Sources, Magnitude, and Mitigation of Erosion and Sedimentation in the Salt River Basin, with Emphasis on Francis and Williams Creek Basins

Prepared for:
Humboldt County Resource Conservation District
California Coastal Conservancy
California Department of Fish and Game

Prepared by:
Lee Benda
Lee Benda and Associates , Inc.
Mt. Shasta, CA
&
Alice Berg
Alice Berg and Associates
Ferndale, CA

April 15, 2007

TABLE OF CONTENTS

Summary 1
1.0 Background 2
2.0 Study Objectives and Methods 5
3.0 Previous Erosion Studies 5
4.0 Analysis 9
4.1 Field Reconnaissance 10
4.1.1 Field Reconnaissance: Principle Erosion Sources 10
4.1.2 Field Reconnaissance: Floodplain Erosion in Lower Valleys 10
4.2 NetMap – Computerized Watershed Analysis 17
4.2.1 Predicted Erosion: Deep-Seated Landslides/Earthflows 17
4.2.2 Predicted Erosion: Shallow Landslides 21
4.2.3 Predicted Erosion: Debris Flows 21
4.2.4 Roads – Erosion Potential Overlaps 24
4.2.5 Coho and Steelhead Intrinsic Potential 26
4.2.6 Roads – Habitat Overlaps 29
5.0 Synthesis and Discussion 29
5.1 Major Erosion Sources and Controllability 29
5.2 Mitigating Sedimentation and Floodplain Erosion 35
5.3 Potential Applications of NetMap In The Salt River Basin 38
5.4 Suggested Future Work 38
6.0 Acknowledgements 40
7.0 References 41

Sources, Magnitude, and Mitigation of Erosion and Sedimentation in the Salt River Basin, with Emphasis on Francis and Williams Creek Basins

Summary

The analysis objective is to verify the Soil Conservation Service's (SCS; 1993) sediment budget for the Salt River basin and to identify those sources of sediment that are controllable. The dominant forms of erosion in the upper basins are associated with rapid movement of earthflow toes, streamside landsliding, and bank erosion; almost the entirety of the upper basins of Francis and Williams Creeks are composed of landslide and earthflow terrain. The SCS (1993) sediment budget did not adequately account for erosion from deep-seated landslides and earthflows and thus likely underestimated sediment yields from the Salt River tributary basins. Nevertheless, their conclusion of erosion focused near stream channels is consistent with our field observations. Given the natural instability and mass wasting characteristics of the upper basins, the major sediment sources are not controllable in the near term. The floodplain environment, located at the base of the Wildcat Range within tributary valley floors is not actively trapping sediment, but rather is eroding and thus contributes sediment through bank erosion to the Salt-Eel floodplain. One hypothesis is that historical and current land uses (on the floodplain) has led to channel incision into a formerly active floodplain thus greatly reducing its ability to trap sediment, and furthermore has enhanced sediment transport and exacerbated sedimentation on the Salt-Eel floodplain and also reduced fish habitat quality. A further hypothesis is that channel incision into the valley floodplains of 2 to 4 m may have propagated upstream into the upper basins, heightening streamside erosion, particularly along unstable toes of deep-seated landslides and earthflows, further increasing sedimentation to the Salt-Eel floodplain. Based on these hypotheses that require further scrutiny, a potential mitigation strategy is to restore the natural functioning of valley floodplains from sources and conveyors of sediment, to sediment sinks. This holistic approach conceivably could reduce downstream sedimentation, reduce upper basin erosion (over decades), and improve habitat for anadromous salmonids.

1.0 Background

The Salt River watershed is located in Humboldt County, 15 miles south of Eureka, near the City of Ferndale. The Salt River flows into the Eel River estuary and has four main tributaries: Williams Creek, Francis Creek, Reas Creek, and Smith Creek. The watershed encompasses approximately 30,425 acres, comprised of the Wildcat Range (12,775 acres) and the Salt River Delta (17,650). The Salt River Delta is a gently sloping alluvial floodplain that is the southern portion of the larger Eel River Delta. The length and function of the mainstem Salt River has been drastically reduced due to channel aggradation.

Historically, the lower Salt River functioned primarily as a migration corridor for adult salmonids reaching spawning habitat in tributaries, and rearing habitat for juveniles migrating downstream to the Eel River estuary. Channel aggradation has severely limited migration opportunities into upper watersheds and has caused drastic population declines of all Pacific salmonids that once utilized the Salt River (coho salmon, steelhead, cutthroat trout and possibly Chinook salmon).

The hydraulic dysfunction of the Salt River has caused significant problems related to flooding and wastewater treatment violations. Historically, the Salt River had sufficient flow necessary for the City of Ferndale Wastewater Treatment Plant (WWTP) to comply with the North Coast Regional Water Quality Control Board wastewater dilution requirements; however, sedimentation has reduced the receiving water flows causing the WWTP to violate water quality standards. In addition, numerous dairy operations and residential areas experience annual flooding due to lack of conveyance capacity in the Salt River.

Prior to European settlement, the Salt/Eel River estuary (tidally influenced area located south of the Eel River) was approximately 3,558-acres. Currently, only approximately 444-acres of the Salt/Eel River estuary are subject to tidal influence, or just over 12-percent of the original tidal wetland area. In addition to direct habitat loss, this change also resulted in a loss of tidal flows, which has contributed to sediment accumulation in

the lower Salt River channel through loss of scour by tidal waters and through establishment of willows in the channel due to loss of saline waters.

The headwaters of the Salt River are within the Wildcat Range. Erosion rates in the Wildcat Range are naturally high due to steep slopes, sedimentary formations (mudstone, sandstone and siltstone), large landslides, and high amounts of rainfall. In addition, headwaters of the Salt River are located within a complex tectonic setting, near the Mendocino Triple Junction, contributing to a high concentration of earthquakes. Dense, fast-growing vegetation helps to limit erosion and sediment yield, however, vegetation may have little effect on primary sources of sediment (deep seated landslides) observed in these tributaries. However, the SCS (1993) reported that historically, when upwards of one-third of tributary watersheds were logged, burned and/or grazed at a given time, erosion and sediment yield rates were estimated to be one to two orders of magnitude greater than current estimates and that more protective land management practices have decreased the impacts of land management.

Steep hillsides of upper tributaries sharply contrast with their flat alluvial canyon floors. Principle land uses in tributary valley floors are rural residential (limited) and grazing, and downstream delta areas have been developed for municipal use, residential and dairy operations. Land uses have severely limited floodplain function at the base of the Wildcat Range and downstream. Historically, as streams in the Wildcat Range left the very steep uplands and flowed out onto lower gradient alluvial canyon floors and onto the delta, water spread out and dispersed overland in multiple channels or in some cases without a defined channel. As water spread out, flows lost channelized energy and sediment carrying capacity. Virtually the entire sediment load from the Wildcat Range was dropped in the vegetated flats that formed an unbroken land cover on canyon floors and in the delta regions of Wildcat tributaries. Tributary waters reaching the Salt River did not contain much sediment as evidenced by the elevated fans that are topographic features apparent today (SCS 1993). Historic flows at the base of the Wildcat Range were distributory: water *and sediment* were distributed over the landscape. Currently, tributary canyon floors are managed for grazing and stream channels are confined and

deeply entrenched. These old floodplain deposits are now a *source* of fine sediment to the Salt-Eel River floodplain rather than sediment deposition areas.

CDFG conducted an instream habitat inventory of Francis and Williams creeks in June 2003. Valley floor channel segments were characterized similarly as "entrenched, meandering, riffle/pool channel with low gradients, high width to depth ratios and gravel dominated substrates." Upstream of the canyon valley floors, Williams and Francis creeks were defined as "steep, narrow, cascading, step-pool, high energy debris transporting channel."

Francis and Williams creek watersheds are composed of private lands managed for grazing and timber production. Aerial photographs from 1940 to 2000 indicate that these watersheds had undergone widespread harvest some years prior to the 1940 photographs, as evidenced by large open grasslands and areas that lacked dense vegetation overstory. It is likely that open areas were created with the intent of land conversion from timberland to grazing land. Massive earthflow landslides are visible as hummocky ground throughout the area.

Most parcels in Francis and Williams creek watersheds have had timber harvest on them. Intensive logging occurred from the 1940's through the 1960's, and a relatively lower level of harvesting occurred from the late 1960's to the early 1990's. Early logging was via tractor and cable high-lead methods and no protective zones were observed near watercourses. Since the mid-1970's, when modern Forest Practice Rules were enacted, increased protection of watercourses occurred. Forests are currently composed of naturally regenerated young growth conifers and red alder. From 1988-1997, approximately 2,000 acres were harvested or potentially harvested (i.e. analyzed in Timber Harvest Plans) in Francis and Williams creek watersheds. Since 1997, limited (~75 acres) harvest has occurred in Francis Creek. Harvest under Non Industrial Timber Management Plans (NTMPs) has occurred in Williams Creek to an unknown extent. Vegetative recovery has occurred in these watersheds over time and conifers have been re-established (since 1982) under an organized effort to reforest areas that were converted

to grazing under previous land management practices. There is ongoing road and erosion control improvement and maintenance programs on large parcels in headwater areas.

Currently, the County of Humboldt and the Humboldt County Resource Conservation District (RCD) is preparing an Environmental Impact Report (EIR) for the Salt River Ecosystem Restoration Project. The Salt River Ecosystem Restoration Project includes restoration of fish passage and water quality in the mainstem Salt River and lower Francis Creek, estuarine restoration on Riverside Ranch (within the Salt River estuary), and restoration of controllable sediment sources in Francis Creek, Williams Creek and Reas Creek watersheds.

2.0 Study Objectives and Methods

The primary objective of this review is to verify, through field observations and computerized watershed analysis, the major sources of erosion described in the sediment budget prepared by the SCS (1993) covering major tributaries of the Salt River. A second objective is to determine whether the identified sources of sediment are controllable (i.e., through mitigation strategies such as road crossing improvements and revegetation).

Materials used in the analysis include the SCS (1993) analysis of erosion sources in the Salt River Watershed, the detailed background materials covering that analysis (including maps and notes) provided by the SCS (in January, 2007), map of erosion sources from the California Division of Mines and Geology (Open File Reports 84-35 and 85-1), aerial photographs of primarily Francis and Williams Creek basins (hard copies 1948, 1954, 1963, 1988 and digital photos 1996 and 2000), computerized watershed analysis (NetMap, Benda et al. 2007), and two days of field reconnaissance during March, 2007.

3.0 Previous Erosion Studies

The analysis focused primarily on the Francis and Williams Creek basins. Francis and Williams creeks are primary sources of sediment that contribute to flooding problems on the greater Salt-Eel floodplain, including in the Salt River.

California Division of Mines and Geology (DMG) developed erosion maps for the Salt River basin (Open File Reports 84-35 and 85-1) that depict the location of deep-seated (rotational) slides and earthflows, as well as "disrupted ground" defined as "irregular ground surface caused by complex landsliding processes resulting in features that are indistinguishable or too small to delineate individually at this scale; may also include areas affected by downslope creep, expansive soils, and/or gully erosion; boundaries are usually indistinct". The DMG maps show that the upper portions of both Francis and Williams Creek basins contain discreet large landslides as well as significant amounts of disrupted ground (Figure 1).

Previous quantitative analysis of the erosion and sedimentation characteristics of the Salt River basin is limited to the SCS (1993) report, which covered the major tributaries of the Salt River including Russ, Smith, Reas, Francis, Williams, and Coffee creeks. The SCS (1993) sediment yield estimates are very approximate considering that only a small portion of the study area was examined. The SCS (1993) sediment budget contained estimates for six forms of erosion, including 1) sheet and rill erosion, 2) landslides, 3) stream bank erosion, 4) roads (permanent), 5) skid trails, and 6) quarries. Landslides and stream bank erosion were identified as the dominant sources of erosion in the Salt River basin (72%; Table 1).

Due to limited access on private property during the SCS (1993) study, only 1640' of channel length was observed out of a total of 38.7 miles of 2nd - through 4th-order channels, or about 0.8% of the total channel network. Estimates of erosion rates obtained from limited field observations were extrapolated to the remaining 99.2% of the channels. This created the potential for significant errors in the estimate of basin wide erosion, since processes that were not observed and recorded in the channels were not included, such as earthflows in Francis Creek (described below).

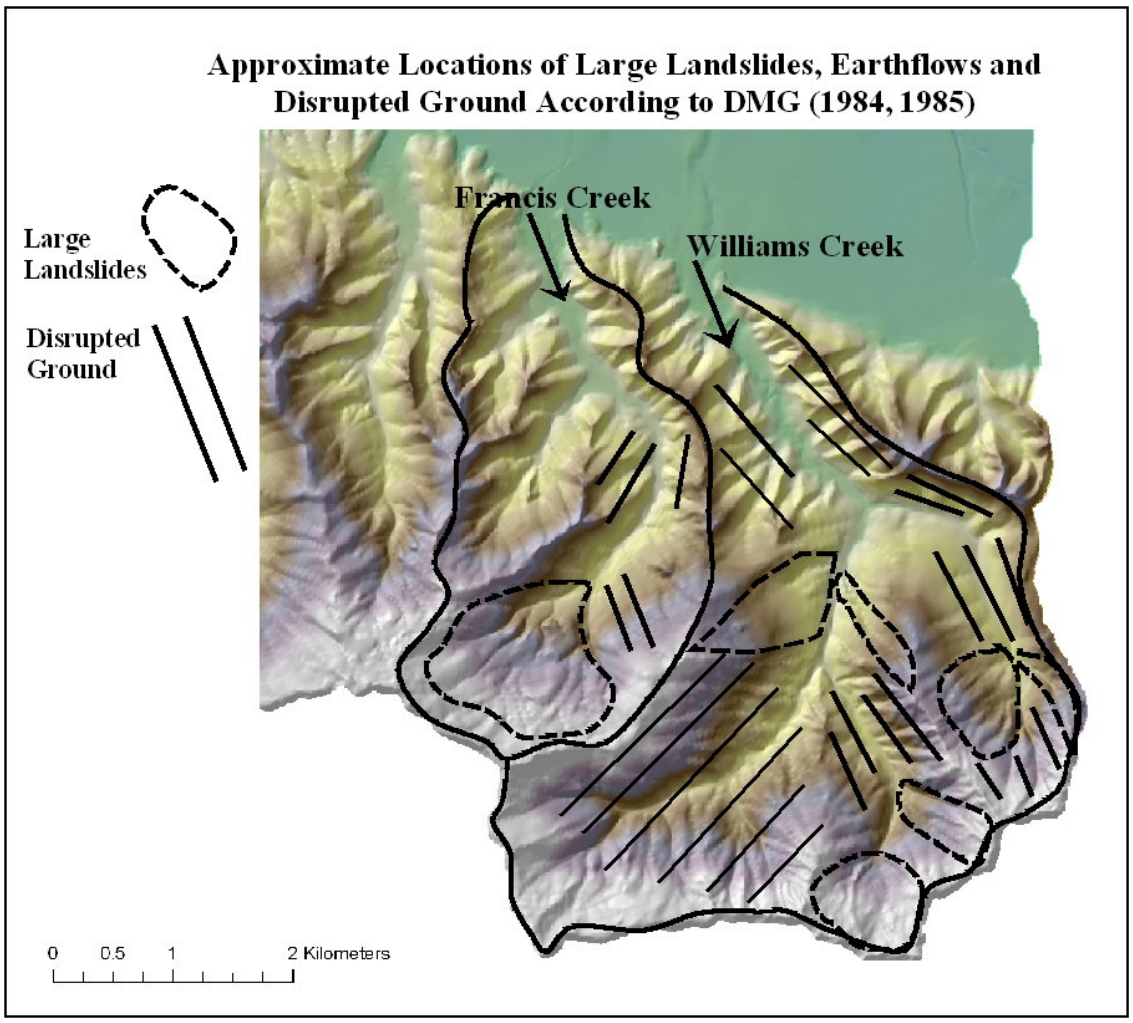

Figure 1. Map of landslides and disrupted ground (landslide terrain with indistinguishable boundaries) in Francis and Williams Creek basins, adapted from Division of Mines and Geology (DMG) maps.

Table 1. Sediment sources and estimated sediment yields in the Salt River Watershed (SCS 1993).

Upland Erosion Source	**Annual Sediment Yield (tons/year); %**
Sheet and Rill Erosion	860 (3%)
Landslides (85% on streams)	9,950 (34%)
Stream bank erosion	11,180 (38%)
Roads	3,470 (12%)
Skid Trails	2,290 (8%)
Quarries	1,510 (5%)
Total	29,300

Other methods used in the development of the SCS (1993) sediment budget contribute to its very approximate nature. The estimated erosion rate from landsliding was derived from a one years' sample of observed landslide scars along the surveyed channels; in general, more accurate estimates of landsliding require a time series of measurements, considering the stochastic nature of the process (Reid and Dunne 1996). In addition, large deep-seated landslides and earthflows were not included in the (1993) budget because of difficulty of gaining access to private property [this contrasts with the present analysis that had access to private property in upper Francis and Williams Creek basins].

The Universal Soil Loss Equation (USLE) and Modified USLE were used by the SCS (1993) for estimating sheet and rill erosion on roads and on "disturbed" areas within the Salt River basin. Other methods are now more commonly used to predict surface erosion from roads (e.g., SEDMOD, WNDR 1997; WEPP, Elliot et al. 2000). Nevertheless, the MUSLE provides rough estimates of erosion from roads and other compacted areas, such as landings (e.g., for timber harvest purposes) or residential areas. It is generally recognized, however, that sheet and rill erosion do not occur in forested areas (or timber harvest areas, other than on compacted lands such as skid roads and landings) since infiltration capacity exceeds precipitation intensity (Dyness 1969). Thus, MUSLE estimates of erosion (sheet and rill erosion represented 13% of sediment delivery) in uncompacted "disturbed" areas in the SCS (1993) budget are likely inappropriate.

Estimates of stream bank erosion are typically derived from field-measured bank retreat rates (Reid and Dunne 1996) or from wood budgets (Benda and Sias 2003). The SCS (1993) study employed a methodology that related visual and qualitative estimates of bank erosion with rates of bank retreat using four categories: slight (0.01 – 0.05 ft/yr [0.015 m/yr]), moderate (0.06-0.2 ft/yr [0.016 – 0.06 m/yr]), severe (0.3-0.5 ft/yr [0.09 – 0.15m/yr]), and very severe (0.5 ft/yr [0.15m/yr]). It is uncertain how these bank retreat rates were derived and if they are applicable to the study area (particularly in the context of earthflows). Nevertheless, they do relate rates of bank erosion with indices of bank disturbance and hence they are somewhat useful as a relative measure of streamside sediment yield. However, such categorical estimates of bank erosion should not be applied to areas of rapid soil movement such as the toes of earthflows. Earthflow erosion rates in northern California can range from tens of centimeters to meters per year (Kelsey 1980).

Based on the available information in the SCS (1993) sediment budget and the limited scope of the present review, it is not feasible to comprehensively and numerically audit SCS's (1993) erosion rates in the Salt River basin. The SCS (1993) did not estimate sediment flux from the large and pervasive landsliding documented during this review and mapped by DMG (see below). As a consequence, there are likely serious errors of approximation in the SCS (1993) budget, which could not have been avoided given the limited access of SCS personnel to the upper basins (due to private property restrictions). Specifically, given the absence of earthflow sources of streamside landsliding and bank erosion in the SCS (1993) sediment budget, the erosion rates and total sediment yields (Table 1) are likely underestimated. Despite these limitations, the SCS (1993) finding of erosion concentrated near stream channels is consistent with our observations.

4.0 Analysis

The analysis included review of available aerial photographs (1948-2000), two days of field reconnaissance in the lower and upper basins of Francis and Williams Creek basins, and computerized watershed analysis. Stereoscopic review of available aerial photography was of limited value because the dominant erosion processes focused near stream channels were not discernable given photo scale and vegetative cover.

4.1 Field Reconnaissance

4.1.1 Field Reconnaissance: Principle Erosion Sources

Field observations indicated that much of the 'disrupted ground' (mapped by DMG) in upper Francis and William Creek basins occur in association with large (unmapped) landslides and earthflows. Several large, active and previously unmapped deep-seated landslides and earthflows were observed in the upper Francis Creek basin (Figure 2). The observed and mapped (e.g. DMG, Figure 1) deep-seated landslides have the general topographic characteristics shown in Figure 3, including arcuate scarps (some approaching the drainage divides in Francis Creek), benches, inverted topography, and areas near streams of accelerated sediment movement driven by channel incision, stream side landsliding, bank erosion, and accelerated soil flow or creep. One major zone of such erosion is demarcated in Figure 2 and provides substantial amounts of sediment to Francis Creek (Figure 4). Although the entire stream network was not reviewed, we surmise that other channels in the Francis and Williams Creek basins that are bordered by deep-seated landslides and disrupted ground (e.g., Figures 1 and 2) have similar patterns of streamside landsliding and bank erosion, although perhaps not of the magnitude shown in Figure 4. For example, extensive zones of streamside, deep-seated landslides were observed in the lower Williams Creek watershed (Figure 5).

Our observations, along with the DMG map and computerized terrain analysis (see below) indicate that *the majority of the upper basins of both Francis and Williams Creek watersheds are comprised of landslide terrain* (e.g., Figure 3). This has important implications for erosion processes, rates, and controllability.

4.1.2 Field Reconnaissance: Floodplain Erosion in Lower Valleys

Steep tributary watersheds of Williams and Francis creeks transition at the base of the Wildcat Range to alluvial canyon floors. Valley floors of both Williams and Francis creeks have extensive floodplain deposits (Figure 6**)**. These wide valley floors, characterized by low gradients and extensive sandy floodplain deposits, coincide with NetMap's predicted zones of highest sedimentation those watersheds (Figure 7); high sedimentation potential means that floodplain areas represent a sediment sink. Although

historically the lower portions of Francis and Williams creek watersheds were depositional zones for fine sediment, field observations reveal they are presently

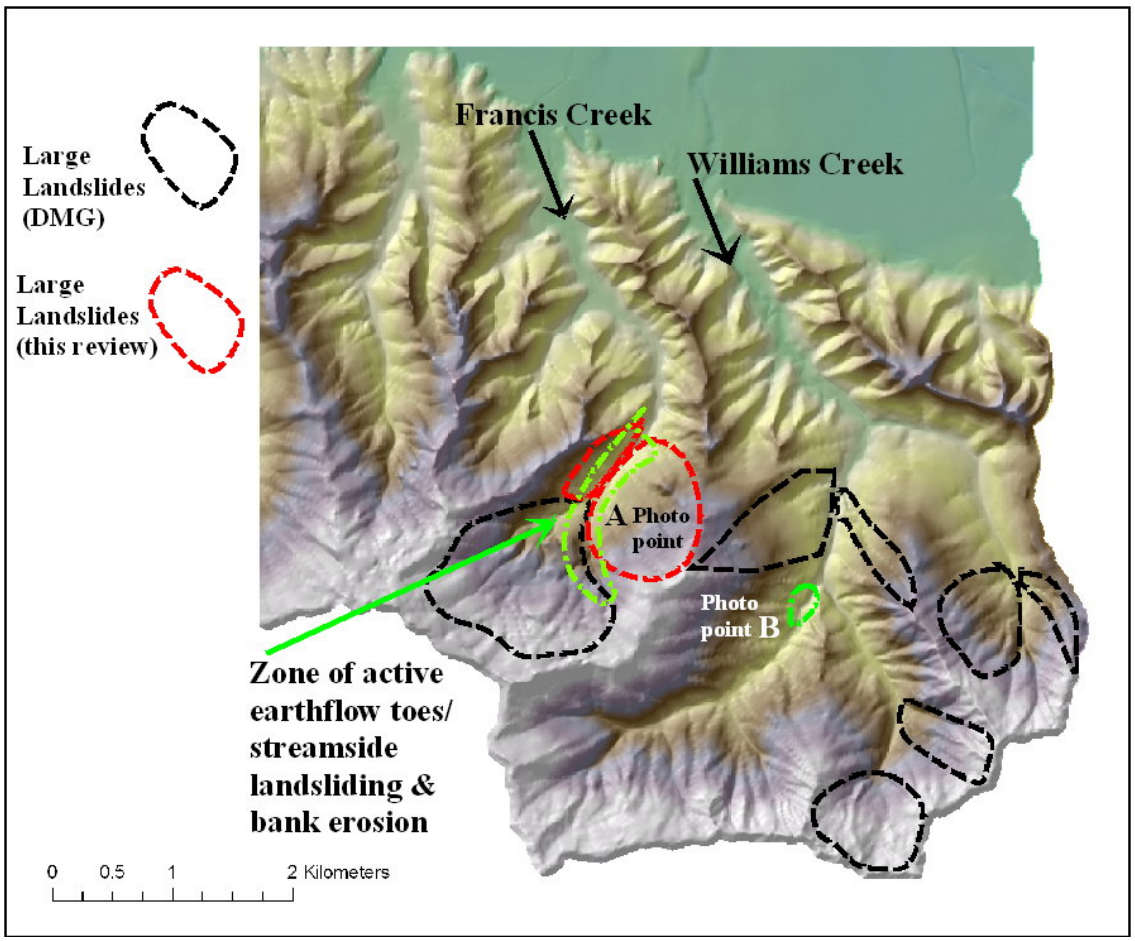

Figure 2. Large landslides in upper Francis and Williams Creek basins derived from DMG maps and this study. Photo point (A) corresponds to Figure 4 and photo point (B) to Figure 5.

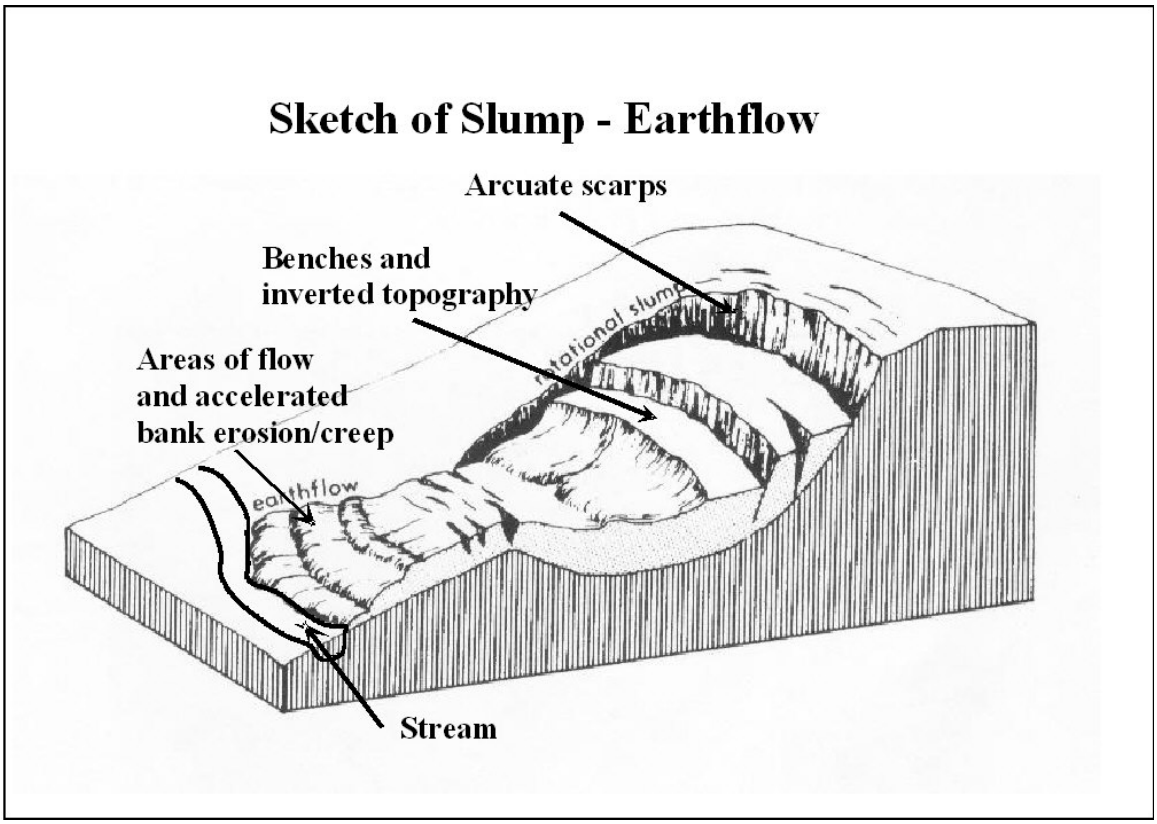

Figure 3.An idealized sketch of earthflow terrain that shows its characteristic topographic features.

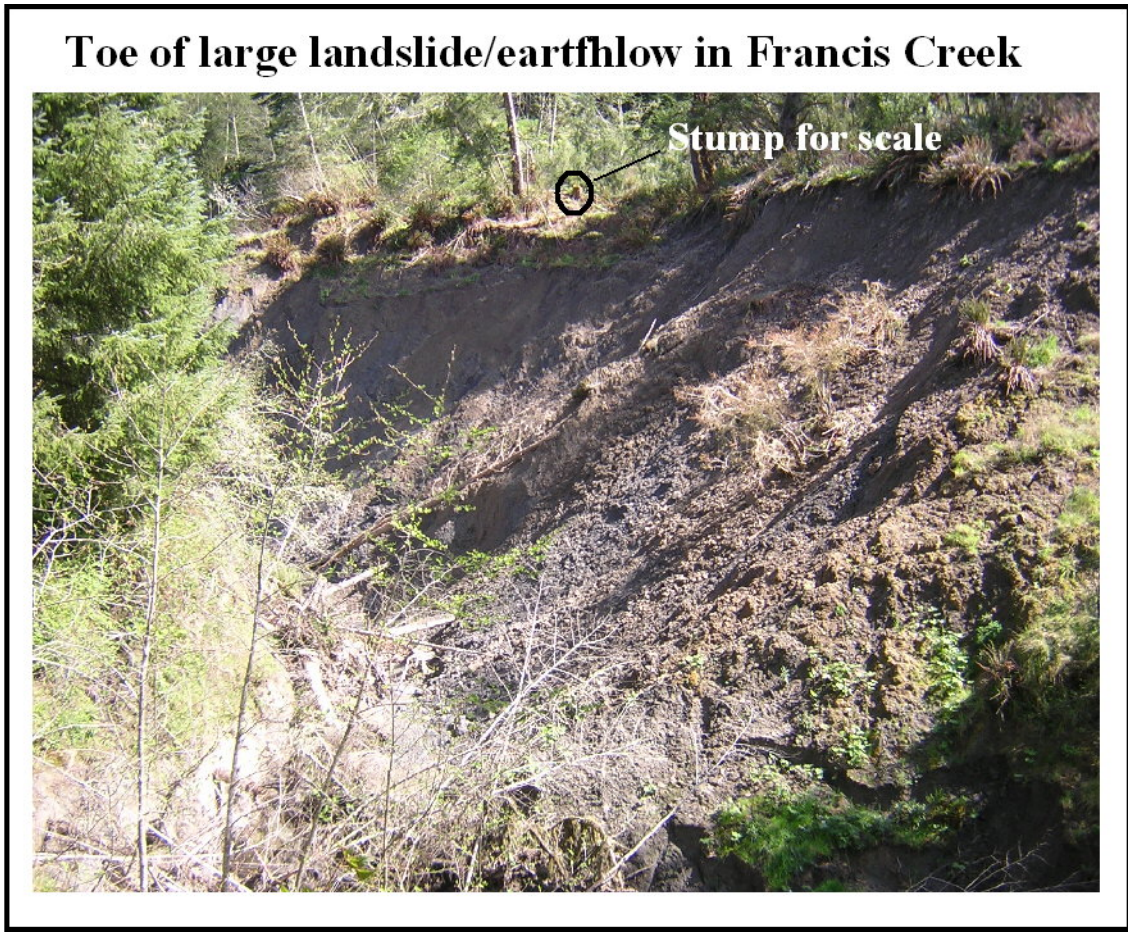

Figure 4. A rapidly moving and eroding toe of an earthflow is located in upper Francis Creek basin; Francis Creek is on left side. The location of the photo is shown on Figure 2 (photo point A).

Streamside Deep-Seated Landslides - Eartfhlows in Williams Creek

Figure 5. Deep-seated landslide and earthflows border upper Williams Creek. The location of the photo is shown on Figure 2 (photo point B).

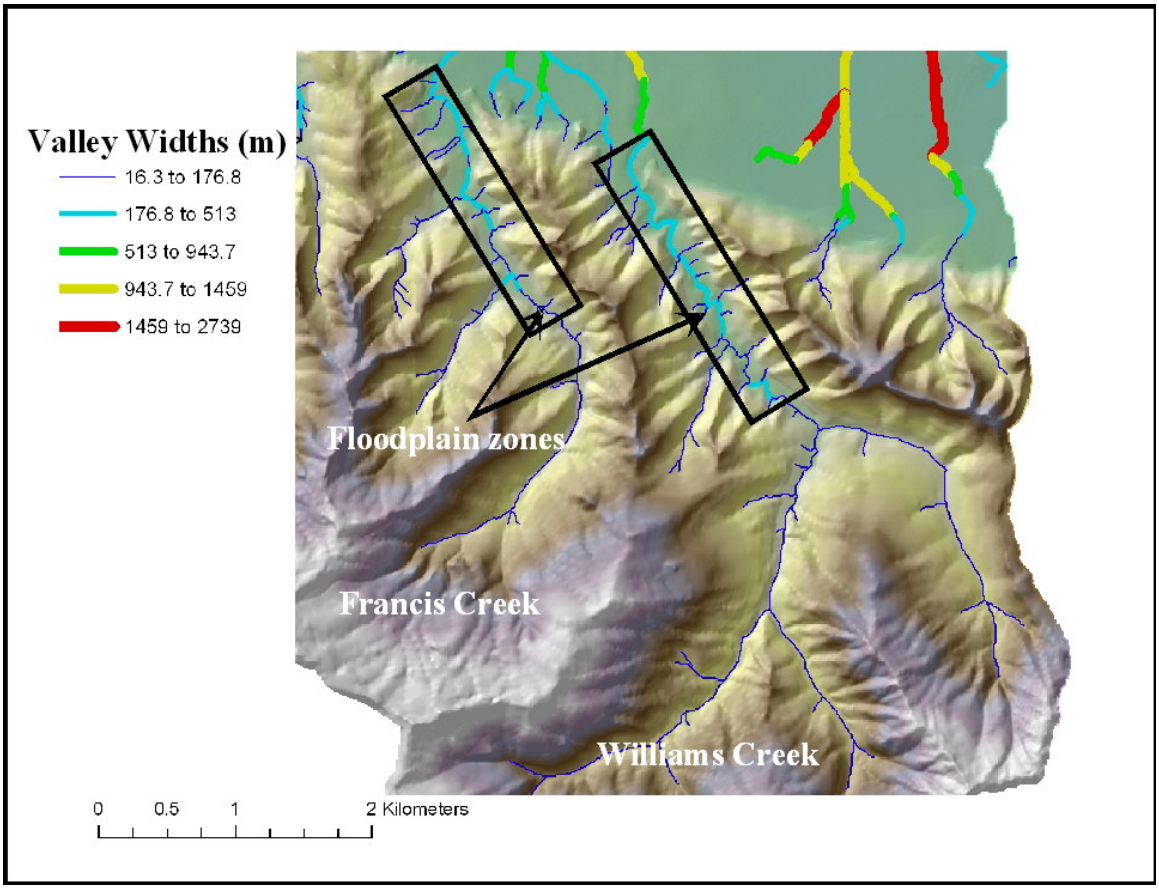

Figure 6. Valley widths that are predicted by computerized watershed analysis (NetMap) show locations of lower valley floodplain zones

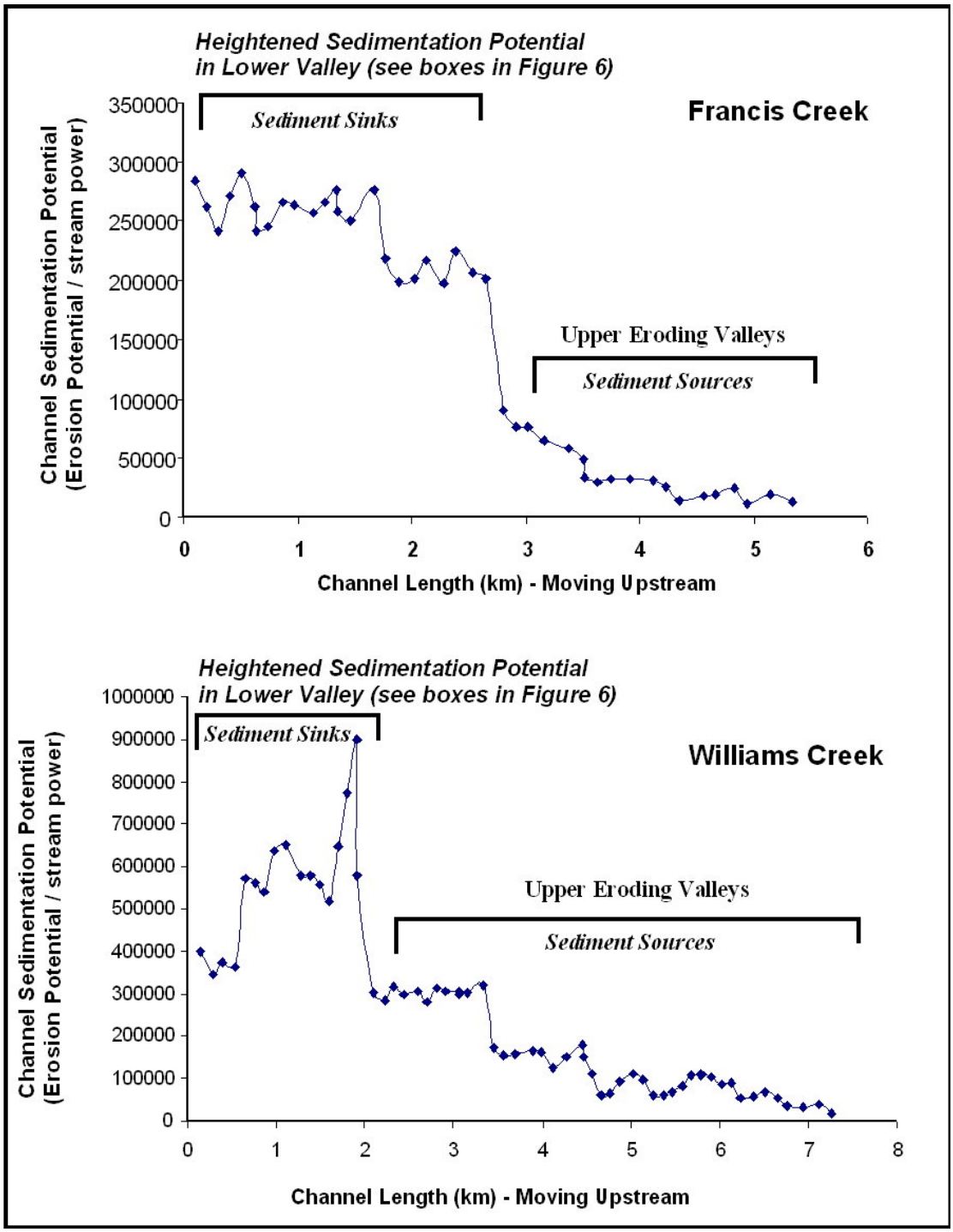

Figure 7. NetMap is used to predict variation in sedimentation potential along the main channels of Francis and Williams Creek basins. The plot illustrates how the lower valleys (mapped in Figure 6) are preferential sites for sediment deposition based on stream power considerations.

characterized by stream erosion/channel incision. In lower Williams Creek, the channel appears to have *incised* 2 to 4 meters (6.5 to 13 feet), exposing bedrock and old weathered gravels in some areas (Figure 8). Although a floodplain system, by definition, should exhibit net deposition (creating wide, braided channels), channels in Williams and Francis creeks are eroding, particularly at outside of meanders. Landowners in the affected areas (valley floors) are using various erosion control measures (boulder berms, log berms, and revegetation) to reduce erosion of the floodplain deposits (Figure 9).

4.2 NetMap – Computerized Watershed Analysis

A computerized watershed analysis tool, NetMap (Benda et al. 2007), was used to provide an overview of erosion, channel, and habitat conditions in the Salt River tributaries and hence to support this analysis. NetMap software that can be used to evaluate numerous watershed attributes will be made available to the public agencies involved with this study; other interested parties should contact Earth Systems Institute to access the software that runs with ArcGIS 9.1/9.2. Additional information on NetMap is found at www.earthsystems.net.

4.2.1 Predicted Erosion: Deep-Seated Landslides/Earthflows

NetMap is used to predict the likely occurrence of deep-seated landslide and earthflow terrain using the model developed by Roering et al. (2005; refer to *Technical Help* in NetMap software for technical background and additional details). The Roering model uses estimates of slope gradient and hillslope profile information to identify topographic characteristic of deep-seated landslides (e.g. Figure 3). The model predicts that virtually all of the upper regions of Salt River tributaries are comprised of topography indicative of deep-seated landslides and earthflows (Figure 10). The earthflow model does not indicate the level of landslide activity, such as dormant or active.

In Francis Creek and Williams Creek basins specifically, NetMap's prediction of potential deep-seated landslide and/or earthflow activity is consistent with aerial photo and field based estimates of deep-seated landsliding (including disrupted ground) made by DMG (Figure 1) and observations made during field reconnaissance for this study (Figure 2).

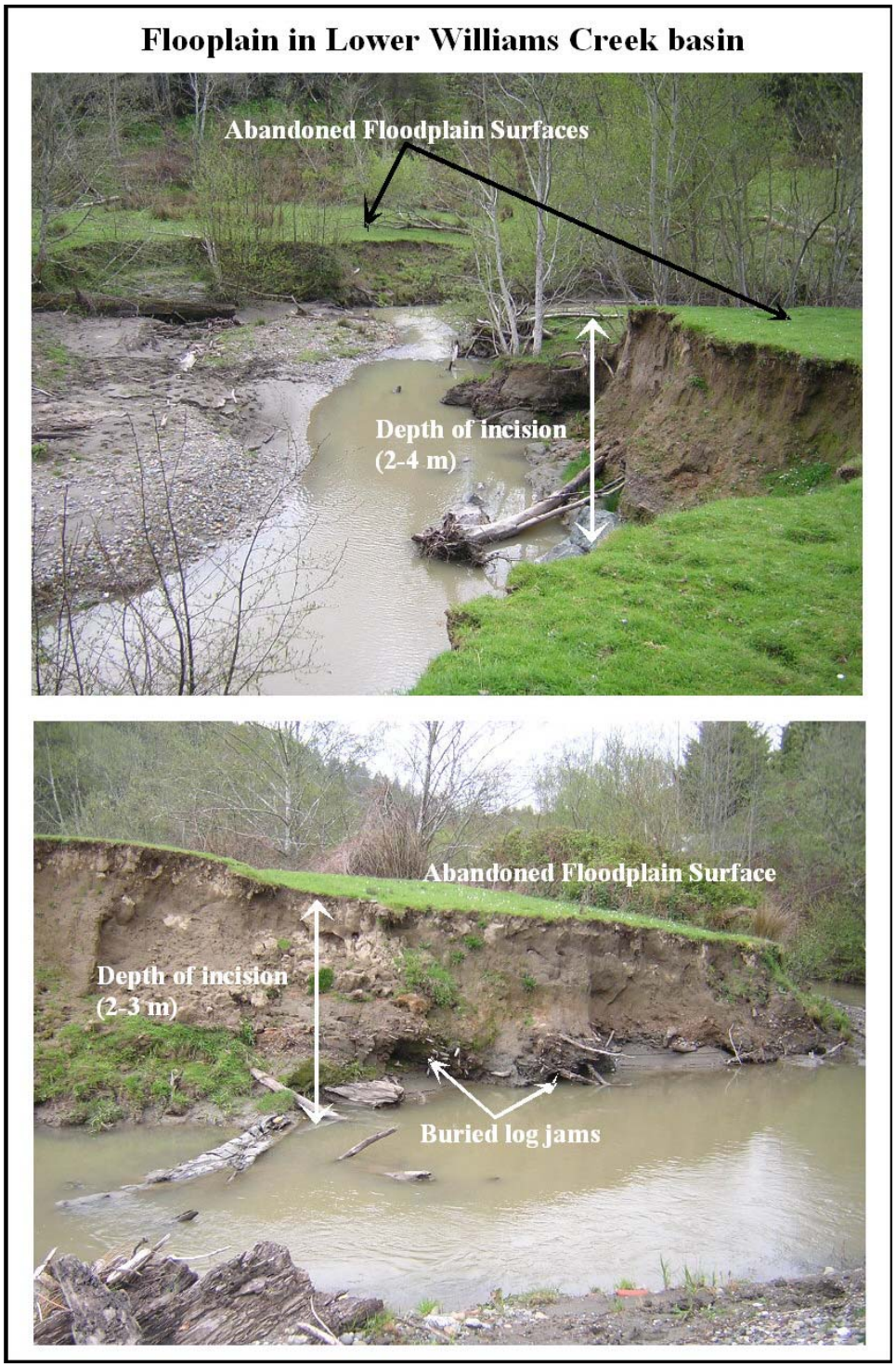

Figure 8. Photographs illustrate the intense bank erosion that is occurring in the lower valley floodplains, shown here is Williams Creek. Note buried log jams in lower photo. It appears that the floodplain channels have incised in some areas exposing bedrock and ancient river gravels, leaving the floodplain surface abandoned (i.e., no overbank flows).

Figure 9. Land owners along the lower valley floodplains are employing various methods to reduce bank erosion along the eroding channels.

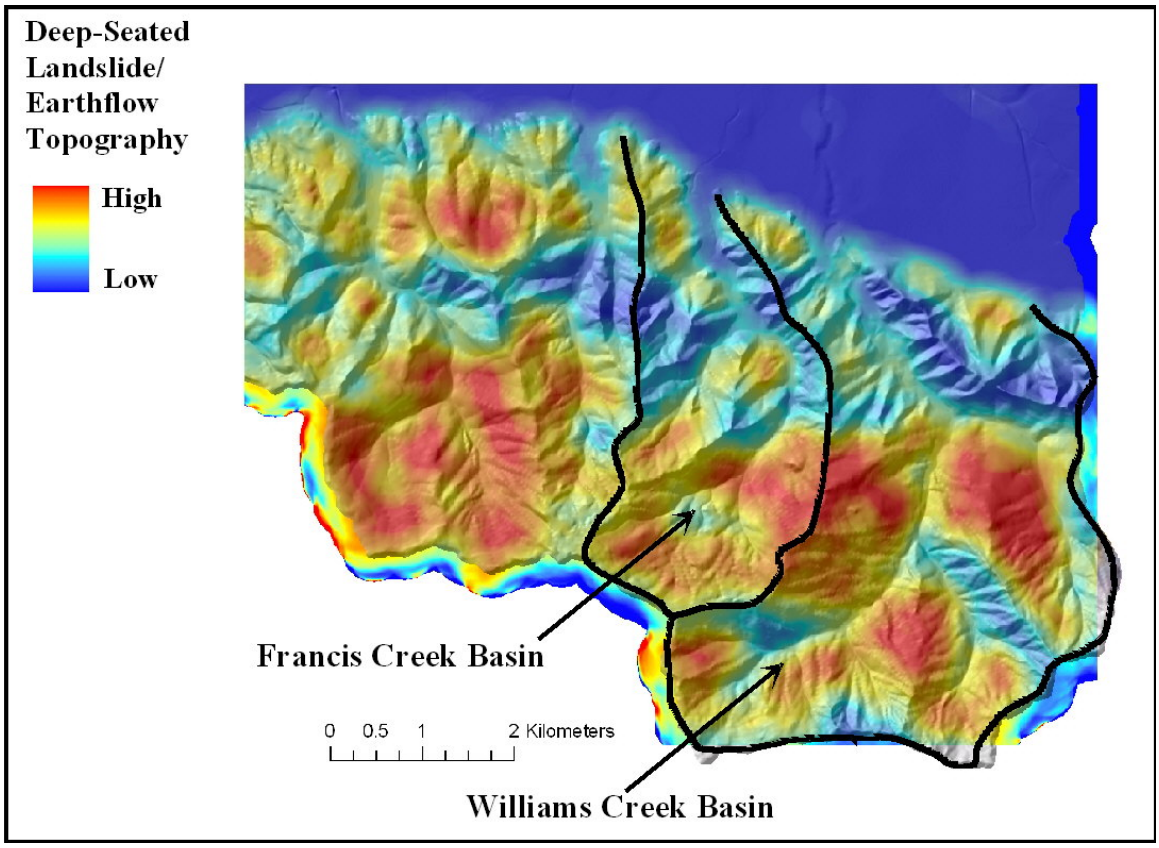

Figure 10. NetMap is used to predict topography indicative of deep-seated landslide and earthflows using the model of Roering et al. (1995). Virtually the entirety of the upper basins of the Salt River tributaries are characterized by deep-seated landslide and earthflow terrain. This is consistent with DMG maps and with observations made during this analysis (Figures 1 and 2).

4.2.2 Predicted Erosion: Shallow Landslides

Netmap was used to predict the potential for shallow landslides using an empirical model developed by Miller and Burnett (2007; refer to *Technical Help* in NetMap software for technical details). The highest potential for shallow failures occurs in relatively confined areas in Francis and William Creek basins that are very steep (> 70 to 80%) and convergent (convergent refers to spoon-shaped depressions within the soil or bedrock that concentrates subsurface flow) (Figure 11); a field example of a shallow landslide in the Williams Creek basin is also shown in Figure 11. The areas designated as high shallow landslide potential do not have the topographic characteristics of deep-seated landslides and earthflows (i.e., compare Figures 10 and 11). In general, shallow failure potential is confined to areas that trend NW-SE and likely reflect a stronger sandstone rock within the larger Wildcat lithology.

The predicted high shallow landslide potential does not necessarily indicate that shallow landslides are a major sediment source to stream channels, since sediment delivery potential (to streams) is not included in the model. However, sediment delivery potential from shallow landslides *that create debris flows* can generally be high. Thus, potential sediment delivery and the likelihood of debris flows are addressed below.

4.2.3 Predicted Erosion: Debris Flows

NetMap was used to predict the likelihood of debris flows, defined as liquefied landslide debris that travels down through convergent topography, particularly within steep headwater channels (refer to *Technical Help* in NetMap software for additional details on this parameter). Overall the study area has a low likelihood of debris flow potential and thus low sediment delivery to stream channels from upslope landslide sources (Figure 12). High debris flow potential in Francis and Williams creek basins is limited to only a few areas where very steep hillslopes abut stream channels (primarily along the NW-SE trending ridges that form the lower northeast watershed boundaries of both basins).

The low sediment delivery potential from upslope shallow landslides and debris flows is due primarily to the predominance of deep-seated landslide terrain that lowers hillslope gradients over time, particularly near stream channels (e.g., Figure 3). Overall, shallow

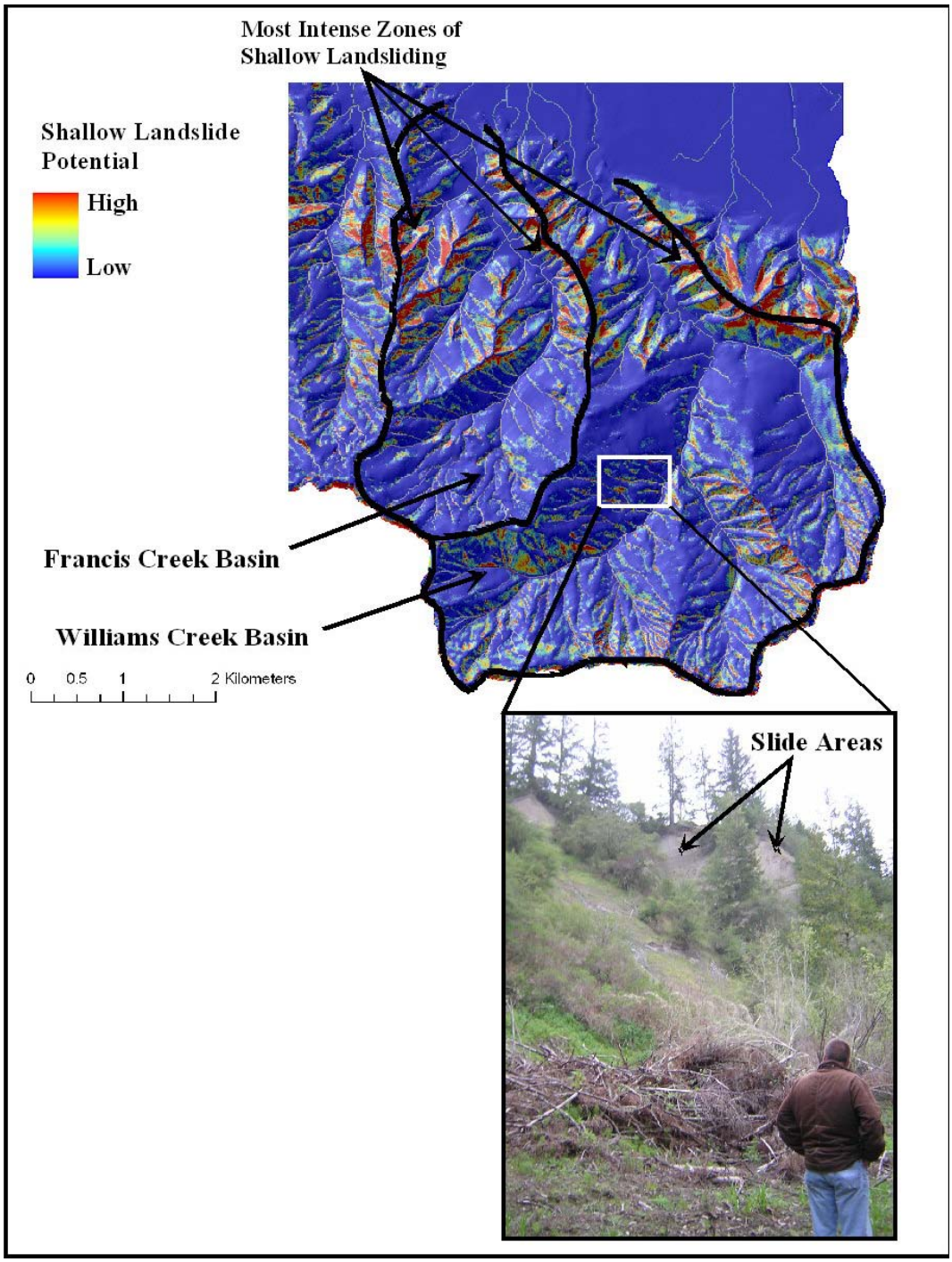

Figure 11. NetMap is used to predict the susceptibility of shallow landslides; refer to NetMap Tools for technical background and further details. High shallow landslide potential is concentrated in several areas that are steeper and lack the topographic signature of deep-seated landslides and earthflows (compare with Figure 10).

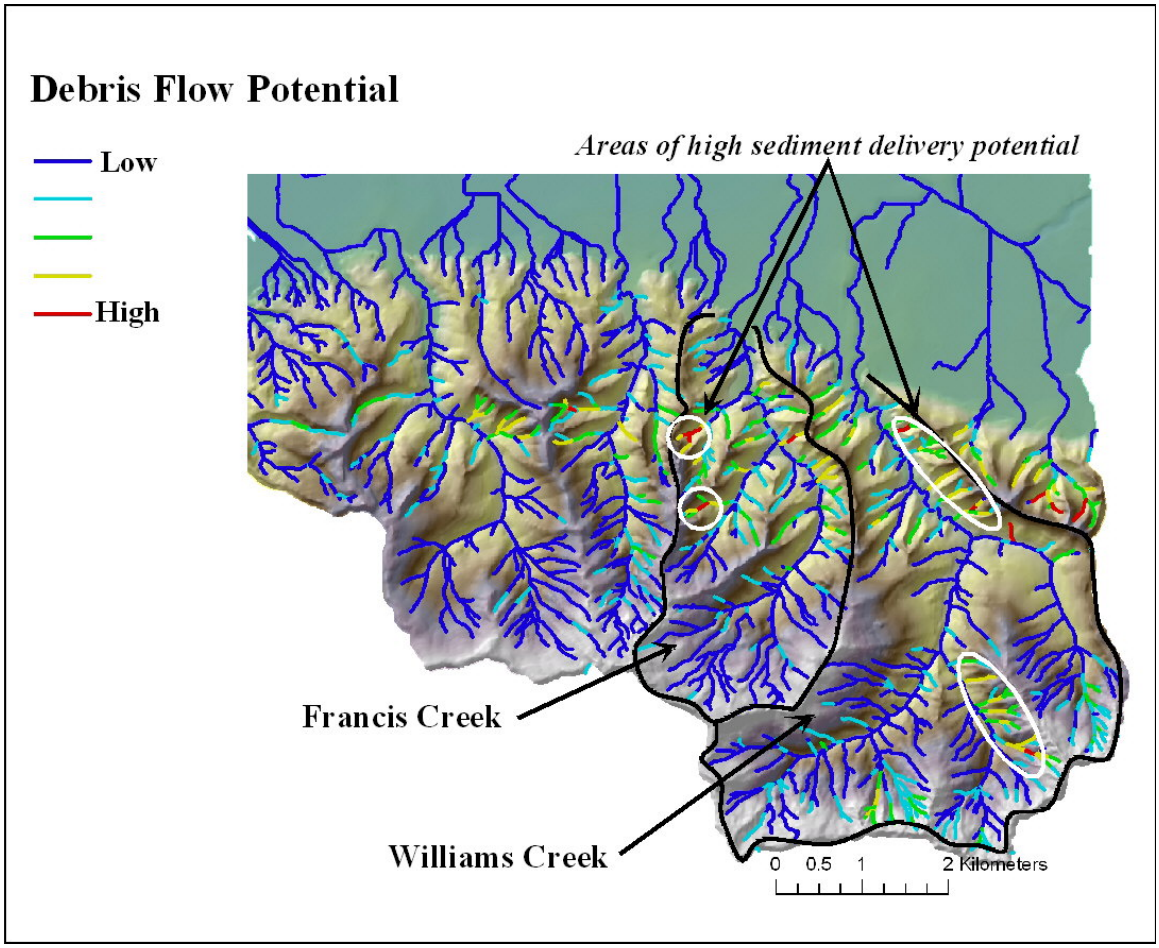

Figure 12. Predictions of shallow landslide susceptibility (Figure 11) do not address sediment delivery potential to streams. Debris flows that move through steep headwater channels often has high sediment delivery potential. NetMap is used to predict debris flow potential using a model by Miller and Burnett (accepted); refer to NetMap Tools for technical background and further details. Overall, debris flow potential is low and it is confined to those areas where steep hillslopes that are dissected by headwater channels abut larger streams.

landslides and debris flows are judged relatively minor sources of in-stream sediment compared to the near streamside landslides and accelerated bank erosion within the deep-seated landslide and earthflow terrain based on NetMap's analysis.

4.2.4 Roads – Erosion Potential Overlaps

Roads can be a major source of erosion problems in watersheds, particularly where they intersect erosion-prone hillslopes or channels. Only partial road coverage was available for this analysis, and road information was primarily concentrated within the Francis and Williams Creek basins. In Francis Creek, the majority of drivable roads were mapped and input to the model. Overgrown logging roads were not available or included in this analysis. Despite the lack of a complete road coverage, the evaluation of available mapped road networks provide an illustration of what can be done with more comprehensive road data.

NetMap evaluates roads in the context of erosion and habitat potential, thus allowing a screening of potential problem areas within a watershed. Using one of NetMap's tools, the partial road network for the Salt River basin was classified (10-m road segments) based on the predicted slope stability of the hillslope upon which the road is constructed for both deep seated terrain (e.g., Figure 10) and shallow landslide potential (e.g., Figure 11). The resultant maps depict potential variation in the underlying road stability (Figure 13). In deep-seated terrain, the road likely has a minimum effect on the stability of the hillside. In contrast, in shallow landslide terrain, the road (if poorly designed, constructed, or maintained) could trigger failures both within the road prism or on nearby hillslopes. NetMap's analysis reveals road segments that might be of potential concern (e.g., Figure 13) and thus the analysis provides a means to prioritize future road surveys. Overall, the relationship between roads and shallow landslide potential is minimal in Francis and Williams Creek basins based on analysis of the available road network.

Although the relationship between roads and landsliding is a potential concern in the Salt River basin, the delivery of sediment to streams is a more important consideration. In this analysis, sediment delivery from upslope shallow landslides was considered in the context of debris flows (e.g., Figure 12). In NetMap's analysis of roads, all road-stream

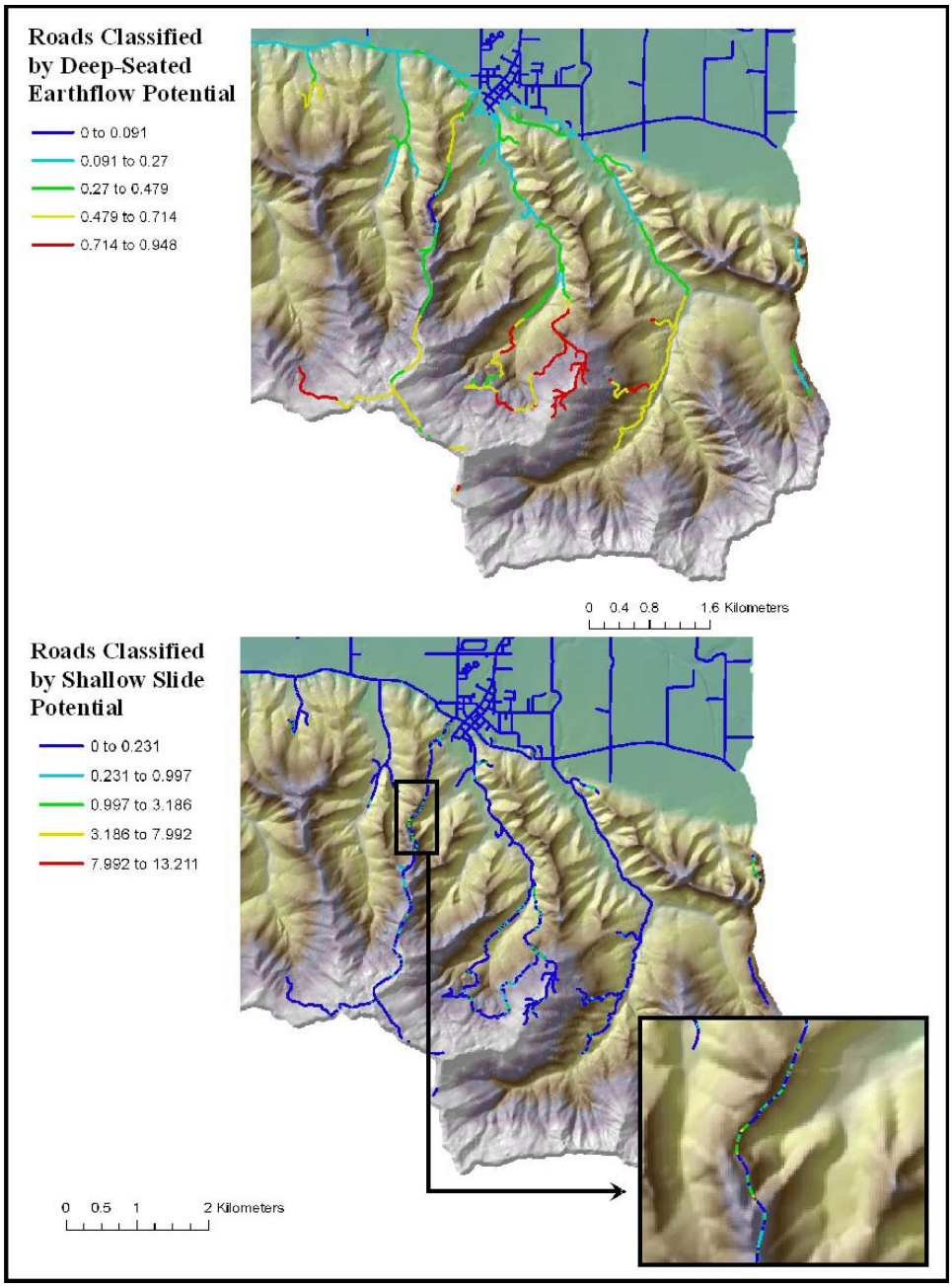

Figure 13. NetMap is used to classify road segments in Francis and Williams Creek basins with respect to the underlying hillslope stability, shown here for deep-seated landslides (top) and shallow failures (bottom). Such maps can be used to prioritize future road surveys.

crossings are classified according to the potential (of the stream) to trigger, or to transport, debris flows (Figure 14). In this analysis, the stream segment (average length = 100 m, range 20 – 200 m) that the road crosses is classified according to debris flow susceptibility. This prediction does not address road stability specifically but rather, given a road failure, the likelihood of triggering a debris flow and the potential for delivering sediment to larger stream channels. The analysis reveals numerous areas where roads intersect channels that are prone to debris flows.

4.2.5 Coho and Steelhead Intrinsic Potential

When evaluating options for reducing erosion and sedimentation in the Salt River tributaries, it is informative to understand the distribution of fish habitats across the basins. NetMap was used to estimate coho and steelhead habitats throughout all major tributaries.

Empirical relationships among three physical channel characteristics (gradient, confinement, and mean annual flow) and salmon abundance have been used to create a habitat index called "intrinsic potential"; intrinsic potential (IP) indices have been developed for rearing habitat of coho salmon and steelhead trout in Oregon (Burnett et al., 2003). High IP values for coho require channel gradients between 1 and 4 percent and unconfined channel environments (wide valleys). Intrinsic potential does not account for existing conditions that may reflect natural or land use disturbances. NetMap's habitat creator automates the calculation of IP using published relationships, with values ranging from 0 to 1 (1 = highest potential).

The predicted distribution of IP for coho rearing habitat in the Salt River tributaries is shown in Figure 15. The valley floor/lower floodplain portions of all of the major Salt River tributaries, as well as all channels on the larger Salt-Eel River floodplain, are predicted to have relatively high coho rearing habitat potential (e.g., values > 0.8). Above the wide floodplain valleys, in the Wildcat Range, coho habitat drops off significantly.

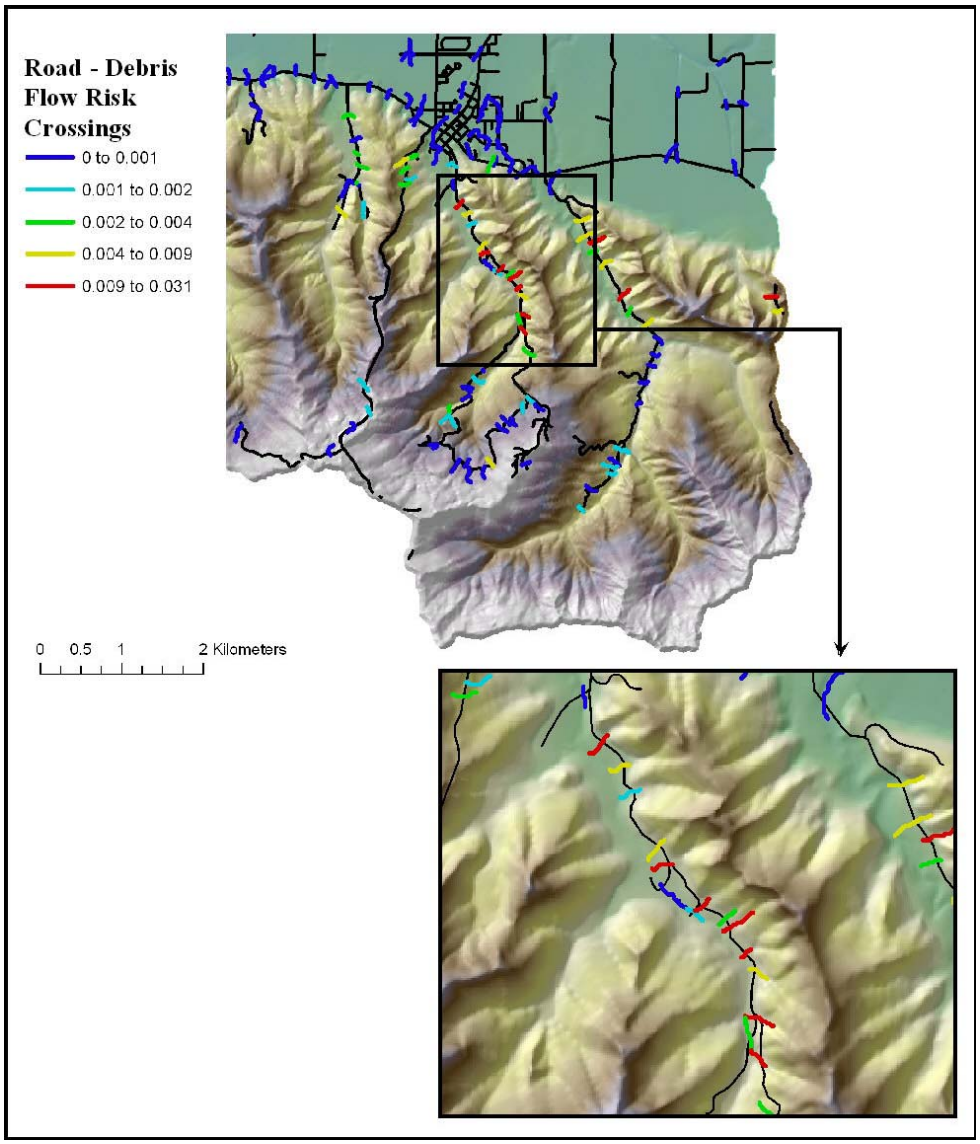

Figure 14. NetMap is used to classify road segments in Francis and Williams Creek basins with respect to debris flow potential. Such maps can be used to prioritize future road surveys.

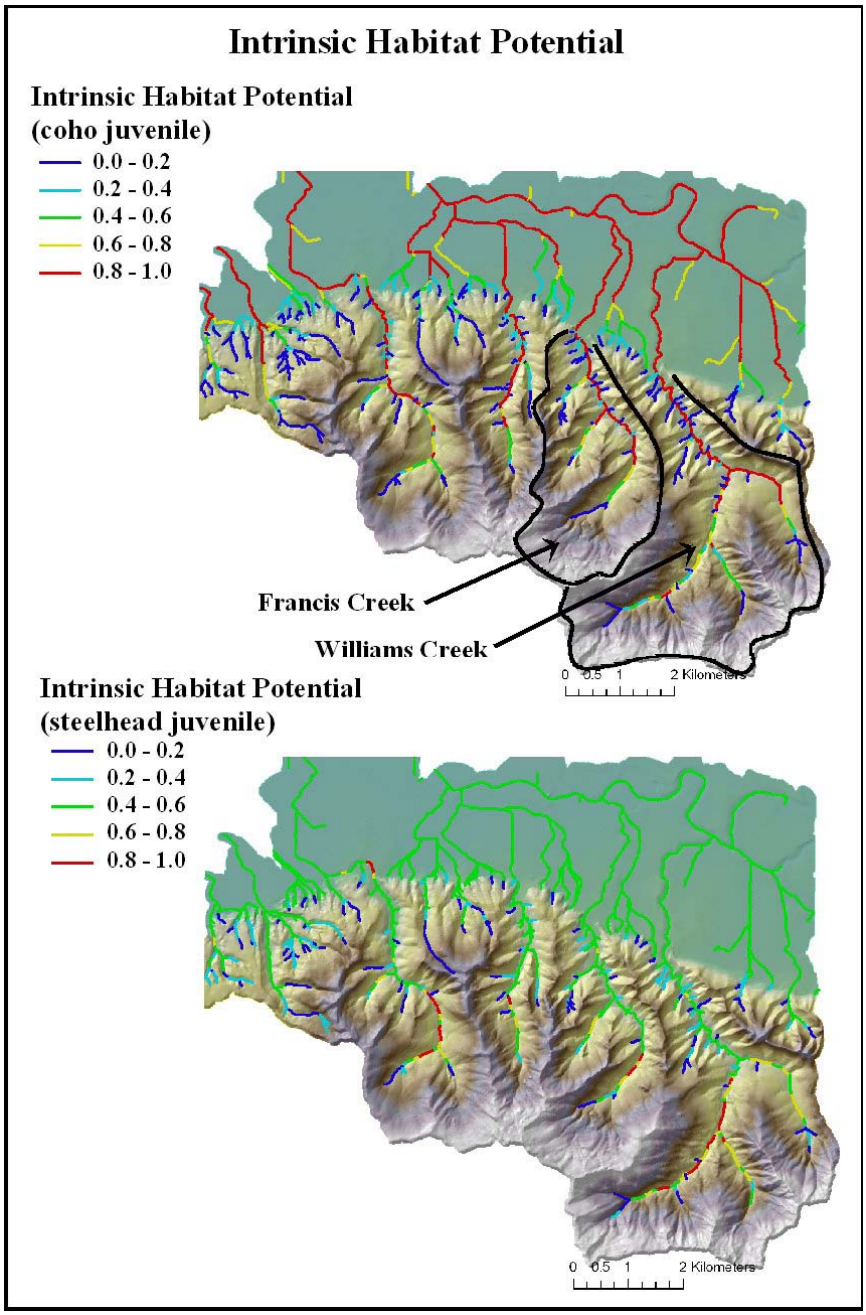

Figure 15. NetMap is used to classify stream segments according to intrinsic habitat potential (based on Burnett et al. 2003) across all Salt River tributaries. Values range from 0 to 1, with 1 being the highest potential. Rankings do not reflect current habitat conditions, which may be degraded, but rather reflect "intrinsic" properties of watersheds, specifically channel gradient, valley confinement, and mean annual flow.

High coho IP values requires wide, floodplain valleys and thus unconstrained channels. It is important to note that the 10-m DEMs used in NetMap cannot resolve the current incised condition of the valley floor channels (e.g., Figures 8-9), which create confined channel conditions. Thus, the IP model for coho does not represent current conditions but rather likely historical conditions when the channels were not incised (see discussion of floodplain environments in 5.0).

The IP index for steelhead trout requires gradients between 4 and 8 percent and confined channels. Consequently, NetMap predicts moderate to high IP values for steelhead in the upper portions and mainstems of tributaries (Figure 15). The IP analysis reveals that the best coho and steelhead-rearing habitat are, for the most part, spatially segregated.

Although sediment accumulation in the lower Salt River has all but prevented migration of salmonids, steelhead, coho salmon and cutthroat trout have been recently documented in Francis Creek.

4.2.6 Roads – Habitat Overlaps

NetMap is used to identify the relationship (overlaps) between roads and fish habitats, defined by coho and steelhead IP values. Stream segments (100-m average) are identified at locations where they are intersected by a road. This applies to both coho and steelhead and the identified channel segments are classified according to the predicted IP values (Figure 16).

5.0 Synthesis and Discussion

5.1 Major Erosion Sources and Controllability

Based on our field reconnaissance of Francis and Williams Creek basins and review of the SCS (1993) sediment budget and DMG maps, we conclude that the dominant source of erosion in those basins (and likely in other Salt River tributaries) is streamside landsliding, bank erosion, and accelerated soil creep in association with deep-seated landslides and earthflows. Deep-seated landslide terrain (including earthflows that have chronic rates of downslope movement or flow [e.g., Figures 3-5]) and so-called "disrupted ground" (also classified as landslide terrain with indistinguishable boundaries)

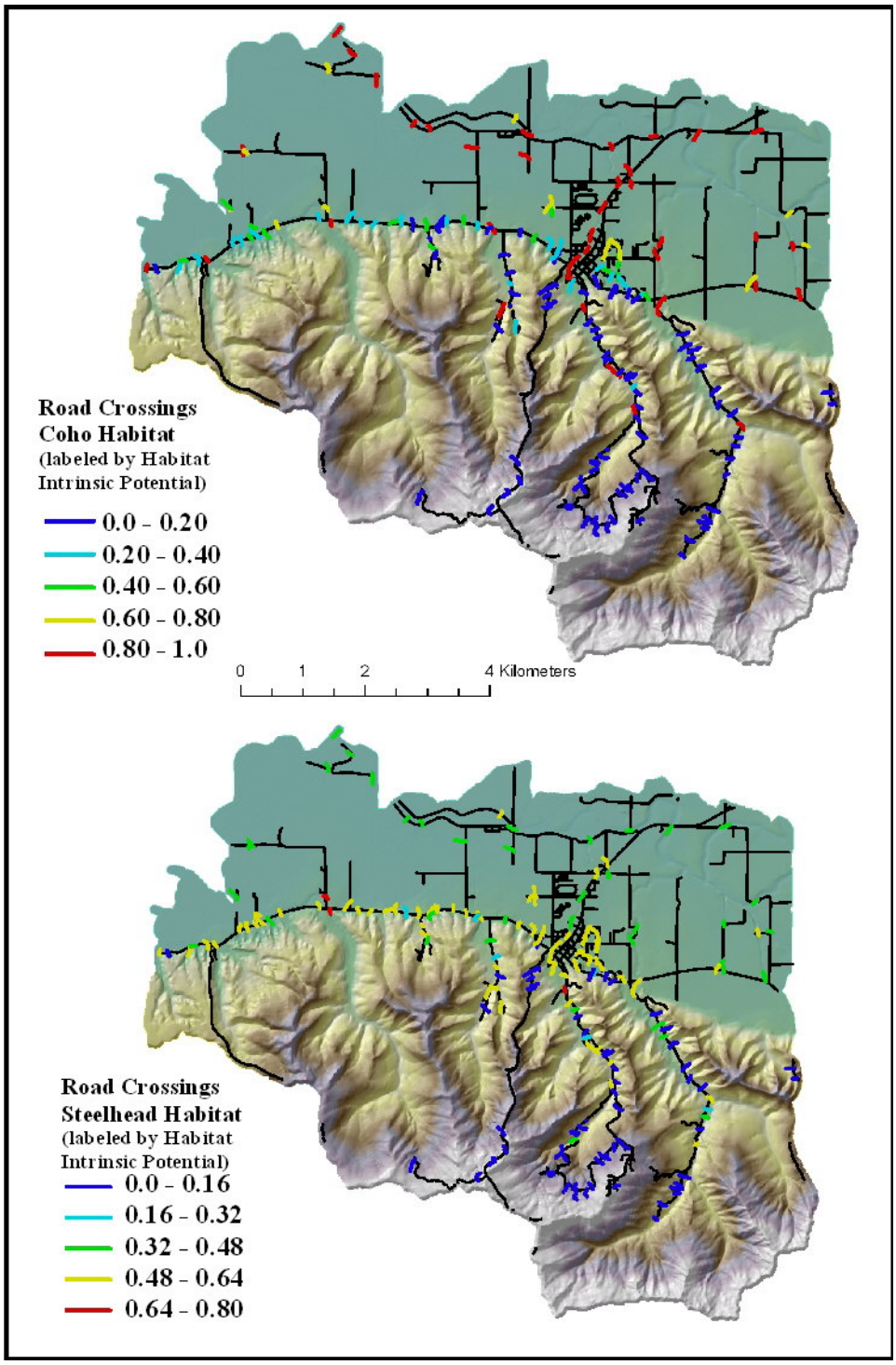

Figure 16. NetMap is used to classify road segments in Francis and Williams Creek basins with respect to habitat intrinsic potential, shown here for coho (top) and steelhead trout (bottom).

is the dominant landform in Francis and Williams Creek subbasins. This is also likely the case in other Salt River tributary basins (Figure 10). The landslide terrain can be highly active (Figure 4), moderately active (Figure 5), or dormant.

Our findings are consistent with the conclusions reached by the SCS (1993) sediment budget in which landslides (85% near streams) and bank erosion accounted for 72% of the estimated sediment yield. However, the SCS (1993) budget did not account for the high rates of erosion at toes of active landslides, in part, because SCS staff did not have access to those areas, such as those observed in this reconnaissance in Francis and Williams Creek basins (e.g., Figures 4-5). Because the SCS (1993) sediment budget did not account for deep-seated landslide and earthflow terrain, used categorical estimates of bank erosion that may be unsuitable for bank erosion processes related to landslide toes near streams, and extrapolated field estimates of erosion from less than 1% of the channel network across all Salt River tributaries, we conclude that the SCS (1993) estimated sediment yields are likely underestimates by as much as 100% and possibly much more. Nevertheless, because of the limited scope of the present analysis, we cannot provide precise quantitative estimates of erosion processes in the Salt River basin. In addition, since earthflows and deep-seated landslides (and related bank erosion and streamside failures) are not visible from aerial photographs, it would be very difficult to make accurate estimates of sediment yields even in a more detailed sediment budget. Further, since these sources are largely uncontrollable, of greater concern is the loss of sediment retention functions within valley floor floodplain areas at the base of the Wildcat Range.

Based on NetMap's predictions of shallow landslide and debris flow potential (Figures 11-12), it appears that these erosion processes, while being locally significant in areas that lack deep-seated or earthflow characteristics, are a secondary source of erosion and sediment delivery to streams. In addition, rill and sheetwash erosion is probably a minor sediment source outside of compacted areas, such as roads, skid trails, and landings. Thus, surface erosion from roads, landings, and other disturbed areas are overall probably a minor source of erosion in the Salt River tributaries. Finally, bank erosion of floodplain sediments in the lower valleys represent a chronic source of sediment to the Salt-Eel

floodplain but of a lesser magnitude compared to erosion processes in the upper basins. Although directly related, the magnitude of sediment contributed by erosion of entrenched channels located in valley floors/floodplain areas is less of a concern than the loss of sediment retention function in these areas.

The driver of relatively high erosion rates in the Salt River tributaries is the combination of mechanically weak rocks (Wildcat group), high precipitation, rapid uplift (leading to high relief as well as weak rocks), and intense seismic activity (many earthquakes due to the proximity of the Mendocino Triple Junction). Thus, the pervasiveness of landslide terrain in the upper Salt River tributaries (Figures 1-2) is an outcome of thousands of years of geologic history.

Based on the available information, it is difficult to determine whether erosion activity in the upper basins has been increasing in recent decades, including following early settlement and logging. The relationship between timber harvest (and even road construction) and deep-seated landslides/earthflows in bedrock (as compared to glacial sediments) is not well documented in the scientific literature, suggesting that the link is tenuous at best. Although an acceleration of erosion in the form of deep-seated landslides and earthflows due to land use in the upper basins remains a possibility, presently there is no data to support such a relationship.

Another factor that may be associated with an increase in erosion in the last several decades in the Salt River tributaries is heightened seismic activity, such as the most recent large earthquake which occurred in 1992, which caused significant ground shaking, landsliding, coastal uplift and liquefaction. Anecdotal evidence for ground cracking or ruptures following the 1992 earthquake in some of the Salt River tributary basins indicates that this earthquake could have led to heightened erosion and increased sediment delivery during and following major rainstorms (Don Tuttle, personal communication, March, 2007). Nevertheless, this process has not been documented and thus remains speculative.

Given the nature and magnitude of the streamside erosion linked to large ancient landslides and earthflows, *the dominant source of sediment is mostly uncontrollable*. Revegetation of landslide toes would probably have minimal effect in slowing erosion, provided that erosion is driven by geologic and other larger scale processes (e.g., earthquakes, channel incision, etc.). Moreover, current forest practices already require significant vegetative buffers near streams, particularly on or near actively eroding areas. The spatial extent and size of rotational movements observed in Francis Creek that were impacting roads, suggest that roads are, for the most part, are not a major destabilizing factor, other than locally. Although road surface erosion mitigation could be conducted and would reduce the fine sediment load to streams, it would only constitute a band-aid on a larger problem. These conclusions indicate that mitigation may need to focus, not on the source of sediment, but rather on the sinks (sedimentation zones), although a recommended mitigation measure (see below) involving enhancing floodplain storage of sediment may also act to curb streamside erosion in the upper basin.

The eroding floodplain deposits in the lower valleys of Francis and Williams Creek basins are another source of fine sediment to the Salt-Eel River floodplain (and to the town of Ferndale and downstream) (Figures 8-9). Erosion is taking place mainly at the outside of meanders. The present day erosion of floodplain sediments, however, is incongruous: floodplain systems, by definition, are areas of net deposition rather than net erosion. Thus, it seems plausible that the floodplain landforms along the lower two valleys (Francis and Williams) have incised 2 to 4 meters leaving the floodplain surfaces (now grazing land) abandoned by the current stream channels (Figure 17, A-C). One source of incision would be historical land uses that were designed to reduce flooding and sediment-related disturbances by removing wood jams (that traps sediment and causes channel anastomosing), cutting large floodplain forests (that supply large wood), and filling in channels and thus creating a single channel system in an environment that likely had multiple (braided) channels. Removal of wood jams from floodplain rivers can cause channel incision (Brummer et al 2006). Although more study would be necessary to further evaluate this hypothesis (e.g., Figure 17, A-C), it has major ramifications for the

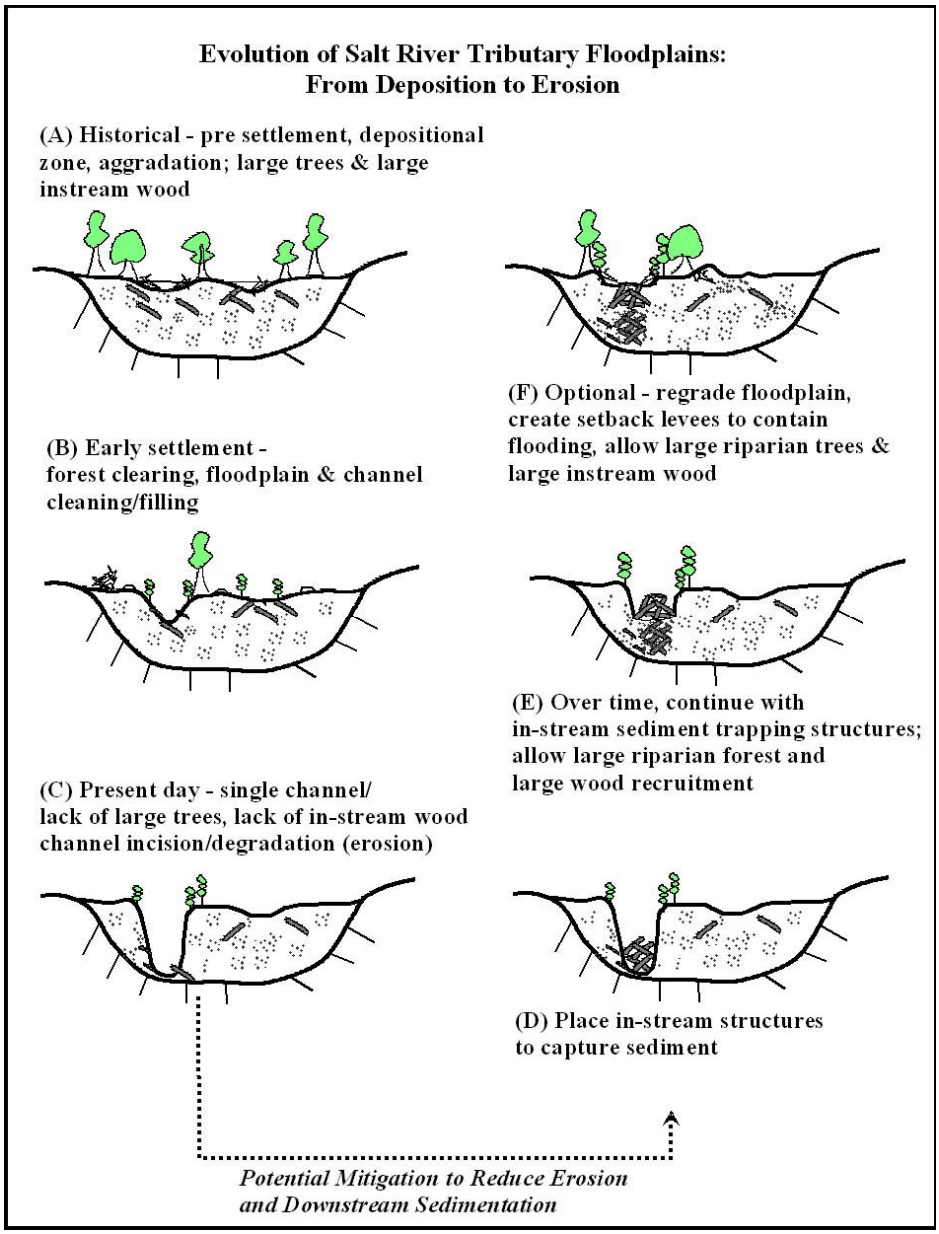

Figure 17. A hypothesized sequence of events that illustrate how historical and current land uses on the lower valley floodplains of the Salt River tributaries could have led to channel incision (A-C), thus rendering the floodplain system from one of sediment deposition to one of erosion and sediment routing. D-F illustrates a recommended mitigation strategy for restoring the floodplain system to normal functioning, including reducing floodplain erosion (e.g., Figures 8-9), reducing downstream sedimentation, and restoring salmonid habitats.

question of increased erosion and sedimentation of the Salt River system and on mitigation that might be applied to address the problem.

For example, under pre-settlement conditions, valley floodplains would have been an important sediment sink, accumulating a certain proportion of sediment prior to transport of sediment to the main Salt-Eel River floodplain. Although sedimentation would have still occurred on the main Salt-Eel floodplain (and in the area now occupied by the town of Ferndale), it should have been less than it is today. This is because the lower valleys no longer function as floodplains (trapping overbank sediments) but rather function as effective conduits transporting all sediment from the main sediment source areas in the upper basins directly to the Salt-Eel floodplain (Figure 18).

Our field reconnaissance also revealed channel incision (into alluvial sediments) along both Francis and Williams Creeks in the upper basins. Channel incision into the base of unstable landslide toes and earthflow toes in the upper basin could trigger a spate of hillslope erosion in the form of streamside landslides and accelerated bank erosion and soil creep (e.g., Figures 4-5). Channel incision can result from natural cycles of accelerated erosion followed by degradation or by tectonic processes. However, channel incision that is occurring along the lower valley floodplains (that may be due to historical and present day land uses on the floodplains, e.g., Figure 17, A-C) could be migrating upstream leading to channel incision in the upper basins. Floodplain incision of 2 to 4 meters represents an effective drop in the channel's base level, and base level instabilities can migrate upstream (Schumm 1977). This is only a hypothesis (Figure 18), but it has important implications in the context of mitigation measures to stem erosion and sedimentation, discussed below.

5.2 Mitigating Sedimentation and Floodplain Erosion

Given the near term uncontrollable sources of sediment in the upper basins, the most feasible mitigation appears to be at the base of the Wildcat Range, within valley floor/floodplain areas. One strategy would be to construct sediment catchment basins that would need to be periodically cleaned. This was recommended in the SCS (1993)

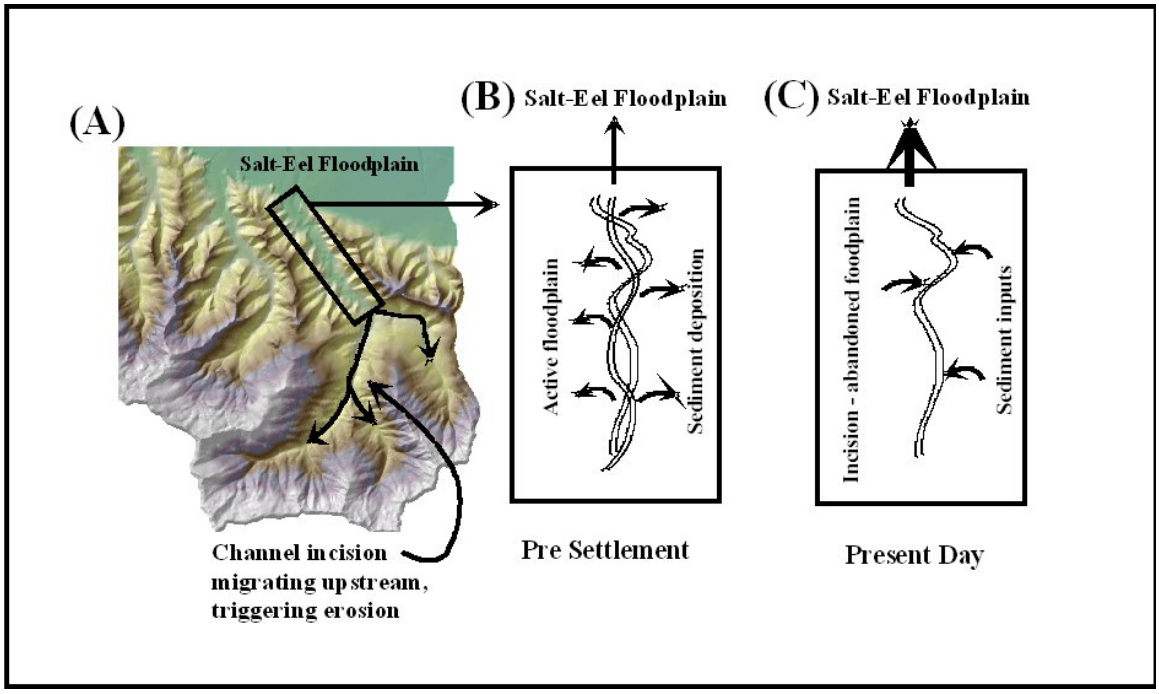

Figure 18. An illustration of the hypothesis whereby the lower valley floodplain systems (A) have evolved from an overbank depositional environment (B) to incision and an eroding environment (C) where the floodplains are actually a *source* of sediment to the greater Salt-Eel floodplain, including to the town of Ferndale. This may be due to historical and current land use practices on the floodplains. Channel incision on the floodplains may have migrated upstream triggering accelerated streamside erosion in the upper basins (D).

report and they made estimates of the size of the catchment needed (for a specific basin) and the rate of maintenance. However, caution is advised since the estimated sediment yields in the SCS (1993) budget are likely underestimated.

Another option would be to repair the degraded floodplain environments located at the base of the Wildcat Range within valley bottom/floodplain areas by encouraging deposition (rather than erosion) and thus to reestablish the floodplains as sediment traps or sinks, rather than sediment sources as they are now (e.g., Figure 17, A-C). This would require installation of structures in the channel to trap sediment and restore floodplain function. Options include creating a step-pool morphology by installing a series of structures (log gabions, rocks) across the channel to mimic the recruitment of large wood that would in turn promote upstream deposition of fine sediments (Figure 17, D-F) or plug and pond techniques (Feather River CRM 2001). As the channel bed increased in elevation by sedimentation, more log trapping structures would be placed until floodplain erosion was greatly reduced and some overbank flow and sedimentation onto the floodplain surface was beginning to occur. Riparian forest trees would be allowed to grow larger, to mimic the natural forest that was once located there. Other related engineering options could involve construction of set back levees to contain the overbank flooding. Over time, land surface area should increase due to channel filling. In addition to reducing downstream sedimentation (this could be done in concert with sediment control basins that would then need less maintenance), changing an eroding floodplain environment to a more natural sedimentation environment would presumably enhance the floodplain ecosystem, including creating higher quality fish habitat (e.g., Figure 15) that moves conditions towards higher intrinsic potential values. Such a restoration strategy could be done locally on a proof-of-concept basis.

One major advantage of the floodplain restoration option (Figure 17, D-F) is that by raising the base level of the channel in the floodplain environment by 2 to 4 meters, a wave of channel aggradation may begin to migrate upstream. Channel-valley aggradation in the upper basins could reduce the intensity of stream bank erosion and landsliding. This process could take decades before any noticeable reduction in upper

basin erosion occurs. This strategy represents a holistic, long-term solution to upper basin erosion, floodplain channel erosion, downstream sedimentation in Ferndale and beyond on the greater Salt-Eel River floodplain, and degraded fish habitats. Even if floodplain incision is unrelated to erosion in the upper basin, restoring floodplain function would still contribute to reduced sedimentation on the Salt-Eel floodplain as well as enhance fish habitats.

More field work, however, is warranted to verify the "bottom up" hypothesis on upper basin erosion and the hypothesis regarding the transition of floodplain environments from erosion to deposition due to historical and current land use practices (on the floodplain) (e.g., Figures 17 and 18). It is important to keep in mind that this analysis does not address the other important factors that are contributing to sedimentation and flooding problems outlined at the beginning of this report. This includes construction of the Leonardo levee that hydrologically decoupled the Salt River from the Eel River; see the SCS (1993) report for additional details.

5.3 Potential Applications of NetMap In The Salt River Basin

NetMap, comprised of a suite of numerical models, was run on the Salt River basin and produced many of the figures in this report (1, 2, 6, 7, 10-16). The base parameter files (n = 20) are freely available to all, including private parties. The software, NetMap Tools (Benda et al. 2007), is available to public agencies involved with this study. NetMap Tools are designed to be user friendly and thus practitioners are encouraged to create their own analyses; over 400 pages of technical support material on the tools and on the parameters are available through hyperlinked manuals. See www.earthsystems.net and see "NetMap" for additional details.

5.4 Suggested Future Work

Additional field work and analysis could be focused on improving the calculated rates of erosion and sediment yield made by the SCS (1993). However, increased access onto private lands in the upper basins would be required. Even if that were available, it will be difficult to make accurate estimates of erosion and sediment yield given the nature of the erosion mechanisms (focused on streamside areas) and the inability to observe these

processes (and their changing rates and locations) from the historical time series of available aerial photographs.

Perhaps the most promising area of future studies is to further examine and verify the hypotheses proposed in this study regarding 1) floodplain erosion due to historical and current land uses on the floodplain (e.g., Figure 17, A-C) and 2) on the upstream propagating wave of channel incision (linked to the floodplain incision) that may be causing accelerated streamside erosion in the upper tributary basins (Figure 18). Furthermore, more validation is needed to examine the feasibility of the proposed floodplain restoration strategy that has the potential to mitigate a variety of impacts (Figure 17, D-F).

6.0 Acknowledgements

County of Humboldt

California Coastal Conservancy

California Department of Fish and Game

Humboldt County Resource Conservation District

USDA Natural Resource Conservation Service

Timberland Resource Consultants

7.0 References

Benda, L., Miller, D., Andras, K., Begelow, P., Reeves, G., and Michael, D. 2007. NetMap: A New Tool in Support of Watershed Science and Resource Management Forest Science, Vol. 53, No. 2. (April 2007), pp. 206-219

Brummer, C.J., Abbe, T.B., Sampson, J.R., and Montgomery, D.R. 2006. Influence of vertical channel change associated with wood accumulations on delineating channel migration zones, Washington, USA. Geomorphology 80: 295-309.

Burnett, K., Reeves, G., Miller, D. Clarke, S., Christiansen, K. and Van-Borland, K. 2003. A first step toward broad scale identification of Freshwater protected areas for pacific salmon and trout in Oregon, USA. *in* J. P. Beumer, A. Grant, and D. C. Smith, editors. Aquatic Protected Areas: What Works Best and How Do We Know? Proceedings of the World Congress on Aquatic Protected Areas. Austrain Society of Fish Biology, North Beach, WA, Australia, Cairns, Australia.

Dryness, C.T. 1969. Hydrologic properties of soils in three small watersheds in the western Cascades of Oregon. Res. Note PNW-111, USFS, Portland, Or. 12p.

Elliot, W.J., Hall, D.E., and Dayna L. Scheele. 2000. Disturbed WEPP (Draft 02/2000) WEPP Interface for Disturbed Forest and Range Runoff, Erosion and Sediment Delivery. USDA. Forest Service Rocky Mountain Research Station and San Dimas Technology and Development Center.

Kelsey, H. M. 1980. A sediment budget and an analysis of geomorphic process in the Van Duzen River basin, north coastal California, 1941-1975: Summary (Bigelow). Geological Society of America Bulletin 91:190-195.

Miller, D.J., and Burnett, K.M. 2007(in press). Topographic and forest-cover controls on debris-flow landslide density in the Oregon Coast Range, Water Resources Research.

Reid, L. M., and Dunne, T. 1996. Rapid Evaluation of Sediment Budgets. Catena Verlag, Reiskirchen, Germany

Roering, J.J., Kirchner, J.W. and Dietrich, W.E. 2005. Characterizing structural and lithologic controls on deep-seated landsliding: Implications for topographic relief and landscape evolution in the Oregon Coast Range, USA, *Geological Society of America Bulletin*, v. 117, p. 654-668.

Schumm, S. A. 1977. The Fluvial System. Pages 338 *in*. John Wiley and Sons, New York.

Soil Conservation Service (SCS). 1993. Salt River Watershed, Local Implementation Plan, Humboldt County, CA.

Washington Department of Natural Resources (WDNR). 1997. Methods for Conducting Watershed Analysis.