge of the 100-year flood, for the development of various rating curves that were then integrated over the flood hydrographs.

After normalizing the calculated energies for each flood event at each cross section, the resulting BEI values were categorized using quartiles. The BEI values in the first quartile (Q1) represent the locations along the channel where the lowest relative energy is applied to the banks; the BEI values in the fourth quartile (Q4) represent the greatest relative energy applied to the banks. **Table 3-1** presents the categories assigned to the various quartiles. When compared across flood events, consistency was observed in the categorization of a particular cross section by quartile.

Table 3-1. Fluvial Erosion Potential by BEI Quartile

	Q1	Q2	Q3	Q4
Fluvial Erosion Potential	*Low*	*Low*	*Moderate*	*High*

The BEI values were calculated as an indication of the relative potential for fluvial processes to initiate/maintain bank erosion. The quartile rankings were compared to observations made during the field reconnaissance as an informal check of the rankings. In general, the locations categorized in Q4 or Q3 were either 1) locations where active bank erosion was observed during the field reconnaissance, 2) locations where mass wasted bank materials were not being retained along the toe of the bank, 3) locations along the outside of bends, or 4) were locations where existing bank protection measures were observed. This indicates the BEI is a reasonable indicator of locations where fluvial processes contribute to bank erosion, or where these processes historically presented such a risk that bank protection measures were installed (commonly on an emergency basis in response to erosion that posed a threat to infrastructure). Locations categorized in Q1 tended to be cross sections that exhibited some combination of graded banks, relatively wider channels, large radii of curvature or straight reaches, inset floodplains, and hydraulically-connected overbank areas. Consequently, the categorization of the fluvial erosion potential by quartile produced results that were in general agreement with observations of existing conditions. The BEI quartiles are provided in **Table 3-2** and **Table 3-3** along the east (left) and west (right) banks, respectively. Greater potential for fluvial processes to erode the banks and/or remove the products of mass failure of the banks is not the only factor contributing potential for destabilization of the proposed pipeline alignments; incorporation of the fluvial erosion potential along with other factors in rating the risk to the proposed pipeline alignments is addressed in Section 3.5.

3.3.2 Categorization of Fluvial Erosion Potential

The potential for fluvial processes to initiate or maintain bank erosion processes was categorized using the BEI quartiles and observations made during the field reconnaissance. The BEI was calculated to categorize fluvial energy exerted on a bank, so this is the primary basis in the categorization of fluvial erosion potential. However, comparison of fluvial erosion potential across sites using the BEI quartiles is most meaningful when conditions that resist fluvial erosion are similar (e.g., vegetation, presence and condition of bank protection measures, bank materials, stratification of bank materials). The field reconnaissance indicated that bank conditions affecting erosion resistance vary widely along the proposed FM 1 and FM 2 pipeline alignments.

3.3.2.1 Erosion Resistance Provided by Bank Materials

The resistance of the bank materials to fluvial erosion was investigated by reviewing available mapping and compiling boring logs from previous subsurface investigations along lower Aliso Creek.

3.3.2.1.1 Review of Geologic Mapping

According to geologic mapping of the San Juan Capistrano Quadrangle, in which the lower Aliso Creek watershed is included, the valley bottom containing Aliso Creek is composed of alluvium (Morton et al. 1974). Alluvium is typified as unconsolidated to poorly consolidated, fine to coarse sand and gravel, with very high erodibility on slopes greater than five degrees (about 11.4H:1V), and poor to fair slope stability. More recently, digital geologic mapping of the Santa Ana Quadrangle was compiled (Morton 2004) and this mapping classifies the valley bottom containing Aliso Creek as young axial channel deposits (Holocene and late Pleistocene) (**Figure 3-2**). This mapping unit (*Qyaa*) is typified by fluvial deposits along canyon floors, consisting of unconsolidated sand, silt, and clay-bearing alluvium. The hillslopes from the CTP to approximately the ACWHEP diversion structure are mapped as Topanga Formation (*Tt*); hillslopes from approximately the ACWHEP diversion structure to the AWMA Road Bridge are mapped as Monterey Formation (*Tm*). Both of these mapping units are typified by marine siltstones and sandstones. The only other mapping unit bordering the valley bottom is young landslide deposits (Holocene and late Pleistocene). This mapping unit (*Qyls*) contains a range of highly fragmented to largely coherent landslide deposits (unconsolidated to consolidated). Many of these landslides in part reactivated during the late Holocene. The mapping units include both the scarp areas as well as the slide deposit.

At a regional scale, the available geologic mapping (Morton et al. 1974, Morton 2004) categorizes the alluvium that makes up the channel boundaries of undifferentiated gravel, sand, silt, and clay. These materials exhibit varying degrees of resistance to fluvial erosion, and varying properties that affect geotechnical slope stability.

The NRCS soil survey of Orange and Western Part of Riverside Counties (2008) was reviewed to evaluate whether surface soils mapping is more refined than the geologic mapping. Unfortunately, much of the valley bottom is generally classified as *Riverwash* which is composed of various sandy, silty, and clayey loams. Little information is provided to distinguish the locations with clay-bearing materials versus silts and sands.

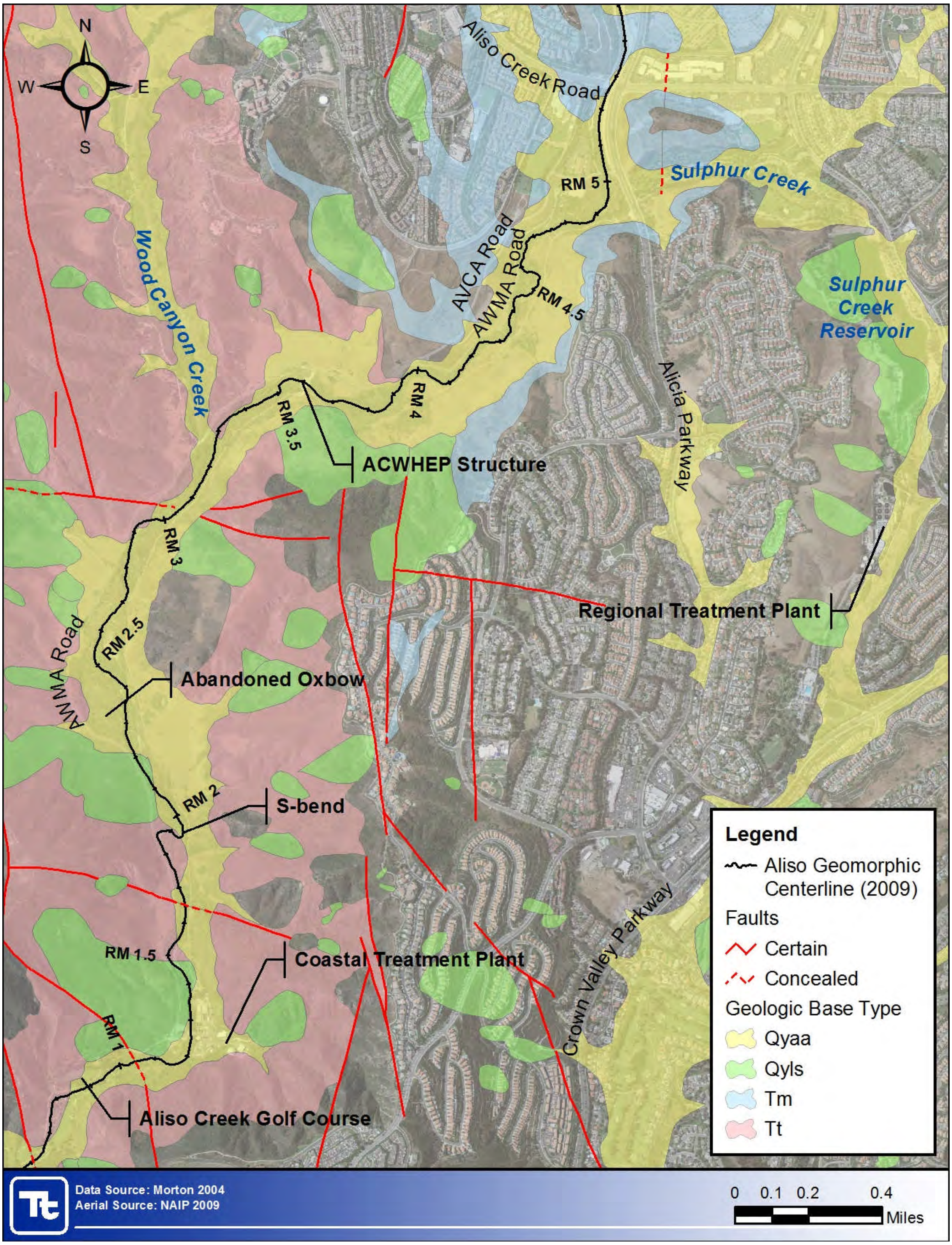

Figure 3-2. Geologic Mapping in the Lower Aliso Creek Watershed (Morton 2004)

3.3.2.1.2 Compilation of Subsurface Exploration Data

While the regional geologic mapping is not of fine enough resolution to differentiate 1) the potential resistance of the bank material to fluvial erosion, and 2) the potential differences in geotechnical properties that affect slope stability, previous studies (Woodward-Clyde Consultants 1975, Ninyo & Moore 2009, Diaz Yourman & Associates 2009, Ninyo & Moore 2011) have documented subsurface explorations. These studies include boring logs that include USCS classifications (ASTM D2487-11) of soil type. The locations of these borings along lower Aliso Creek are shown in **Figure 3-3**.

To facilitate comparisons of the geotechnical influence on erosion resistance, the borings were grouped by their bank location (i.e., east or west). The approximate station along the Aliso Creek centerline was assigned to each boring. A common symbology was developed for the various USCS classifications, and the symbols were plotted along the longitudinal profile of Aliso Creek. Clay-bearing, cohesive materials that provide greater resistance against erosion are colored green (e.g., CL, CH, SC). Low to non-cohesive, silty and granular materials that are more susceptible to erosion are colored red (e.g., SP, SM, ML, MH). Materials with a mix of clay-bearing and silty materials are colored yellow (e.g., SC-SM, CL-ML, CL-SM). The east (right) bank data is presented in **Figure 3-4** and the west (left) bank data in **Figure 3-5**. The channel thalweg and top of bank profiles are included for reference.

Figure 3-4 and **Figure 3-5** illustrate the variability in the distribution of clay-bearing alluvium throughout the valley bottom. Thus, the influence of the bank materials and stratification on resistance to erosion was considered only on a case-by-case basis; the profiles are too varied to make reach-based generalizations.

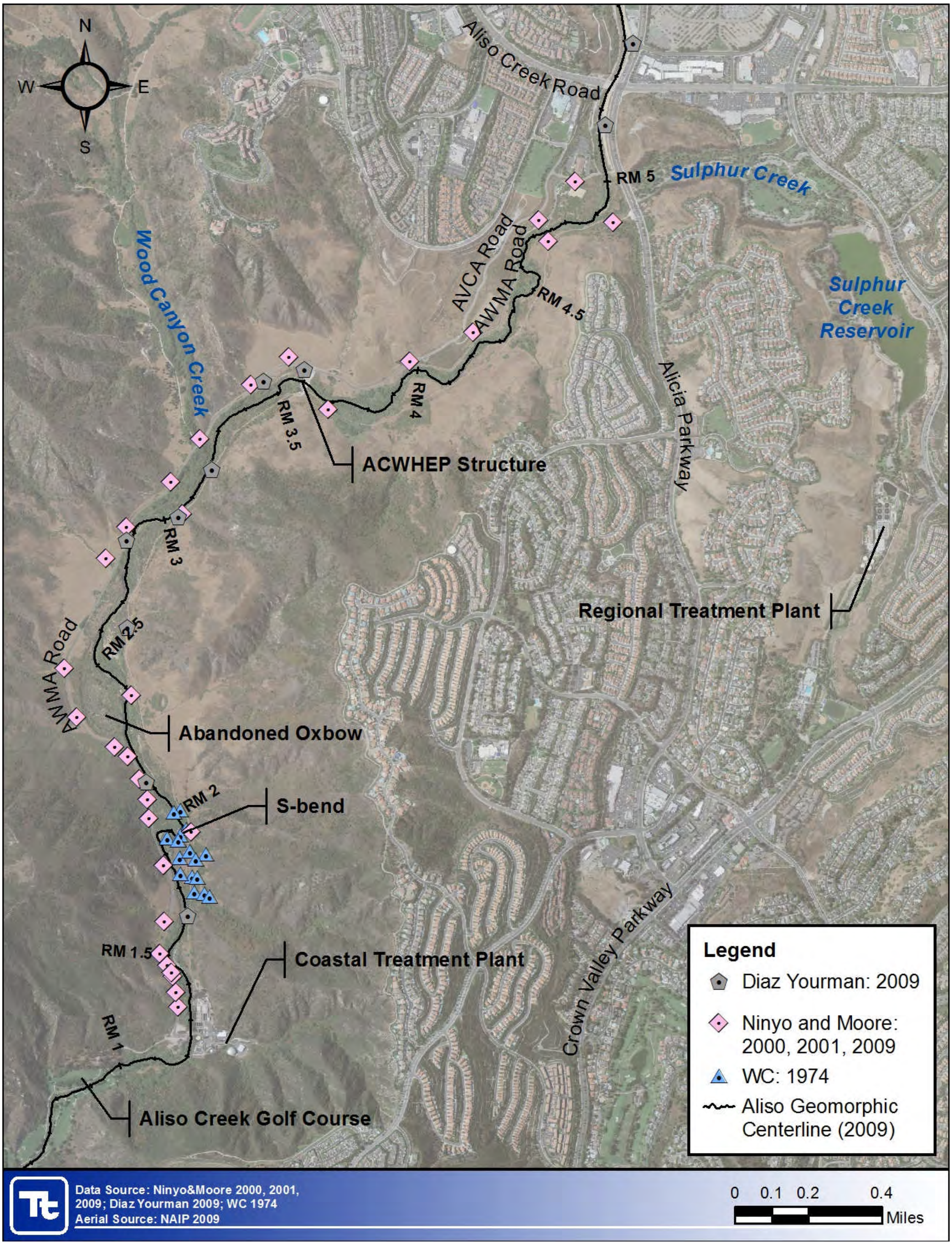

Figure 3-3. Available Geotechnical Boring Locations

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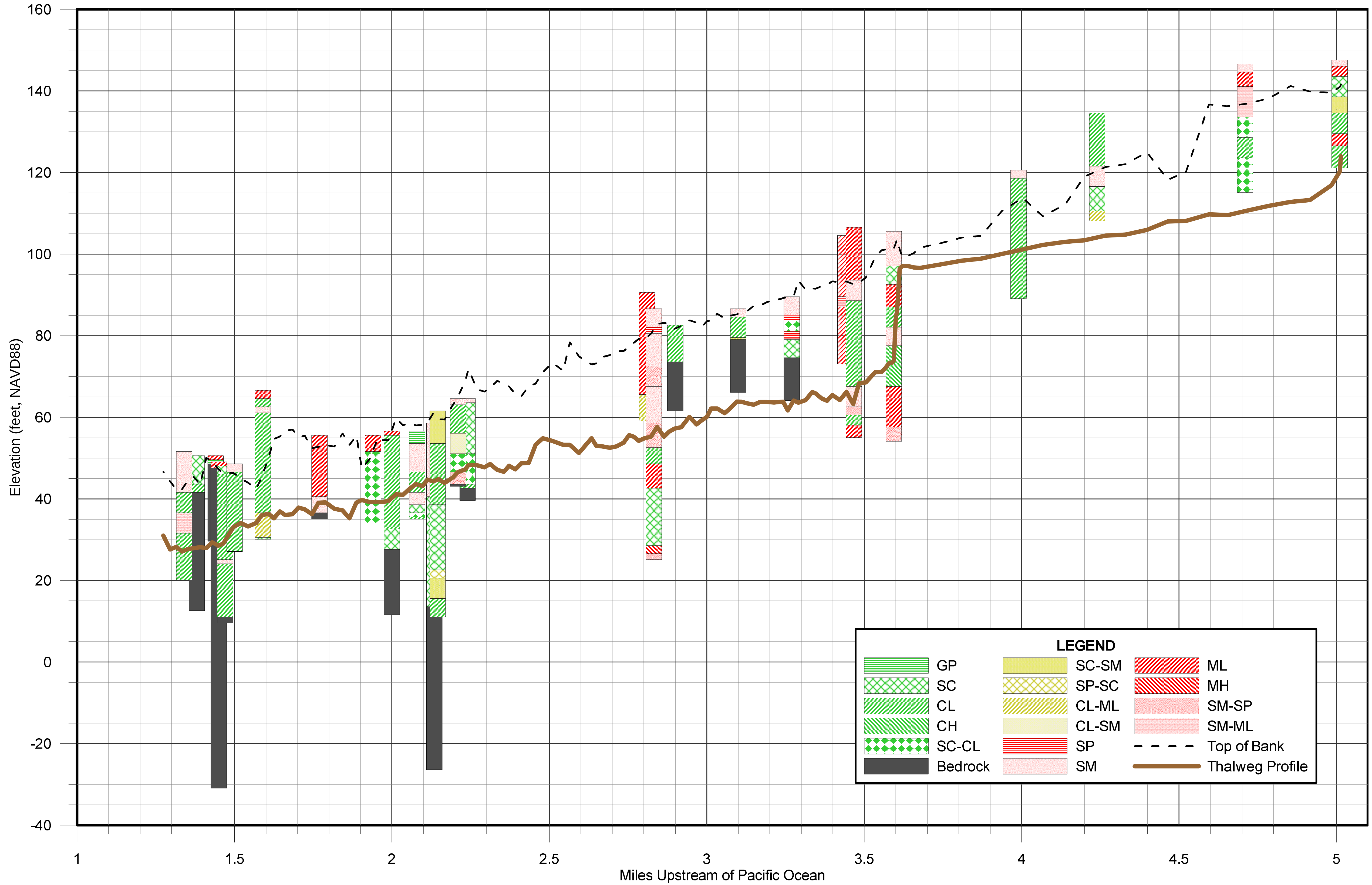

Figure 3-4. East (Right) Bank Geotechnical Boring Profiles

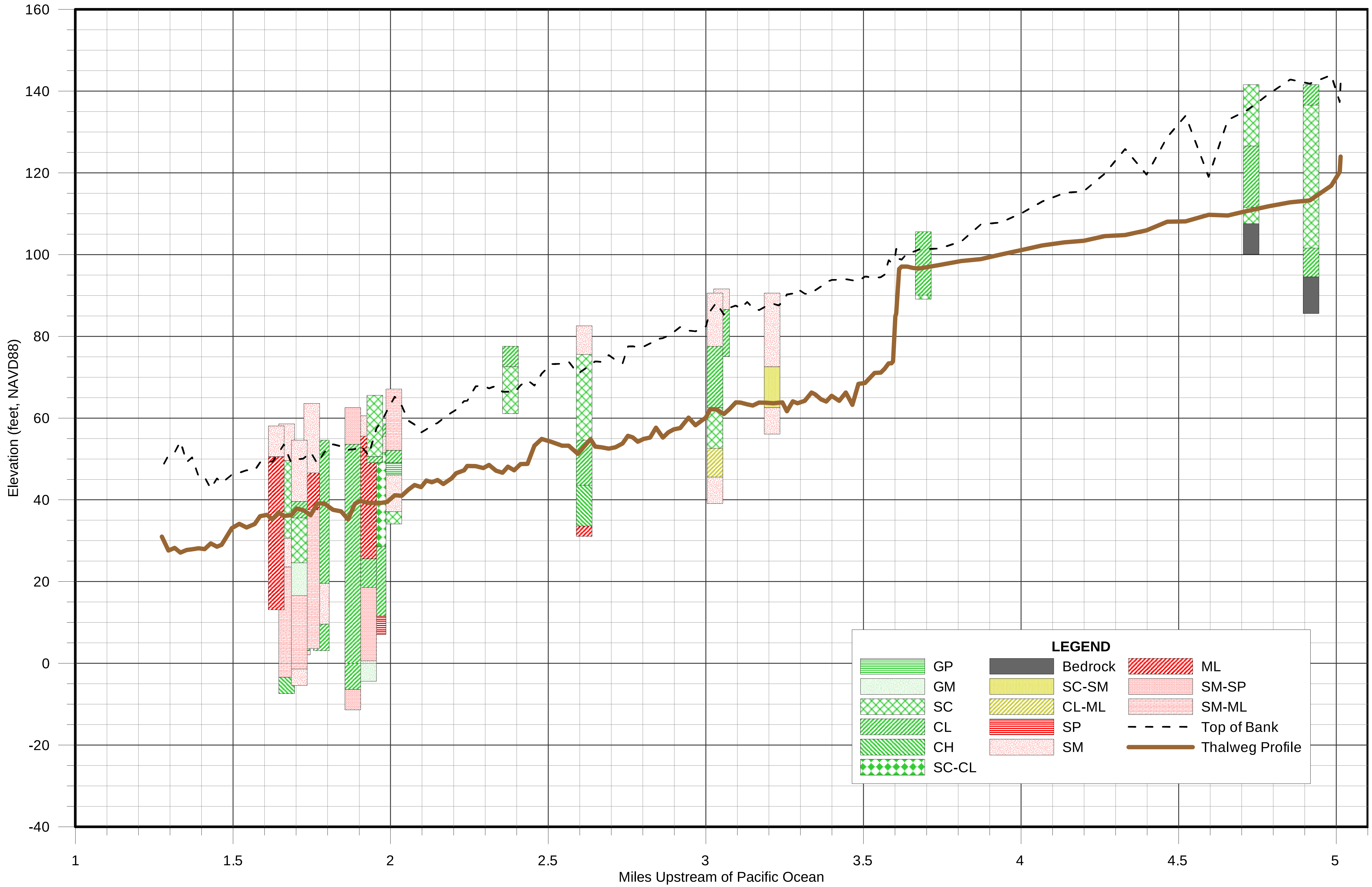

Figure 3-5. West (Left) Bank Geotechnical Boring Profiles

3.3.2.2 Fluvial Erosion Categorization

While the BEI provides a basis for comparing the potential for fluvial forces to contribute to destabilization of the banks along lower Aliso Creek, physical factors observed during the field reconnaissance (i.e., clay or bedrock in the toe of bank, a depositional berm along the toe, woody vegetation established along the toe, and existing bank protection measures in good condition) can mitigate some of the erosion potential. **Figures B-3** and **B-4** in Appendix B show examples of stable banks. **Table 3-2** and **Table 3-3** summarize the combined influence of the BEI and these physical factors on the fluvial erosion potential for the east (left) and west (right) banks, respectively. Each cross section included in the hydraulic model is categorized for fluvial erosion potential (i.e., *H* = high; *M* = moderate; *L* = low). The categories generally follow the BEI categories, unless physical factors are present that would reduce this potential. It was assumed that the physical factors were sufficient to reduce the BEI one category (e.g., *High* to *Moderate*, *Moderate* to *Low*). When a cross section is located along the inside of a bend – these areas are frequently low energy and promote deposition – these location were assigned a fluvial erosion potential of *Low* since the BEI values are not representative of conditions along the inside of a bend.

Table 3-2. Summary of Fluvial Erosion Potential along East (Left) Bank

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential				Fluvial Erosion Potential
					Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	
Sulphur Creek									
0.120			3	Mod.					M
0.105	X		4	High					H
0.088	X		1	Low					L
0.067			4	High					H
0.036			4	High					H
0.023			3	Mod.					M
Aliso Creek									
4.854			3	Mod.				X	L
4.785			3	Mod.					M
4.717		X							L
4.656		X							L
4.595		X							L
4.522	X		3	Mod.					M
4.464		X							L
4.398			1	Low					L
4.330	X		2	Low		X	X		L
4.266		X							L
4.199			1	Low					L
4.138	X		3	Mod.		X	X		L
4.067			4	High					H
4.003		X							L
3.937			3	Mod.					M

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential				Fluvial Erosion Potential
					Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	
3.872	X		2	Low			X		L
3.810			3	Mod.					M
3.741		X							L
3.677	X		2	Low	X		X		L
3.657			2	Low					L
3.639			3	Mod.					M
3.621			4	High					H
3.613			3	Mod.					M
3.604			4	High					H
3.601			4	High					H
3.594		X							L
3.589		X							L
3.580		X							L
3.567		X							L
3.555		X							L
3.535		X							L
3.505	X		3	Mod.		X	X		L
3.484			4	High					H
3.465			1	Low					L
3.444			3	Mod.					M
3.423			2	Low					L
3.399			2	Low					L
3.382			1	Low					L
3.366		X							L
3.346		X							L
3.335		X							L
3.314		X							L
3.291		X							L
3.276		X							L
3.257	X		1	Low			X		L
3.243	X		2	Low			X		L
3.231	X		1	Low			X		L
3.214	X		1	Low			X	X	L
3.191	X		1	Low		X	X		L
3.169	X		2	Low		X	X	X	L
3.149	X		1	Low		X	X	X	L
3.131	X		2	Low		X	X	X	L
3.110	X		4	High		X	X	X	M
3.095	X		4	High		X	X	X	M
3.074	X		3	Mod.					M
3.057	X		3	Mod.					M
3.033	X		3	Mod.	X				L

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential				Fluvial Erosion Potential
					Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	
3.014	X		4	High					H
3.000	X		4	High					H
2.985	X		1	Low					L
2.967		X							L
2.945		X							L
2.919		X							L
2.898			4	High					H
2.881			3	Mod.					M
2.864			3	Mod.					M
2.842			4	High					H
2.823			2	Low					L
2.802			2	Low				X	L
2.784			1	Low				X	L
2.768	X		2	Low		X	X	X	L
2.753	X		2	Low		X	X	X	L
2.736	X		1	Low				X	L
2.713	X		2	Low					L
2.692	X		2	Low					L
2.668	X		1	Low					L
2.649			1	Low					L
2.634			2	Low					L
2.594			1	Low					L
2.565		X							L
2.544		X							L
2.509		X							L
2.479		X							L
2.456	X		4	High					H
2.434	X		2	Low					L
2.412	X		2	Low					L
2.392	X		1	Low					L
2.372	X		2	Low					L
2.355		X							L
2.334		X							L
2.312		X							L
2.294		X							L
2.270		X							L
2.243		X							L
2.233		X							L
2.208		X							L
2.193		X							L
2.167			2	Low					L
2.149			3	Mod.					M

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential				Fluvial Erosion Potential
					Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	
2.131			3	Mod.					M
2.113			4	High					H
2.097			2	Low					L
2.076			3	Mod.					M
2.056			4	High					H
2.035			3	Mod.					M
2.013			4	High					H
1.989			3	Mod.				X	L
1.971	X		4	High				X	M
1.955	X		4	High	X				M
1.930	X		2	Low	X				L
1.904		X							L
1.887		X							L
1.865		X							L
1.843			1	Low					L
1.817			2	Low					L
1.789			3	Mod.					M
1.767			4	High					H
1.746			1	Low					L
1.723			1	Low					L
1.703	X		2	Low		X	X		L
1.684	X		3	Mod.	X	X	X		L
1.661	X		3	Mod.	X	X	X	X	L
1.644	X		3	Mod.				X	L
1.625	X		3	Mod.				X	L
1.608	X		4	High				X	M
1.586	X		4	High					H
1.569	X		3	Mod.					M
1.543	X		2	Low					L
1.520		X							L
1.496		X							L
1.464	X		2	Low		X			L
1.449	X		2	Low		X			L
1.429	X		2	Low		X			L
1.410	X		1	Low		X			L
1.391	X		1	Low					L
1.370	X		1	Low					L
1.353			1	Low					L
1.333			1	Low					L
1.315			1	Low					L
1.295			1	Low					L

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential: Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	Fluvial Erosion Potential
1.274			3	Mod.				X	L

Table 3-3. Summary of Fluvial Erosion Potential along West (Right) Bank

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential: Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	Fluvial Erosion Potential
Sulphur Creek									
Not Applicable									
Aliso Creek									
5.014		X							L
5.011		X							L
4.984		X							L
4.916		X							L
4.854		X							L
4.785			3	Mod.					M
4.717	X		3	Mod.	X		X		L
4.656	X		2	Low			X		L
4.595	X		4	High			X		M
4.522		X							L
4.464	X		4	High					H
4.398			1	Low					L
4.330		X							L
4.266	X		3	Mod.			X		L
4.199			1	Low					L
4.138		X							L
4.067			4	High					H
4.003	X		3	Mod.	X				L
3.937			3	Mod.					M
3.872		X							L
3.810			3	Mod.					M
3.741	X		4	High			X		M
3.677		X							L
3.657			2	Low					L
3.639			3	Mod.					M

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential				Fluvial Erosion Potential
					Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	
3.621			4	High					H
3.613			3	Mod.					M
3.604			4	High					H
3.601			4	High					H
3.594	X		4	High	X				M
3.589	X		4	High	X				M
3.580	X		4	High					H
3.567	X		4	High					H
3.555	X		4	High					H
3.535	X		4	High					H
3.505		X							L
3.484			4	High					H
3.465			1	Low					L
3.444			3	Mod.					M
3.423			2	Low					L
3.399			2	Low					L
3.382			1	Low					L
3.366	X		2	Low		X	X		L
3.346	X		2	Low		X	X		L
3.335	X		3	Mod.		X	X		L
3.314	X		3	Mod.		X	X		L
3.291	X		1	Low		X	X		L
3.276	X		1	Low	X	X	X		L
3.257		X							L
3.243		X							L
3.231		X							L
3.214		X							L
3.191		X							L
3.169		X							L
3.149		X							L
3.131		X							L
3.110		X							L
3.095		X							L
3.074		X							L
3.057		X							L
3.033		X							L
3.014		X							L
3.000		X							L
2.985		X							L
2.967	X		1	Low					L
2.945	X		4	High				X	M
2.919	X		3	Mod.	X			X	L

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential				Fluvial Erosion Potential
					Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	
2.898			4	High					H
2.881			3	Mod.					M
2.864			3	Mod.					M
2.842			4	High					H
2.823			2	Low					L
2.802			2	Low					L
2.784			1	Low					L
2.768		X							L
2.753		X							L
2.736		X							L
2.713		X							L
2.692		X							L
2.668		X							L
2.649			1	Low					L
2.634			2	Low					L
2.594			1	Low					L
2.565	X		1	Low					L
2.544	X		1	Low					L
2.509	X		3	Mod.					M
2.479	X		4	High					H
2.456		X							L
2.434		X							L
2.412		X							L
2.392		X							L
2.372		X							L
2.355	X		1	Low					L
2.334	X		1	Low					L
2.312	X		1	Low					L
2.294	X		2	Low					L
2.270	X		3	Mod.					M
2.243	X		4	High	X				M
2.233	X		2	Low	X				L
2.208	X		4	High				X	M
2.193	X		2	Low				X	L
2.167			2	Low					L
2.149			3	Mod.					M
2.131			3	Mod.					M
2.113			4	High					H
2.097			2	Low					L
2.076			3	Mod.					M
2.056			4	High					H
2.035			3	Mod.					M

River Mile	Bank Along Outside of Bend	Bank Along Inside of Bend	BEI Quartile	BEI Category	Physical Factors Decreasing Fluvial Erosion Potential				Fluvial Erosion Potential
					Clay/ Bedrock in Toe	Depositional Berm At Toe	Woody Vegetation Along Toe	Existing Bank Protection in Good Condition	
2.013			4	High					H
1.989			3	Mod.					M
1.971		X							L
1.955		X							L
1.930		X							L
1.904		X							L
1.887	X		2	Low					L
1.865	X		1	Low					L
1.843			1	Low				X	L
1.817			2	Low					L
1.789			3	Mod.					M
1.767			4	High					H
1.746			1	Low					L
1.723			1	Low					L
1.703		X							L
1.684		X							L
1.661		X							L
1.644		X							L
1.625		X							L
1.608		X							L
1.586		X							L
1.569		X							L
1.543		X							L
1.520	X		4	High					H
1.496	X		4	High	X				M
1.464			2	Low		X			L
1.449		X							L
1.429		X							L
1.410		X							L
1.391		X							L
1.370		X							L
1.353			1	Low					L
1.333			1	Low					L
1.315			1	Low					L
1.295			1	Low					L
1.274			3	Mod.				X	L

3.4 Geotechnical Erosion Risk to Proposed Pipeline Alignments

The bank materials and stratification characterized in Section 3.3.2.1 influence not only the resistance to fluvial erosion, they also affect the potential for gravity driven geotechnical forces to initiate and continue erosion of geotechnically unstable banks. As part of the process for assessing the overall risk of bank erosion to impact proposed pipeline alignments, an evaluation of the geotechnical stability of existing bank slopes was performed. The geotechnical data contained in previous subsurface investigation reports were used to characterize the soil types and basic engineering properties of the alluvial soils encountered along lower Aliso Creek. These data generally consisted of boring logs and a limited amount of laboratory testing of soil samples taken from the borings.

3.4.1 Slope Stability Analysis Methodology

Slope stability analyses were performed through simulations using SLIDE computer software (Version 6.011, released May 10, 2011) developed by Rocscience, Inc. The software can simulate the influences of various types of soil stratification, slope geometry, and groundwater conditions using limit equilibrium to calculate the factor of safety for various scenarios. The factor of safety is defined as the ratio of resisting forces to driving (destabilizing) forces. The factor of safety of various bank slope heights and slope angles were evaluated in order to estimate the required setback from the stable bank slope associated with different tolerances for risk.

3.4.1.1 Limitations of Slope Stability Analyses

As identified in Section 2.1, available documentation indicates only cursory slope stability analyses have previously been applied along the banks of lower Aliso Creek. Given the lack of extensive soil strength data that are typically required for detailed slope stability analyses, the results presented in this study are subject to the following limitations:

- The slope stability analyses performed as part of the geotechnical assessment of bank instabilities were based on the existing conditions and very limited soil strength data.
- The analyses were based on generalized estimates regarding soil stratigraphy and strength properties. In locations where the proposed pipeline alignments are categorized as *High* risk due to the proximity to a currently unstable slope bank, additional detailed geotechnical analyses should be performed during subsequent design phases.
- The current study only addressed stability issues with regard to alluvial soils exposed in the creek banks. The regional geologic conditions include numerous landslides in the bedrock formations along both banks of lower Aliso Creek. In any area where bedrock or landslide materials are exposed or found to be in the near-surface within the channel bed and/or banks, additional detailed study should be performed.
- The current study included fairly conservative assumptions regarding groundwater conditions and surface cracking; however, field observations indicate that surface runoff from upland areas has been problematic at various locations along the creek alignment. Areas where surface erosion of the bank is occurring due to concentrated upland runoff should be evaluated, and appropriate remedial drainage measures and/or slope protection should be implemented.

3.4.1.2 Model Input Data

Due to the lack of soil strength data typically available for detailed slope stability analyses, several simplifications regarding soil and slope conditions were applied for the slope stability analyses.

Previous geologic studies, observations made during field reconnaissance, and regional geologic mapping confirm substantial variation of soil types within the alluvial valley bottom containing Aliso

Creek. Further, these sources confirm interbedded stratification of different soil types. As described in Section 3.4.1.2, bank materials can generally be categorized into two groups: 1) soils bearing cohesive clays or 2) low cohesive silty soils. The clayey soils are typically low plasticity clays and clayey sands whereas the silty soils are typically silty sands and sandy silts. Localized layers of more coarse grained sands and gravels were encountered in some of the borings logs but comprise a fairly small portion of the overall stratigraphy. Therefore, the slope stability analyses were run for only two types of bank materials: clayey soils and silty soils. By grouping the various soils into these two classes, the influence of stratification was not further considered. For simplicity, the slope stability analyses were performed without consideration of stratification of clayey and silty soils.

Strength and density properties of the two soil categories were estimated based on Standard Penetration Test (SPT) (ASTM 1586-11) blow-counts (N-values) and on data from the two direct shear tests available from the existing geotechnical data (MACTEC Engineering and Consulting, Inc. 2007, Ninyo & Moore 2009). A summary of the assumed soil parameters is presented in **Table 3-4**.

Table 3-4. Estimated Values of Selected Bank Material Properties

Bank Material Type	Total Unit Weight (lbs/ft^3)	Cohesion (lbs/ft^2)	Angle of Internal Friction (degrees)
Clayey Soils (Silty Clays/Clayey Sands)	130	100	27
Silty Soils (Sandy Silts/Silty Sands)	130	50	30

Historical records of flows in Aliso Creek indicate that water-surface elevations rise and recede relatively quickly due to the flashy nature of the urban hydrology. The peak water-surface elevations during the 100-year flood, as calculated using the HEC-RAS model (Section 3.3), are around 10 feet above the channel bottom. To account for potential unbalanced water pressure within the banks following periods of rapid hydrograph recession (i.e., drawdown), a residual piezometric surface five feet above the toe of slope was incorporated in the model. This piezometric surface is considered a conservative allowance for unbalanced water pressure because the full rising limb of flood hydrographs including sustained peak flows are of relatively short duration (i.e., up to 18 hours during the 100-year flood). As a result, the depth of saturation into the slope face is anticipated to be limited.

Field observations of existing slope failures and instabilities along lower Aliso Creek indicate that tension features (i.e., near-vertical cracks) parallel to the top of slope appear to be a contributing cause of bank instability. These cracks initially develop as a result of desiccation of the upper soils above the slope and/or stress fractures due to slope deformation of the bank (creep). These open fissures can fill with surface water during rains, increasing the destabilizing forces on the portion of the slope riverward of the tension crack. The initial tension features typically extend several feet below the ground surface; however, as failure of the slope progresses these tension cracks develop into deep shear fractures which can extend to the basal plane of the failure wedge. Conservatively, a depth of initial tension cracking equal to one-quarter of the overall slope height was incorporated into the SLIDE simulations.

3.4.1.3 Results of Slope Stability Analyses

The results of the slope stability analyses are presented by bank material in **Figure 3-6** (clayey soils) and **Figure 3-7** (silty soils). For clayey soils, curves relating calculated factors of safety to stable bank slopes are shown for various overall slope heights (10 to 30 feet). For silty soils, simulation results confirmed that the factor of safety is not substantially influenced by slope height; thus, only one curve representative of all slope heights is shown. The curves are used to identify a stable slope for a desired factor of safety (i.e., tolerance for risk) given the bank materials and bank height. Typically a minimum factor of safety of 1.5 is utilized for slope stability considerations, and this value is identified in both **Figure 3-6** and **Figure 3-7**. A factor of safety of 1.0 is indicative of incipient failure, so for comparison purposes, this value is also shown in **Figure 3-6** and **Figure 3-7**. Building codes frequently specify minimum setbacks from stable slopes for permanent construction. The California Building Code specifies a minimum foundation setback of one-third of the slope height, up to a maximum setback of 40 feet, from the top of a stable slope (California Building Standards Commission 2010). In cases where a proposed pipeline is located at an elevation below the top of slope, this setback was applied at the elevation of the proposed pipeline.

Figures B-1, B-2, B-5, B-6, B-7, and **B-8** in Appendix B show examples of the projected stable slope as compared to the current existing bank slope.

The other key factor in assessing appropriate setback from the existing bank slope is the establishment of the effective toe of slope. The toe is the anchor point that determines the reference location for application of the stable slope provided in **Figure 3-6** and **Figure 3-7**. The effective toe of slope should be established at no higher an elevation than the expected maximum extent of vertical degradation and no farther riverward than the expected extent of lateral erosion/migration of the bank. The degradation and erosion potentials are described in Section 3.3.

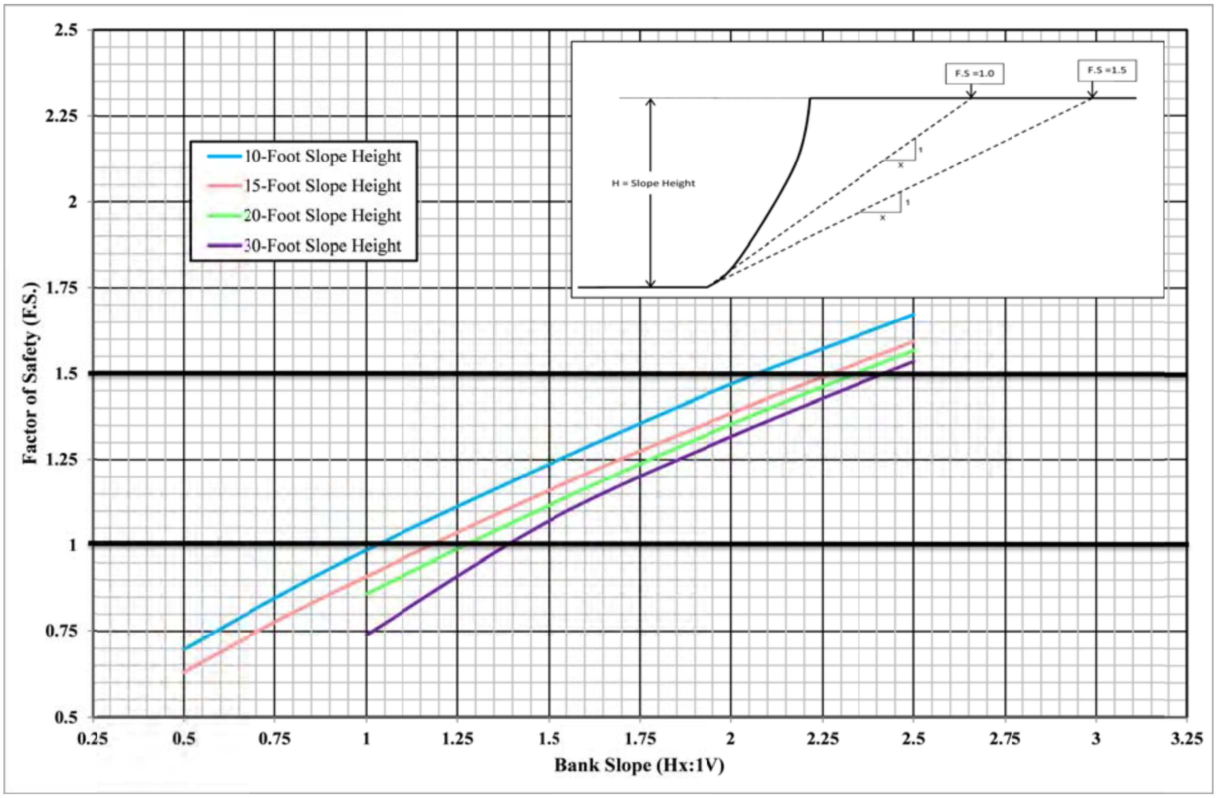

Figure 3-6. Equilibrium Slope Relationships for Clayey Bank Materials

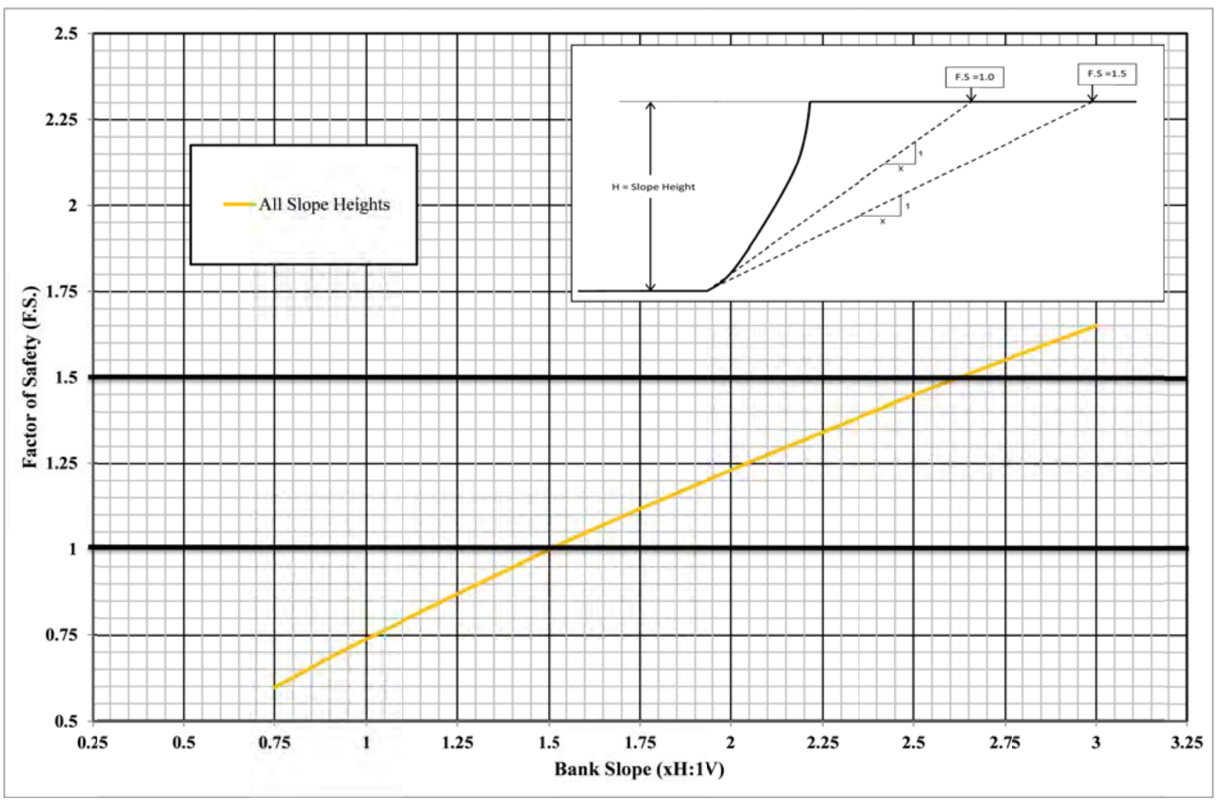

Figure 3-7. Equilibrium Slope Relationships for Silty Bank Materials

3.4.2 Categorization of Geotechnical Erosion Risk to Proposed Pipeline Alignments

Existing bank heights and slopes in many locations along lower Aliso Creek are geotechnically unstable, and geotechnical failures of the banks (e.g., mass wasting) will continue to erode the banks. The results of the slope stability analyses (Section 3.4.1) were used to categorize predicted geotechnically stable bank slopes relative to the proposed pipeline alignments. This was done as a two-step process. The first step was to screen, in a conservative manner, locations where the proposed alignment is likely to be outside the influence of future geotechnical bank failures. A buffer was delineated along the existing top of banks (**Figure 3-8**) using an estimated maximum bank height of 35 feet, the stable slope of 2.6H:1V for silty materials applying a factor of safety of 1.5, and the setback distance based on California Building Code of one-third of the slope height. This results in a buffer width of approximately 100 feet. The alignment of the proposed FM 1 and FM 2 pipelines was compared to the extents of the bank buffers. If the alignments were within the buffers, site-specific calculations using actual bank heights and bank materials were required; if the alignments were outside the buffers, the potential for geotechnical instabilities of the banks to impact the stability of the proposed pipelines was automatically categorized as *Low* (**Figure 3-9**).

Where site-specific calculations were required to assess the risk of geotechnical erosion on the proposed pipelines, bank heights were calculated using the cross section geometry in the hydraulic model. Where the geotechnical borings show the banks contain clay-bearing materials, bank heights were rounded up to the categories shown in **Figure 3-6**. If geotechnical boring data indicated clay-bearing materials in the bank, the bank slope curves presented in **Figure 3-6** were used; if the borings indicated silty materials, or if no information was available, the curve for silty material shown in **Figure 3-7** was used. Locations within the 100-foot top of bank buffer are discretely located along the length of the banks (**Figure 3-8**); for simplification, the site specific calculations were conducted on the critical section at each location. The critical section was identified by evaluating the following factors: slope height, slope angle, bank materials, and the distance between the existing bank and the proposed pipeline alignments. Appendix C includes schematics illustrating the stable slope calculations applied to the critical sections. After applying the recommended setback of one-third of the bank height to the stable bank slope, the geotechnical erosion potential was categorized as illustrated in **Figure 3-9**.

Despite the frequent observations made during the field reconnaissance of geotechnically unstable banks, the proposed pipeline alignments are generally landward of the stable bank angles (F.S. = 1.5) including the recommended setback distance of one-third the slope height. The geotechnical erosion risk is rated *Low* along both proposed alignments except for a single reach along the east (left) bank (FM 1 pipeline alignment) from approximately RM 4.49 to RM 4.55 that is rated *Moderate*.

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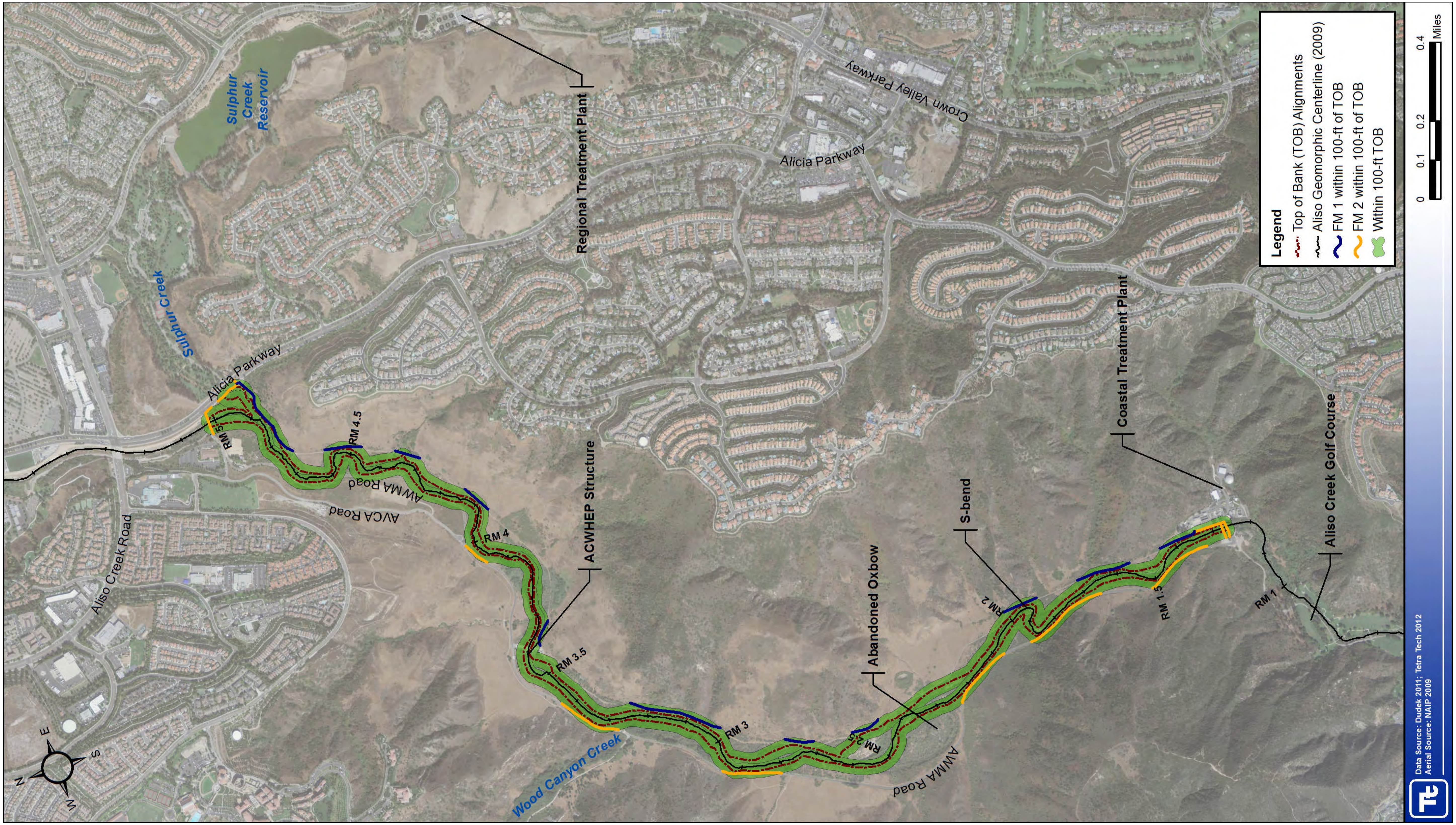

Figure 3-8. Screening of Proposed Pipeline Alignments for Areas Potentially Impacted by Geotechnically Unstable Banks

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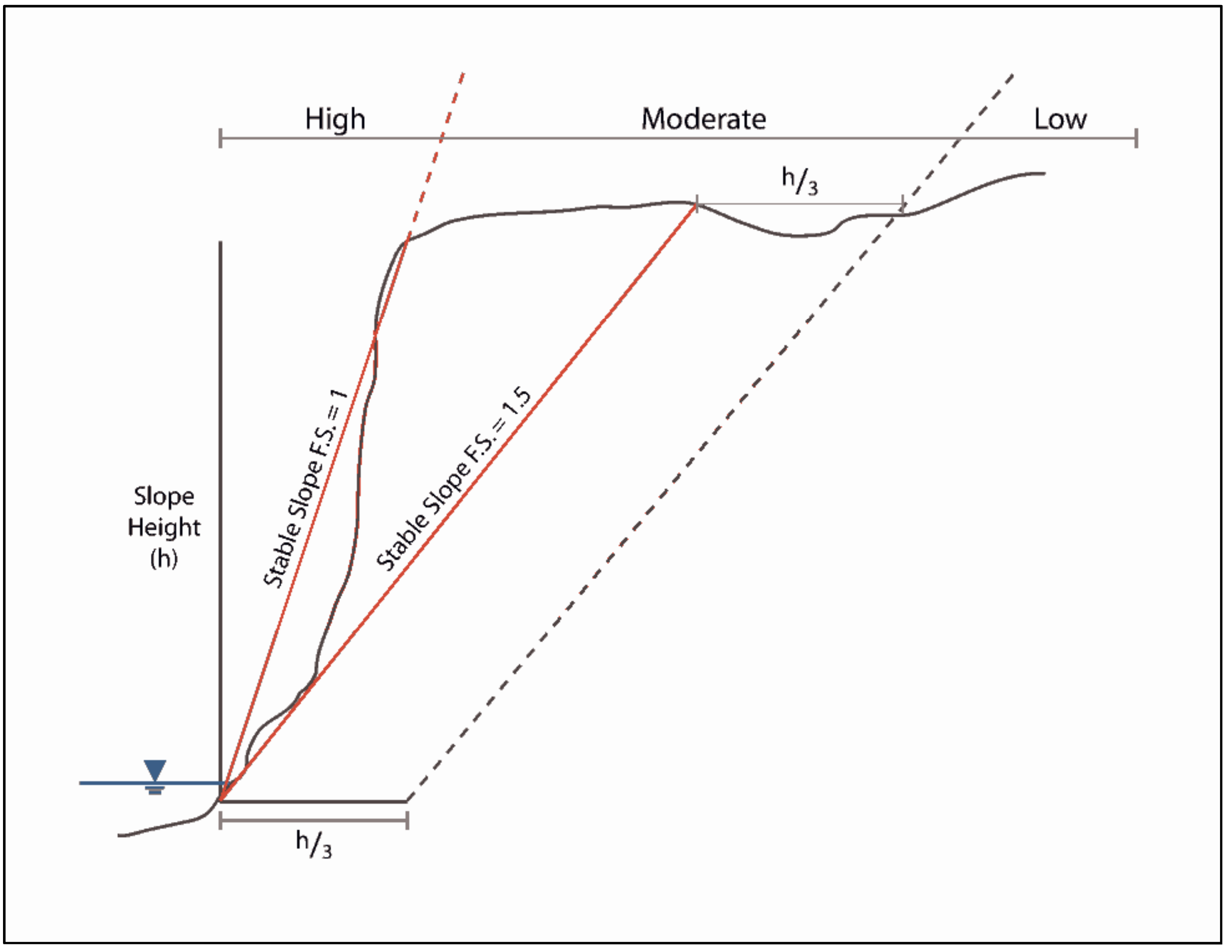

Figure 3-9. Categories of Geotechnical Erosion Risk

3.5 Erosion Risk Associated with Bend Migration

As addressed at the end of Section 3.4.1.3, the evaluation of risk posed to the proposed pipelines depends in part on the establishment of the toe of the bank. While the geomorphic characterization (Section 2.2) provides a basis for expecting limited future systemic channel incision and widening, localized changes from existing conditions are likely. One such change could be the landward translation of the toe of a bank along the outside of a bend due to bend migration. The valley bottom containing lower Aliso Creek is alluvial, so there is the potential for bank erosion along the outside of bends to migrate toward the proposed alignments. Fluvial removal of failed bank materials from the toe of banks along the outside of bends keeps the bank slopes near-vertical, and this continues the mass wasting erosional processes. Such a lateral translation of the bank will cause the predicted stable bank slopes to move landward a distance equivalent to any landward migration of the toe of slope. Data to quantify historical rates of bend migration are not available for lower Aliso Creek. In the absence of such data, the 2009 centerline delineation has been overlaid on 1939 aerial photography to illustrate the consistency in the planform of the channel (**Figure 3-10**). Of approximately two dozen bends along lower Aliso Creek, comparison of the 1939 centerline to the 2009 centerline shows about half of these bends have migrated. Where the banks along the outside of the bends have not been protected, average rates of migration range from approximately 0.5 to 1.3 feet per year, with an average of approximately 0.9 feet per year. While the planform of lower Aliso Creek has generally persisted since 1939, the cross sectional-area of the channel has enlarged approximately eight-fold between the early 1970s and the late 1990s (Tetra Tech, Inc. 2010) as shown on **Figure B-1**. Bend migration is a common occurrence in alluvial rivers, but the comparison illustrated in **Figure 3-10** doesn't indicate substantial bend migration processes occurring in lower Aliso Creek, despite the highly dynamic processes of downcutting and channel widening, over this period of approximately 70 years.

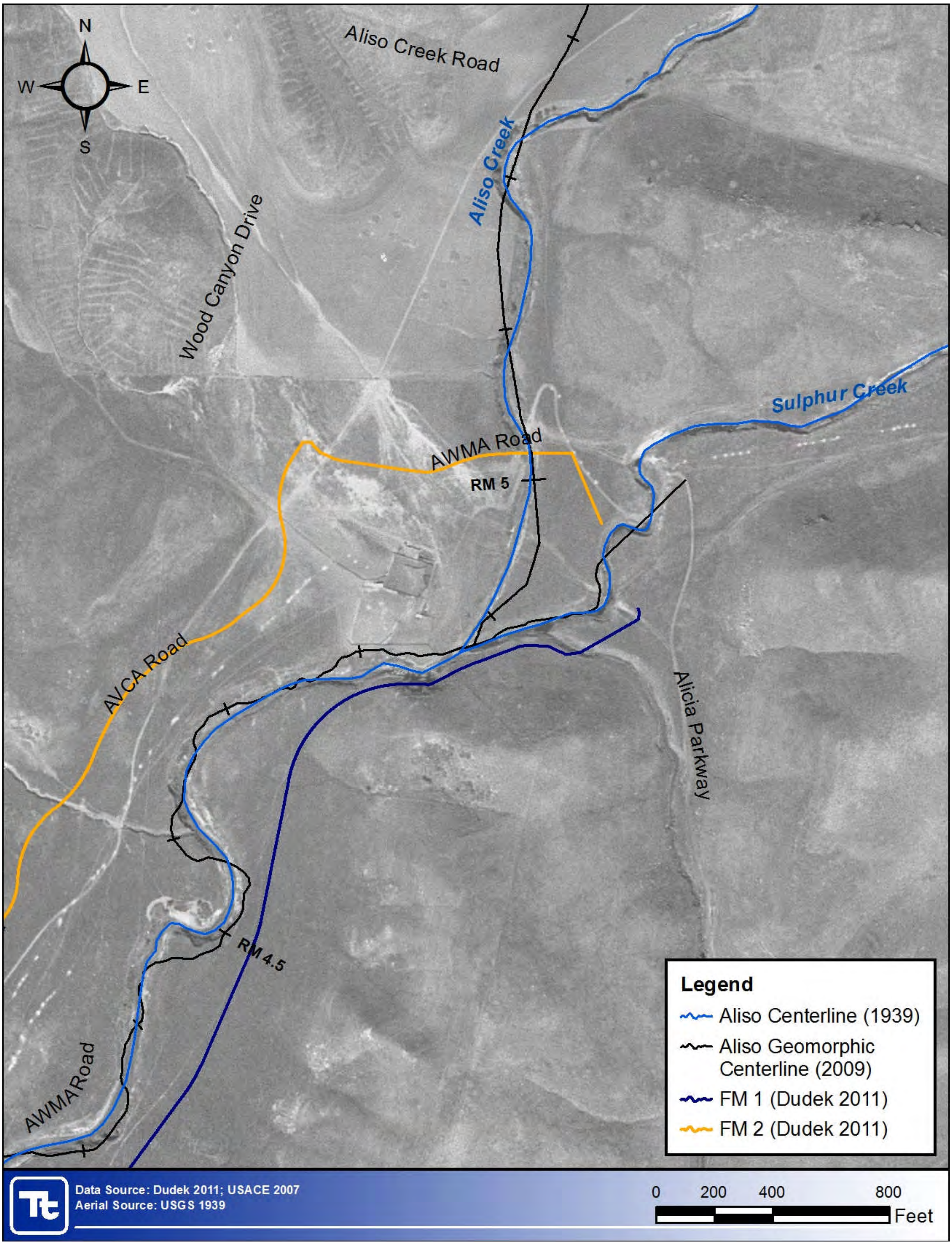

Figure 3-10 (Map 1 of 5). 2009 Channel Alignment Overlaid on 1939 Aerial Photography

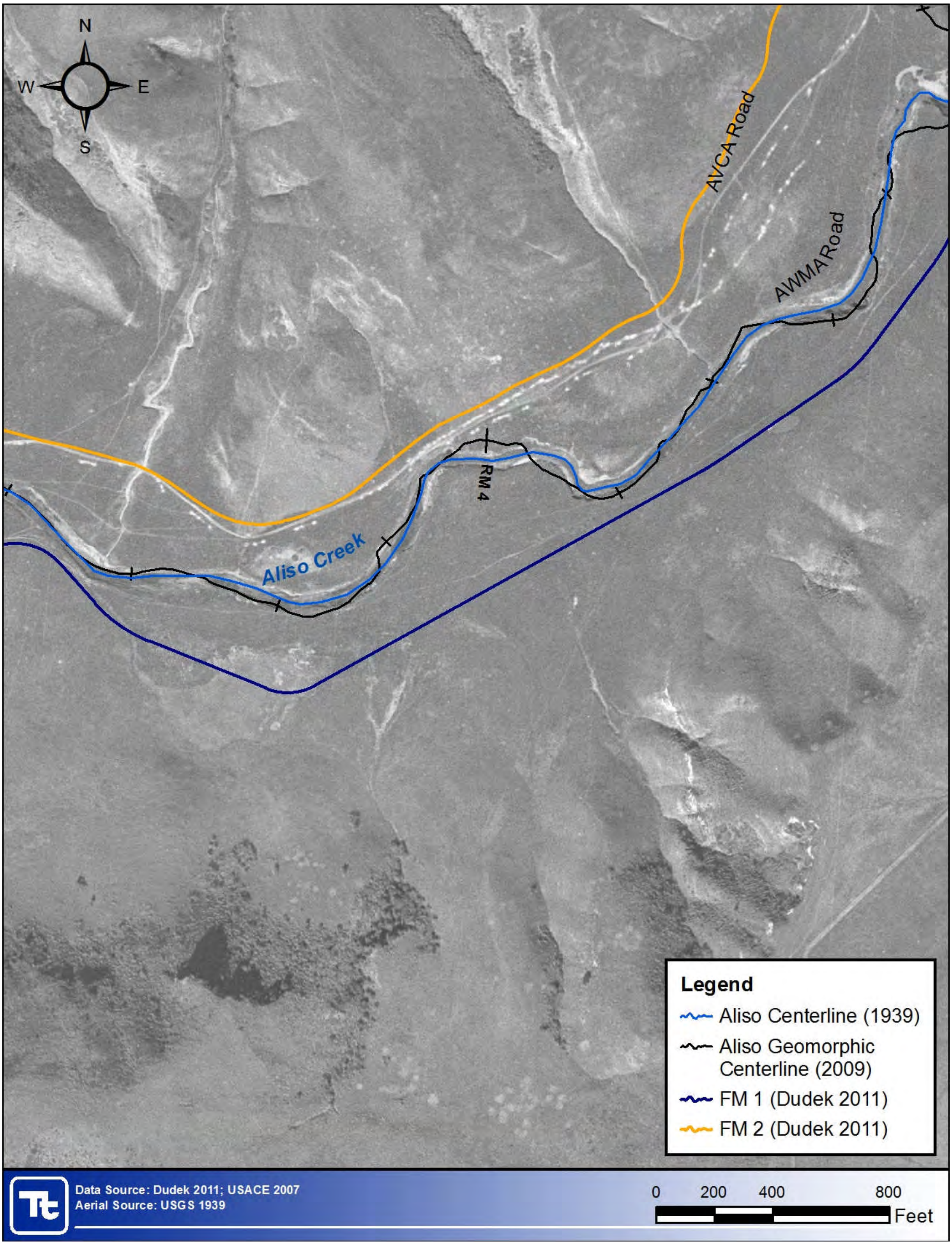

Figure 3-10 (Map 2 of 5). 2009 Channel Alignment Overlaid on 1939 Aerial Photography

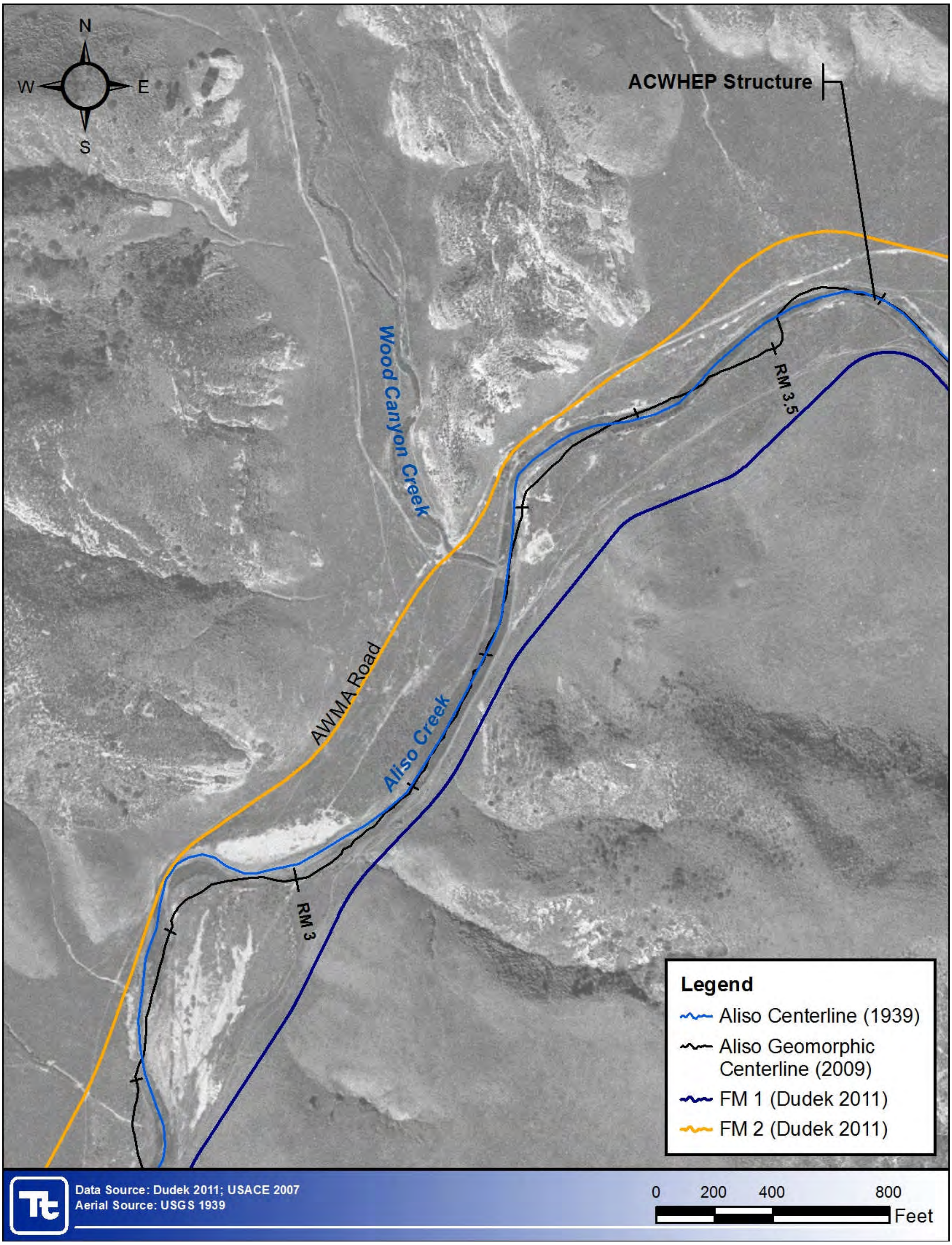

Figure 3-10 (Map 3 of 5). 2009 Channel Alignment Overlaid on 1939 Aerial Photography

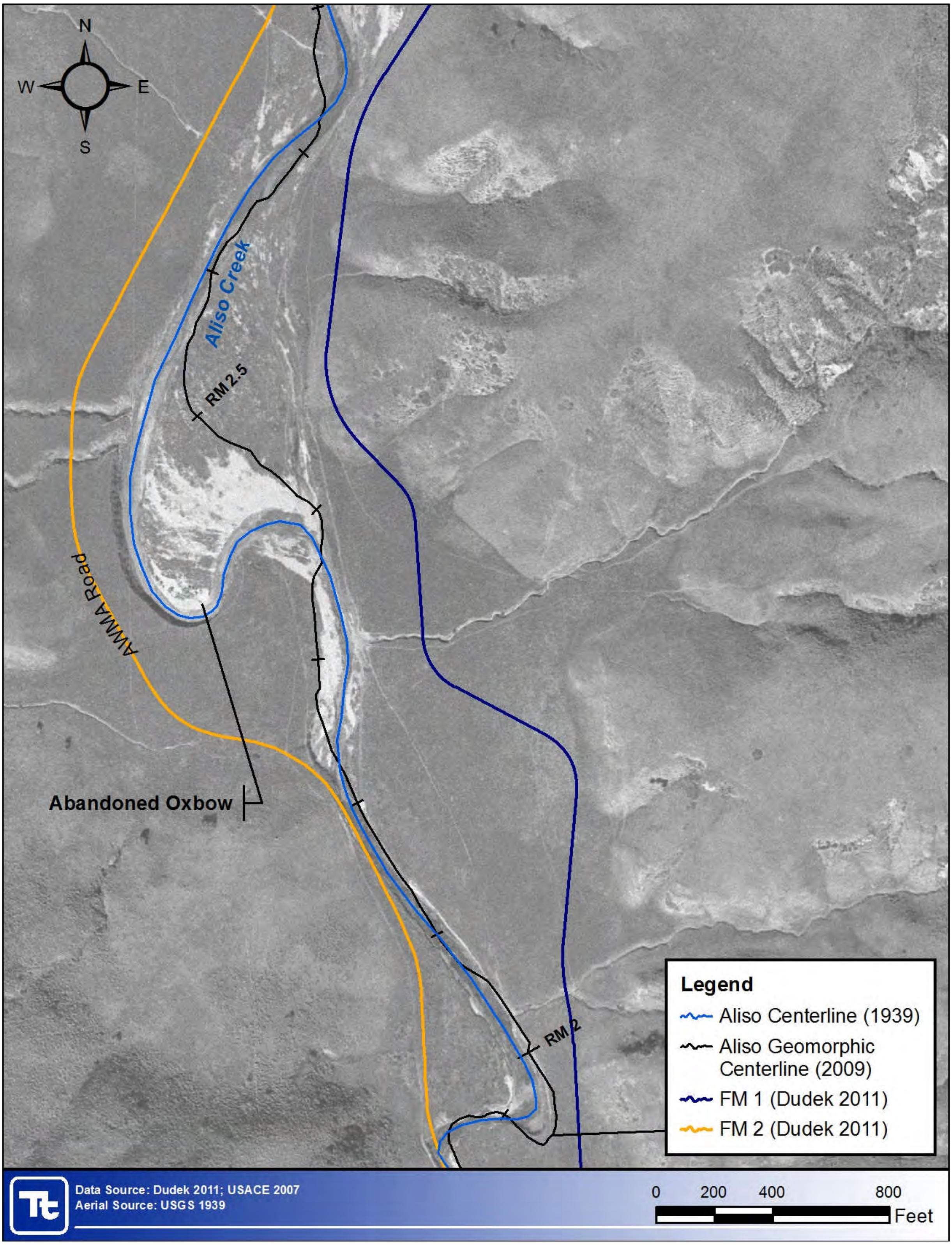

Figure 3-10 (Map 4 of 5). 2009 Channel Alignment Overlaid on 1939 Aerial Photography

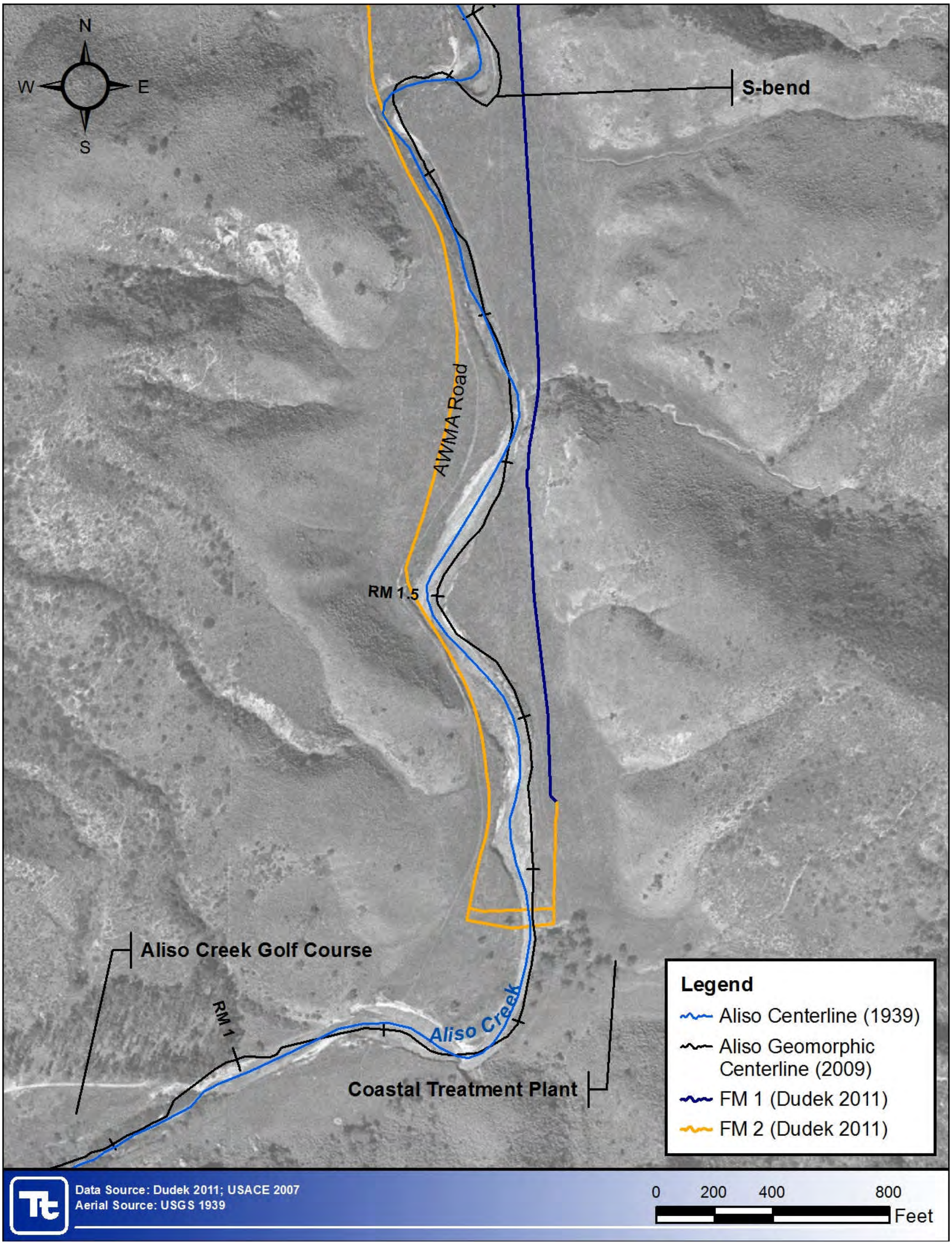

Figure 3-10 (Map 5 of 5). 2009 Channel Alignment Overlaid on 1939 Aerial Photography

Even though the historical record indicates a limited propensity for bend migration, the potential impact on the proposed pipeline alignments of bank erosion induced by bend migration was assessed. The fluvial erosion potential was evaluated along the outside of bends (**Table 3-5** and **Table 3-6**). If the fluvial erosion potential is rated *Moderate* or *High*, bend migration is more likely to occur over the 50-year planning period. This potential for migration could be mitigated by the presence of properly designed and installed bank protection measures maintained in good condition; however, due to the absence of engineering designs associated with the installation of existing emergency bank protection measures, it was assumed there would be limited effectiveness for these measures to mitigate the long-term potential for bend migration. Using the results from the slope stability analyses, the distance was calculated between the predicted stable bank slope (including the setback equal to one-third of the slope height) and the proposed pipeline at the proposed elevation of the pipeline (Appendix C). These calculations were made for critical sections (taken to be applicable to conditions along the outside of a bend of interest).

For sites where the distance between the predicted stable bank slope and the proposed pipeline is less than 50 feet and the fluvial erosion potential (based on the highest rating of any section within the full extent of the bend) is rated *High* or *Moderate*, the risk to the proposed pipelines of bank erosion associated with bend migration was rated *High*. Since the comparison of the 2009 channel centerline to the 1939 centerline revealed that unprotected banks along the outside of bends along lower Aliso Creek have migrated at an average rate of about 1.0 feet per year, a distance of 50 feet was selected to represent an estimate a reasonable threshold of bend migration over the 50-year planning period. If the fluvial erosion potential is *Low*, the erosion potential due to bend migration was rated *Moderate*.

For sites where the distance between the calculated stable bank slope (including the setback equal to one-third the slope height) and the proposed pipeline is greater than 50 feet, the risk to the proposed pipelines of bank erosion induced by bend migration is rated *Low* – independent of the fluvial erosion potential.

The results of this analysis are presented in **Table 3-5** and **Table 3-6** for the east (left) bank and west (right) bank, respectively.

Table 3-5. Erosion Risk Associated with Bend Migration along the East (Left) Bank

Approximate Bend Extents (RM)	Critical Section (RM)	Fluvial Erosion Potential	Approximate Offset from Stable Slope[1] (feet)	Erosion Risk Associated with Bend Migration
0.105 – 0.074[s]	0.088[s]	High	30	High
4.88 – 4.83	4.854	Low	10	Mod.
4.56 – 4.464	4.522	Mod.	0	High
4.36 – 4.29	4.330	Low	65	Low
4.138 – 4.08	4.138	Low	85	Low
3.71 – 3.657	3.677	Low	70	Low
3.257 – 2.985	3.095	High	5	High
2.768 – 2.668	2.713	Low	65	Low
2.58 – 2.479	2.509	Low	15	Mod.
1.989 – 1.91	1.989	Mod.	35	High
1.703 – 1.56	1.608	High	30	High
1.44 – 1.353	1.370	Low	10	Mod.

Note:

[s] Indicates river mile is measured upstream along Sulphur Creek from the Aliso Creek confluence.

[1] Offset is estimated as the distance between the setback of one-third the slope height from the stable slope and the proposed pipeline alignment.

Table 3-6. Erosion Risk Associated with Bend Migration along the West (Right) Bank

Approximate Bend Extents (RM)	Critical Section (RM)	Fluvial Erosion Potential	Approximate Offset from Stable Slope[1] (feet)	Erosion Risk Associated with Bend Migration
4.03 – 3.937	4.003	Mod.	100	Low
3.580 – 3.505	3.555	High	90	Low
3.366 – 3.291	3.346	Low	20	Mod.
2.967 – 2.89	2.898	High	10	High
2.26 – 2.167	2.193	Mod.	5	High
1.90 – 1.817	1.817	Low	10	Mod.
1.52 – 1.464	1.449	High	5	High

Note:

[1] Offset is estimated as the distance between the setback of one-third the slope height from the stable slope and the proposed pipeline alignment.

4 Erosion Assessment Summary

The analyses described in this report were conducted in support of the ongoing preparation of an EIR for the SOCWA CTP Export Sludge Force Main Replacement Project. Previous studies and historical infrastructure maintenance along lower Aliso Creek have highlighted the key influence bank erosion plays in the stability of roads and pipelines adjacent to the channel. The following sections summarize the combined influence of fluvial erosion potential, geotechnical erosion risk, and risk of bank erosion associated with bend migration to the stability of proposed force main alignments for the 50-year planning period.

The combined erosion risk rating was assigned based primarily on the risk to the stability of the proposed pipeline alignments of bank erosion induced by bend migration, with consideration given to the risk of bank erosion due to geotechnical instabilities. The combined erosion risk rating was assigned based on the higher erosion risk rating assigned to either the geotechnical erosion or the bend migration. A *High* erosion risk implies, based on the analyses conducted, that the proposed pipeline alignment will likely be impacted by bank erosion over the 50-year planning period, so pipeline realignment or bank protection measures are recommended. A *Moderate* risk implies, based on the analyses conducted, that the pipeline alignment could be impacted over the planning period, so bank erosion should be monitored on a regular basis (i.e., after all floods) and bank protection measures installed if necessary. A *Low* risk implies, based on the analyses conducted, that the pipeline alignment is unlikely to be impacted by bank erosion, so occasional monitoring is recommended (i.e., every few years, or after major floods, whichever occurs first).

4.1 Proposed FM 1 Alignment

The proposed FM 1 alignment along the east (left) bank is potentially subject to approximately 3,300 feet of *High* erosion risk and approximately 1,250 feet of *Moderate* erosion risk; the remainder of the proposed alignment (approximately 12,050 feet) is rated *Low* risk. The locations associated with these ratings are shown in **Table 4-1** as well as in **Figure 4-1**. The Fluvial Erosion Potential is presented for reference in **Table 4-1** but was not directly incorporated into the combined erosion risk rating since it was previously factored into the bend migration risk ratings. For ease of interpreting **Table 4-1** and to highlight potential areas of concern, the *Low* ratings are not shown.

Table 4-1. Summary of Erosion Risk to the Proposed FM 1 Alignment along the East (Left) Bank

River Mile	Fluvial Erosion Potential	Geotechnical Erosion Risk[1]	Bend Migration Risk[1]	Combined Erosion Risk[1]
Sulphur Creek				
0.120	M			
0.105	H		H	H
0.088	L		H	H
0.067	H			
0.036	H			
0.023	M			
Aliso Creek				
4.854	L		M	M
4.785	M			
4.717	L			
4.656	L			
4.595	L			
4.522	M	M	H	H
4.464	L		H	H
4.398	L			
4.330	L			
4.266	L			
4.199	L			
4.138	L			
4.067	H			
4.003	L			
3.937	M			
3.872	L			
3.810	M			
3.741	L			
3.677	L			
3.657	L			
3.639	M			
3.621	H			
3.613	M			
3.604	H			
3.601	H			
3.594	L			
3.589	L			
3.580	L			
3.567	L			
3.555	L			
3.535	L			

River Mile	Fluvial Erosion Potential	Geotechnical Erosion Risk[1]	Bend Migration Risk[1]	Combined Erosion Risk[1]
3.505	L			
3.484	H			
3.465	L			
3.444	M			
3.423	L			
3.399	L			
3.382	L			
3.366	L			
3.346	L			
3.335	L			
3.314	L			
3.291	L			
3.276	L			
3.257	L		H	H
3.243	L		H	H
3.231	L		H	H
3.214	L		H	H
3.191	L		H	H
3.169	L		H	H
3.149	L		H	H
3.131	L		H	H
3.110	M		H	H
3.095	M		H	H
3.074	M		H	H
3.057	M		H	H
3.033	L		H	H
3.014	H		H	H
3.000	H		H	H
2.985	L		H	H
2.967	L			
2.945	L			
2.919	L			
2.898	H			
2.881	M			
2.864	M			
2.842	H			
2.823	L			
2.802	L			
2.784	L			
2.768	L			
2.753	L			
2.736	L			

River Mile	Fluvial Erosion Potential	Geotechnical Erosion Risk[1]	Bend Migration Risk[1]	Combined Erosion Risk[1]
2.713	L			
2.692	L			
2.668	L			
2.649	L			
2.634	L			
2.594	L			
2.565	L		M	M
2.544	L		M	M
2.509	L		M	M
2.479	L		M	M
2.456	H			
2.434	L			
2.412	L			
2.392	L			
2.372	L			
2.355	L			
2.334	L			
2.312	L			
2.294	L			
2.270	L			
2.243	L			
2.233	L			
2.208	L			
2.193	L			
2.167	L			
2.149	M			
2.131	M			
2.113	H			
2.097	L			
2.076	M			
2.056	H			
2.035	M			
2.013	H			
1.989	L		H	H
1.971	M		H	H
1.955	M		H	H
1.930	L		H	H
1.904	L			
1.887	L			
1.865	L			
1.843	L			
1.817	L			

River Mile	Fluvial Erosion Potential	Geotechnical Erosion Risk[1]	Bend Migration Risk[1]	Combined Erosion Risk[1]
1.789	M			
1.767	H			
1.746	L			
1.723	L			
1.703	L		H	H
1.684	L		H	H
1.661	L		H	H
1.644	L		H	H
1.625	L		H	H
1.608	M		H	H
1.586	H		H	H
1.569	M		H	H
1.543	L			
1.520	L			
1.496	L			
1.464	L			
1.449	L			
1.429	L		M	M
1.410	L		M	M
1.391	L		M	M
1.370	L		M	M
1.353	L		M	M
1.333	L			
1.315	L			
1.295	L			
1.274	L			

Note:
Ratings of *L* not shown to facilitate interpretation of results in the table, and to highlight potential problem areas.

Figure 4-1 (Map 1 of 4). Combined Erosion Risk To Proposed FM 1 and FM 2 Alignments

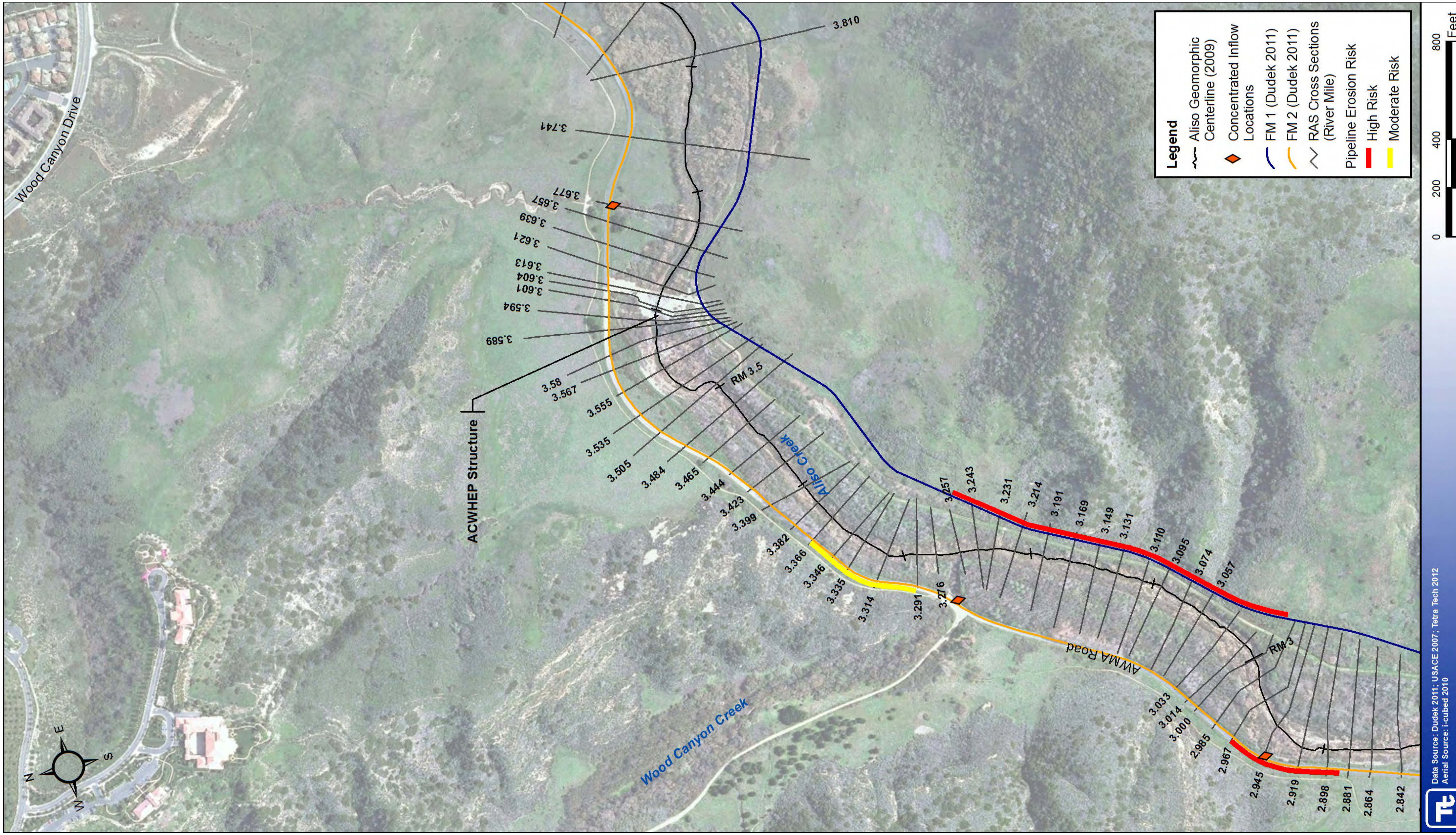

Figure 4-1 (Map 2 of 4). Combined Erosion Risk To Proposed FM 1 and FM 2 Alignments

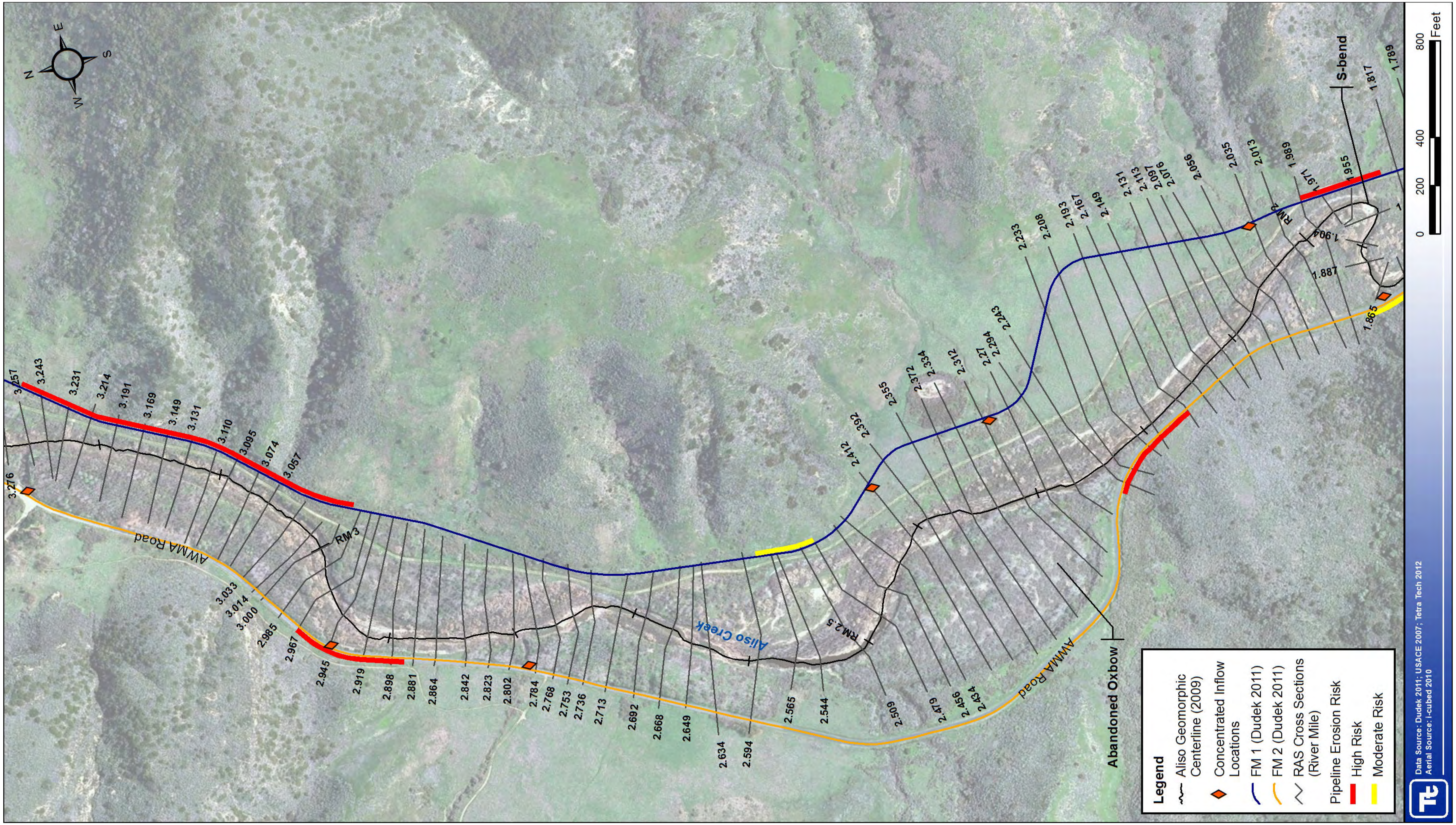

Figure 4-1 (Map 3 of 4). Combined Erosion Risk To Proposed FM 1 and FM 2 Alignments

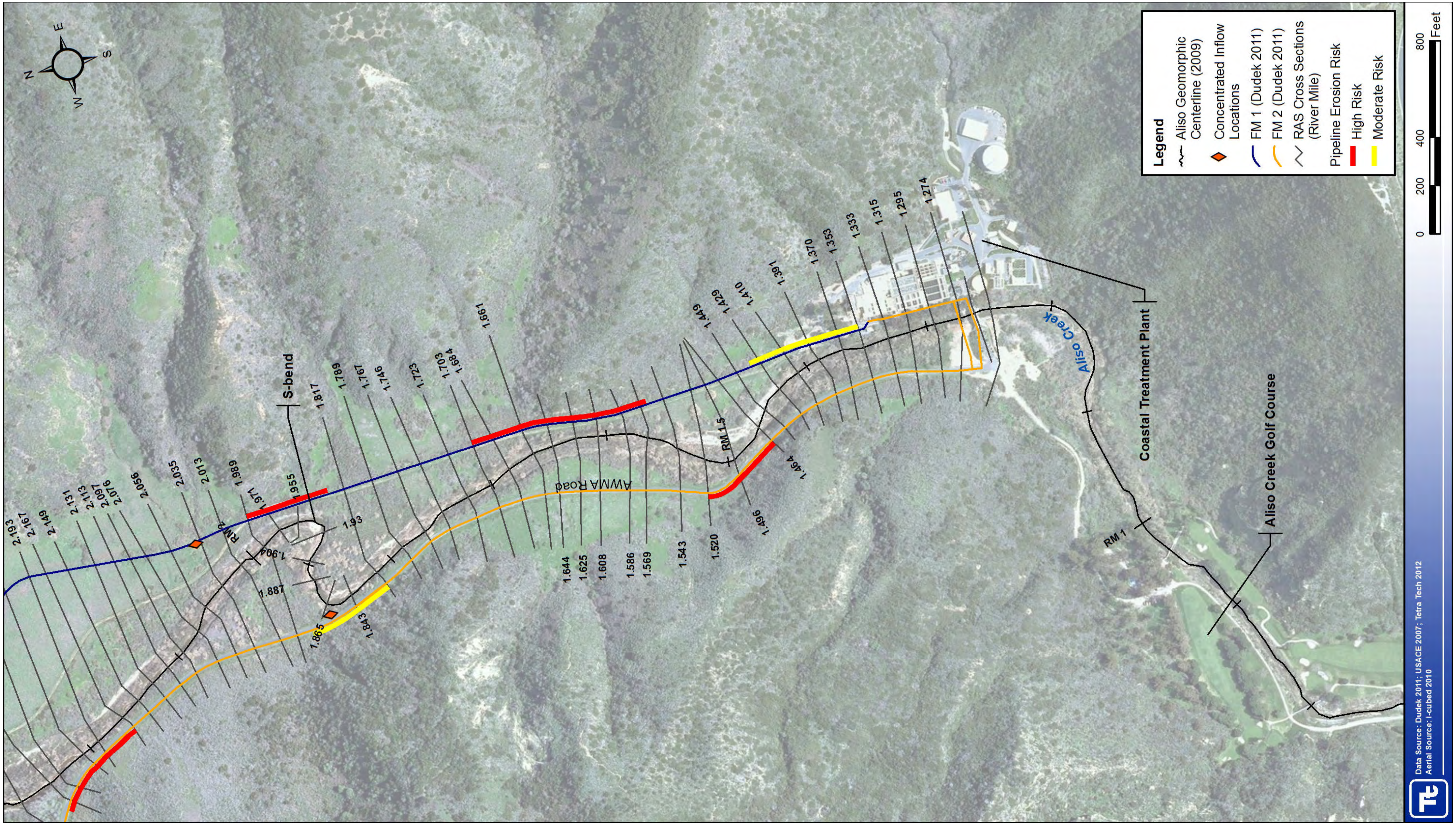

Figure 4-1 (Map 4 of 4). Combined Erosion Risk To Proposed FM 1 and FM 2 Alignments

4.2 Proposed FM 2 Alignment

The proposed FM 2 alignment along the west (right) bank is potentially subject to approximately 1,200 feet of *High* erosion risk and 850 feet of *Moderate* erosion risk; the remainder of the proposed and existing alignment (approximately 17,350 feet) is rated *Low* risk. The locations associated with these ratings are shown in **Table 4-2** as well as on **Figure 4-1**. The Fluvial Erosion Potential is presented for reference in **Table 4-2** but was not directly incorporated into the combined erosion risk rating since it was previously factored into the bend migration risk ratings. For ease of interpreting **Table 4-2** and to highlight potential problem areas, the *Low* ratings are not shown.

Table 4-2. Summary of Erosion Risk to the Proposed FM 2 Alignment Along the West (Right) Bank

River Mile	Fluvial Erosion Potential	Geotechnical Erosion Risk[1]	Bend Migration Risk[1]	Combined Erosion Risk[1]
Sulphur Creek				
Not Applicable				
Aliso Creek				
5.014	L			
5.011	L			
4.984	L			
4.916	L			
4.854	L			
4.785	M			
4.717	L			
4.656	L			
4.595	M			
4.522	L			
4.464	H			
4.398	L			
4.330	L			
4.266	L			
4.199	L			
4.138	L			
4.067	H			
4.003	L			
3.937	M			
3.872	L			
3.810	M			
3.741	M			
3.677	L			
3.657	L			
3.639	M			
3.621	H			

River Mile	Fluvial Erosion Potential	Geotechnical Erosion Risk[1]	Bend Migration Risk[1]	Combined Erosion Risk[1]
3.613	M			
3.604	H			
3.601	H			
3.594	M			
3.589	M			
3.580	H			
3.567	H			
3.555	H			
3.535	H			
3.505	L			
3.484	H			
3.465	L			
3.444	M			
3.423	L			
3.399	L			
3.382	L			
3.366	L		M	M
3.346	L		M	M
3.335	L		M	M
3.314	L		M	M
3.291	L		M	M
3.276	L			
3.257	L			
3.243	L			
3.231	L			
3.214	L			
3.191	L			
3.169	L			
3.149	L			
3.131	L			
3.110	L			
3.095	L			
3.074	L			
3.057	L			
3.033	L			
3.014	L			
3.000	L			
2.985	L			
2.967	L		H	H
2.945	M		H	H
2.919	L		H	H
2.898	H			

River Mile	Fluvial Erosion Potential	Geotechnical Erosion Risk[1]	Bend Migration Risk[1]	Combined Erosion Risk[1]
2.881	M			
2.864	M			
2.842	H			
2.823	L			
2.802	L			
2.784	L			
2.768	L			
2.753	L			
2.736	L			
2.713	L			
2.692	L			
2.668	L			
2.649	L			
2.634	L			
2.594	L			
2.565	L			
2.544	L			
2.509	M			
2.479	H			
2.456	L			
2.434	L			
2.412	L			
2.392	L			
2.372	L			
2.355	L			
2.334	L			
2.312	L			
2.294	L			
2.270	M			
2.243	M		H	H
2.233	L		H	H
2.208	M		H	H
2.193	L		H	H
2.167	L		H	H
2.149	M			
2.131	M			
2.113	H			
2.097	L			
2.076	M			
2.056	H			
2.035	M			
2.013	H			

River Mile	Fluvial Erosion Potential	Geotechnical Erosion Risk[1]	Bend Migration Risk[1]	Combined Erosion Risk[1]
1.989	M			
1.971	L			
1.955	L			
1.930	L			
1.904	L			
1.887	L		M	M
1.865	L		M	M
1.843	L		M	M
1.817	L		M	M
1.789	M			
1.767	H			
1.746	L			
1.723	L			
1.703	L			
1.684	L			
1.661	L			
1.644	L			
1.625	L			
1.608	L			
1.586	L			
1.569	L			
1.543	L			
1.520	H		H	H
1.496	M		H	H
1.464	L		H	H
1.449	L			
1.429	L			
1.410	L			
1.391	L			
1.370	L			
1.353	L			
1.333	L			
1.315	L			
1.295	L			
1.274	L			

Note:
Ratings of *L* not shown to facilitate interpretation of results in the table, and to highlight potential problem areas.

4.3 Additional Considerations

The previous tables focus on the potential risk impacting the pipeline from bank erosion; however, other factors may influence the potential for bank erosion to destabilize/undermine the proposed pipeline alignments. The following sections identify additional considerations that apply to both the pipeline alignments and should be considered as part of the overall understanding of potential erosion impact at the pipelines.

4.3.1 Concentrated Runoff and Tributaries

Along the length of Aliso Creek, runoff from upland areas is conveyed into the river. This occurs via concentrated overland flow, storm drains, drainage channels, and tributaries. At many of these inflow points, there is the potential for localized bank erosion. **Figures B-6** and **B-8** in Appendix B illustrate the impacts associated with concentrated surface runoff. Where the inflows, particularly concentrated runoff and tributaries, cross the proposed pipeline alignments (**Table 4.3** and **Figure 4-1**), there is the potential that the localized erosion could propagate landward from the bank and expose the pipeline. Thus, the crossings should be addressed as part of the pipeline replacement design.

Table 4-3. Concentrated Inflow Locations along Lower Aliso Creek

River Mile	Type of Inflow
FM 1 Alignment	
Sulphur 0.050	Tributary channel
4.522	Concentrated surface runoff
4.340	Tributary channel
2.412	Concentrated surface runoff
2.312	Tributary channel
2.040	Tributary channel
FM 2 Alignment	
3.677	Tributary channel
3.257	Tributary (Wood Canyon)
2.945	Concentrated surface runoff
2.784	Tributary channel
1.858	Concentrated surface runoff

Special consideration of the inflow from Wood Canyon Creek is warranted. The existing confluence of Wood Canyon Creek with Aliso Creek has undergone considerable erosion downstream of the AWMA Road crossing. This crossing has been protected with a riprap revetment, but observations indicate the protection is being flanked. The Wood Canyon watershed contains numerous recreational crossings of the creek, as well as environmental resources (e.g., the Wood Canyon Emergent Wetland) that could be impacted if the grade control provided by the crossing is lost. Additionally, downcutting that would propagate upstream from the crossing would contribute a substantial volume of sediment to Aliso Creek that could exacerbate bank erosion and lead to avulsions that could threaten existing and proposed pipeline alignments. Thus, the stability of this crossing is imperative from various perspectives.

4.3.2 Existing Bank Protection

Prior the field reconnaissance conducted for this study, the locations and extents of existing bank protection were not well documented. Where vegetation permitted access for observation, the extents and condition of bank protection measures were recorded. Due to the emergency conditions under which much of these protection measures were installed, standard engineering designs were likely not performed. Rather, the material is commonly dumped from the top of bank down the slope. In some instances, the riprap revetments appear to be in good condition. In these cases, the protection may limit future bank erosion over the 50-year planning period for the proposed pipelines. However, since specifications for factors such as toedown depths, layer thickness, rock durability, gradation, and filter blankets are not available, the existing good condition may not persist. Degradation (e.g., slumping, displacement, and weathering of older riprap) of the bank protection was observed during the field reconnaissance in places along both banks. While credit for mitigating fluvial erosion potential was provided for existing bank protection measures in good condition, it is necessary that these measures be maintained over the project planning period. The emergency measures may need to be replaced with engineered features designed for site specific locations along lower Aliso Creek.

4.3.3 Abandoned Pipelines

The ACWHEP structure was installed in the early 1990s to divert flow into irrigation pipes to restore floodplain vegetation. Between the diversion structure (RM 3.6) and the downstream end of the abandoned oxbow (RM 2.3), the PVC irrigation pipelines still exist in/on both banks of Aliso Creek. Due to breaks in the pipes near the diversion structure, the irrigation system is no longer operational; however, the pipes have simply been abandoned in place. Additionally, portions of 18-inch diameter VCP in the east (left) bank have been undermined; fixes primarily entail bypassing the exposed/broken reach. Both the abandoned irrigation and sewer pipes create flowpaths for seepage into and through the banks that can promote unstable conditions, resulting in bank failures. An extreme example of this process was observed along the east bank near RM 3.014 (represented in **Figure B-7** in Appendix B). Field observations indicate that high flows entered the open end of the irrigation pipe, traveled to a break in the pipe, and leaked into the bank materials contributing to the observed bank erosion and slumping. No attempt has been made to predict where this type of bank failure could occur; without a thorough understanding of the location of all abandoned pipes this type of failure should be considered as one that can and will occur randomly along the extents of the abandoned pipelines.

4.3.4 Vertical Channel Degradation

The processes discussed throughout this report focus on the potential for bank erosion and bend erosion to destabilize the proposed pipeline alignments. It should be noted that isolated potential for vertical degradation exists in the system (Tetra Tech, Inc. 2010). The only location where future vertical degradation is expected within the study area is between approximately RM 2.75 and RM 3.25. Various lengths of both channel banks in this reach have been identified as having a *High* combined erosion risk. If measures were taken to stabilize the channel bank in this reach, the potential for approximately 1 – 4 feet of additional vertical degradation (Tetra Tech, Inc. 2010) near RM 3.25 should be considered during design of the measures (the additional expected vertical degradation tapers to 0 feet at RM 2.75).

Previous studies (Tetra Tech, Inc. 2010) have noted the importance of the integrity of the ACWHEP diversion structure to the geomorphology of lower Aliso Creek. The diversion structure provides grade control to the bed of Aliso Creek, and the influence of this grade control extends considerable distances both upstream and downstream. If the functionality of this structure to hold grade is not maintained, substantial changes in channel morphology (e.g., upstream propagation of downcutting and downstream deposition) may occur.

4.3.5 Bridges

The proposed FM 2 alignment requires crossings of Aliso Creek at two bridges: 1) the CTP Bridge, and 2) the AWMA Bridge. The reliability of these bridges directly affects the vulnerability of this alternative over the 50 year planning period. Assessments of the erosion risk to the integrity of the bridges and evaluations of the structural integrity of the bridges were not conducted within this study; however, more detailed analyses are recommended in the future for further consideration of this alternative.

4.4 Limitations

The summaries of risk previously presented are dependent on the following key limitations:

- Simulations of future flood hydrology show peak flows are likely to be similar to recent historical conditions. However, differences between simulated flood hydrographs and actual flood hydrographs (e.g., flood duration and flood frequency) could exacerbate bank erosion.
- Flood hydrology in lower Aliso Creek is episodic. Therefore, changes in channel morphology are unlikely to change gradually over time; rather, the morphology of the channel (particularly the geotechnical stability of bank slopes and bend migration) will be episodic and flood driven.
- The assessment of the geomorphic stability of lower Aliso Creek is critically dependent upon the stability of the ACWHEP diversion structure. If this structure is not maintained to perform in its current capacity, major changes in channel morphology (including bank erosion, bend migration, and channel avulsions) may occur.
- It was assumed no new bank protection measures installed by any entity would be constructed over the project life, but that the existing condition of observed bank protection measures in good condition would be maintained.
- The slope stability analyses are dependent on limited soil strength data, so locations where likely future erosion risks are greatest may require additional geotechnical testing and analyses during later design phases.
- The geometry of the channels, floodplains, and terraces is based on: 1) 2006 surveys of channel morphology between the CTP and the ACWHEP structure, or 2) topographic mapping collected in 1998. Changes in morphology more recent that these dates are not reflected in the analyses carried out in this study.
- The influence of regional geologic conditions (e.g., landslides in bedrock formations along both banks of lower Aliso Creek) on the stability of the proposed pipeline alignments were not specifically quantified in this study.
- Seismic evaluation of the proposed pipeline alignments was beyond the scope of this current study. Later phases of design of the selected pipeline alignment may require evaluation of potential bank deformation due to earthquake loading, including 1) slope deformation due to seismic shaking and 2) ground subsidence and lateral spreading due to soil liquefaction.

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APPENDIX A – FIELD RECONNAISSANCE MAPPING AND PHOTOGRAPHS

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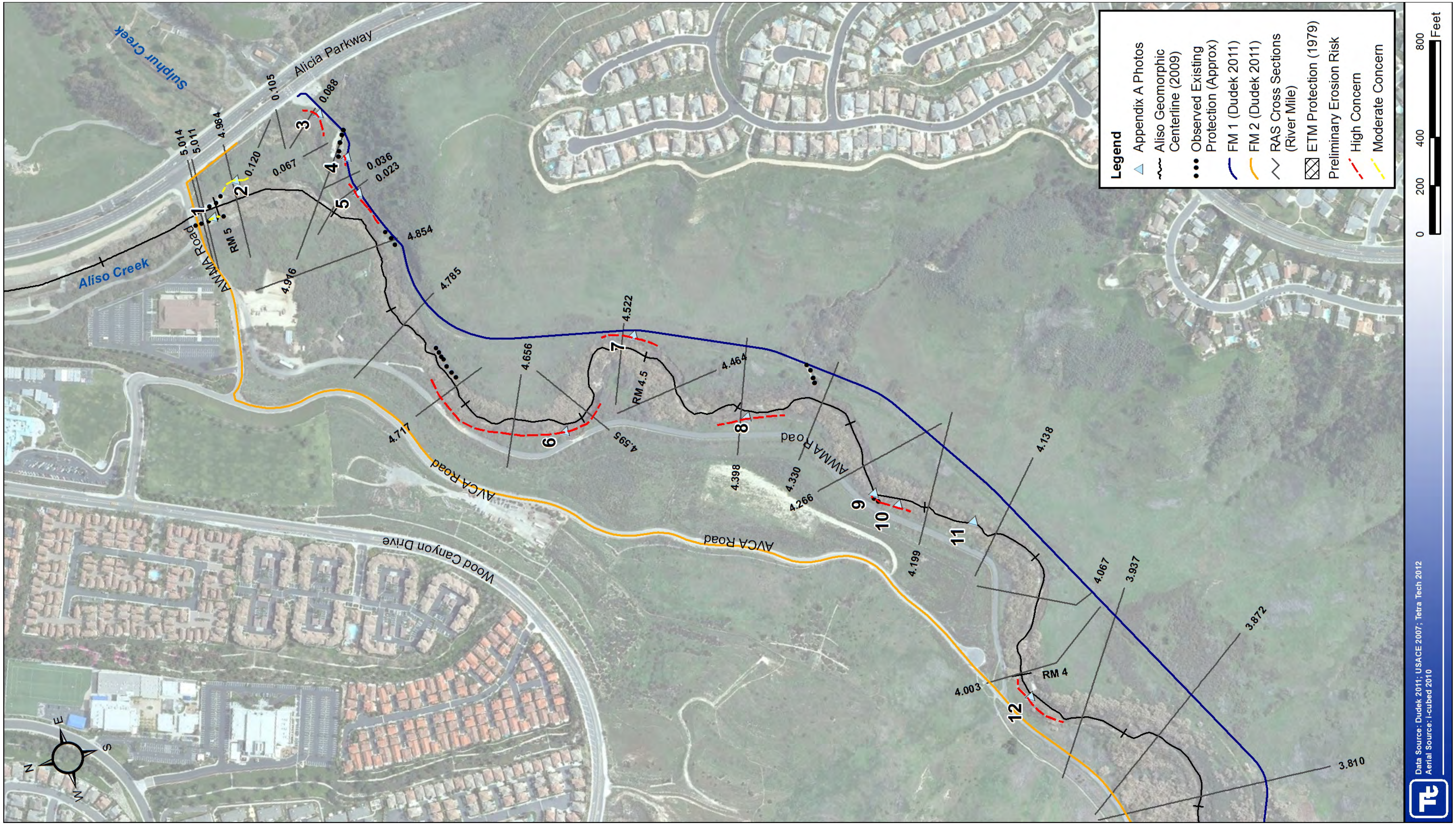
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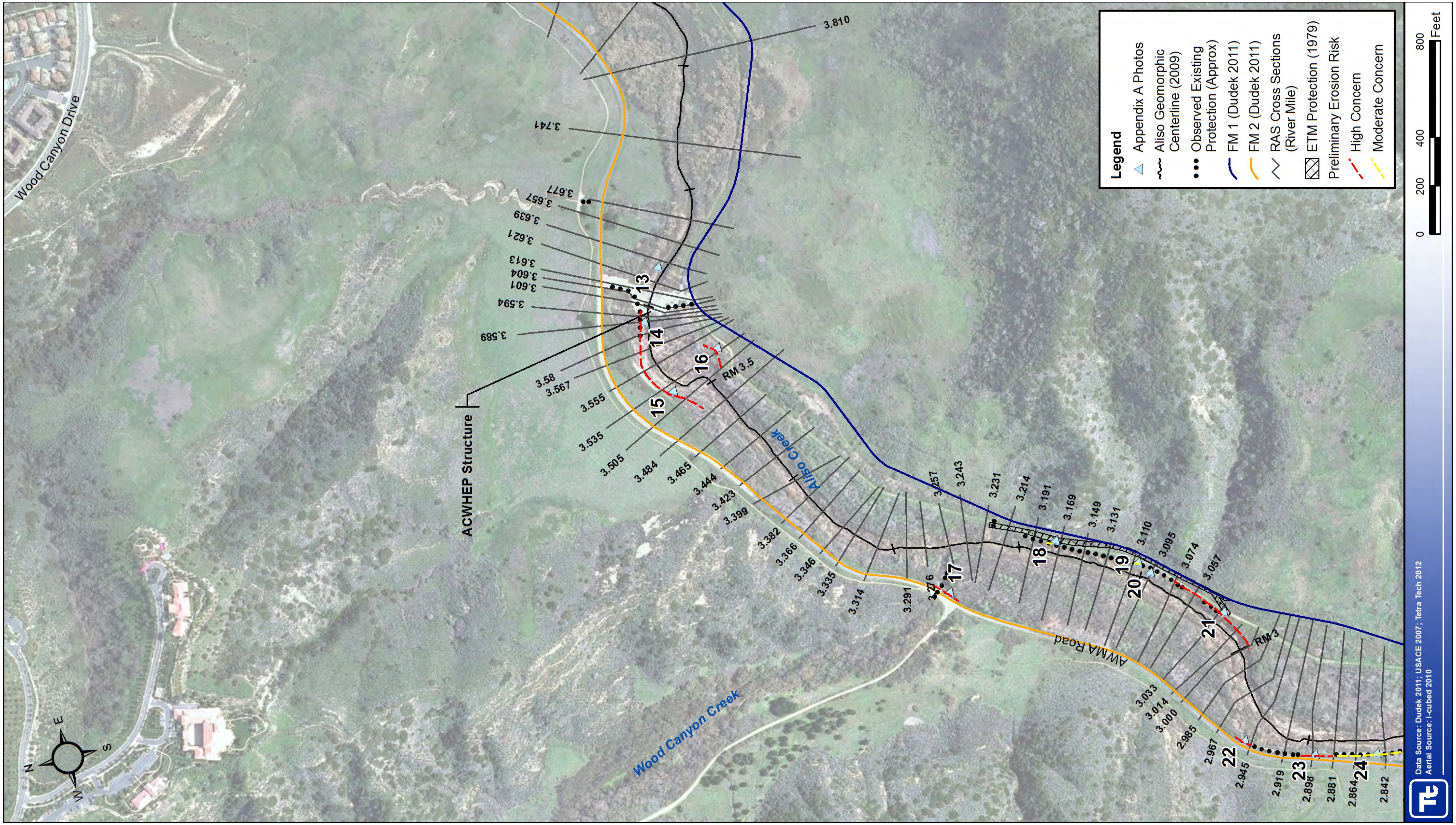
Appendix A Photos
Aliso Geomorphic Centerline (2009)
Observed Existing Protection (Approx)
FM 1 (Dudek 2011)
FM 2 (Dudek 2011)
RAS Cross Sections (River Mile)
ETM Protection (1979)
Preliminary Erosion Risk
High Concern
Moderate Concern
Feet
0 200 400 800
Data Source: Dudek 2011; USACE 2007; Tetra Tech 2012
Aerial Source: i-cubed 2010
Sulphur Creek
Alicia Parkway
Aliso Creek
AWMA Road
AVCA Road
Wood Canyon Drive
RM 5
RM 4.5
RM 4

Figure A-1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FM 2 (Dudek 2011)
RAS Cross Sections (River Mile)
ETM Protection (1979)
Preliminary Erosion Risk
High Concern
Moderate Concern
0
200
400
800
Feet
Data Source: Dudek 2011; USACE 2007; Tetra Tech 2012
Aerial Source: i-cubed 2010
Wood Canyon Drive
Wood Canyon Creek
Aliso Creek
AWMA Road
ACWHEP Structure
RM 3.5
RM 3
N
E
S
W
3.810
3.741
3.677
3.657
3.639
3.621
3.613
3.604
3.601
3.594
3.589
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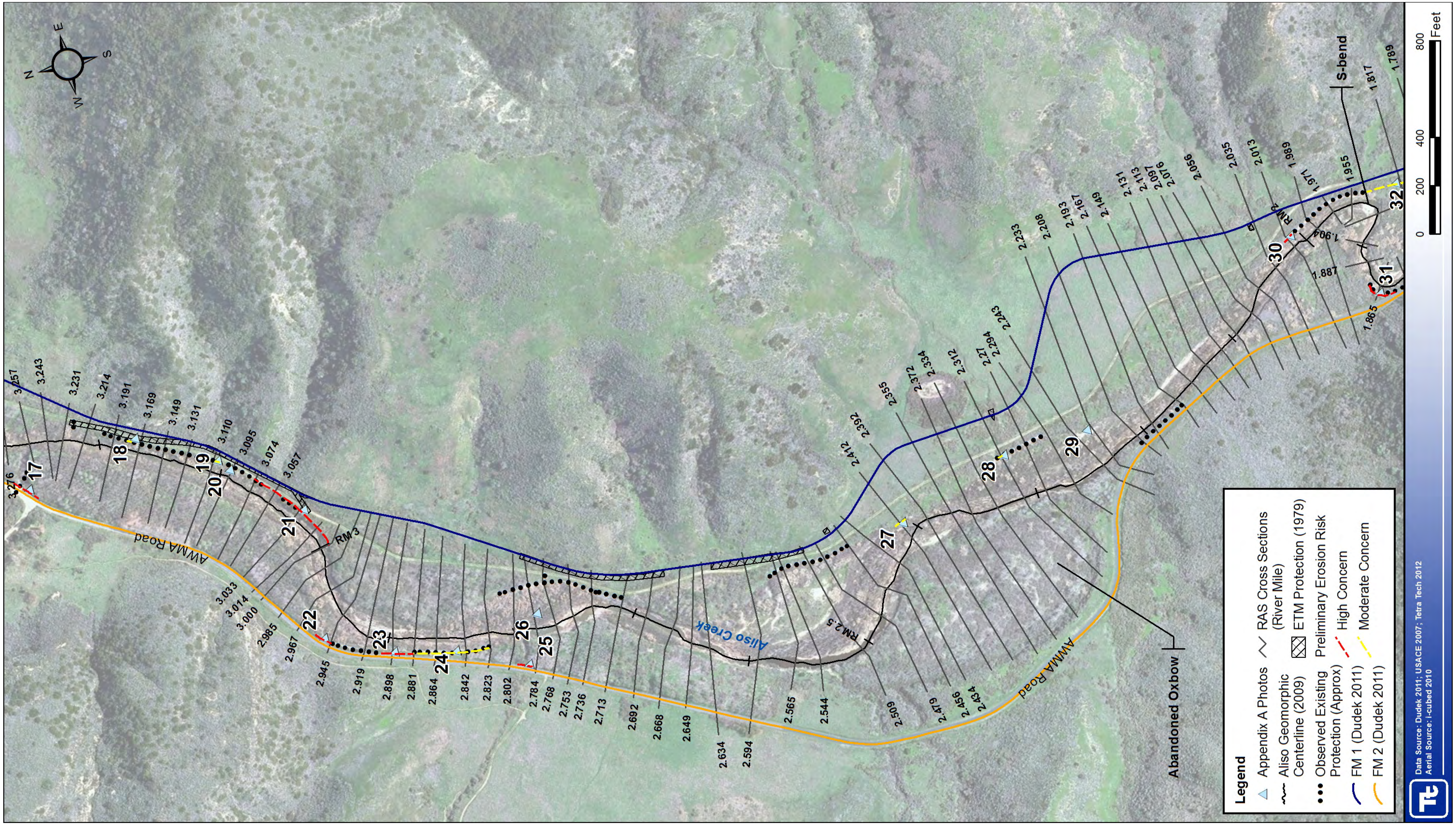
Figure A-2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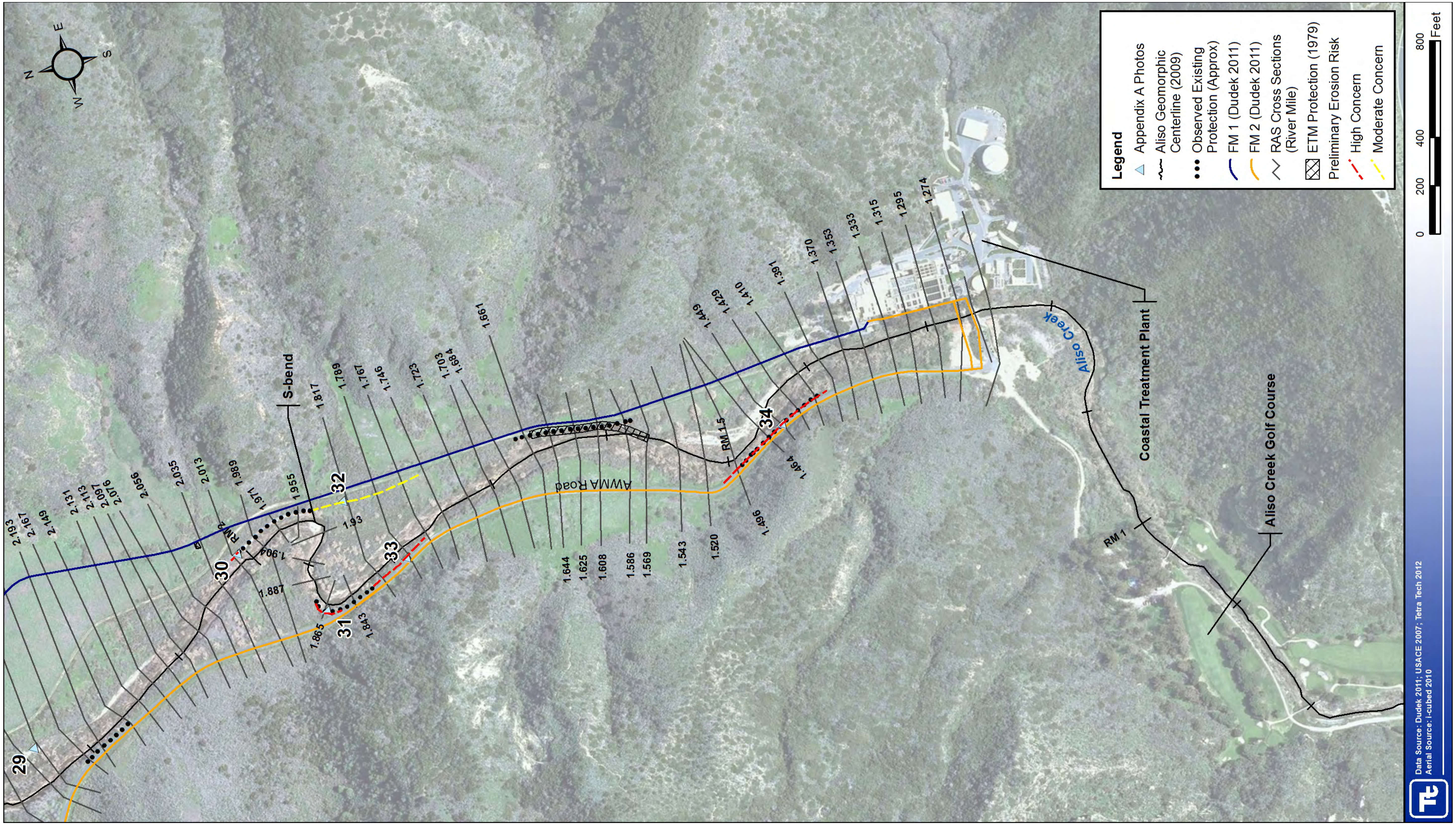
ETM Protection (1979)
Preliminary Erosion Risk
High Concern
Moderate Concern
Data Source: Dudek 2011; USACE 2007; Tetra Tech 2012
Aerial Source: i-cubed 2010
0
200
400
800
Feet
Abandoned Oxbow
S-bend
AWMA Road
Aliso Creek
RM 3
RM 2.5
RM 2
N
S
E
W

Figure A-3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Appendix A Photos
Aliso Geomorphic Centerline (2009)
Observed Existing Protection (Approx)
FM 1 (Dudek 2011)
FM 2 (Dudek 2011)
RAS Cross Sections (River Mile)
ETM Protection (1979)
Preliminary Erosion Risk
High Concern
Moderate Concern
0
200
400
800
Feet
Coastal Treatment Plant
Aliso Creek Golf Course
Aliso Creek
AWMA Road
S-bend
RM 1
RM 1.5
RM 2
29
30
31
32
33
34
Data Source: Dudek 2011; USACE 2007; Tetra Tech 2012
Aerial Source: i-cubed 2010

Figure A-4

34
Oversteep / Undercut Riprap

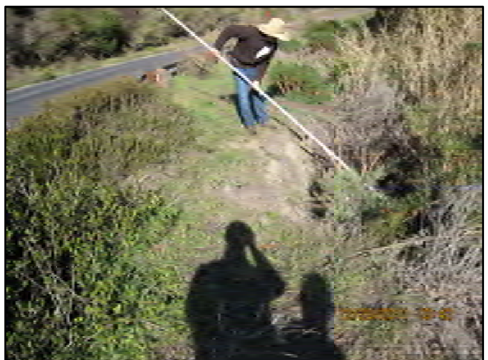
(looking u/s) Emergency rock placement? Near-vertical rock on bank. Stable toe. Geotechnically stable bank?

33
Oversteep Bank, Narrow Setback

(looking d/s) Potential for continued fluvial erosion. Bank not geotechnically stable. Top of unstable bank within 15 feet of AMWA Road.

32
Probable Future Incision

(looking d/s toward bend) Active erosion in chute (red shovel). Bend persists since pre-1930. Clay in toe of bank reduces rate of erosion/migration.



31
Flow Impingement, Narrow Setback

Active flow impingement above elevation of riprap revetment along bank. Narrow setback. Also concentrated runoff down the bank.

30
Flow Impingement

(looking d/s) Flood flows in Aliso Creek erode bank material upstream of existing riprap revetment.

29
Stable Bank

Downstream view of left bank, 2.5H:1V bank slope. Woody shrubs established across bank, stable toe along high flow chute.

No Photo Available

28
Tributary Crossing

Displacement of existing riprap allows headcut to propagate up the tributary.

27
Concentrated Runoff

(looking d/s) Concentrated runoff from upland areas enters Aliso Creek by spilling across the bank, causing erosion.

26
Stable Bank

Landward view of inset floodplain with dense growth of tree-willows and sycamores. Approximately 100-foot buffer to toe of bank.

25
Tributary Crossing

Landward view up tributary channel incised 20 feet. Incision “checked” by culvert; road embankment and proposed alignment is geotechnically unstable.

24
Oversteep Riprap

(lookding d/s) Emergency rock placement? Near-vertical rock on bank. Geotechnically stable bank? Established trees and depositional berm minimize fluvial energy applied on the bank.

23
Slumping

(looking u/s) Slumping of full bank height into Aliso Creek.

22
Concentrated Runoff

(looking u/s) Wood Canyon overflow down AMWA Road enters Aliso Creek by spilling down the bank. A headcut is propagating up the flowpath toward the proposed alignment.

21
Leakage along Abandoned Pipe, Slumping, Impingement

(looking d/s) Leakage into abandoned irrigation line promotes slumping. Bank erosion exacerbated by flow impingement.

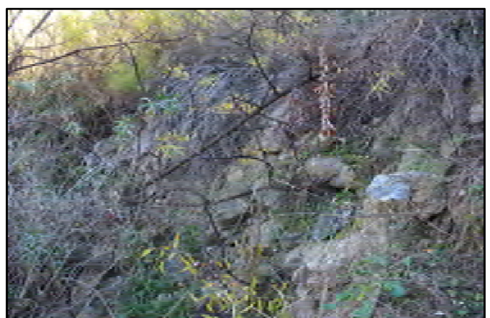
20
Stable Bank

Landward view of depositional berm and vegetation along toe of riprap revetment. Stable bank angle. Sycamore and tree-willows along toe.

No Photo Available

19
Slumping

Local displacement of riprap revetment.

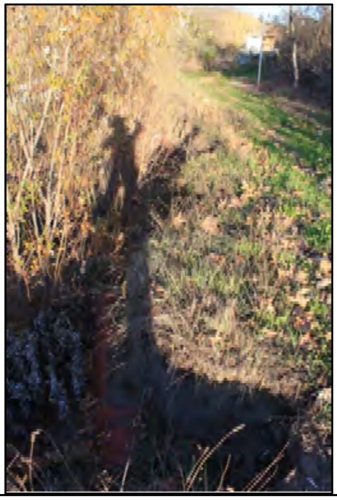


18
Slumping

(looking u/s) Slumping bank displaces riprap along upper bank; lower bank stabilized by depositional berm.

17
Wood Canyon

Riverward view of area scoured by flows overtopping AMWA Road crossing.



16
VCP Exposed, Slumping

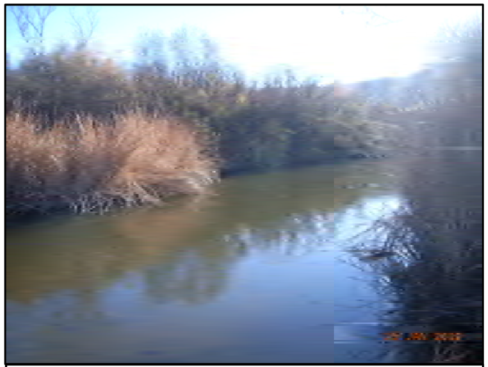
(looking u/s) Slumping due to pipe leakage or geotechnical instability; exposed sewer line.

15
Flow Impingement, Slumping

(looking d/s) Direct impingement of flood flows; slumped material at toe.

14
Undercut Riprap

Threatening ACWHEP diversion structure.



13
Stable Bank

(looking u/s) Low bank height, connected floodplain. Well-vegetated floodplain.

12
Flow Impingement

(looking d/s) Outside bend upstream of ACWHEP backwater influence, unstable bank.

11
Stable Bank

(looking u/s) Stability promoted by 6-foot high, vegetated, depositional berm along toe of bank. Floodplain connected, stable bank angle.

10
Upper Bank Instability

(looking u/s) Close proximity to alignment. Lower bank stable and vegetated, scarp along upper bank.

9
Impingement, Weathered Riprap

(looking u/s) Riprap revetment to protect against impingement is breaking down.

8
Upper Bank Geotechnical Instability

(looking u/s) Close proximity to pipe alignment, further widening as upper bank stabilizes.

7
Impingement & Concentrated Runoff

(Riverward view) Fluvial energy cutting into toe of alluvial fan; concentrated upland runoff contributes to bank failure.
Steep high bank actively failing.

6
Upper Bank Geotechnical Instability

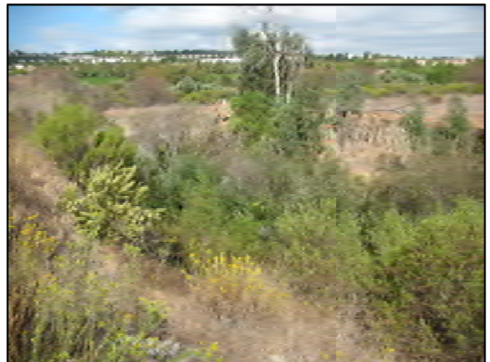
(looking d/s) 30-ft high bank, nearly vertical. Close proximity to AMWA Road.

5
Slumping

(looking d/s) No woody vegetation at toe to hold failed material. No room to lay back slope.

4
Local Scour

(looking d/s) Turbulence from water spilling off grouted rock is locally scouring the bank.



3
Flow Impingement

Riverward view of bend in Sulphur Creek where flood flows directly impinge on bank slope.

2
Upper Bank Geotechnical Instability

(looking u/s) Lower bank stabilized by dense woody vegetation; upper bank will continue to erode to achieve a stable bank angle.

1
Undercut Grouted Riprap

Likely due to scour over bridge drop; grout prevents rock from conforming to scour hole.

APPENDIX B – CROSS SECTION SCHEMATICS

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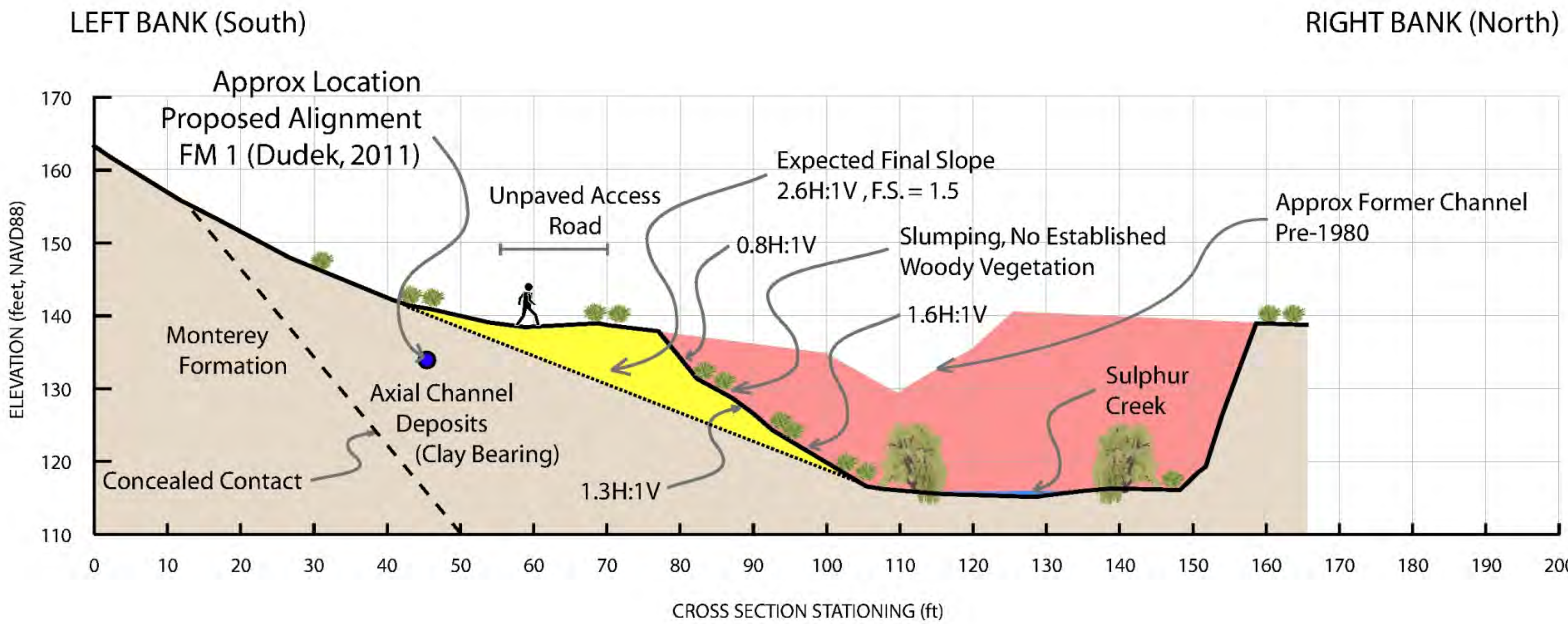

Figure B-1: Bank Slumping due to Geotechnically Unstable Slope

NOTES: Cross Section shown is of Sulphur Creek, 0.023 miles upstream of the Aliso Creek Confluence.

The left (south) bank is slumping due to geotechnical instabilities resulting from channel incision. Factors such as an overly steep bank slope, a slope height of around 20 feet, and a near absence of established woody vegetation along the slope (and particularly along the toe) contribute to the existing unstable bank. It is expected that further erosion of the bank will continue until the slope flattens to approximately 2.6H:1V. Using a factor of safety of 1.5, the stable bank slope is approximately 10 feet from the proposed pipeline alignment, and this distance is further reduced when the recommended setback equal to one-third the bank height is incorporated.

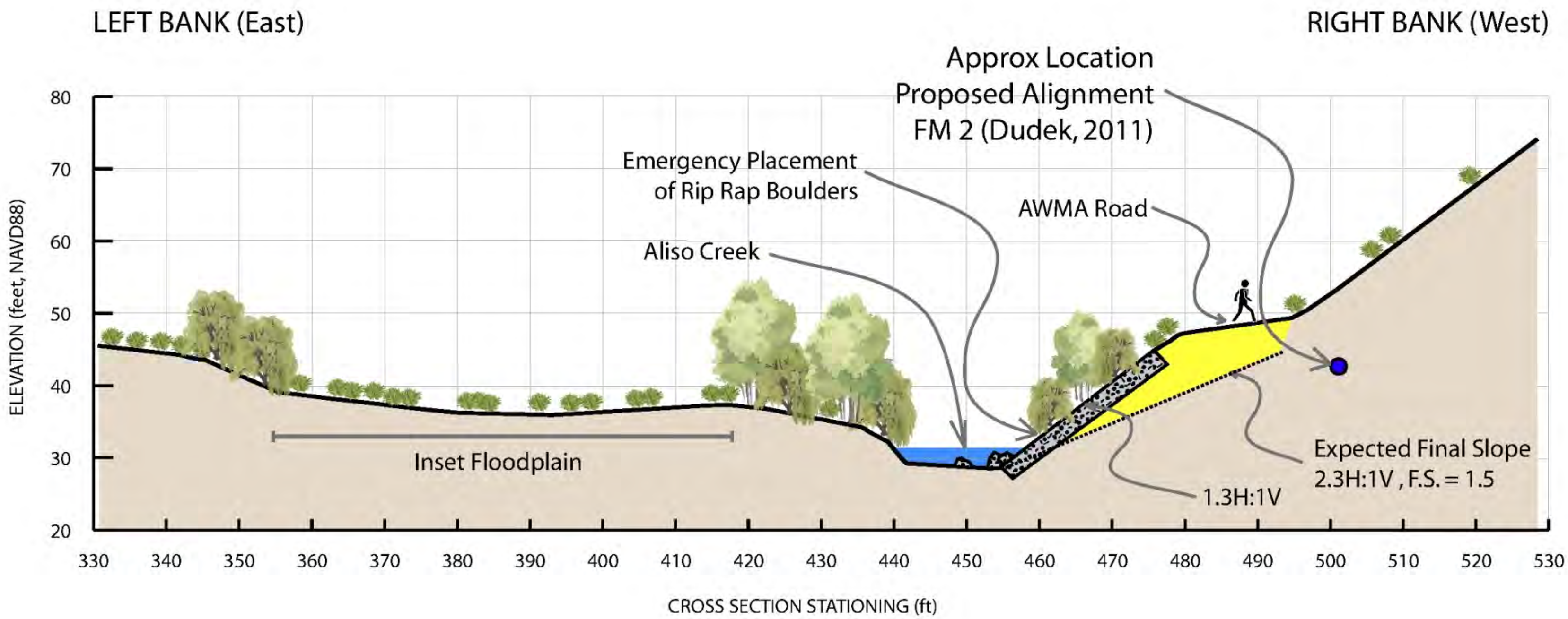

Figure B-2: Over-Steep Existing Riprap Revetment

NOTES: Cross Section shown is of Aliso Creek, 1.449 miles upstream of the Pacific Ocean.

Many of the existing bank protection measures appear to have been installed during emergency situations. For riprap revetments, this means the rock was probably dumped from top of bank, likely without any formal engineering design. As shown here, this can lead to measures that may not provide long-term protection to the bank or the proposed pipelines. Monitoring and maintenance of the protection is recommended as the future pipe alignment could be endangered if bank protection fails. In this example, if the protection was to fail, a stable bank slope would be within approximately 5 feet of the proposed alignment. This situation is representative of conditions at cross sections 1.496 to 1.410 (see **Table 3-3** in the main body of the report).

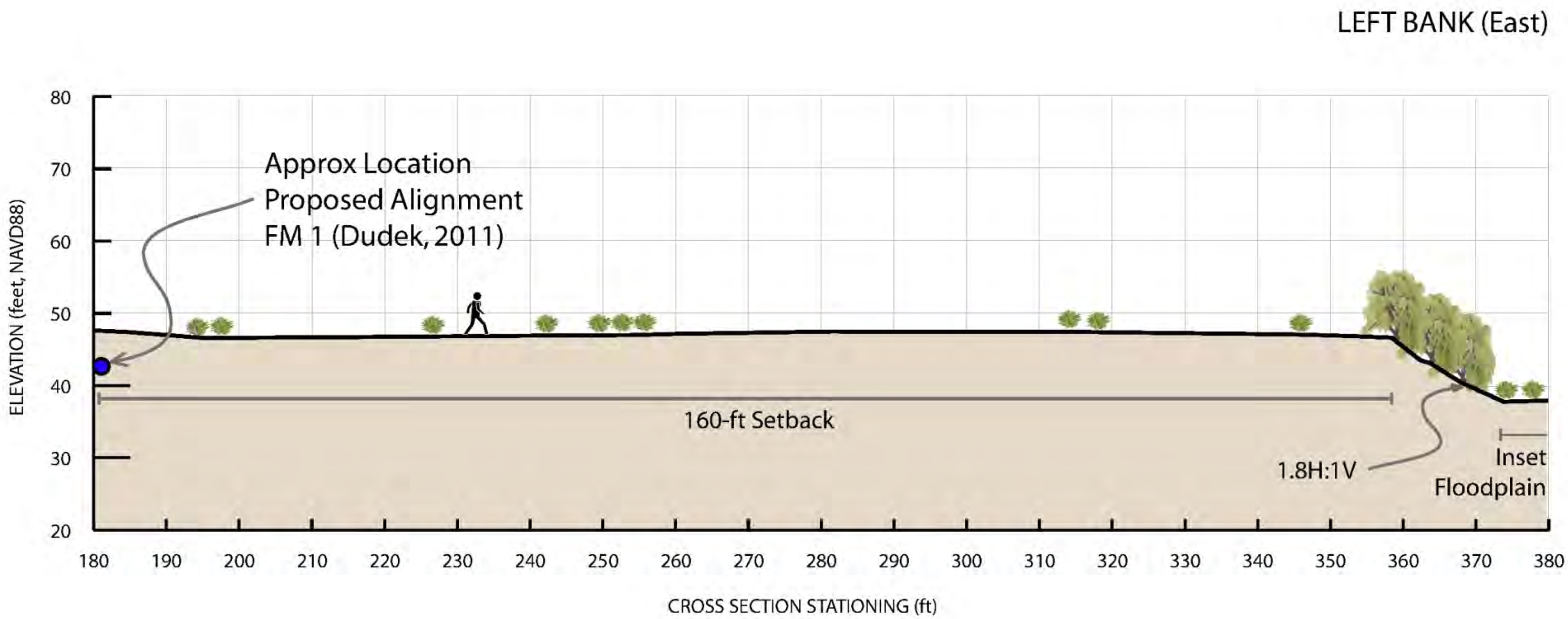

Figure B-3: Stable Bank Angle

NOTES: Cross Section shown is of Aliso Creek, 1.520 miles upstream of the Pacific Ocean.

The proposed FM 1 alignment is setback 160 feet from the relatively stable left bank, as indicated by its low slope height, established woody vegetation, flatter slope angle, and the inset floodplain. Considering historical locations of the channel, there is low potential for the channel to avulse/migrate to a location that would threaten the future integrity of the proposed pipeline. This situation is representative of conditions at cross sections 1.543 to 1.449 (see **Table 3-2** in the main body of the report).

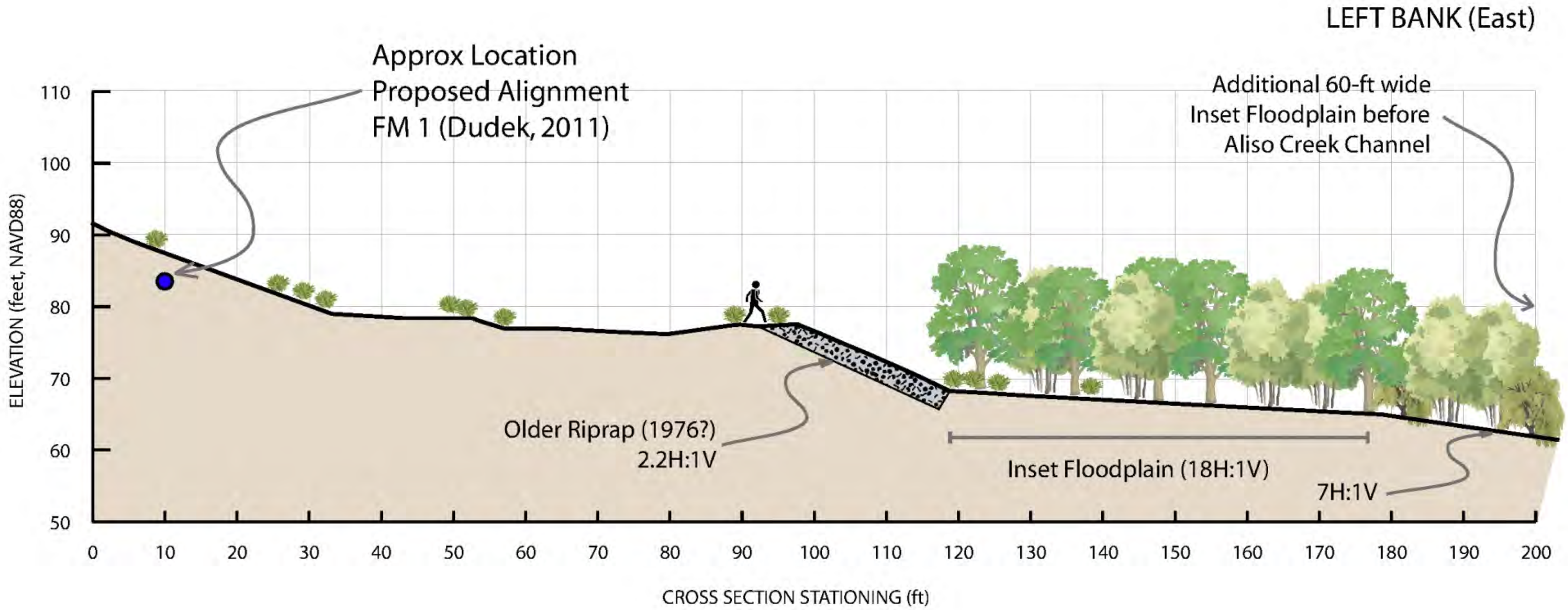

Figure B-4: Establishment of Inset Floodplain

NOTES: Cross Section shown is of Aliso Creek, 2.768 miles upstream of the Pacific Ocean.

Two inset floodplains are have developed between the channel and the toe of the riprap protection. These floodplains support established woody vegetation (e.g., tree willows and sycamore). The riprap was constructed at a stable slope. The proposed pipeline alignment is setback 90 feet from the top of the riprap protection. The potential for channel avulsions and bank erosion is low, so there is low long-term risk of pipeline damage from channel erosion. This situation is representative of conditions at cross sections 2.842 to 2.736 (see **Table 3-2** in the main body of the report).

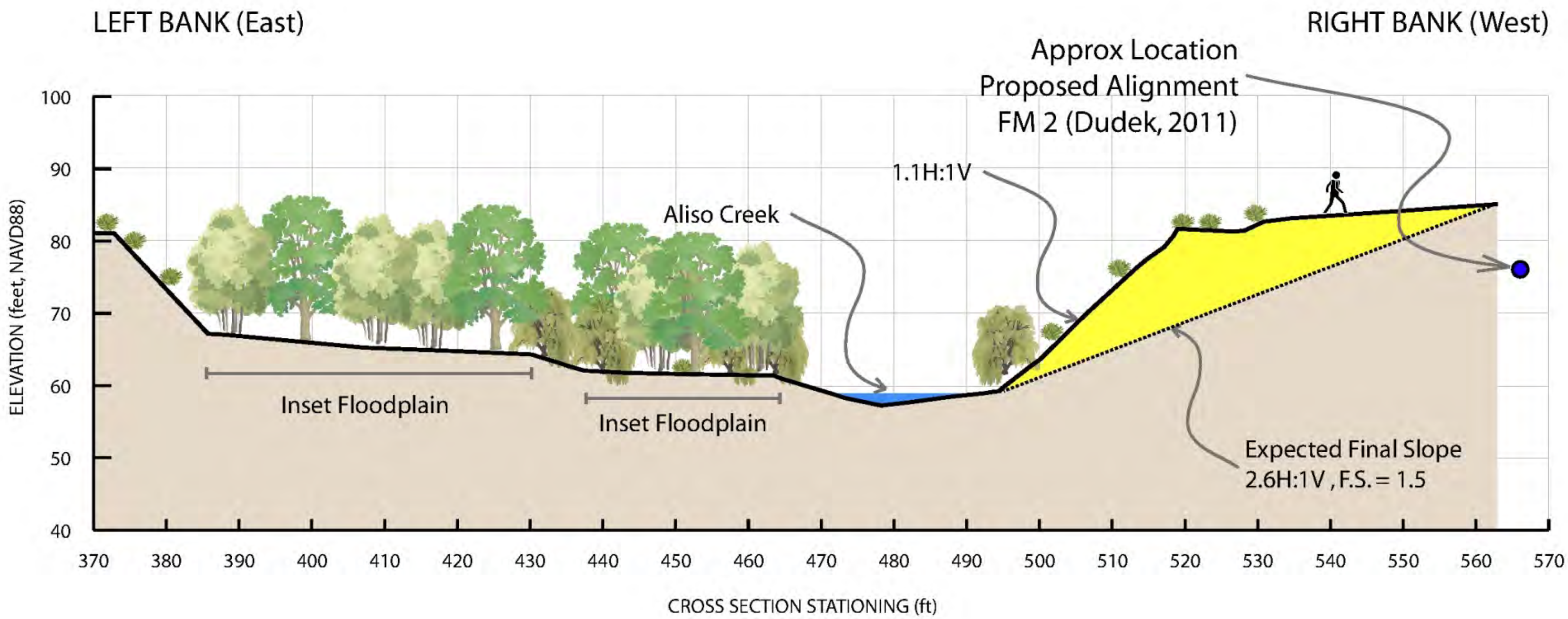

Figure B-5: Bank Instability due to Flow Impingement and Potential Bend Migration

NOTES: Cross Section shown is of Aliso Creek, 2.898 miles upstream of the Pacific Ocean.

The right bank is located along the outside of a bend. Flood flows impinge on the bank, and erode material from the toe. Failed material from the overly steep upper bank is not retained at the toe, so a berm that could reduce effective bank height cannot get established. The bank slope will continue to fail until a stable angle is reached. The new top of bank is projected to be within 10 feet of the proposed FM 2 alignment. If fluvial erosion causes the bend to migrate landward, the calculated stable top of bank location will translate an equal distance to any migration of the toe. The combined influences of geotechnical instabilities and bend migration present *High* erosion risk to the long-term integrity of the proposed FM 2 alignment.

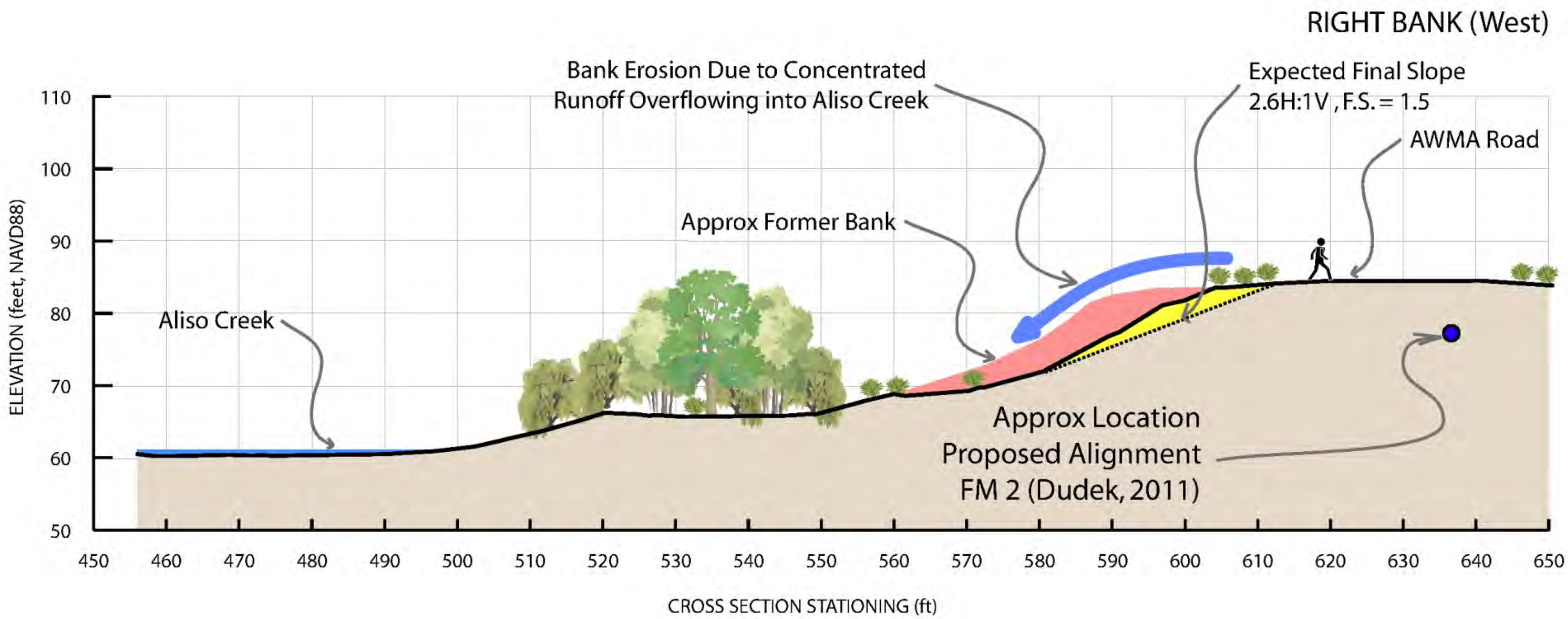

Figure B-6: Bank Erosion due to Concentrated Runoff along AMWA Road

NOTES: Cross Section shown is of Aliso Creek, 2.941 miles upstream of the Pacific Ocean.

Concentrated runoff flowing down AWMA Road spills over the bank into Aliso Creek. The runoff is concentrated on the road by a berm along one of the abandoned ACWHEP irrigation lines. The right bank is expected to continue eroding due to concentrated runoff flowing over the top of bank. Bank retreat may migrate into the FM 2 alignment without bank protection or diversion of the runoff. The geotechnically stable top of bank is projected to be within 25 feet of the proposed FM 2 alignment, but this distance does not account for additional erosion caused by the runoff.

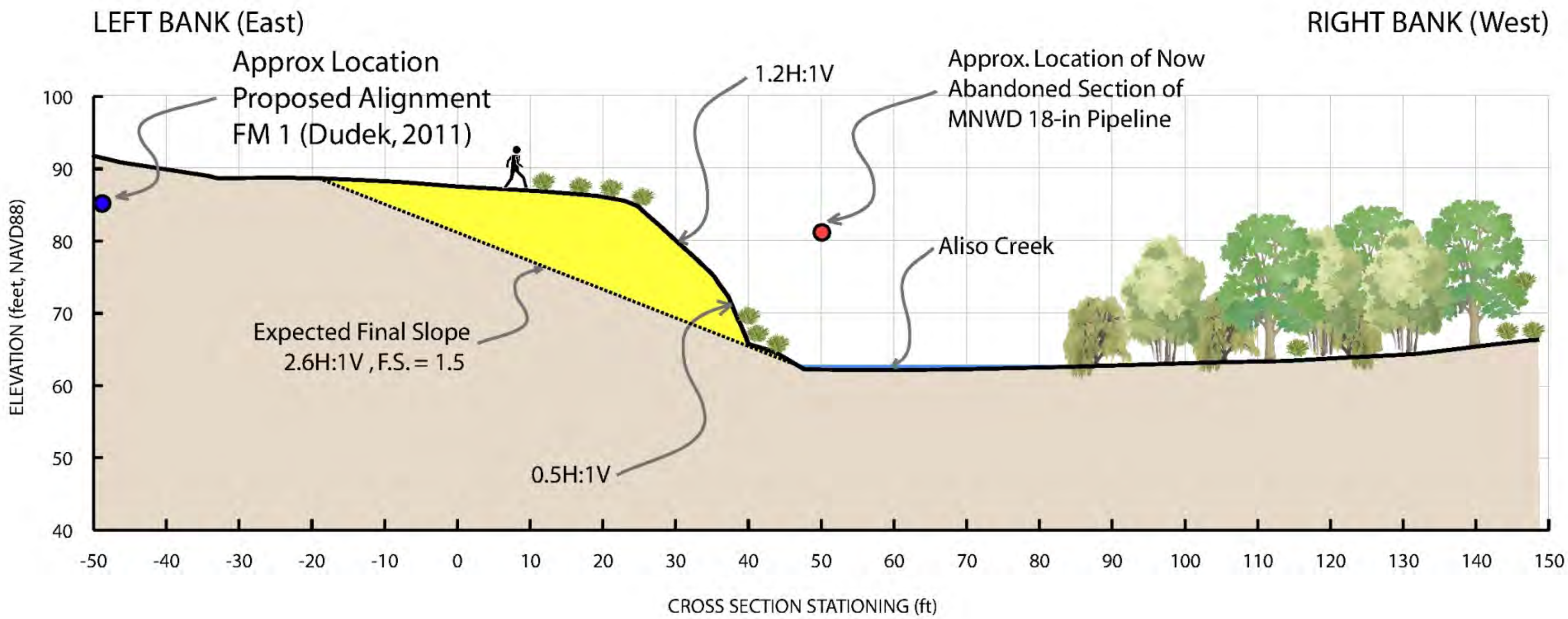

Figure B-7: Existing Exposure of East (Left) Bank Infrastructure

NOTES: Cross Section shown is of Aliso Creek, 3.014 miles upstream of the Pacific Ocean.

The abandoned ACWHEP irrigation pipelines in the left bank appear to have provided seepage pathways into the bank. Slump failures apparently initiated by seepage from the pipeline were observed. The left bank is expected to lay back to a stable slope of 2.6H:1V. Due to fluvial erosion potential it is expected that there will be continued erosion along outside of bend in the channel, progressing towards the proposed FM 1 alignment. Active erosion has already eroded a section of the 18-inch diameter vitrified clay pipe sewer line; a new line has been installed and the eroded section has been abandoned in place. This situation is representative of conditions at cross sections 3.033 to 3.000 (see **Table 3-2** in the main body of the report).

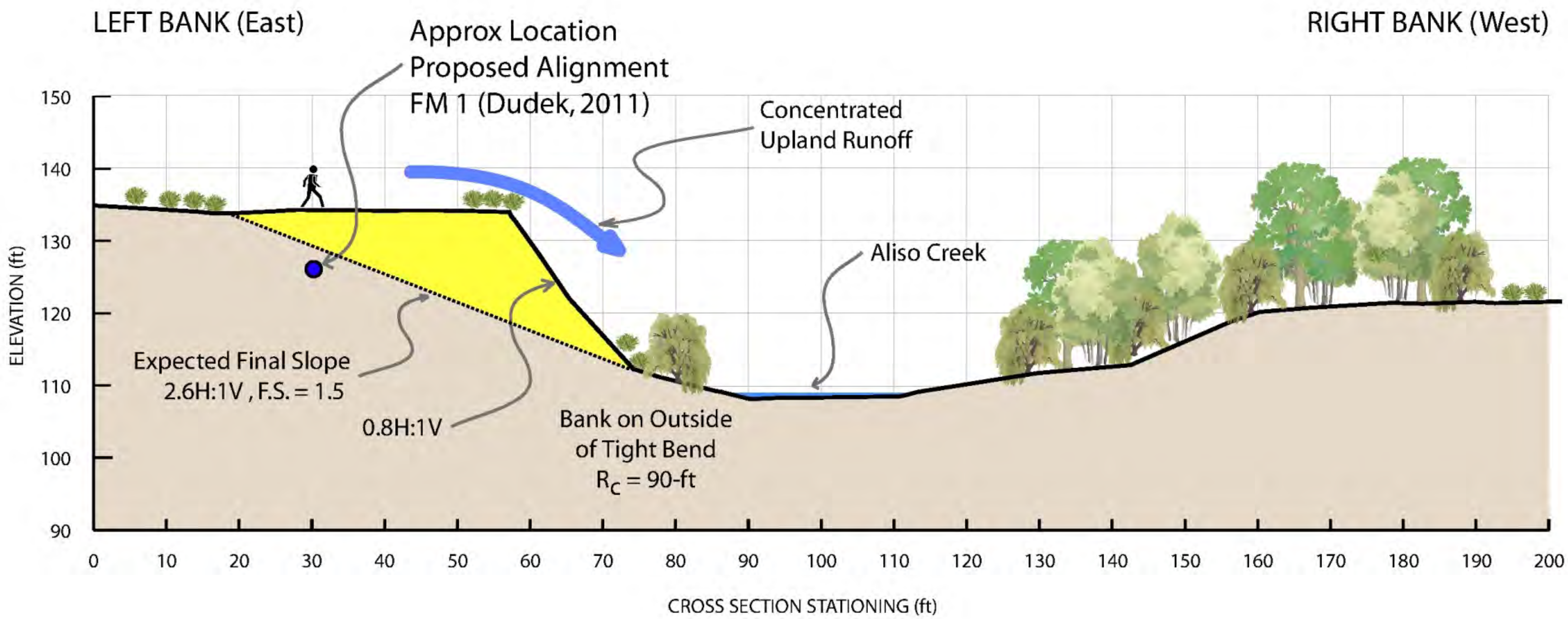

Figure B-8: Bank Erosion Exacerbated by Concentrated Upland Runoff

NOTES: Cross Section shown is of Aliso Creek, 4.522 miles upstream of the Pacific Ocean.

Instability of the left bank is caused by unstable geotechnical conditions, fluvial erosion around the outside of a bend, and concentrated upland runoff spilling down the bank. The left bank is being cut into alluvial fan deposits, and the concentrated runoff flowing across the fan spills into Aliso Creek over the top of bank. The left bank is expected to fail geotechnically to a stable slope of 2.6H:1V. The proposed FM 1 alignment is at the calculated stable bank slope plus the recommended setback. The risk of geotechnical erosion is *Moderate*, but when coupled with the upland runoff and the potential for bend migration into the fan deposits, the erosion risk over the 50-year design life of the proposed FM 1 alignment is *High*.

APPENDIX C – SITE SPECIFIC CALCULATIONS OF GEOTECHNICAL SLOPE STABILITY

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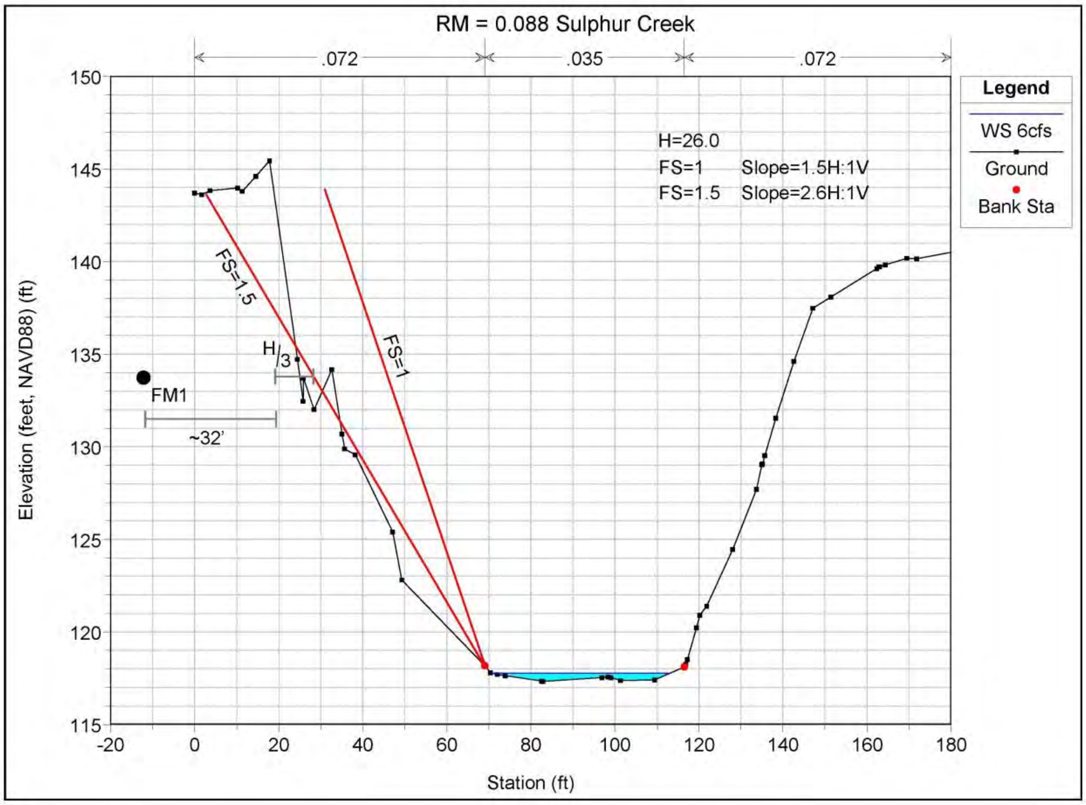
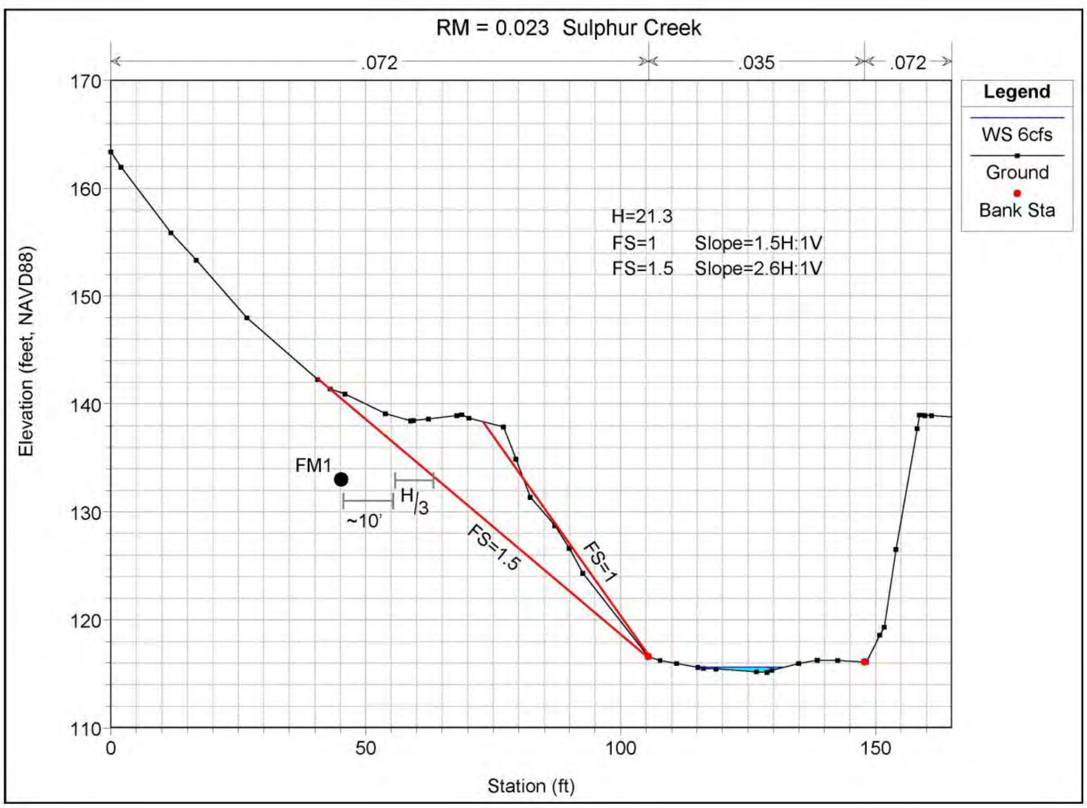
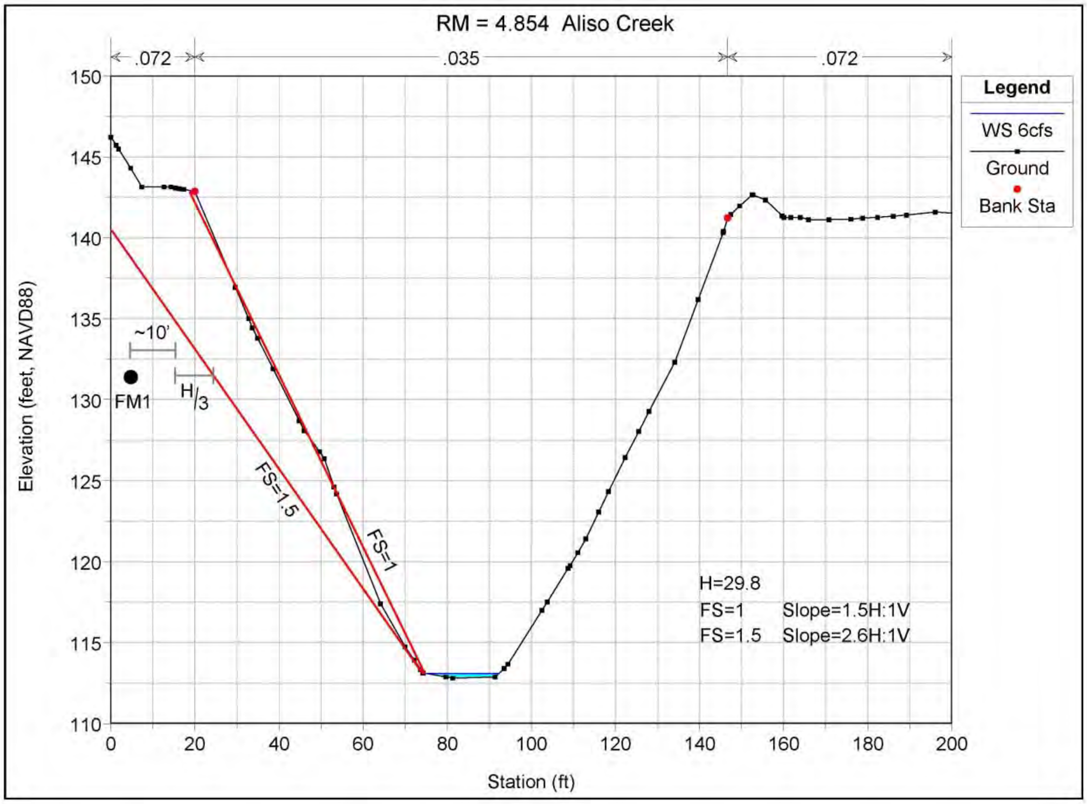
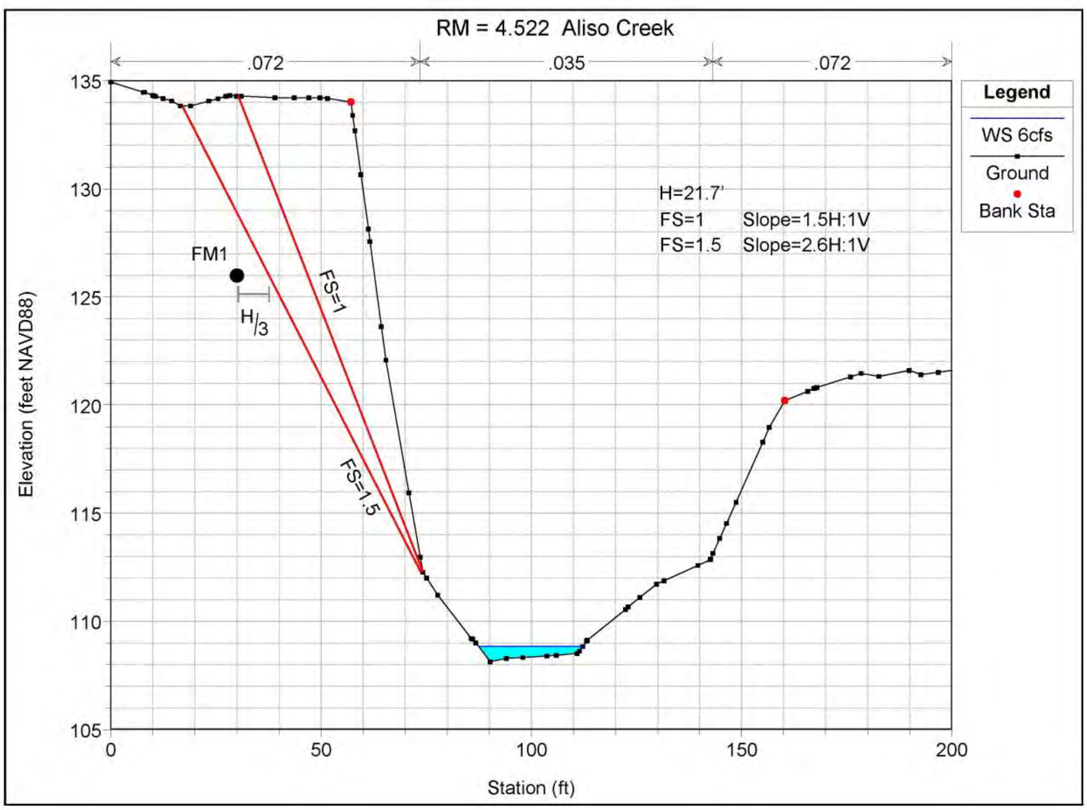
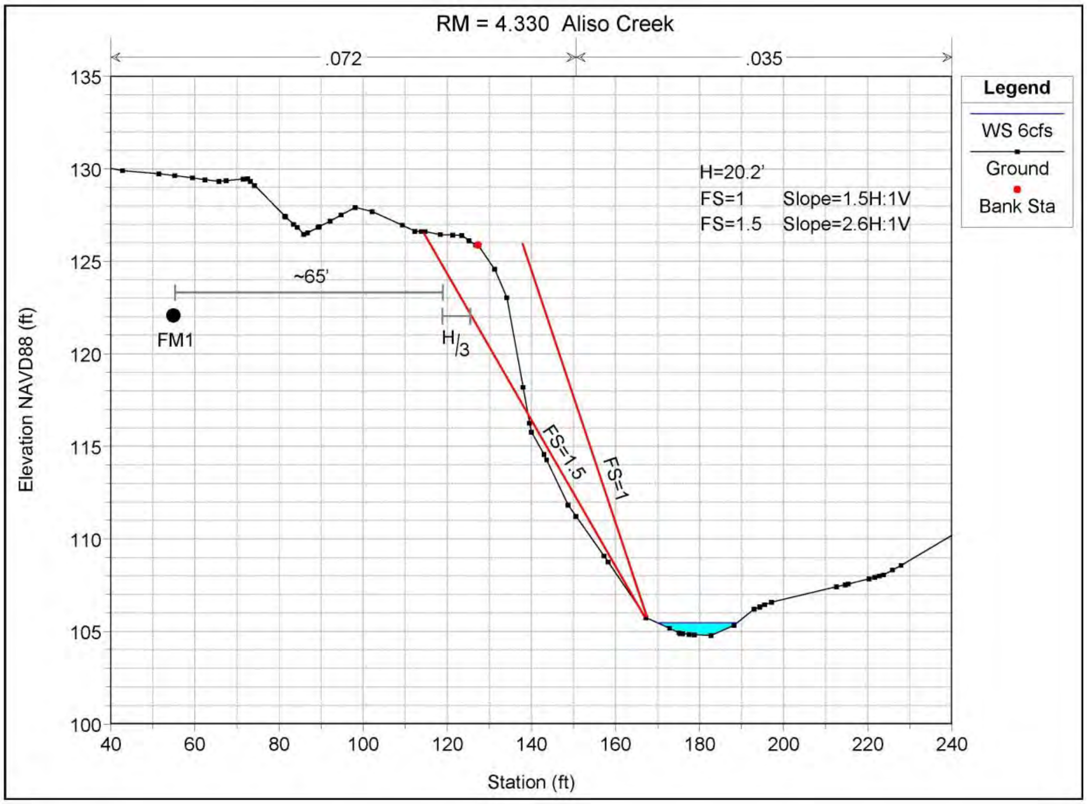
EAST (LEFT) BANK – PROPOSED FM 1 ALIGNMENT






RM = 4.854 Aliso Creek
.072
.035
.072
Legend
WS 6cfs
Ground
Bank Sta
Elevation (feet, NAVD88)
Station (ft)
~10'
FM1
H/3
FS=1.5
FS=1
H=29.8
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V


RM = 4.522 Aliso Creek
.072
.035
.072
Legend
WS 6cfs
Ground
Bank Sta
Elevation (feet NAVD88)
Station (ft)
FM1
H/3
FS=1
FS=1.5
H=21.7'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V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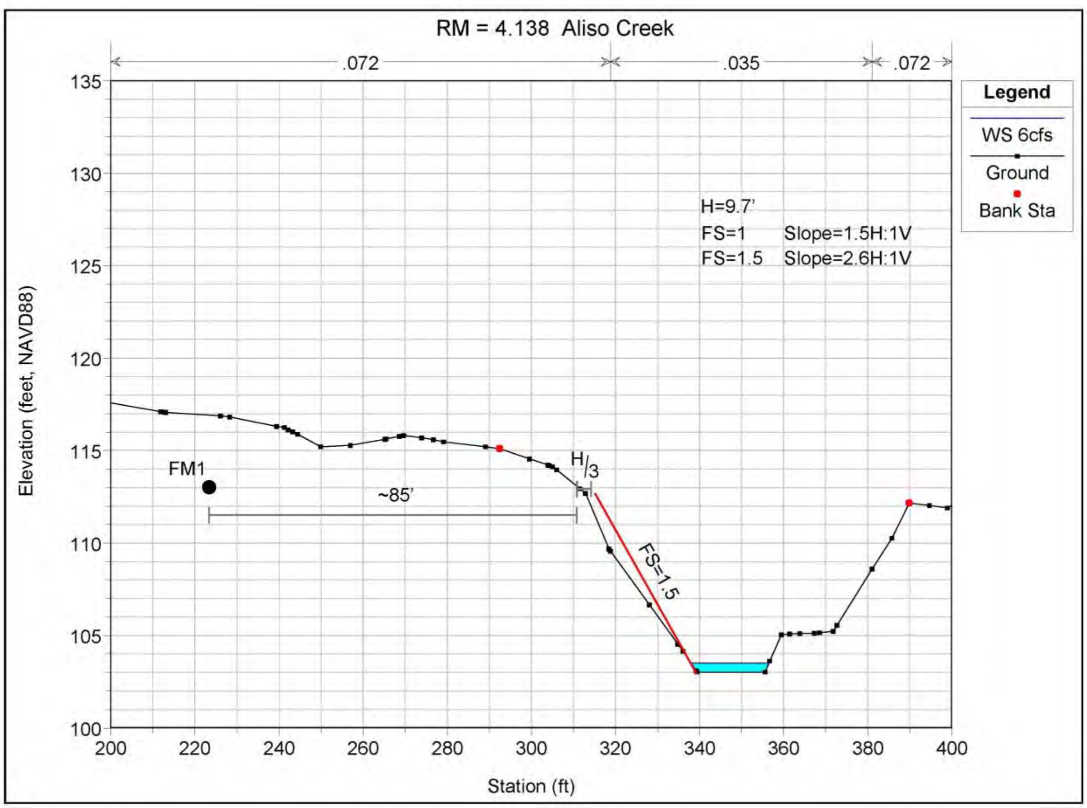
.072
.035
Legend
WS 6cfs
Ground
Bank Sta
H=20.2'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
~65'
FM1
H/3
FS=1.5
FS=1
Elevation NAVD88 (ft)
Station (ft)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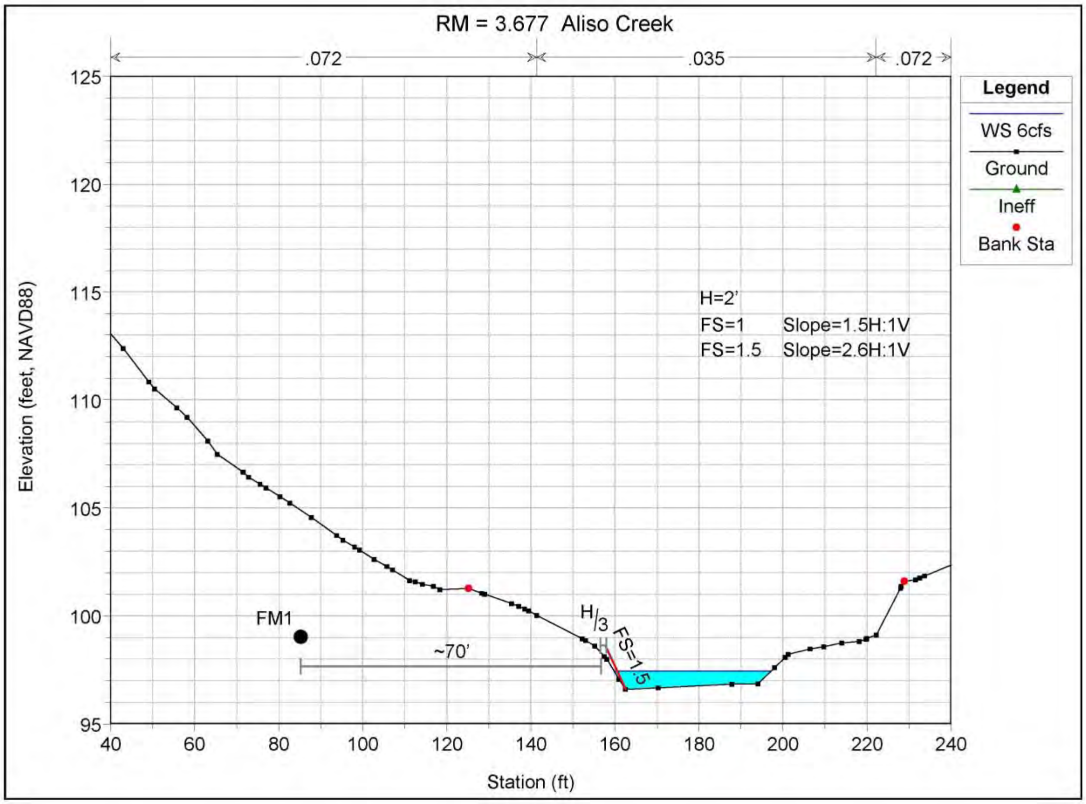
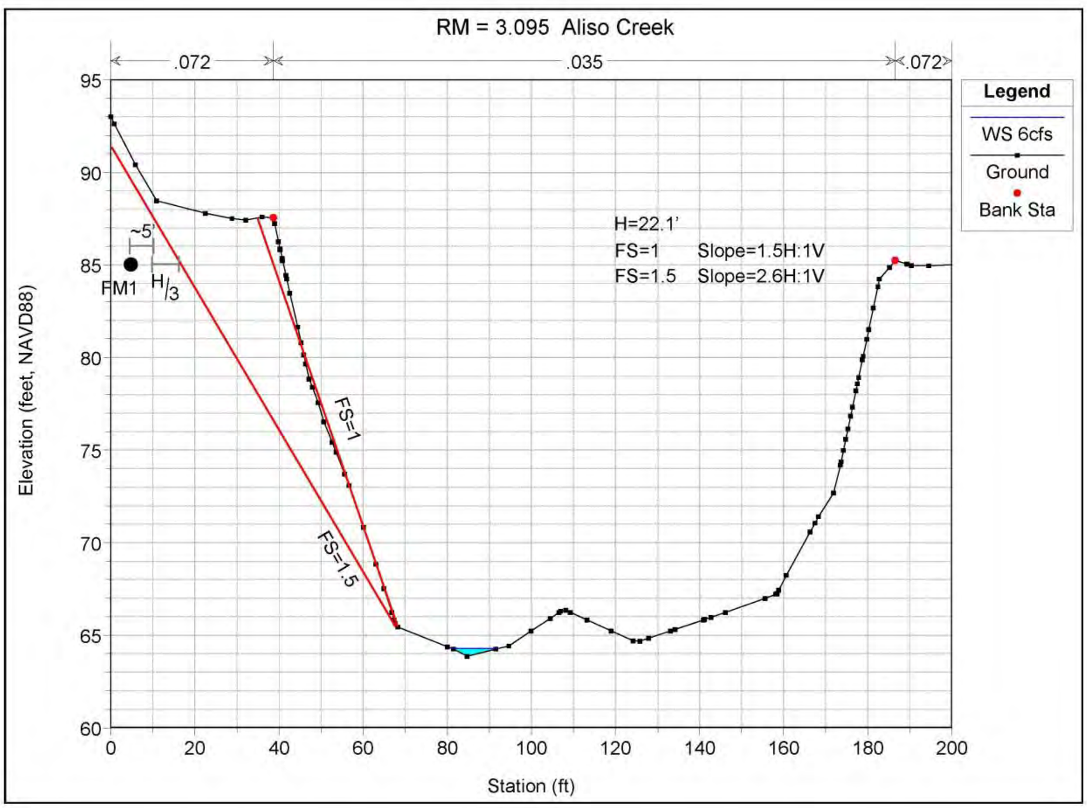
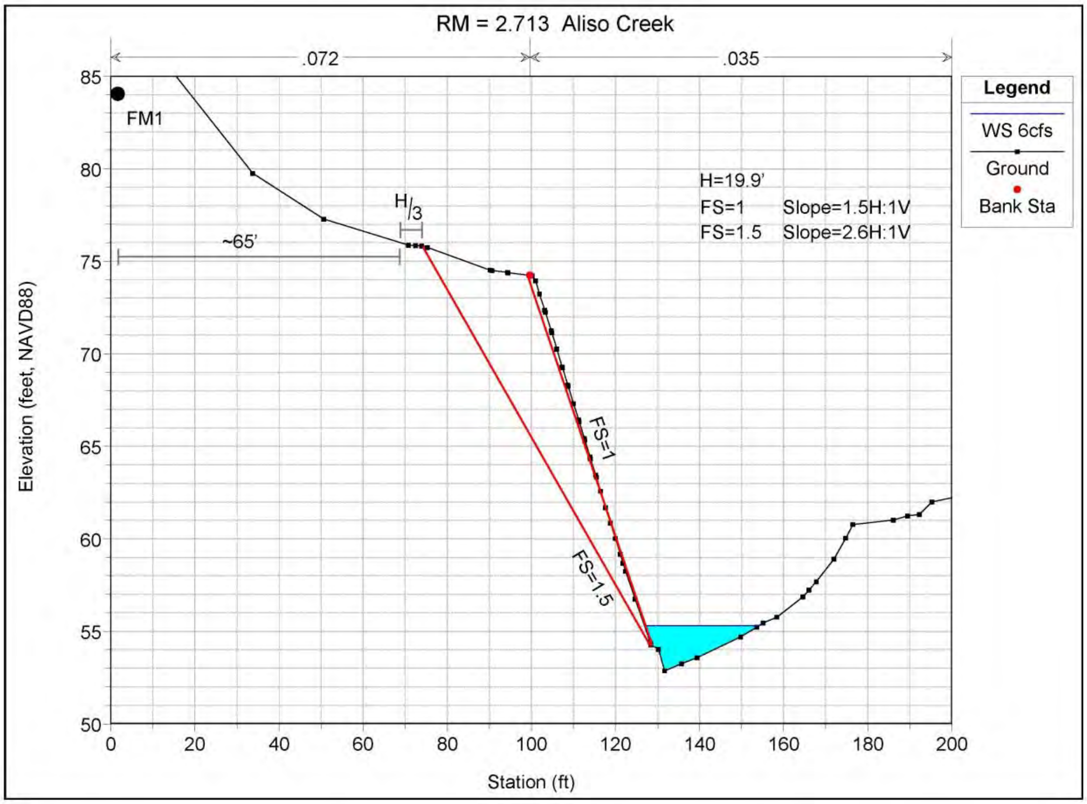
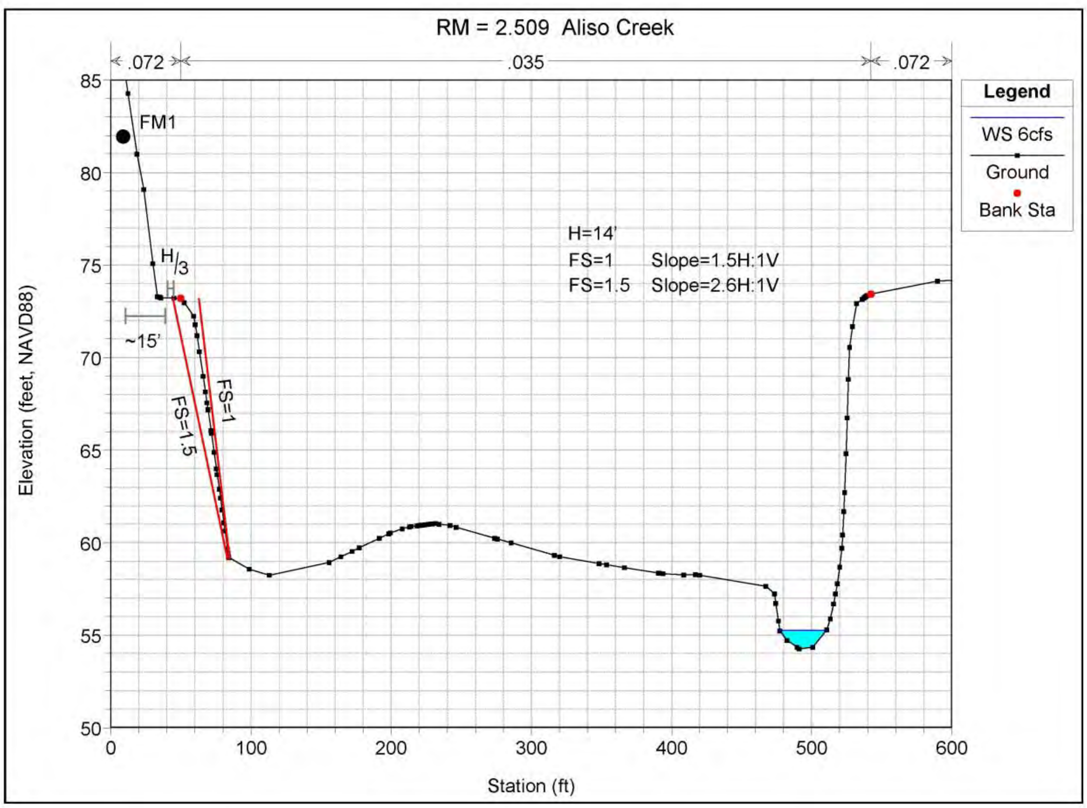
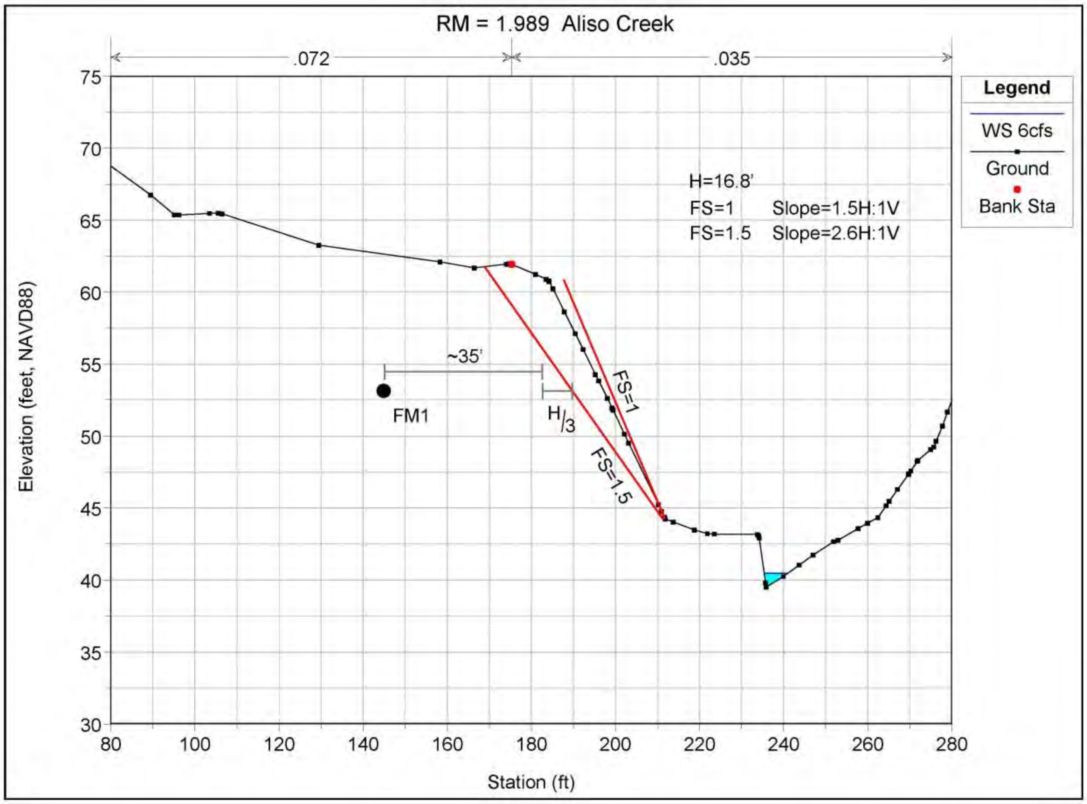
.072
.035
.072
Legend
WS 6cfs
Ground
Bank Sta
H=9.7'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
FM1
~85'
H/3
FS=1.5
Elevation (feet, NAVD88)
Station (ft)

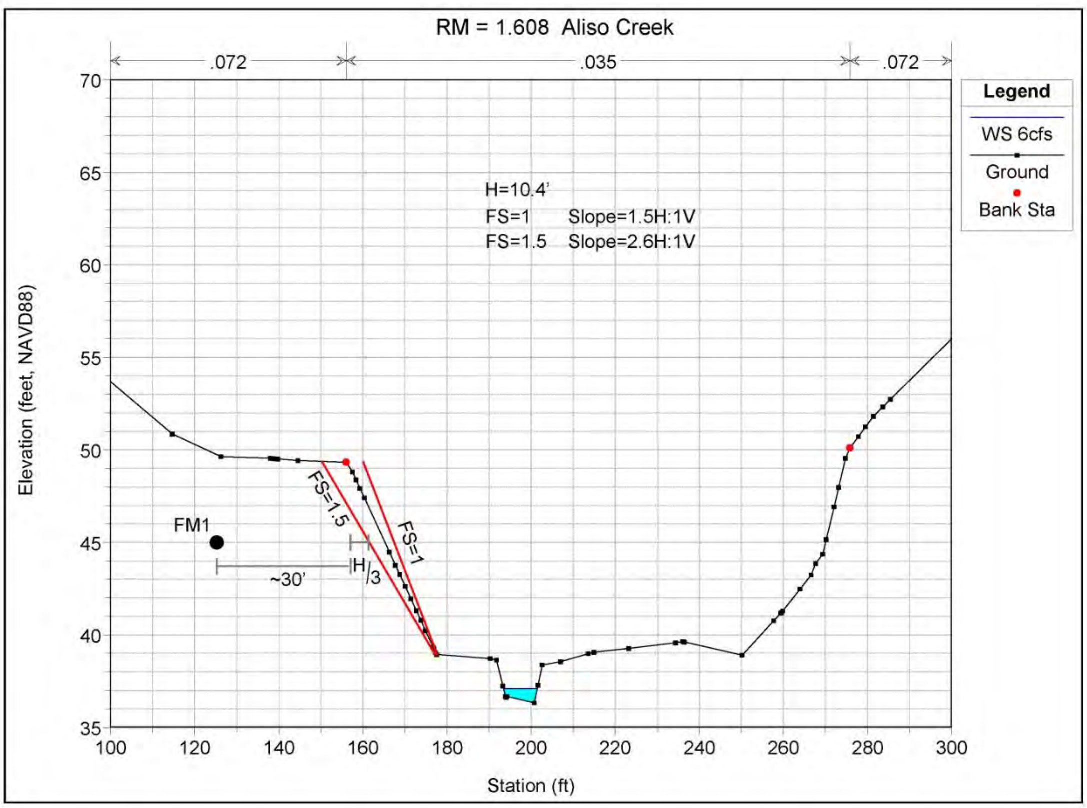

RM = 3.677 Aliso Creek
.072
.035
.072
Legend
WS 6cfs
Ground
Ineff
Bank Sta
H=2'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
FM1
~70'
H/3
FS=1.5
Elevation (feet, NAVD88)
Station (ft)

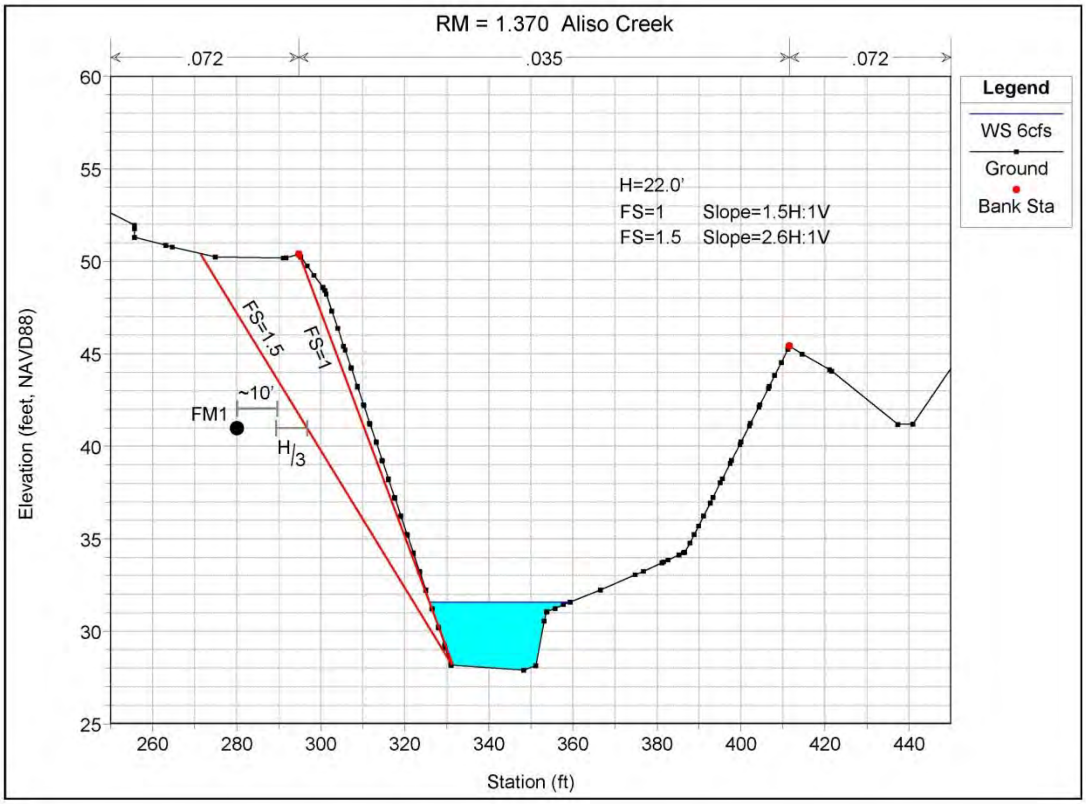

RM = 3.095 Aliso Creek
.072
.035
.072
Legend
WS 6cfs
Ground
Bank Sta
H=22.1'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
~5'
FM1
H/3
FS=1
FS=1.5
Elevation (feet, NAVD88)
Station (ft)


RM = 2.713 Aliso Creek
.072
.035
FM1
H/3
~65'
H=19.9'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
FS=1
FS=1.5
Legend
WS 6cfs
Ground
Bank Sta
Elevation (feet, NAVD88)
Station (ft)
85
80
75
70
65
60
55
50
0
20
40
60
80
100
120
140
160
180
200


RM = 2.509 Aliso Creek
.072
.035
.072
FM1
H/3
~15'
FS=1
FS=1.5
H=14'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
Legend
WS 6cfs
Ground
Bank Sta
Elevation (feet, NAVD88)
Station (ft)
85
80
75
70
65
60
55
50
0
100
200
300
400
500
600


RM = 1.989 Aliso Creek
.072
.035
Legend
WS 6cfs
Ground
Bank Sta
H=16.8'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
~35'
FM1
H/3
FS=1
FS=1.5
Elevation (feet, NAVD88)
Station (ft)
30
35
40
45
50
55
60
65
70
75
80
100
120
140
160
180
200
220
240
260
280


RM = 1.608 Aliso Creek
.072
.035
.072
Legend
WS 6cfs
Ground
Bank Sta
H=10.4'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
FM1
~30'
H/3
FS=1.5
FS=1
Elevation (feet, NAVD88)
Station (ft)
35
40
45
50
55
60
65
70
100
120
140
160
180
200
220
240
260
280
300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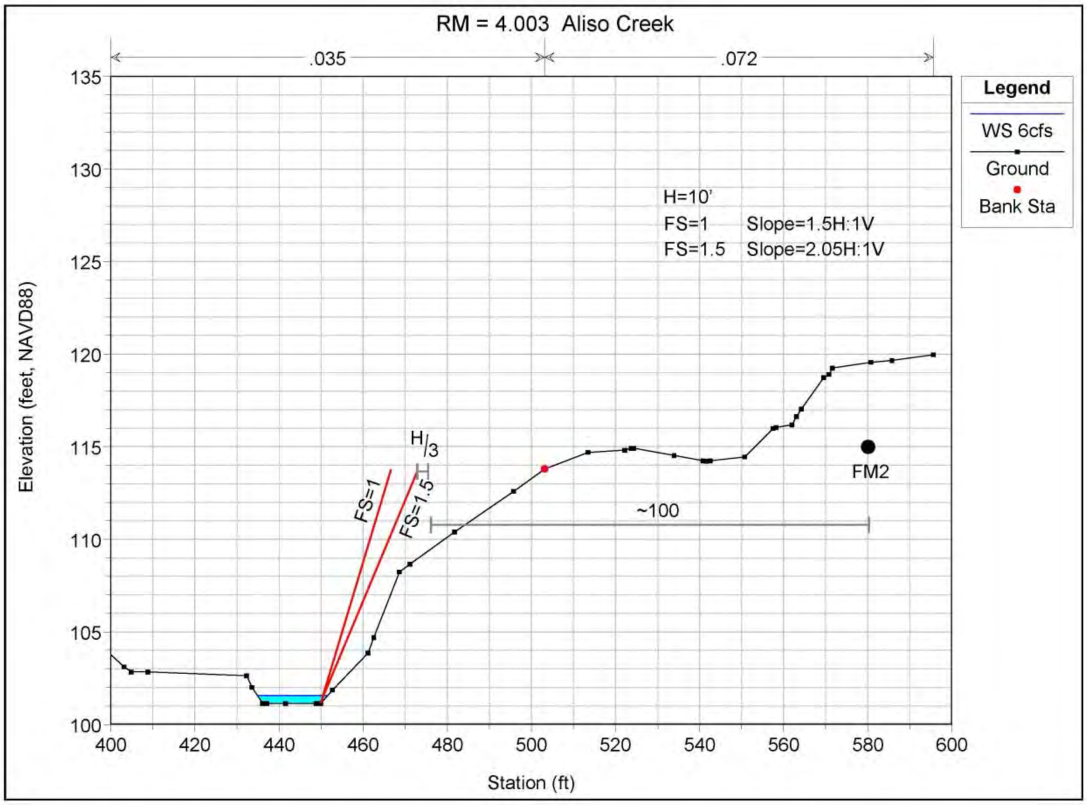
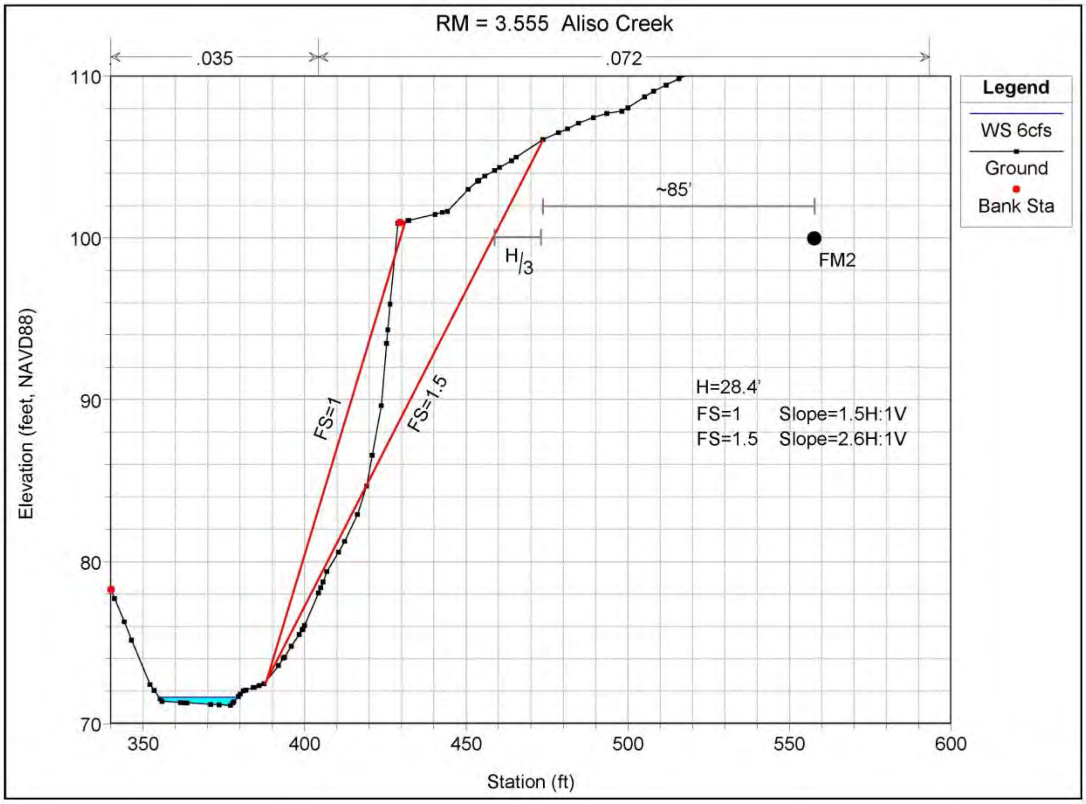
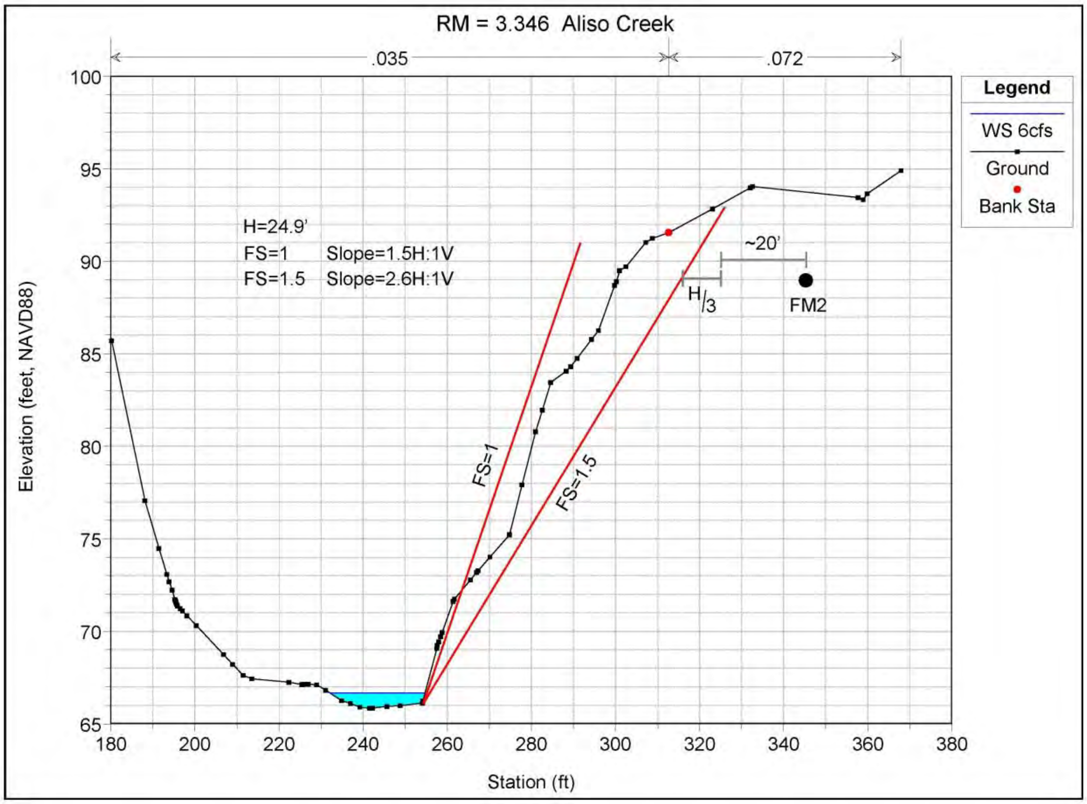
.072
.035
.072
Legend
WS 6cfs
Ground
Bank Sta
H=22.0'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
FS=1.5
FS=1
~10'
FM1
H/3
Elevation (feet, NAVD88)
Station (ft)
60
55
50
45
40
35
30
25
260
280
300
320
340
360
380
400
420
440

WEST (RIGHT) BANK – PROPOSED FM 2 ALIGNMENT



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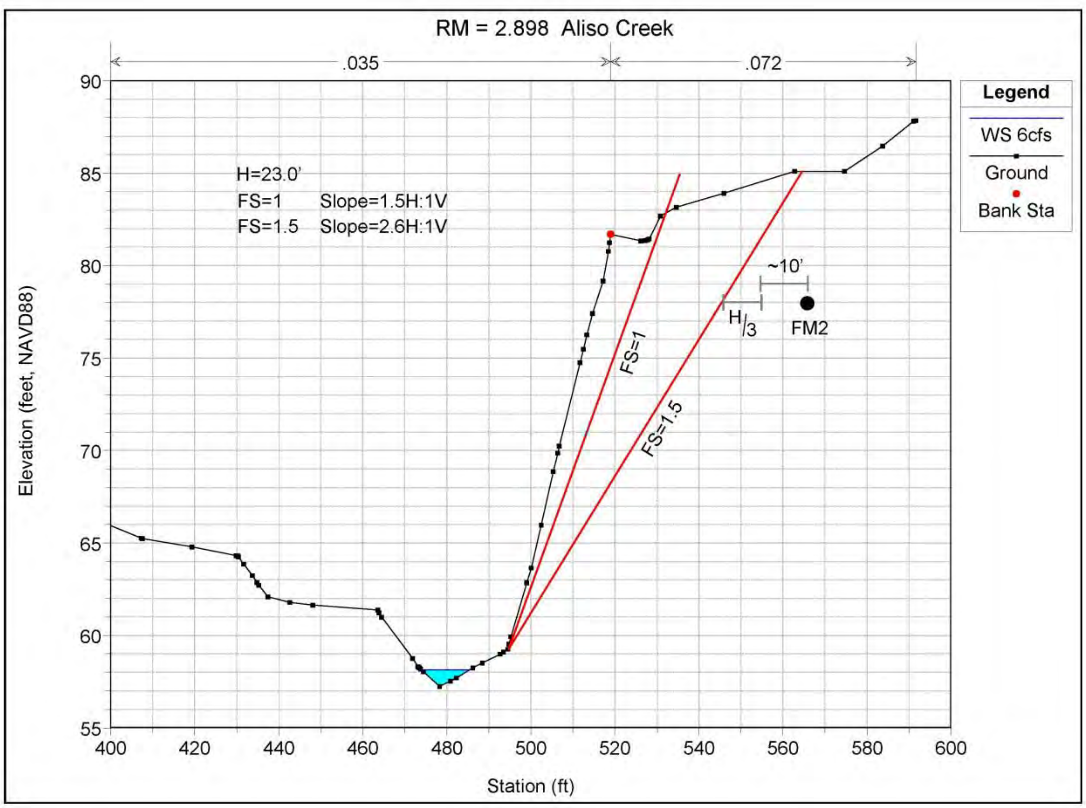
.035
.072
Legend
WS 6cfs
Ground
Bank Sta
H=24.9'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
~20'
H/3
FM2
FS=1
FS=1.5
Elevation (feet, NAVD88)
Station (ft)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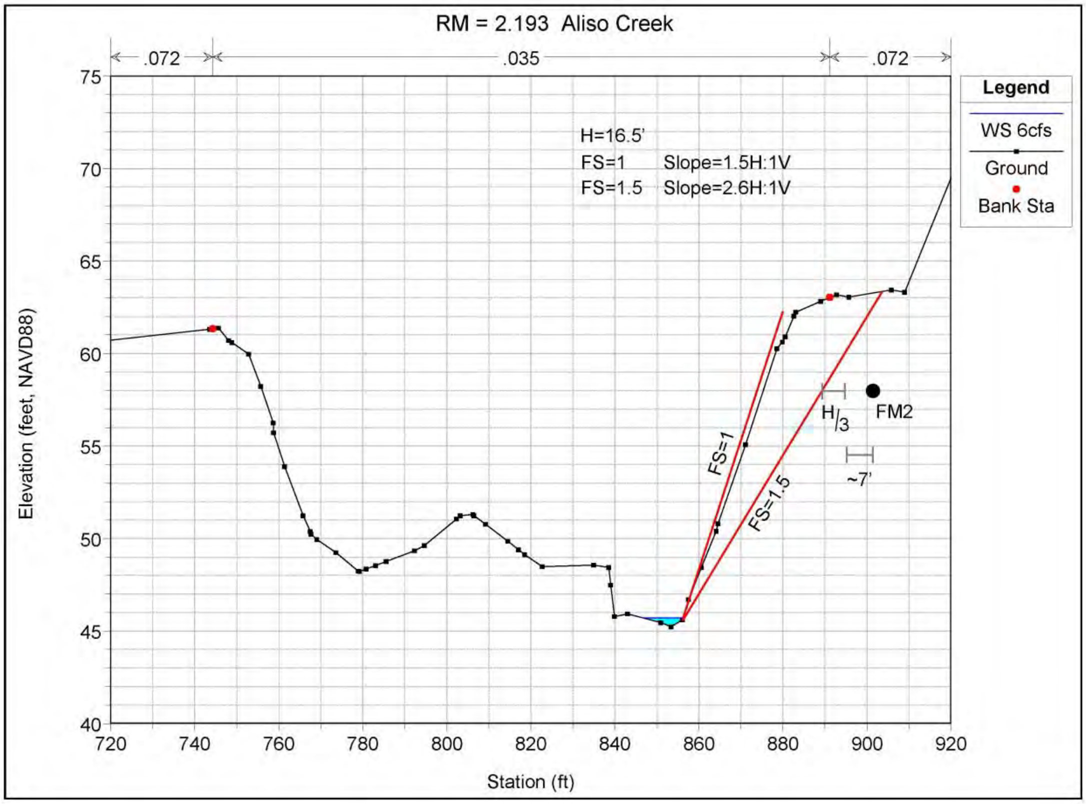
.035
.072
Legend
WS 6cfs
Ground
Bank Sta
H=23.0'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
~10'
H/3
FM2
FS=1
FS=1.5
Elevation (feet, NAVD88)
Station (ft)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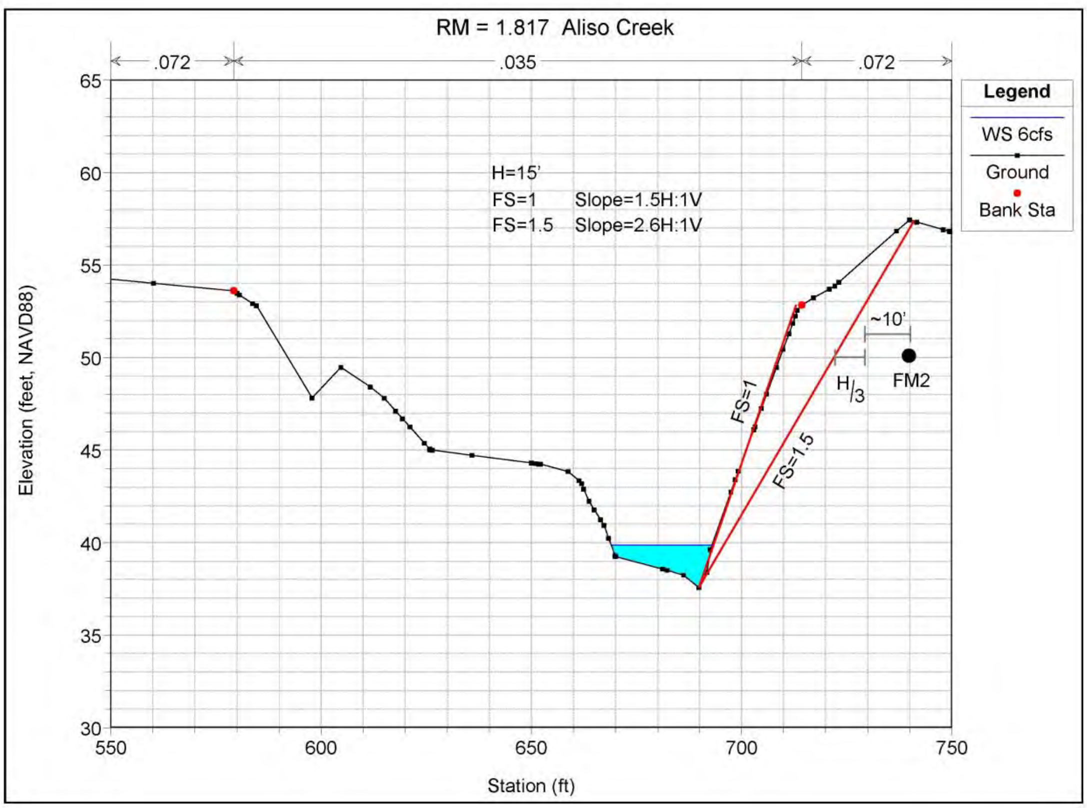
.072
.035
.072
H=16.5'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
Legend
WS 6cfs
Ground
Bank Sta
FS=1
FS=1.5
H/3
FM2
~7'
Elevation (feet, NAVD88)
Station (ft)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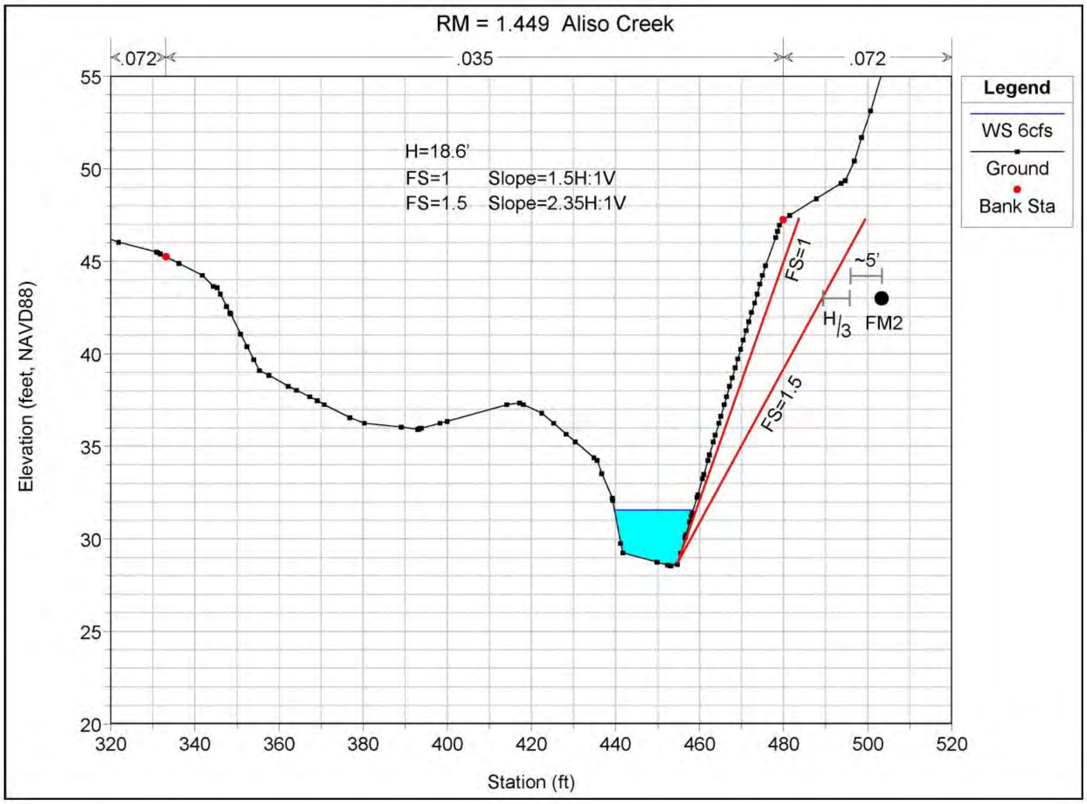
.072
.035
.072
H=15'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.6H:1V
Legend
WS 6cfs
Ground
Bank Sta
FS=1
FS=1.5
~10'
H/3
FM2
Elevation (feet, NAVD88)
Station (ft)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.072
.035
.072
H=18.6'
FS=1 Slope=1.5H:1V
FS=1.5 Slope=2.35H:1V
FS=1
FS=1.5
~5'
H/3
FM2
Legend
WS 6cfs
Ground
Bank Sta
Elevation (feet, NAVD88)
Station (ft)
55
50
45
40
35
30
25
20
320
340
360
380
400
420
440
460
480
500
520