Geomorphic and hydrologic assessment and restoration planning in the Salt Creek watershed, Lower Klamath River Sub-basin, California

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Introduction

Yurok People inhabiting the Lower Klamath have relied on the areas resources for their subsistence, cultural, and economic livelihood since time immemorial. Subsistence harvest of Klamath River fish populations is central to the Yurok Tribe. Anthropogenic activities over the past century have resulted in substantial declines to Klamath Basin fish runs and have dramatically altered or degraded associated habitats. Investigations conducted in many Lower Klamath tributaries have documented substantial channel aggradation, channel widening, and loss of riparian forests due to historic logging practices, large floods, and livestock grazing (Gale and Randolph 2000). Perhaps no aspect of natural functioning has been altered more in the Klamath Basin than river flows. Dams and water diversion projects occurring in the upper basin and in several major tributaries (Trinity, Shasta and Scott) have significantly reduced Klamath River flows and drastically altered the natural hydrograph.

The Klamath River estuary serves as a vital nursery and staging area for spring and fall-run chinook salmon, coho salmon, steelhead trout, coastal cutthroat trout, sturgeon, eulachon, flounder, and lamprey. It is likely that tens of millions of juvenile salmonids migrate through the Klamath River estuary every year on their way to the ocean (Wallace 1995). Studies conducted by the Yurok Tribal Fisheries Program (YTFP) and California Department of Fish and Game (CDFG) suggest that off-estuary tributaries of the Klamath River provide critical, high quality rearing habitat for natal and non-natal salmonids (Wallace 2001, Beesley and Fiori 2004, Hiner and Brown 2004, YTFP In Progress).

Salt Creek is the lower-most anadromous tributary to the Klamath River, entering the estuary less than one mile upstream of the Pacific Ocean (Figure 1). The watershed is comprised of a diverse range of habitats including the deep ponds and shallow marshes of Salt Creek (Figure 2) and the alluvial reaches of High Prairie Creek (Salt Creek's major tributary) (Figure 3). YTFP recently completed a watershed assessment of Salt Creek that documented existing water quality, instream habitat and riparian conditions and fish distribution; assessed changes in land cover and channel patterns for the period 1936 – 2001; and presented prioritized restoration recommendations (Beesley and Fiori 2004).

One of the most difficult areas to assess during the 2004 study was the confluence reach of High Prairie Creek and Salt Creek. High Prairie Creek terminates in a fairly extensive alluvial delta colonized by dense mats of invasive reed canary grass and to a lesser extent with sedges, rushes, and red alder (Figure 4). Aerial photograph analysis revealed that wetland habitats have steadily increased in the watershed over the last few decades (Beesley and Fiori 2004). Increased inundation of the valley is likely a result of the complex interaction of vegetation conversion occurring in the watershed, natural and man-made levees, land-use activities, channel alteration and aggradation, and beaver activity (Beesley and Fiori 2004).

Beaver activity in the watershed has also increased in the last few decades and several prominent and remnant beaver dams exist in the watershed (Figure 5). Pollock and others (2003) compiled research pertaining to the geomorphic effects of beaver dams and their influence on fish populations in North America. They reported beaver dams measurably affect groundwater recharge rates and retention, increase summer flows, and elevate local water tables allowing riparian and wetland vegetation to expand. Beaver dams may retain enough sediment to cause substantial changes to valley floor morphology. In general they found salmonid productivity, especially for coho, was higher in stream reaches upstream of beaver dams than in reaches where dams were absent. They further stated that larger coho (age 1+) consistently used beaver pond habitats over all other available habitats.

Although emergent and open water wetland habitats of Salt Creek provide seasonal, high quality salmonid rearing, the resulting backwater effects on the discharge of High Prairie Creek currently limits fish passage to habitats located in this tributary. Improving year-round fish passage through this confluence reach would likely improve spawning success by allowing adults unimpaired access to spawning grounds, as well as increase juvenile survival by allowing unimpaired access to preferred rearing habitats (e.g. beaver ponds, sloughs, and the estuary) on both seasonal and diurnal time scales. Therefore, the Salt Creek watershed assessment identified the need to conduct a more comprehensive study to assess how High Prairie Creek and Salt Creek function together (historically and presently) and how sediment and water inputs affect salmonid production.

Project Summary

Project objectives were to expand on the watershed assessment performed by Beesley and Fiori (2004) by: 1) characterizing geomorphic and hydrologic conditions limiting salmonid populations in the confluence reach of High Prairie Creek and Salt Creek; and 2) developing reasonable and effective treatment alternatives aimed at optimizing juvenile rearing capacity while improving fish passage conditions. Critical issues addressed included: how beaver and land management activities affected the water budget, salmonid habitat and riparian conditions in the watershed; how sediment production (from upslope sources) affected channel stability in the confluence reach; and how to optimize natal and non-natal rearing capacity in Salt Creek while providing improved channel function and fish access to habitats located in High Prairie Creek.

This project provided a unique opportunity to examine conditions affecting salmonid habitats in an off-estuary watershed affected by beaver activity, wetland expansion, agricultural use, and upslope land use activities that result in excessive sediment yield. This project will be a critical addition to YTFP's efforts to develop and implement restoration and management strategies to improve salmonid habitats in off-estuary tributaries, wetlands, and sloughs of the Klamath River.

Success of restoration efforts in this watershed will depend on landowner cooperation and stakeholder support of proposed restoration alternatives. Therefore, YTFP and Fiori GeoSciences organized site visits and provided project overviews to multiple stakeholders and technical experts including staff from the Yurok Tribe Environmental Program, California Department of Fish and Game, United States Fish and Wildlife Service, and California Department of Transportation, a local environmental planner, and a local vegetation specialist. A few landowners were essential to YTFP's assessment.

This preliminary report will be presented to a technical review committee comprised of fisheries and restoration specialists to obtain technical input on the information presented and the proposed treatment alternatives. During the review period, YTFP will be working to inform landowners of watershed assessment findings and discussing proposed restoration strategies, treatment alternatives, and conservation easement strategies. Technical review comments and landowner input will be summarized and incorporated into a finalized document detailing the preferred treatment alternative.

Figure 1. Map of the Salt Creek watershed, Lower Klamath River Sub-basin, California. Base image: portions of the 2005 NAIP imagery, 1 meter resolution.

a. b.

c.

Figure 2. Photographs of the channel and marsh habitats of Salt Creek, Lower Klamath River Sub-basin, California (photograph a. 30 June 2003, photograph b. 18 December 2003, and photograph c. 10 January 2002).

Figure 3. Photographs of large wood at a location in High Prairie Creek, Lower Klamath River Sub-basin, California (5 January 2004).

a. High Prairie Creek

b. Wetlands adjacent to channel during winter flows

Figure 4. Photographs of High Prairie Creek just upstream of the confluence with Salt Creek (Left) and the adjacent floodprone areas (Right), Lower Klamath River Sub-basin, California (December 2003).

Figure 5. Photographs of beaver dams located in Salt Creek just downstream of the High Prairie Creek confluence (top photograph, 9 December 2004) and in lower High Prairie Creek (bottom photograph, 18 December 2003). Lower Klamath River Sub-basin, California.

Study Area

Salt Creek drains 5.9 sq mi of low-lying forested hillsides and an expansive valley comprised of wetland habitats and pastures (Figures 1 and 2). High prairie Creek, a fairly steep, alluvial tributary, enters Salt Creek approximately 1.6 miles upstream of the Klamath River estuary (Figures 1 and 3). The watershed supports populations of coastal cutthroat trout (*Oncorhynchus clarki clarki*), steelhead (*O. mykiss*), and coho salmon (*O. kisutch*), which are currently listed as "threatened" under the federal and California state Endangered Species Acts (Beesley and Fiori 2004). YTFP has also documented the presence of juvenile chinook salmon (*O. tshawytscha*) in lower Salt Creek during winter and spring months (Beesley and Fiori 2004, YTFP In Progress). The watershed also supports multiple lamprey species (*Lampetra* spp.), threespine stickleback (*Gasterosteus aculeatus*), sucker (*Catostomus* sp.), speckled dace (*Rhinichthys osculus*), prickly sculpin (*Cottus asper*), and coastrange sculpin (*C. aleuticus*).

Physiographic and geologic characteristics of High Prairie Creek and Salt Creek proper are summarized in Table 1. Climate of the area is classified as Marine West Coast, with the Pacific Ocean maintaining relatively moderate air temperatures with cool summers and wet winters. The U.S. Geological Survey (USGS) gage located on the north side of the Klamath River near the Terwer Creek confluence (Latitude: 41º51'20"; Longitude: 123º99'90") provides long-term precipitation data for the area (CDEC 2007). Average annual precipitation at the USGS gage for the period of record 1948 – 2006 was 80.09 inches. Maximum annual precipitation for the period of record was 124.37 inches and occurred in water year (WY) 1983 and minimum annual precipitation was 44.27 inches in WY 1976 (CDEC 2007). Precipitation generally falls as rain and typically accumulates from October through April with occasional, low magnitude summer storms. Winter storms result in highly variable runoff patterns with flows ranging from flood stage to critically low. The lack of summer storms in this area typically results in periods of low flow or subsurface flow conditions in the lower reaches of many Lower Klamath River tributaries (Beesley and Fiori 2007).

Table 1. Physiographic and geologic characteristics of High Prairie and Salt Creek, Lower Klamath River Sub-basin, California.

Location	Drainage Area (mi^2)	Relief (ft)	Mean Slope (%)	Blueline Stream Length (mi)	Bedrock Type Franciscan Melange (%)	Bedrock Type Franciscan Broken Formation (%)	Quaternary (%)
High Prairie Creek	3.6	1626	36	4.6	0	96	4
Salt Creek	2.3	820	36	3.3	18	62	20

Geological evidence suggests that Wilson Creek, a third order watershed now draining to the Pacific Ocean, formed the valley currently inhabited by Salt Creek. Tectonic processes and coastal erosion are believed responsible for the capture of Wilson Creek by the Pacific Ocean. Geotechnical drill logs, obtained from the California Department of Transportation (CalTrans) (Miller 2006), for several U.S. Highway 101 Bridge crossings in the valley indicated the area was a large backwater feature of the Klamath River estuary, comprised of complex wetlands, tidally influenced sloughs, and a network of anastamosing streams.

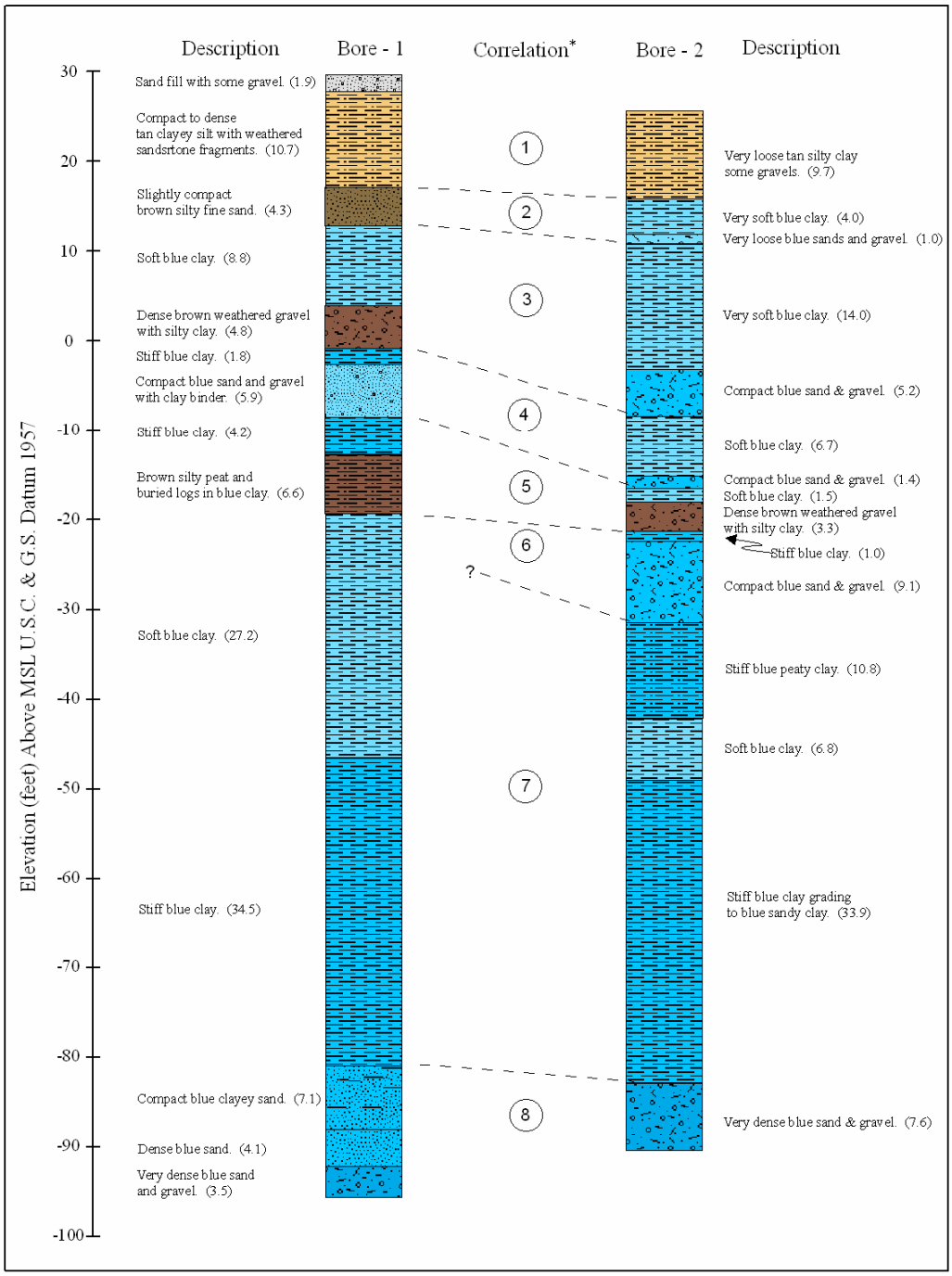


Figure 6. Geotechnical drill logs for the U.S. Highway 101 Bridge crossing High Prairie Creek, Lower Klamath River Sub-basin, California (Provided by the California Department of Transportation).

The drill logs for High Prairie Creek bridge were reproduced from the logs obtained from CalTrans (Miller 2006) (Figure 6). These logs showed hydric soils including blue clays, sands, and gravels dominated the > 100 ft borings (Figure 6). These redoxamorphic soils require long periods of inundation and fluctuations in groundwater levels to form, further indicating the study area was historically comprised of complex wetland habitats. The uppermost 30 ft of the bores contained alternating sequences of brown and tan, coarse sediments with soft blue clays (Figure 6). The coarser sediments may have been derived from landslide material emanating from High Prairie Creek forming the present delta.

Land Use History

Agriculture

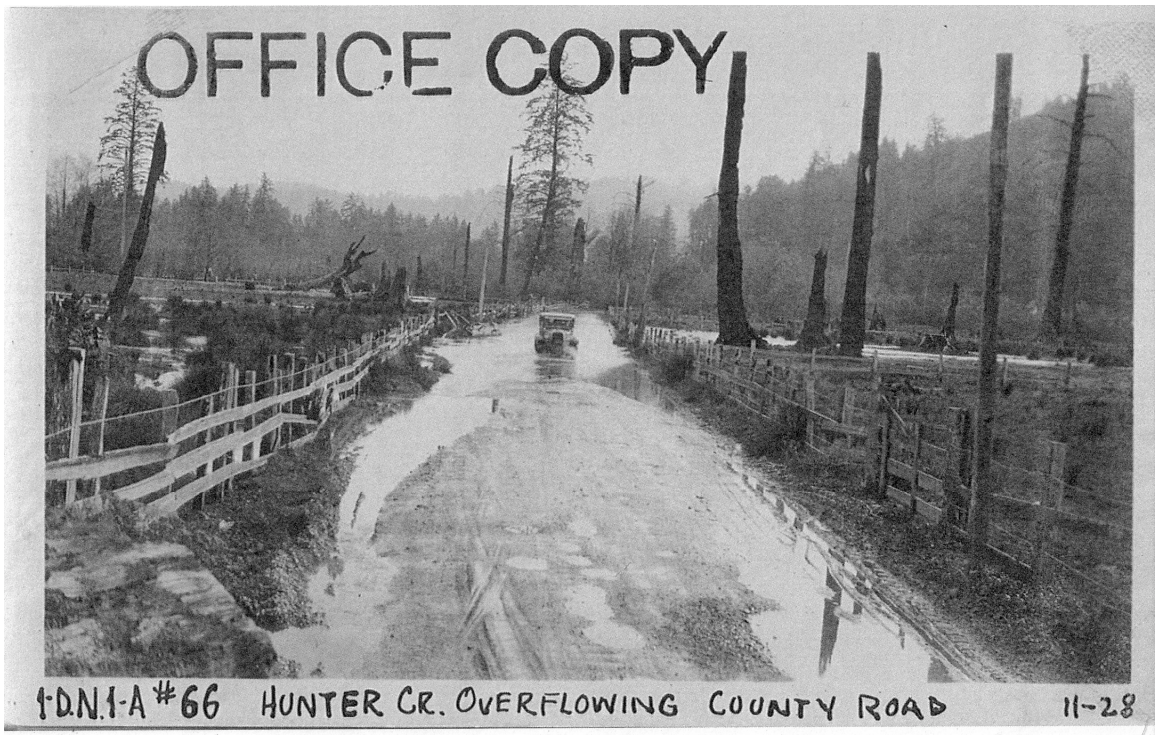
Agricultural landowners began converting the complex off-estuary wetlands of lower Salt Creek to pastureland in the mid to late 1800s (Figure 7). The dynamic confluence area of Salt Creek, Hunter Creek, Panther Creek, and Mynot Creek was converted to pastures by removing riparian vegetation and channelizing the lower reaches of these streams with levees and rip rap. Lower Salt Creek was relocated to the western edge of the valley and forced to terminate at the Klamath River estuary instead of joining Hunter Creek (Figure 1). A majority of lower Salt Creek and Hunter Creek valley continues to be used for agricultural purposes. Current landowners have worked with CDFG, the California Conservation Corps, and U.S. Fish and Wildlife to constructed fences along lower Salt Creek to exclude cattle from the active channel.

Although we were unable to obtain aerial or historic photographs of the High Prairie Creek confluence reach pre-dating 1948, agricultural conversion of this area also likely began in the mid to late 1800s. Historic review of aerial photographs and digital ortho-rectified photo-quadrangles (DOQs) (1948 – 2005) revealed agricultural activities occurred downstream of the confluence reach until just recently (Appendix A). By 1948, High Prairie Creek, downstream of U.S. Highway 101, was re-aligned and levees were constructed. During this period, High Prairie Creek floodplains upstream of U.S. Highway 101 were also being used for agricultural purposes (Appendix A).

By 1965, High Prairie Creek upstream of U.S. Highway 101 was re-aligned along the valley wall and levees were constructed (Appendix A). Fur trappers and efforts to eradicate beaver from the valley appeared fairly successful at limiting beaver activity during this early period (Gibson and Simms 2007). As agricultural use of the pastures located in the vicinity of U.S. Highway 101 ceased, colonization by vegetation and inundation of these fields by backwater and storm events steadily increased (Appendix A). These events also corresponded to increased beaver activity in the valley resulting from reduced eradication effort. Active pastures exist on the north side of High Prairie Creek just upstream of the confluence with Salt Creek (Appendix A).

Timber Harvest

As mentioned above, timber removal began in lower Salt Creek in the 1800s (Figure 7). Timber harvest in upper Salt Creek (upstream of High Prairie Creek) progressed slowly until the early 1960s with only 23% of the sub-watershed harvested by 1962 (Figure 8). However, in roughly one year, nearly 80% of



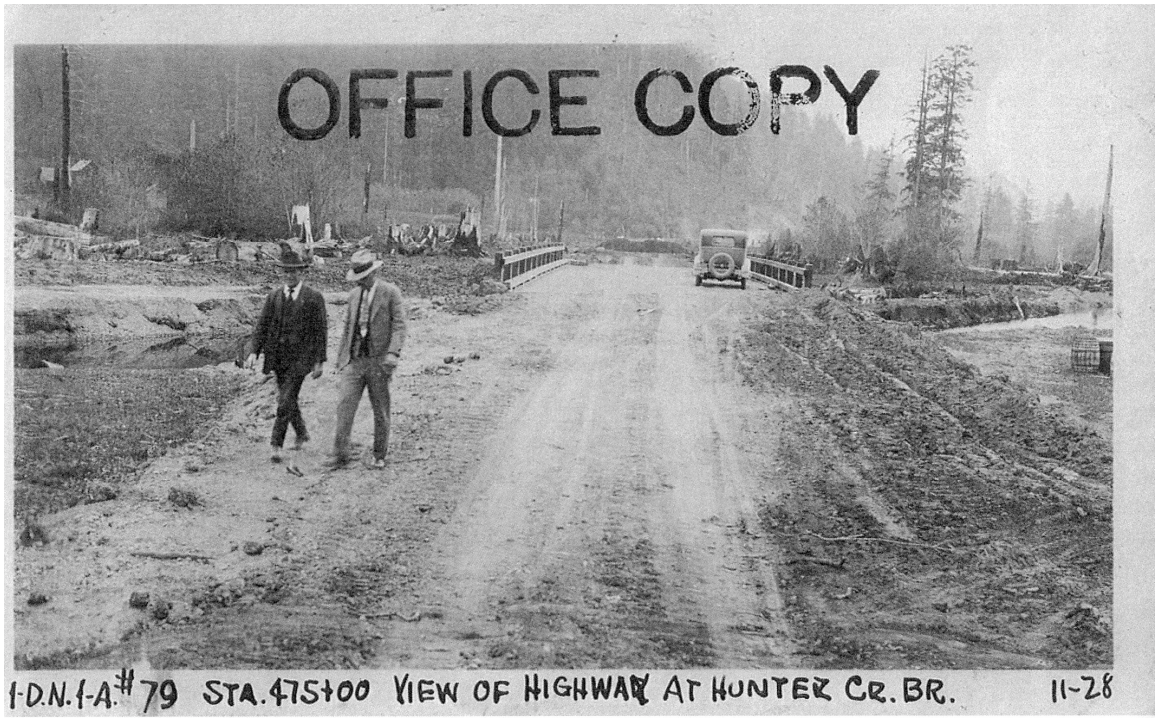


Figure 7. Historic photographs of lower Hunter Creek and Salt Creek Valley in the vicinity of Requa, Lower Klamath Sub-basin, California (Provided by the California Department of Transportation, November 1928).

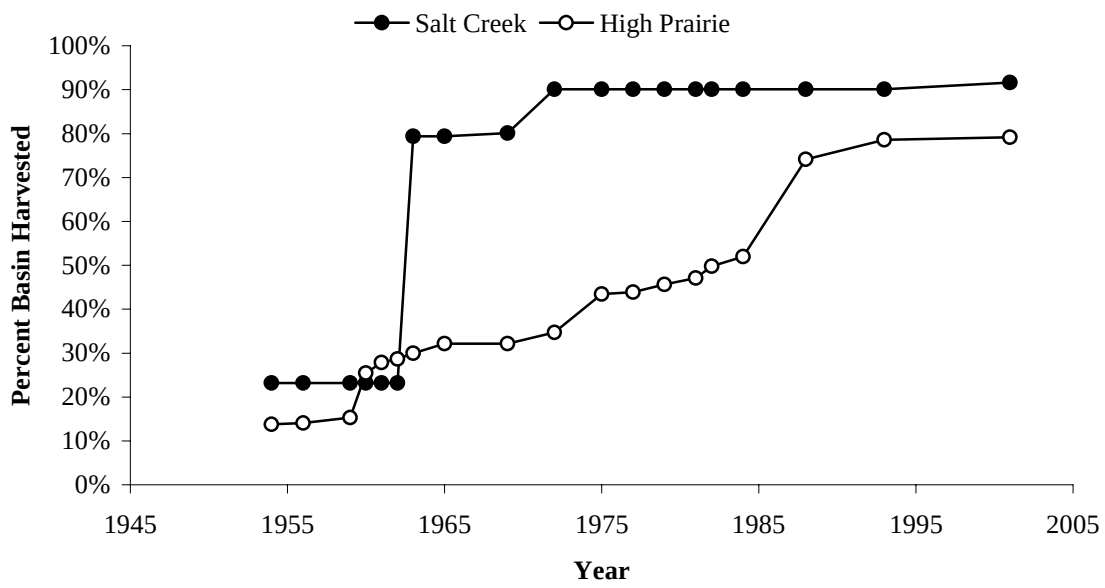


Figure 8. Historic review of timber harvest activities occurring in the Salt Creek watershed, Lower Klamath River Sub-basin, California.

the timber had been cleared. Harvest was minimal during the late 1960s but activities resumed in 1972 with an additional 10% of the remaining timber cleared. By 2001, 92% of timber had been removed from upper Salt Creek (Figure 8). Green Diamond Resource Company (GDRC), formerly Simpson Resource Company, owns most of the western hillslopes of Salt Creek and continues to manage those lands for timber harvest.

Only a small portion of High Prairie Creek was harvested by 1959 (Figure 8). Timber harvest continued at a relatively slow rate from 1960 – 1984. Harvest rates increased dramatically in High Prairie Creek during the late 1980s with nearly 75% of the timber harvested by 1988. Harvest rates declined from 1988 with only a small portion of the remaining timber being harvested from 1988 – 2001 (Figure 8). The Yurok Redwood Experimental Forest was established in High Prairie Creek in 1940 to conduct silvicultural research on coastal redwoods (USFS 1990). Approximately 45 percent of this forest was clearcut during 1956 – 1985. However, a research and natural area, comprising 16 percent of the forest was established to maintain and research unmanaged forest conditions. GDRC owns most of upper High Prairie Creek and continues to manage the land for timber harvest.

Residential

Agricultural fields and ranches dominated the confluence area of High Prairie Creek during 1948 (Appendix A). During this time, small residential communities existed just north of the High Prairie Creek confluence. By 1965, residential communities to the north were increasing and a small waste water treatment facility was built just upstream of the confluence to accommodate these residents (Appendix A). The facility consisted of a series of small treatment ponds and associated infrastructure (Figure 9). The facility was decommisioned and partially dismantled after a new facility was constructed on the north side of U.S. Highway 101 in the mid 1980s (Karnes 2007). The defunct facility and land remain property of the local water service district and currently no operations are underway.

Figure 9. Photographs of the defunct waste water treatment facility located upstream of the confluence of High Prairie Creek and Salt Creek, Lower Klamath River Sub-basin, California (23 March 2007).

Hydrology

Surface Water

Stream gages were installed at key locations in High Prairie Creek and Salt Creek during fall 2005 to examine stream flow and wetland storage and outflow relations in the watershed (Figure 10). Water stage was recorded at these sites every ten minutes using Global Water Level Loggers and permanent cross sections were established at all three gage locations (Figure 11). We examined stage and discharge data for WY 2006 and a portion of WY 2007 (1 October 2006 – 14 March 2007). Crest stage gages were installed in winter 2006 and 2007 to document peak flow elevations and estimate water surface profiles for critical reaches in the watershed (Figures 10 and 11).

Discharge was measured at various flow levels over the study period to develop stage rating curves for High Prairie Creek and lower Salt Creek. High Prairie Creek discharge measurements ranged from 2.39 cfs on 15 February 2006 to 221 cfs on 11 December 2005 (Appendix B1). Discharges measured at the lower Salt Creek gage ranged from 2.03 cfs on 16 September 2006 to 149.8 cfs on 2 January 2006 (Appendix B1). The lower Salt Creek gage experienced occasional Klamath River backwater effects due to the proximity of the estuary (Figure 10).

Storm runoff peaks began in the watershed in early November during both WYs (Figure 12). However, winter 2006 was considerably wetter relative to the same period during WY 2007. A wide-spread, large magnitude storm event occurring in December 2005 resulted in multiple high flow peaks at all three gages (Figure 12). These storm events caused the Klamath River to flood to an estimated peak discharge of 470,000 cfs at the USGS gage station: Klamath River near Klamath on 31 December 2005 (CDEC 2007).

The December 2005 Klamath River flood event caused fairly substantial backwatering at both of the Salt Creek gages on 31 December 2005 (Figure 12). Maximum mean daily water surface elevations were 18.4 ft at the Salt Pond gage and 15.1 ft at the lower Salt Creek gage. The estimated discharge of 1,780 cfs for the lower Salt Creek gage was included to provide continuity in the hydrograph, however, the value is likely erroneous due to the backwater conditions persisting on this date. The crest stage gage located downstream of the High Prairie Creek confluence (Figure 10) measured a peak water surface elevation for this flood event at 22.7 ft. Peak mean daily discharge in WY 2006 at the High Prairie Creek gage was estimated at 233 cfs on 11 January 2006 (Figure 12). Although High Prairie Creek peaked after Salt Creek and the Klamath River, this flood represented a symmetric flow event in the sense that mainstem flows were high w Salt Creek and High Prairie Creek flows were high.

Low flows occurred in the watershed during late February 2006 and High Prairie Creek went subsurface at the gage from 24 – 26 February 2006 (Figure 12). Storm events of late February – mid April 2006 resulted in higher base flows and multiple peaks at all three gages. Surface flows declined during late April and went subsurface at the High Prairie Creek gage from 4 May – 3 June 2006. A small storm event caused surface flows to resume in High Prairie Creek from 4 – 10 June 2006. Small peaks resulting from this early June storm were also observed at the two Salt Creek gages. Low flow conditions resumed after this storm and persisted until early November 2006 (Figure 12).

Base flow levels in the watershed increased and multiple moderate peaks occurred through November and early December 2006 (Figure 12). Maximum flow events occurred in mid and late December 2006 at all three gages. The peak mean daily flow at High Prairie Creek on 26 December 2006 was estimated

Figure 10. Map of monitoring locations in the Salt Creek watershed, Lower Klamath River Sub-basin, California. Base image: portions of the 2005 NAIP imagery, 1 meter resolution.

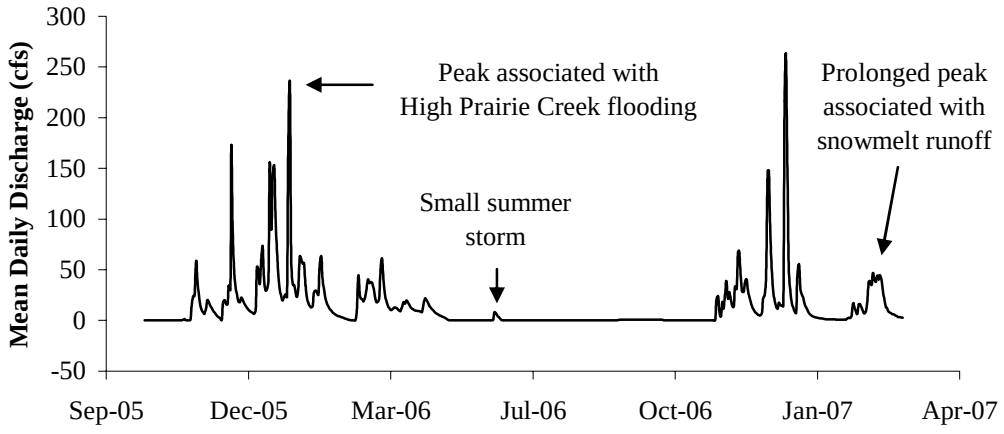
a. Lower Salt Creek Gage - 18 April 2006

b. High Prairie Creek Gage - October 2006 and February 2007

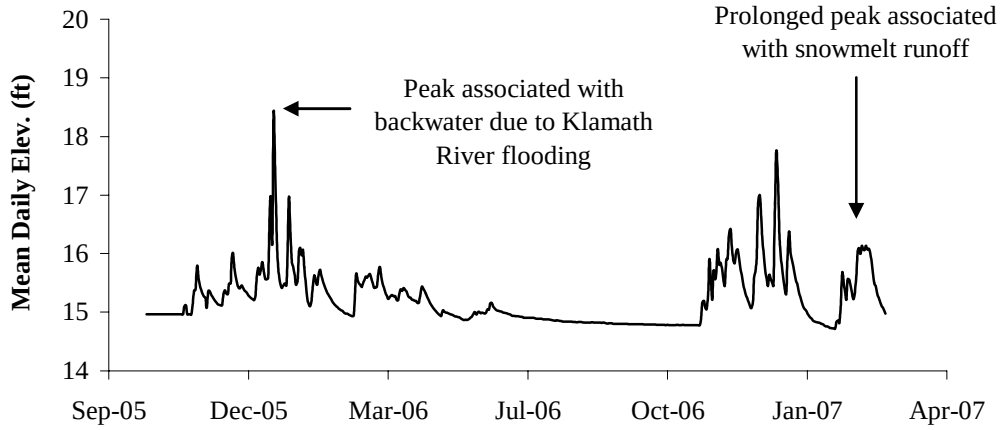
c. High Prairie Creek Crest Stage Gages – December 2005 and January 2007

Figure 11. Photographs of stream gages and crest stage gage stations in the Salt Creek watershed, Lower Klamath River Sub-basin, California.

a. High Prairie Creek Gage (HP 1)



b. Upper Salt Creek Gage (Salt Pond)



c. Lower Salt Creek Gage (Salt 1)

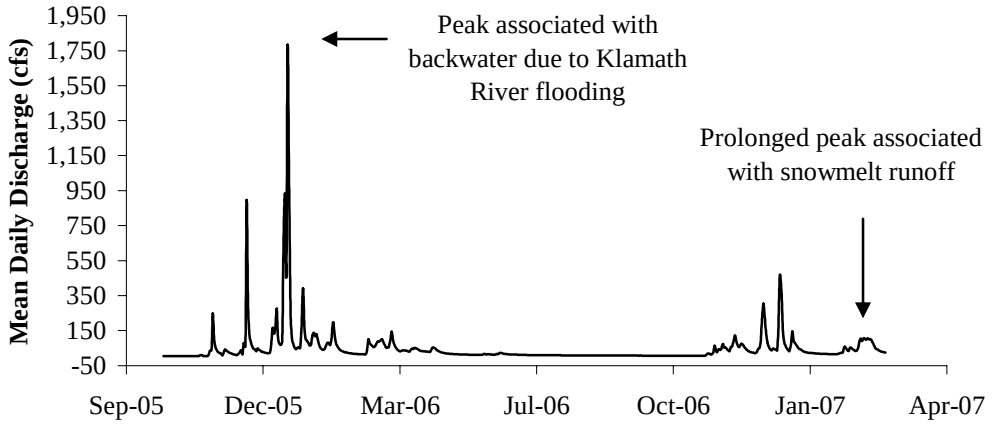


Figure 12. Mean daily discharge (plots a. and c.) and water surface elevations (plot b.) at three stream gage sites in the Salt Creek watershed, Lower Klamath River Sub-basin, California.

at 262 cfs and was higher than the peak estimated during January 2006. The peaks observed on 26 December 2006 at both Salt Creek gages were substantially lower than the peaks observed during December 2005. However, the flow events of mid and late December 2006 represented an asymmetrical flow event in the sense that tributary flows were relatively high when Klamath River flows were moderate. Klamath River flows were 20,000 cfs on 25 December and peaked at 106,000 cfs on 27 December 2006 at 02:00 a.m. (CDEC 2007).

Surface flows declined in the watershed from late December 2006 – early January 2007 and remained low until early February 2007 (Figure 12). Storms in late February 2007 resulted in a fair amount of snow accumulation at higher elevations. Cold weather persisting during this time allowed for slow rates of snowmelt and resulted in prolonged flood peaks at all three gages. With a lack of precipitation, surface flows in the watershed declined once again in early March 2007 (Figure 12).

We examined drainage discharge relationships with four regional gaged watersheds to develop a flood frequency curve and extend the flow duration curve for High Prairie Creek (McGarvey Creek, Smith River, Little River and Redwood Creek). We recognized the importance of locating a similar sized watershed to relate to our gage data, however, similarities in proximity to the coast and physiographic province were also key factors in computing acceptable hydrologic estimates based on drainage area. Drainage area and discharge relationships were strongest between High Prairie Creek and the Smith River gage (R^2 0.96). This was most likely because both Little River and Redwood Creek are located further south and possibly experienced storm cells differing in magnitude and intensity relative to those experienced by High Prairie Creek and the Smith River. Smith River data also differed from Little River and Redwood Creek during peak flows (Appendix B2). And although McGarvey Creek provided a fairly strong relationship to our gage data, the short period of record excluded use of this gage for our assessment. Smith River data was used to develop a flood frequency curve for High Prairie Creek based on the drainage area ratio (Appendix B3). Flow duration curves for High Prairie Creek, lower Salt Creek, and the Smith River were also constructed for planning and assessment purposes (Appendix B4).

Water Budget Assessment

Field observations and recent hydrologic monitoring of Salt Creek revealed that surface water inflows were likely augmented by groundwater inflows, especially during the dry season. Measurements at various springs indicated subsurface flow contributions were important sources of cold water with dissolved oxygen concentrations above 6.0 mg/l. Therefore, we estimated the magnitude of groundwater contributions to surface water outflows, by monitoring the primary surface water inflow, outflow and storage components of the Salt Creek water budget. Groundwater inflow was then estimated using the following mass balance equation:

$$dS = P + SWI + GWI - ET - SWO - GWO \quad (1)$$

where dS was equal to change in storage, P was precipitation inflow, SWI was surface water inflow, GWI was groundwater inflow, ET was evapotranspiration, SWO was surface water outflow, and GWO was groundwater outflow.

Equation (1) was rearranged to solve for groundwater inflow as presented below.

$$GWI = (ET + SWO) - (P + SWI) + dS \quad (2)$$

For this application, equation (2) was based on the assumption that groundwater outflow was zero. This was a conservative assumption that did not effect the calculation of groundwater inflow. Groundwater outflow may have been calculated if the hydraulic conductivity of the subsurface materials were known using Darcy's Law, but was beyond the scope of this report. Equation (2) was also based on the assumption that surface and groundwater flows drained towards the lower Salt Creek gage. Geomorphic mapping and topographic surveys generally support the assumption that flows from contributing areas of Salt Creek and portions of Hunter Creek drained to the bedrock boundary located on the down gradient side of the valley and towards the lower Salt Creek gage (Figure 1). The starting point for the storage volume calculation was assumed zero in October 2005 for the wetland and large beaver pond.

Calculations for each hydrologic component of the water budget were computed based on daily values and reported as monthly averages. The change in storage at the large beaver pond and wetland was determined by relating differences in measured stage to the stage-area-volume relations developed for these features (Figures Area and Volume). Precipitation measured at the nearby USGS gage located on the north side of the Klamath River upstream of the Terwer Creek confluence (Latitude: 41º51'20"; Longitude: 123º99'90") was used for the precipitation inflow (CDEC 2007). Surface water inflow from High Prairie Creek, the largest contributing stream, was measured from the continuous gage data. Ungaged surface water inflows were estimated by normalizing the discharge record for High Prairie Creek with the drainage area ratio of High Prairie Creek and the ungaged streams. Evapotranspiration was estimated using the Penman-Monteith equation (Monteith 1965) using coefficients for wetland plants obtained from Allen and others (1998) and Johns (1989).

The turnover rate and residence time for water in the beaver pond and wetland (at flood stage) was estimated by the following equations:

$$T = I/V \quad (3)$$

$$R = V/I \quad (4)$$

where T was equal to the time period, R was residence time, I was the quantity of water over the time period, and V was the volume of the beaver bond for the same time period.

Topographic information was used to develop relationships between water stage and inundated area, and volume of water stored in the large beaver pond and wetland areas of the Salt Creek valley. The lower beaver dam was found to impound water to a spill elevation of approximately 14.6 ft. Therefore, two stage rating curves were developed to reflect the differences in area and storage volume under low flow and high flow conditions (Appendices B5 and B6). The Salt Creek water budget indicated two distinct hydro-periods operating within the watershed with high surface flows resulting in high outflow during winter months and low surface inflow during summer months (Figure 13). The fairly substantial difference in surface flow input and outflow during December 2005 – January 2006 was related to Klamath River backwater events occurring during this time. Patterns of surface flow input and outflow observed during the wet hydro-period of WY 2007 represented watershed conditions relatively unaffected by river backwatering. This water budget showed that water outflow was significantly augmented by groundwater inflow, especially during the low flow hydro-period (Figure 14).

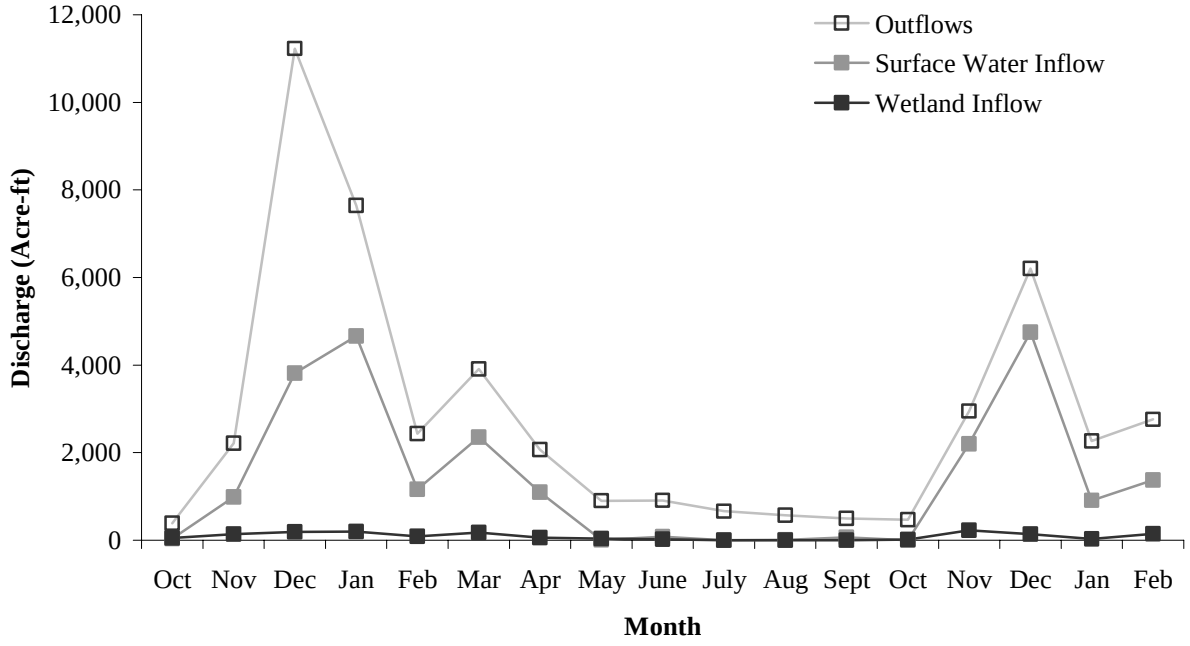


Figure 13. Comparison of measured inflows and outflow for the period October 2005 – February 2007 in the Salt Creek watershed, Lower Klamath River Sub-basin, California.

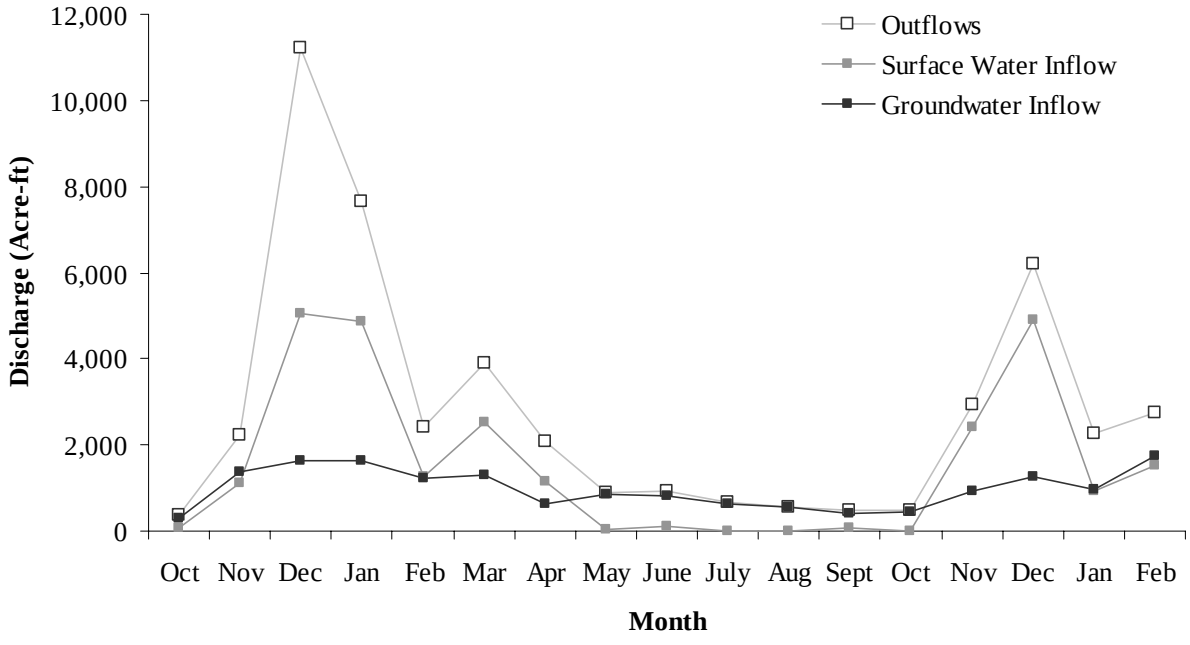


Figure 14. Comparison of measured inflows and outflow with calculated groundwater inflow for the period October 2005 – February 2007 for the Salt Creek watershed, Lower Klamath River Sub-basin, California.

Channel and Valley Morphology

Topography

A topographic model for the Salt Creek valley floor was prepared using a combination of total station surveys of critical features, aerial photograph mapping and U.S. Geological Survey (USGS) 10 meter Digital Elevation Model (DEM) contours. Optical Total Station surveys were based on a network of control points established by GPS Total Stations tied to National Geodetic Survey (NGS) benchmarks with a 1988 North American Vertical Datum (NAVD88) and 1983 North American Datum (NAD83) for horizontal coordinates.

Survey data and aerial photography were used to adjust 1 meter contours generated from the USGS 10 meter DEM to conform to topography, hydrologic features, and vegetation gradients visible on 2005 and 2004 aerial photographs. The adjusted 1 meter contours were then used as breaklines to generate a Digital Terrain Model (DTM) incorporating the total station survey data to produce a topographic map with 1 foot contour intervals (Figure 15). This process was conducted using ArcView GIS software.

In addition, the location and elevation of recording stream gages, staff plates and crest stage gages used in hydrologic monitoring were obtained during the total station surveys. This allowed for the conversion of water surface elevations measured at various locations within the project area to a common vertical datum. Longitudinal survey data was plotted and used throughout this study (Figure 16).

Hydro-Geomorphology

The topographic model, geomorphic mapping, and 2005 aerial photographs were used to prepare a GIS based hydro-geomorphic map for the Salt Creek valley and nearby areas (Figure 17). A majority of Salt Creek valley was comprised of wetlands and low lying terraces or floodprone surfaces. Prominent delta features existed at the mouth of High Prairie Creek and upstream of the Salt Creek wetland. Hunter Creek, its tributaries (Panther Creek and Mynot Creek) and lower Spruce Creek were included in mapping efforts, however, these areas were not mapped to the same level of detail since they were not the focus of this study. Wetlands of Salt Creek appeared to be controlled in part by the beaver dams located upstream of the lower gage and possibly to a greater extent by the alluvial deposits comprising lower High Prairie Creek and Hunter Creek (Figure 17).

Channel Sediment Characterization

Wolman pebble counts (Wolman 1954) were used to characterize surface particle size distributions at three permanent cross section locations in High Prairie Creek in 2002. These methods were repeated at two of these sites in fall 2005 and at all three cross sections in fall 2006. Surface particles were also characterized at the High Prairie Creek gage cross section in fall 2005 and fall 2006, and at a permanent cross section located in Salt Creek in fall 2006. Lisle and others (2000) showed that subsurface sediments approximated particle size distributions of the bed material typically transported. Therefore, subsurface channel substrates were characterized at the High Prairie Creek gage and two of the permanent cross sections in fall 2005 and at the Salt Creek site in fall 2006. These samples were obtained by removing surface particles to the depth of the dominant particles and collecting subsurface materials to a depth of approximately two times the largest surface particle (Figure 18). Subsurface samples were processed according to Church and others (1987).

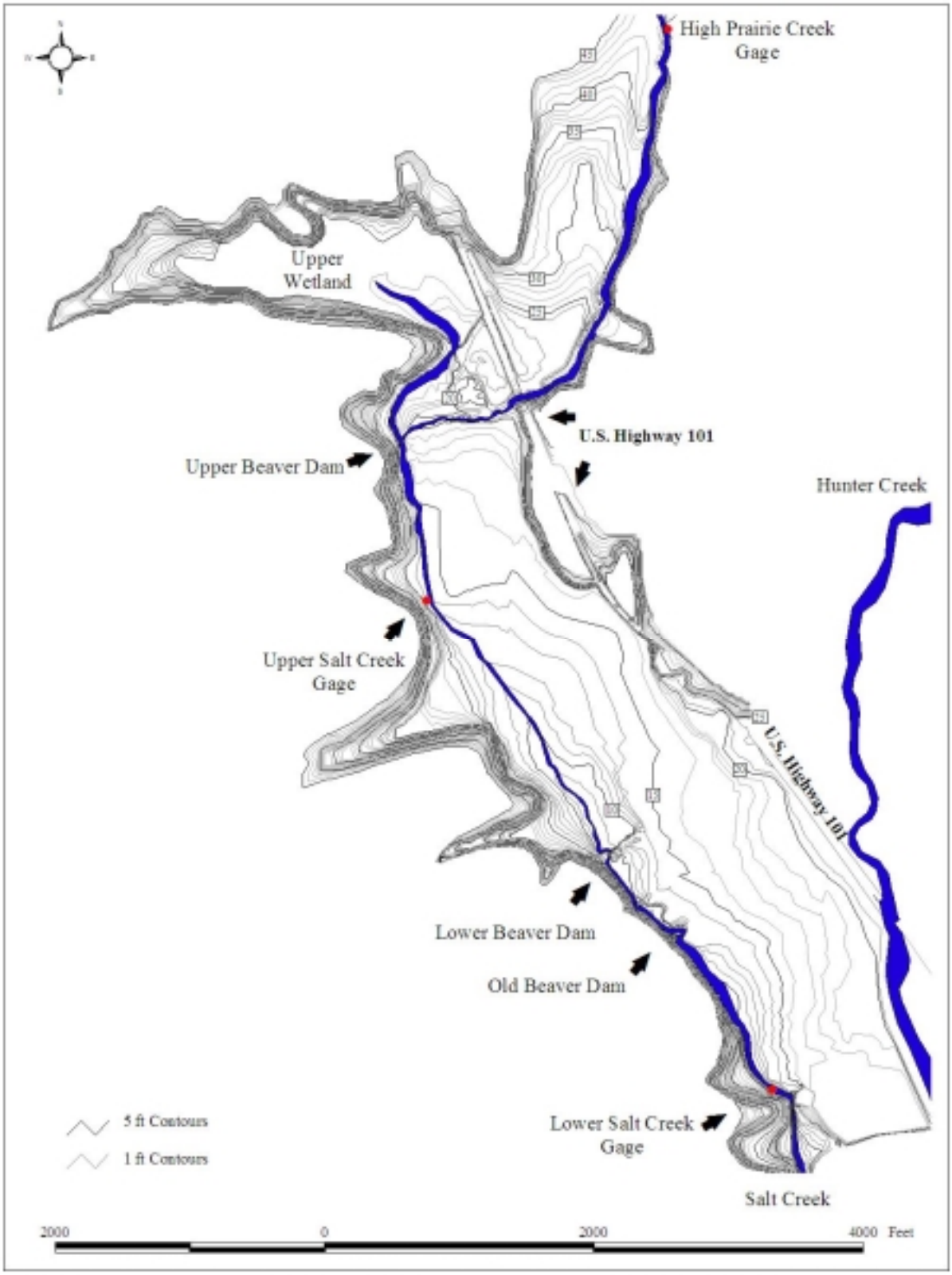
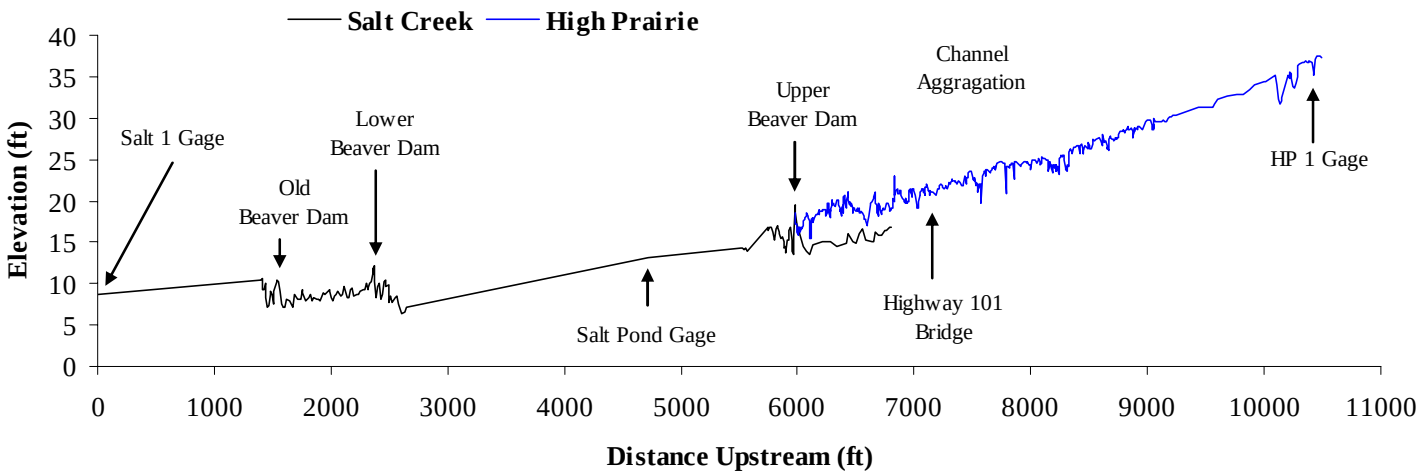


Figure 15. Topographic map developed for the Salt Creek valley, Lower Klamath River Sub-basin, California.



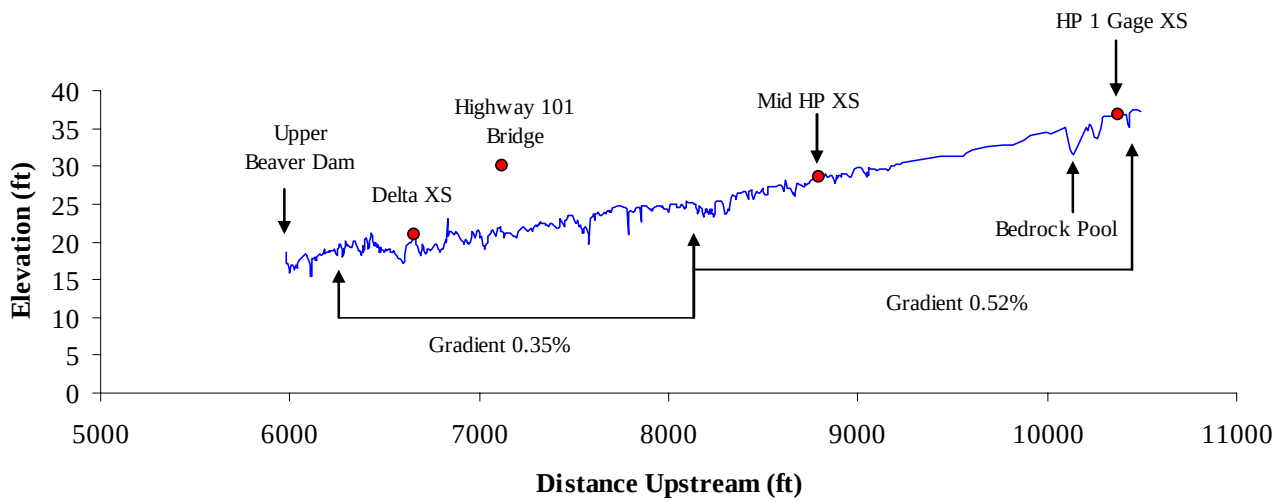


Figure 16. Longitudinal profile surveys of Salt Creek and lower High Prairie Creek, Lower Klamath River Sub-basin, California. Surveys conducted during fall 2006 – winter 2007.

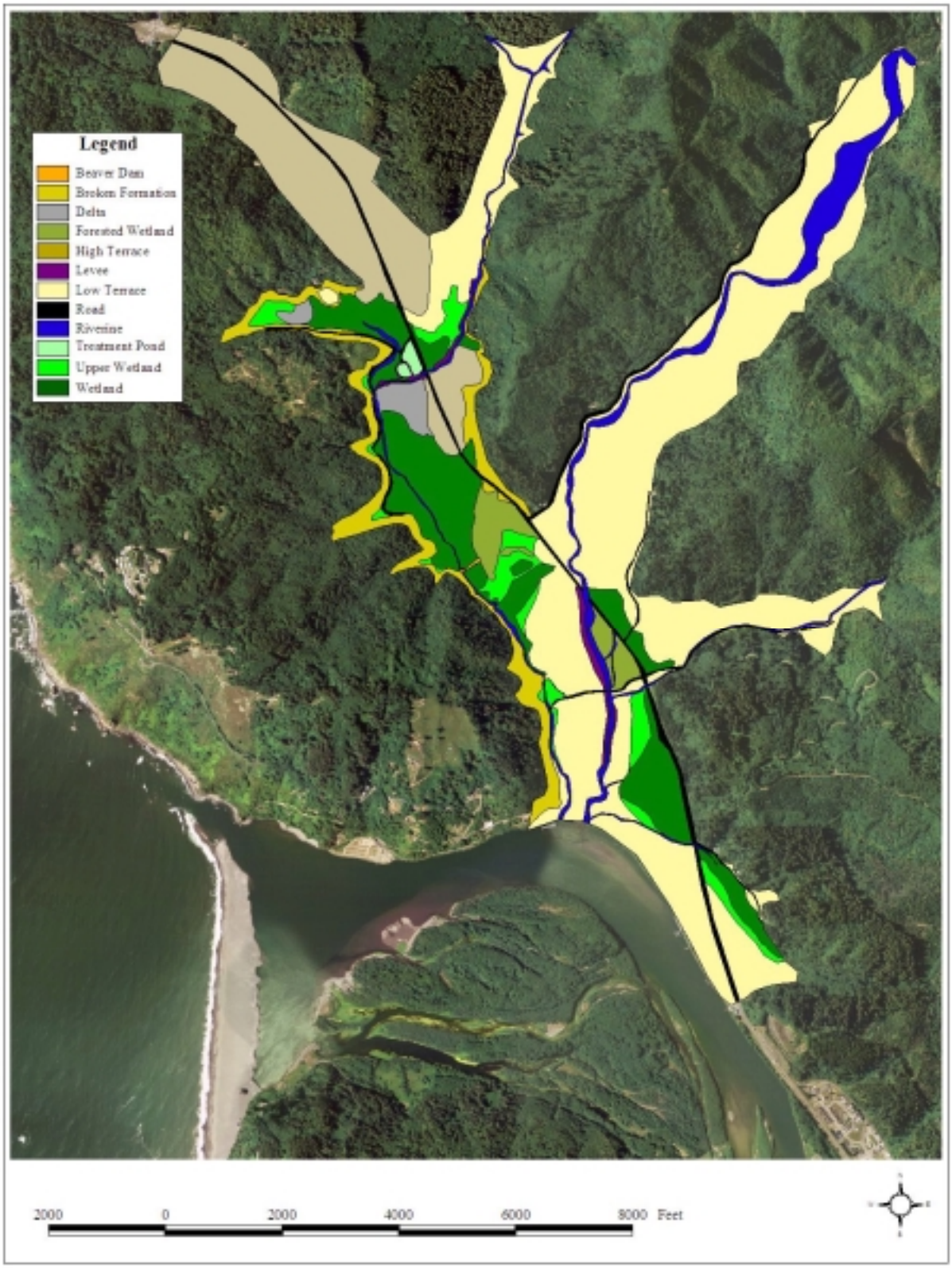


Figure 17. Geomorphic map depicting existing vegetation and hydrogeomorphic units in the Salt Creek Valley, Lower Klamath River Sib-basin, California. Base image: portions of the 2005 NAIP imagery, 1 meter resolution.

a. High Prairie Creek (HP XS 1). b. High Prairie Creek (HP XS 3).

Figure 18. Photographs of subsurface sediment collection sites in High Prairie Creek, Lower Klamath River Sub-basin, California (October 2005).

All particle data were converted to cumulative percent finer than for each fraction size class and size distribution curves were plotted using Microsoft Excel (Appendix C). Percentile values such as the median diameter were calculated for each size distribution using a Microsoft Excel template. To better characterize channel sediments, the following size descriptors were calculated from the subsurface particle data: median (D_{50}), geometric mean (*dg*), graphic mean (*mg*), sorting index (*sg*), and skewness (*sk*) according to methods outlined in Kondolf and Wolman (1993) (Table 2).

Kondolf and Wolman (1993) reviewed published and original size distribution data from salmonid spawning gravels. They reported median diameters (D_{50}) for spawning gravels ranged from 5.4 – 78 mm with 50% of the median diameters ranging from 14.5 – 35 mm. Kondolf and Wolman (1993) presented median diameters for steelhead spawning gravels ranging from 10.4 – 46.3 mm and median diameters for coho salmon gravels ranging from 5.4 – 46.3 mm. Median diameters and the size descriptor values calculated from the subsurface sediment samples fell within the ranges reported by Kondolf and Wolman for steelhead and coho salmon (1993) (Table 2).

Table 2. Sediment size data for samples collected in the Salt Creek watershed, Lower Klamath River Sub-basin, California.

Site	Year	D_{50}	Geometric Mean (dg)	Graphic Mean (mg)	Sorting Index (sg)	Skewness (sk)
XS 3	2005	15.9	8.6	10.5	7.7	-0.30
Gage	2005	10.7	5.7	7.0	5.9	-0.35
XS 1	2005	11.5	6.4	7.7	6.5	-0.31
Confluence	2006	11.5	10.8	11.0	2.1	-0.09

Hillslope and Channel Sediment Dynamics

Hillslope Sediment Source Analysis

A sediment budget was constructed to quantify the dominate hillslope sediment sources within upper Salt Creek and High Prairie Creek to assist development of restoration strategies and design concepts. In north coastal California, sediment budgets generally quantify erosion inputs from landslides, surface erosion from sources including roads and timber harvest units, and fluvial erosion from gullying and streambank erosion. The sediment source investigation presented in this study included a GIS based analysis of landslides and surface erosion, with limited field verification. Estimates of fluvial erosion were not included in this analysis due to limited funding. However, detailed sediment source investigations conducted in other north coastal California watersheds indicate that landslide inputs are the dominant mechanism contributing sediment to streams (Pitlick 1995, Kelsey et al. 1995, Raines 1998). Field reconnaissance and aerial photograph analysis of study area suggested gullies and streambank erosion were minor components of the sediment budget for upper Salt Creek and High Prairie Creek.

Hillslope sediment inputs were estimated for nine mapping periods: 1917 – 1927, 1928 – 1946, 1947 – 1956, 1957 – 1965, 1966 – 1972, 1973 – 1989, 1990 – 1993, 1994 – 1998, and 1999 – 2005. Mapping periods were based on aerial photograph coverage and the regional storm history. These data along with stage of landslide scar revegetation information, formed the basis of calculating sediment input rates. Eleven sets of aerial imagery including aerial photographs, DOQs, and an ortho-rectified color mosaic of Del Norte County were used in these analyses (Table 3). Aerial photographs were scanned at 600 dpi and georectified to the USGS 1993 Requa DOQ using ArcView Image Analyst (ESRI 2006). Georectification of aerial photographs generally followed procedures described by Hughes et al. (2006).

Chronology of landsliding, road construction, and timber harvest was heads-up digitized directly into the GIS project using the sequential imagery. The completeness of the image record, and the combination of digital and hardcopy imagery provided the capability to examine erosion features and landscape changes at varying scales, time periods, and perspectives. This process greatly improved feature interpretation and mapping accuracy compared to traditional methods where features were transferred to GIS from mylar map overlays for analysis.

Sediment yield estimates were separated into fine and coarse material fractions using the following percentages: landslide inputs, fine sediment 33%, coarse sediment 67%; harvest unit surface erosion, fine sediment 80%, coarse sediment 20%; road surface erosion, fine sediment 100%. These percentages were based on field observations, Soil Survey data for Coast Range soils, and streambed bulk samples measured as part of this study.

Landslides are usually triggered during a period of intense rainfall, following a wildfire or seismic event, or a combination of natural and anthropogenic factors. Prior to landslide mapping, the image library was reviewed to assess the time required for vegetation to regenerate on landslide surfaces and harvested areas. Regeneration ages were categorized into ranges: barren, 1 – 5 years, 6 – 10 years, 11 – 20 years, and > 20 years. The landslide date of birth (DOB) was then estimated by subtracting the revegetation age from the aerial photograph year and comparing the DOB with the most likely triggering storm year. This technique was mainly used to estimate landslide age on the 1948 aerial photographs. Landslides identified by Davenport (1984) were verified and active features were re-digitized to conform to the 1993 DOQ image base.

Table 3. List of imagery used for hillslope sediment source analysis in the Salt Creek watershed, Lower Klamath River Sub-basin, California.

Flight Date	Source	Flight Line	Frame Number(s)	Type
6/23/1948	CDF	20	126,127,129 & 179	B&W AP
9/28/1954	AV	2	5 & 6	B&W AP
9/28/1954	AV	3	6,7,8 & 10	B&W AP
9/18/1963	DNC	11	11,12,13 &14	B&W AP
9/18/1963	DNC	12B	9, 10,11,12,14 & 15	B&W AP
9/18/1963	DNC	11	15,16,17 & 18	B&W AP
7/8/1965	EPT	01FF	141,142,143,144,163,165 & 166	B&W AP
7/7/1969	DNC	11A	12,13,14,15,16,17 & 18	B&W AP
7/7/1969	DNC	9	7,8 & 10	B&W AP
7/7/1969	DNC	10	8,14,15,16,17,19 & 20	B&W AP
9/22/1972	DNC	9	9	B&W AP
9/22/1972	DNC	10	12,16,20, & 21	B&W AP
9/22/1972	DNC	11	13	B&W AP
1988/1989	USDA	NA	Requa	Color Infrared DOQ
6/12/1993	USGS	NA	Requa	B&W DOQ
1998	USGS	NA	Requa	B&W DOQ
6/7/2001	Hum	23	1,2,5,7 & 9	Color AP
6/7/2001	Hum	24	3,5,7 & 9	Color AP
2005	USDA	NA	naip_1-1_1n_s_ca015_2005_1	Color Mosaic

A total of 39 landslides were mapped during this study. Three revegetated landslides were identified on the earliest aerial photograph (1948) in the un-harvested areas of High Prairie Creek. The remaining 36 landslides occurred within harvested areas of High Prairie Creek. No landslides were identified in upper Salt Creek. Landslide areas were converted to volume using the following area to volume regression developed for landslides in the adjacent Mill Creek watershed:

$$\text{Landslide Volume} = 0.44(\text{Landslide Area})^{1.135} \quad (R^2 = 0.84,\ n = 46) \tag{5}$$

where the units were yards (CSP unpublished data). A sediment delivery ratio was determined for each landslide during the mapping phase and applied to adjust delivery volumes to account for sediment retained within the landslide scar.

Road surface erosion was estimated by applying published erosion rates for forest system roads (Reid and Dunne 1984) to the roads mapped in this study following the approach outlined by GMA (2001). Harvest unit surface erosion was estimated based on the harvest history and applying erosion rates according to harvest method and a decay function to account for changes in sediment delivery as vegetation stabilizes the site. The following sediment yields were applied to mapped harvest units: 200 tons/mi^2/yr for tractor logged units, 150 tons/mi^2/yr for tractor/cable yarded units, and 100 tons/mi^2/yr for cable yarded units. These values were estimated from the available literature (Lewis and Rice 1989, MaCashion and Rice 1983, Raines 1998, GMA 2001a and 2001b) to reflect the moderate surface erosion rates observed in the study area. Harvest surface erosion was estimated for a 10 year period based on the first appearance of erosion in the image record. Erosion rates were calculated for the first two years using the rates listed above, and then reduced to 25% of those rates for the remaining 8 years.

Table 4 summarizes hillslope sediment yield and input rates for upper Salt creek and High Prairie creek. Sediment production was highest during the intensive management period (1957 – 1993) when the erosion rate averaged 2134 yds^3/yr (3,096 tons/yr). The high erosion rates associated with this period coincided with the most intensive timber harvest activities and several large magnitude storms (1965, 1972, and 1975). The single largest period of sediment delivery occurred during the 1973 – 1989 mapping period where 31% of the total volume was delivered. The delivery rate for the intensive management period (2,134 yds^3/yr) was 3.4 times the preceding Early Management Period (639 yds^3/yr), 130 times the Recent Management Period (5 yds^3/yr), and ~ 1.9 times the delivery rate derived from combining all mapping periods (1,165 yds^3/yr).

Channel Capacity, Hydraulics, and Sedimentation

Channel conveyance capacity has diminished in lower High Prairie Creek due to sedimentation processes that began manifesting in 1972. The hillslope sediment source analysis showed sediment input rates were highest from 1957 – 1993 and the greatest amount of sediment delivery occurred from 1973 – 1989. We analyzed changes in channel bed elevations, conducted hydraulic analysis, and estimated modern and geologic sedimentation rates to better understand the interaction of hillslope sediment delivery and channel processes and apply the information to restoration concepts.

Channel cross section data for surveys conducted from the U.S. Highway 101 Bridge at High Prairie Creek in 1956, 1972, 1993, and 2003 were obtained by CalTrans (Miller 2006). A cross section survey was repeated at this site during our 2006 survey effort and analysis of these and past data indicated the channel has aggraded by 7.7 ft since 1957.

Hydraulic analysis of flow conditions in lower High Prairie Creek was conducted using WinXSPro (Hardy et al. 2005). Representative cross sections at 1) the High Prairie Creek gage, 2) within the levee, and 3) the delta downstream of the U.S. Highway 101 Bridge were used to compute at-a-station hydraulic relationships and bed surface shear stress. Water surface slopes for low flows were approximated from the channel bed slopes measured from the long profile survey. High flow water surface slopes were estimated from bankfull indicators measured during the 2006 survey and from the crest-stage gage data. Channel roughness was approximated using the D_{84} particle size measured at each cross section and was calculated using the Thorne and Zevenbergen equation in WinXSPro. Comparing measured discharges with WinXSPro model outputs for the gage cross section revealed model outputs were very similar to actual results (R^2 0.99). The threshold particle size (the particle size mobilized at a given flow) was estimated using limiting shear stress values provided by Fichenich (2001).

The results of the hydraulic modeling indicated a downstream increase in bankfull discharge (5%) and critical shear stress (30%) between the gage and the levee cross sections (Table 5). Conversely, bankfull discharge decreases by 48% and the critical shear stress decreases by 55% at the delta reach. The decrease in bankfull discharge in the delta reach was related to reduced channel conveyance capacity, where flows > 126 cfs overflow levees and drain to adjacent wetlands. The accompanying reduction in the available critical shear stress suggested that particles > 0.56 inches were at the threshold of particle motion under these flow levels and would likely accumulate in this reach. Topographic and geomorphic mapping of this area revealed multiple ephemeral flow paths emanating from the lower levees and deposition of well sorted gravel has nearly filled the channel from the U.S. Highway 101 Bridge to just downstream of the confluence (Figure 19). Our mapping also showed that gravel deposition abruptly terminated ~ 460 downstream of the upper beaver dam where the channel bottom was covered by 1 – 3 ft of fine sediments.

Table 4. Summary of hillslope sediment delivery and input rates for upper Salt Creek and High Prairie Creek, Lower Klamath River Sub-basin, California.

A) Delivery and Input Rates in Cubic Yards

Mapping Period	Hillslope Sediment Delivery and Input Rates								
	Fine Sediment Fraction			Coarse Sediment Fraction			Combined		
	(yds^3)	(yds^3/yr)	($yds^3/mi^2/yr$)	(yds^3)	(yds^3/yr)	($yds^3/mi^2/yr$)	(yds^3)	(yds^3/yr)	($yds^3/mi^2/yr$)
1917 - 1927	2,829.8	283.0	78.6	5,745.3	574.5	159.6	8,575.1	857.5	238.2
1928 - 1946	2,750.9	152.8	42.5	5,585.1	310.3	86.2	8,336.0	463.1	128.6
1947 - 1956	2,047.1	202.3	60.1	3,717.0	394.5	112.5	5,764.1	596.8	172.6
1957 - 1965	5,732.5	647.3	188.2	10,601.6	1,282.4	363.1	16,334.2	1,929.7	551.3
1966 - 1972	5,456.1	856.8	242.8	10,481.4	1,718.8	481.9	15,937.5	2,575.6	724.7
1973 - 1989	9,446.6	588.3	163.4	18,744.4	1,171.5	325.4	28,191.0	1,759.8	488.8
1990 - 1993	2,260.9	753.6	209.3	4,546.8	1,515.6	421.0	6,807.6	2,269.2	630.3
1994 - 1998	57.2	14.3	4.0	27.0	6.7	1.9	84.2	21.0	5.8
1999 - 2005	39.0	4.5	1.6	51.7	7.1	2.2	90.7	11.6	3.8
Early Management Period Average (1917 - 1956)	7,628	206	60	5,016	426	119	7,558	639	180
Intensive Management Period Average (1957 - 1993)	22,896	694	201	11,094	1,422	398	16,818	2,134	599
Recent Period Average (1994 - 2005)	96	10	3	39	7	2	87	16	5
Combined Total	30,620	389	110	59,500	776	217	90,120	1,165	327

B) Delivery and Input Rates in Tons

Mapping Period	Hillslope Sediment Delivery and Input Rates								
	Fine Sediment Fraction			Coarse Sediment Fraction			Combined		
	(tons)	(tons/yr)	($tons/mi^2/yr$)	(tons)	(tons/yr)	($tons/mi^2/yr$)	(tons)	(tons/yr)	($tons/mi^2/yr$)
1917 - 1927	3,678.7	367.9	102.2	8,503.1	850.3	236.2	12,181.8	1,218.2	338.4
1928 - 1946	3,576.1	198.7	55.2	8,265.9	459.2	127.6	11,842.1	657.9	182.7
1947 - 1956	2,661.2	295.7	78.1	5,501.2	611.2	166.6	8,162.4	906.9	244.7
1957 - 1965	7,452.3	931.5	244.7	15,690.4	1,961.3	537.3	23,142.7	2,892.8	782.0
1966 - 1972	7,093.0	1,182.2	315.6	15,512.4	2,585.4	713.3	22,605.4	3,767.6	1,028.9
1973 - 1989	12,280.6	767.5	212.4	27,741.7	1,733.9	481.6	40,022.3	2,501.4	694.0
1990 - 1993	2,939.1	979.7	272.1	6,729.2	2,243.1	623.1	9,668.3	3,222.8	895.2
1994 - 1998	74.4	18.6	5.2	39.9	10.0	2.8	114.3	28.6	7.9
1999 - 2005	50.7	8.4	2.0	76.5	12.7	3.3	127.2	21.2	5.3
Early Management Period Average (1917 - 1956)	9,916	287	78	7,423	640	177	10,729	928	255
Intensive Management Period Average (1957 - 1993)	29,765	965	261	16,418	2,131	589	23,860	3,096	850
Recent Period Average (1994 - 2005)	125	14	4	58	11	3	121	25	7
Combined Total	39,806	528	143	88,060	1,163	321	127,866	1,691	464

Notes: Sediment volumes (yds^3) were converted to mass (tons) using bulk densities of 1.3 $tons/yds^3$ for fine sediment and 1.48 $tons/yds^3$ for coarse sediment.

Table 5. Summary of hydraulic modeling results for High Prairie Creek, Lower Klamath River Sub-basin, California.

Cross Section Location	Bankfull Discharge (cfs)	Flow Depth (ft)	Critical Shear Stress (lb/ft^2)	Bankfull Discharge Percent Change[1] (%)	Critical Shear Stress Percent Change[2] (%)	D_{84} Particle Size (in)	D_{50} Particle Size (in)	Threshold Particle Size (in)
High Prairie Gage	231	2.1	0.43	-	-	1.34	0.42	0.98
Levee	243	2.25	0.56	5	30	1.63	0.45	1.27
Delta	126	1.54	0.25	-48	-55	0.88	0.45	0.56

Notes: 1) and 2) the percent change is relative to the adjacent upstream cross-section.

Modern sedimentation rates were estimated for lower High Prairie Creek through analysis of stream cross sections surveyed at the U.S. Highway 101 Bridge over High Prairie Creek in 1956, 1972, 1993, 2003, and the 2006 long profile and cross sections surveys. Volumes were estimated as the product of the long profile area and average channel width. Long profile areas were estimated as the area between two successive long profiles. Synthetic long profiles for 1956, 1972, 1993, and 2003 were created based on the channel slope of the 2006 long profile and elevation changes determined from the repeated surveys at the High Prairie Creek bridge. Volumes were further adjusted by subtracting the 2006 reach average pool volume from each survey year.

Channel elevation changes measured at the U.S. Highway 101 Bridge ranged from 0.4 ft in 1972 to 3.5 ft in 2006, with a total channel bed increase of 7.7 ft since 1956 (Table 6). The total volume of in-channel storage for lower High Prairie Creek was estimated at 14,466 yds^3, with the greatest volume increase occurring from 1972 – 1993 (6,891 yds^3) (Table 6). Modern sedimentation rates estimated for lower High Prairie Creek revealed low rates occurred from 1956 – 1972 (12 yds^3/yr), moderate to high rates by 1993 (328 yds^3/yr) and 2003 (203 yds^3/yr), and the highest rates from 2004 – 2006 (1,789 yds^3/yr) (Table 7). The high sedimentation rates associated with the 2004 – 2006 period coincided with channel degradation measured at a monitoring cross section upstream of the levee reach. This coincidence suggests channel stored sediment is becoming a source of sediment being transferred to lower High Prairie Creek.

Figures 20 and 21 present volumes and process rates from hillslope sediment sources and modern sedimentation estimated for High Prairie Creek. These figures graphically depicted the timing between hillslope sediment inputs and downstream sedimentation. Timing and magnitude of fine and coarse sediment delivery was presented in Figure 20. An apparent 20 – 37 year time lag was illustrated for the first significant increase in channel sedimentation in 1993, following high hillslope inputs beginning during the 1947 – 1956 mapping period. Sedimentation estimates in 2006 were in the same order of magnitude as input rates from 1957 – 1993, nearly 13 years after input rates had significantly decreased (Figure 21). We attributed the apparent time lag in downstream sedimentation to in-channel storage and timing of flood producing storms capable of transferring sediment to lower High Prairie Creek. Large wood jams distributed throughout the middle and upper reaches and the topographic bench in upper High Prairie Creek appear effective at metering sediment through the system (Figures 3 and 22).

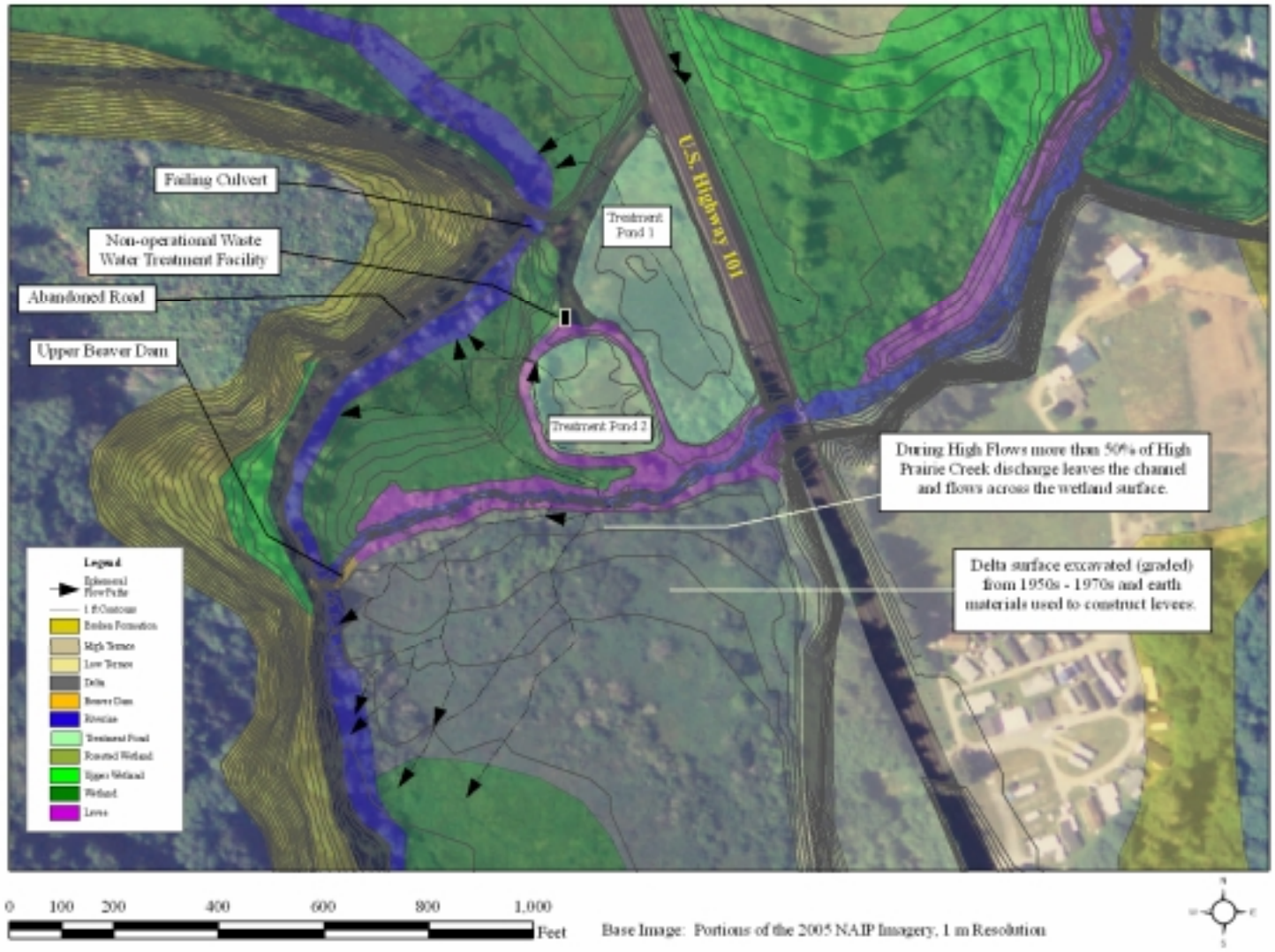


Figure 19. Existing hydro-geomorphic conditions for the confluence reach of High Prairie Creek and Salt Creek, Lower Klamath River Sub-basin, California.

Table 6. Channel elevations at the U.S. Highway 101 Bridge and estimated volume changes in lower High Prairie Creek, Lower Klamath River Sub-basin, California.

Year	Elevation	Elevation Change	Elevation Change	Reach Volume	Cumulative Volume
	(ft)	(ft)	(%)	(yds^3)	(yds^3)
1957	13.8	-	-	-	-
1972	14.2	0.4	5.2	181	181
1993	17.0	2.8	36.4	6,891	7,072
2003	18.0	1.0	13.0	2,026	9,098
2006	21.5	3.5	45.5	5,368	14,466
	Total	7.7	100	14,466	

Table 7. Estimated modern sedimentation rates in lower High Prairie Creek, Lower Klamath River Sub-basin, California.

Period	Sedimentation Rate (yds^3/yr)	Sedimentation Rate (tons/yr)	Sedimentation Rate (ft/yr)
1957 - 1972	12	17	0.001
1973 - 1993	328	474	0.019
1994 - 2003	203	293	0.012
2004 - 2006	1,789	2,584	0.106
Average	583	842	0.034

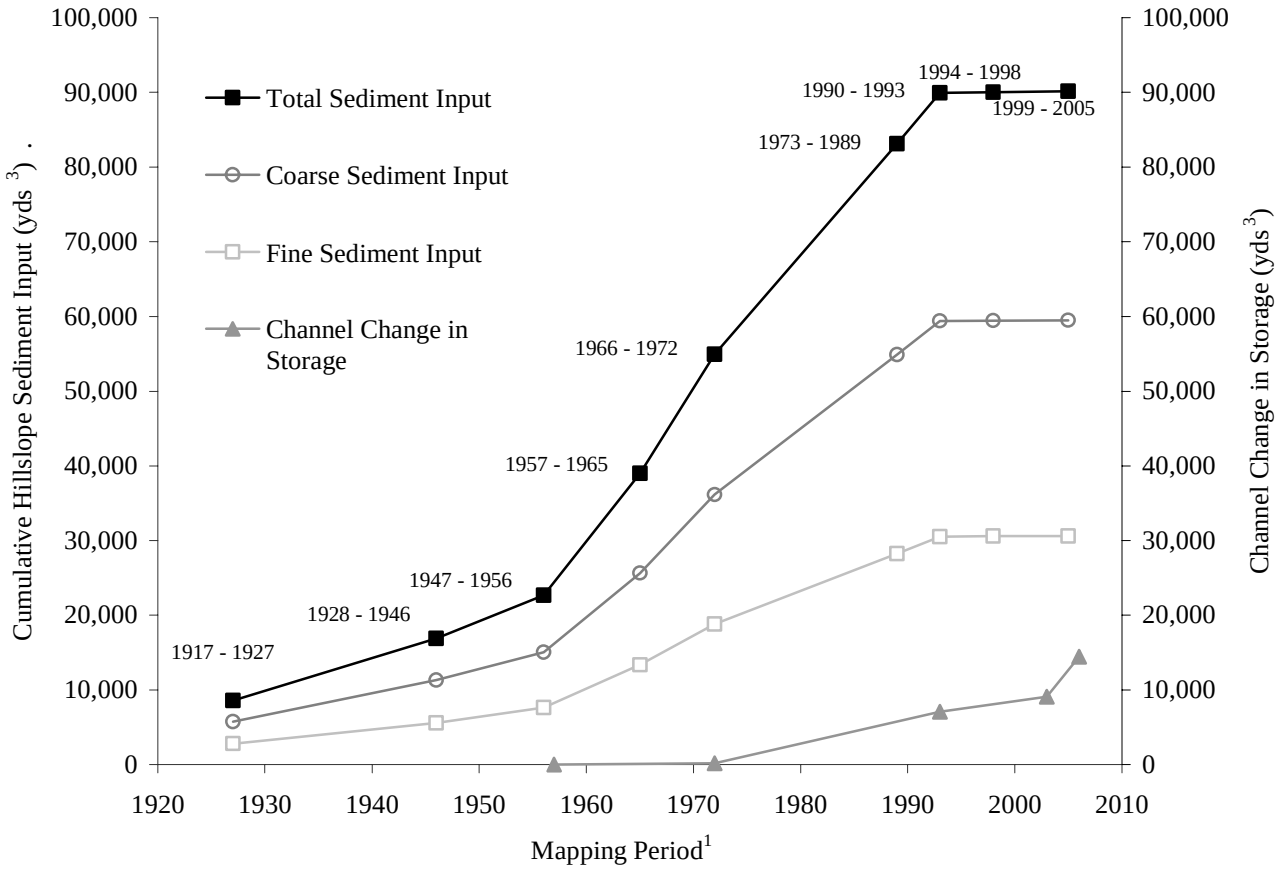


Figure 20. Hillslope sediment input volumes and channel sedimentation volumes for High Prairie Creek. Channel sedimentation volumes are for the levee reach of lower High Prairie Creek. Note: Annotation depicts hillslope sediment input mapping periods.

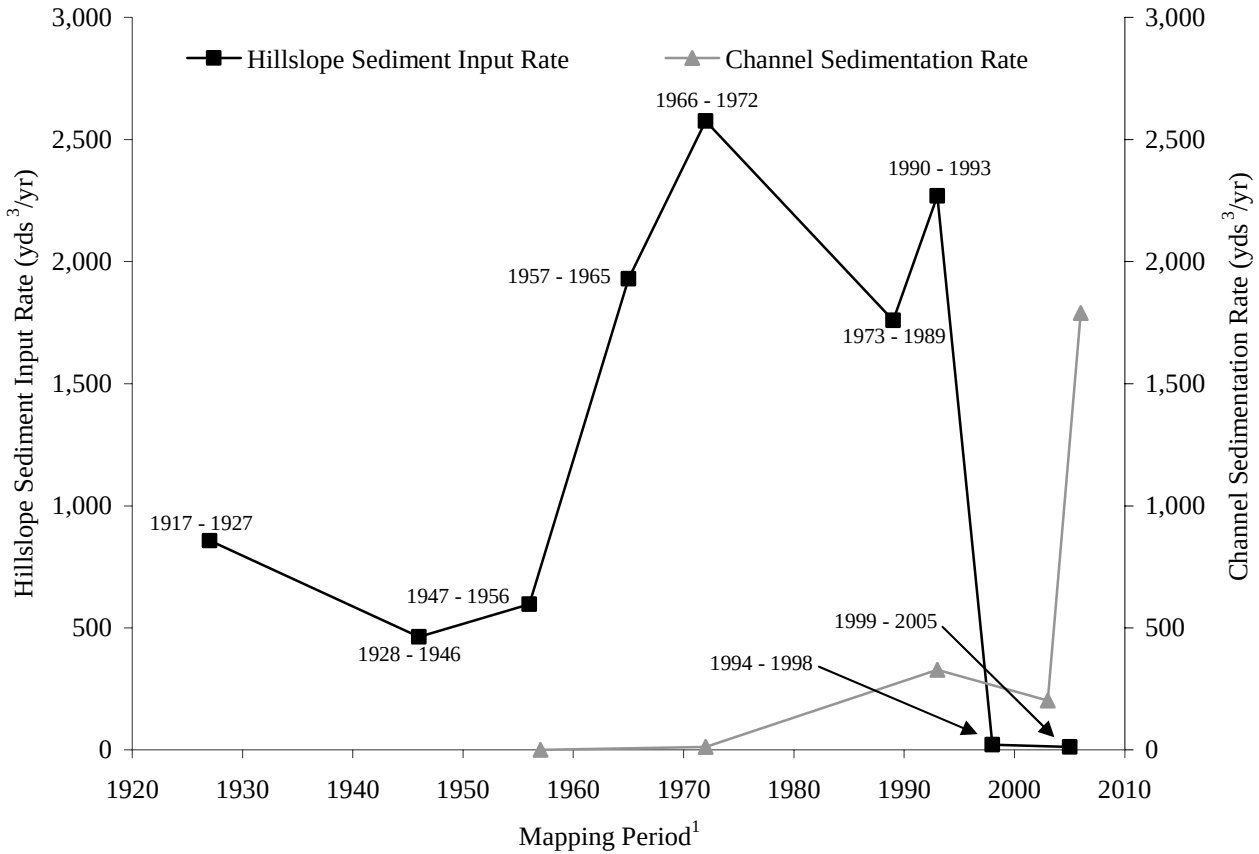


Figure 21. Hillslope sediment input rates and channel sedimentation rates for High Prairie Creek. Channel sedimentation rates are for the levee reach of lower High Prairie Creek. Note: Annotation depicts hillslope sediment input rate mapping periods.

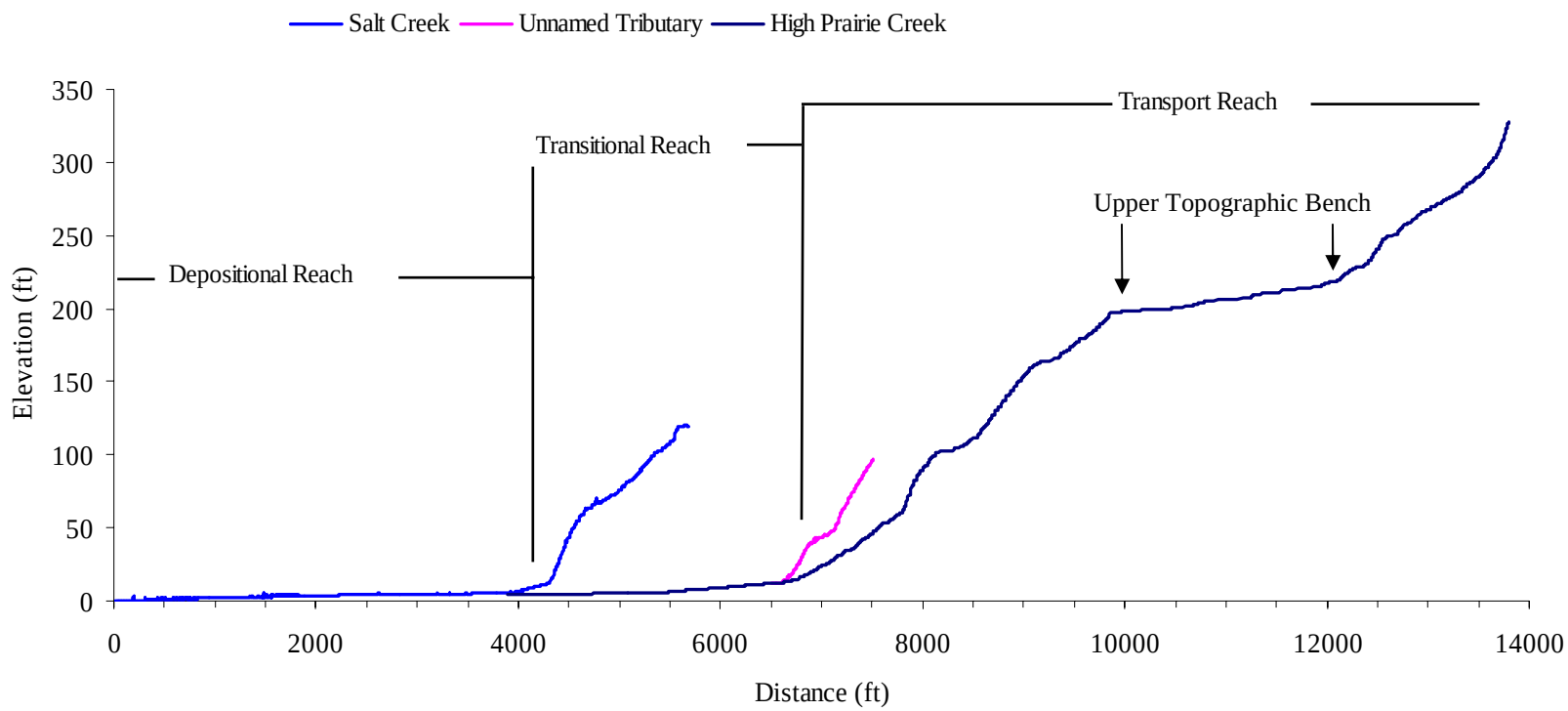


Figure 22. Longitudinal stream profile developed from U.S. Geological Survey 10 meter digital elevation model contours for Salt Creek and its major tributaries, Lower Klamath River Sub-basin, California.

Geologic sedimentation rates provided a means to assess the magnitude of modern rates, and put existing sedimentation processes into context with the future evolution of the study site. This information is also critical to understanding the importance of restoration and its feasibility. We used two different sources of information to estimate geologic sedimentation rates for the wetland and confluence area of High Prairie and Salt Creek; 1) Geotechnical Drill Logs from Miller (2006); and 2) Global Geologic Sea Level Curves from Thompson and others (2006).

The drill logs provided by Miller (2007) described a very dense blue sand and gravel at the base of both borings (Figure 6). We interpreted this unit as a fluvial deposit that graded to the ocean when the sea level was lower than present. The top of this unit in Bore-2 is approximately 80 feet below the modern sea level. Entering this elevation into the sea level curves of Thompson and others (2006) provides two possible ages when paleo-sea levels were 80 feet below the modern sea level: 1) at 80,000 years before present (ybp) and 2) 9,500 ybp. We prefer the younger age of 9,500 ybp for the lower most gravels and sands in Bore-2. The thickness of the sedimentary sequence between the basal gravel unit and modern sea level (80 ft) divided by the paleo-sea level age (9,500 ybp) yields a long-term sedimentation rate of 0.008 ft/yr (2.57 mm/yr).

The long-term sedimentation rate of 0.008 ft/yr (2.57 mm/yr) compared favorably with the tectonic uplift rate of 0.009 ft/yr (2.8 mm/yr) determined for the lower Klamath by Mitchell (1994). The similarity of these rates indicated the long-term sedimentation rate was a reasonable estimate (Burke 2007). The similarity of these process rates also suggests that the Salt Creek valley wetland may have persisted through time, in part, because long-term sedimentation rates have been slightly less than the long-term uplift of a drowned coastal valley.

With the exception of the earliest period shown in Table (Design Life) (1956 - 1972), modern sedimentation rates are 1.5 to over 13 times greater than the long-term geologic sedimentation rate. Combined with a rising sea level, predicted to be 0.0098 ft/yr (3 mm/yr) in response to climate change (IPCC 2001), the increase in sedimentation will create considerable limitations to continued function of the Salt Creek wetlands.

Implications for Management and Restoration of Salt Creek Wetlands

Estuaries and wetland basins are ephemeral features in the geologic record. These features are subject to filling by sedimentation and evolve to form deltas or meadows. These features can persist for long periods of time when sedimentation rates are low, when tectonic subsidence out paces sedimentation, when sea level fluctuations rejuvenate landscapes through base level changes or any combination of these processes. The wetland habitats within the Salt Creek valley appear to have been maintained for at least the past 9,500 years by the synergistic interaction of these processes.

Field observations and data collected for this study generally revealed a resilient landscape degraded by past landuse activities. Resource extraction has been

accompanied by accelerated sedimentation processes and channel simplification efforts that threaten the function and life span of the critical wetland habitats.

The water budget component of this study showed the combination of groundwater contributions to summer outflow levels and beaver activity helped to maintain water levels in riverine and wetland habitats during periods when water levels in many other Lower Klamath tributaries are sub-surface.

Analysis of sediment sources and sinks indicated that modern erosion and sedimentation rates were 1.5 to 13 times greater than the long-term geologic rate. Even if hillslope sediment production was reduced to pre-anthropogenic disturbance levels, the sediment currently stored in the fluvial system would provide a considerable amount of material to manage over the next 10 – 100 years. Sedimentation of low lying areas will be exacerbated when rising sea levels begin to affect base level.

Protecting and enhancing the critical salmonid habitats within the Salt Creek valley will require restorationists and land managers to work together to reduce sediment production from upslope source areas and improve habitats that will maintain populations while other areas recover.

Key issues for Salt and High Prairie Creeks include:

- Protect and enhance existing wetland habitats as outlined in the next section.
- Maintain large wood jams that meter sediment from source areas in High Prairie Creek.
- Encourage upslope restoration efforts. Road removal projects should be implemented that use full recontouring techniques where slope stability allows. Observations comparing full recontouring with other treatment methods indicate full recontouring provided both sediment reduction and hydrologic recovery of the groundwater system. This latter benefit may be critical method needed to improve summer base flows as the climate changes.
- Continue stream gaging efforts to improve the resolution of the water budget to assess the effects of restoration and land management.

Regulatory Compliance Planning

The following section presents general information necessary for acquiring Federal, State, and Local permits for conducting watershed restoration in California. This section was based on a Regulatory Compliance Planning outline developed by Aldaron Laird (Environmental Planner) and Geoff Hales (Geologist), both local consultants. Once the restoration plan has been finalized, YTFP would work closely with an environmental planner and affected regulatory agencies to adequately describe the environmental setting and to analyze potential environmental impacts associated with the project.

Project Area Description

The first step in acquiring any necessary project permits would be to develop a detailed description of the project area. This description would be necessary for all of the implementation alternatives presented in this report.

- **Project Location**

Township 14N - Range 1E - Sections 28, 33
Geographic (decimal degrees): Longitude 124.0710, Latitude 41.5657;
UTM NAD27 10 N: Northing 4,602,121.94, Easting 410,695.72

- **Directions**

From the north side of the U.S. Highway 101 Bridge crossing the Klamath River, drive approximately four miles north to the U.S. Highway 101 Bridge crossing High Prairie Creek. Turn left onto a small private road located approximately one-tenth of a mile north of High Prairie Creek crossing. Park vehicles off of the road on the north side and be aware of large truck traffic. The project area is located to the south of this parking area and consists of the lower 0.5 miles of High Prairie Creek and approximately 20 acres of Salt Creek wetland habitats (Figure 1).

- **Property Ownership**

YTFP obtained property ownership information for the project area and is in the process of informing affected landowners of watershed assessment findings and proposed treatment alternatives. When a final treatment alternative has been selected, YTFP will obtain the necessary written documentation from participating landowners granting permission to use their property for restorative activities.

- **Easements**

At this time, YTFP does not know of existing easements located in the project area. Developing conservation easement opportunities for participating landowners will be critical to restoration efforts and will be addressed in the final treatment plan.

- **Access and Staging Areas**

Most access routes are pre-existing but would require upgrading to accommodate heavy equipment and trucks. New access routes may need to be established and may involve crossing or entering wetland habitats. Any implementation project would incorporate

measures to avoid damage to sensitive wetland habitats. Staging areas for any implementation project would need to be developed with the participating landowners and the permitting agencies.

- **Vegetation Removal and Revegetation**

A few of the treatment alternatives presented in this study would require the removal of vegetation from the project site. A majority of the project area is colonized with reed canary grass, an invasive plant species that limits plant diversity and inhibits channel and wetland function. Treatment alternatives presented take into account existing spruce, willow, and red alder stands to try and maximize future wood recruitment to the area. YTFP has been working to obtain detailed vegetation information for the project area. Spatially accurate maps of plant assemblages and native riparian species lists would be critical for evaluating potential impacts, developing revegetation strategies, and for assessing effectiveness of future restoration efforts.

A high priority objective of the Yurok Tribe is restoring riparian habitats of the Lower Klamath River Sub-basin. YTFP has recently developed a native plant database and a small-scale nursery, located approximately one mile north of the project area. Species identified in mapping efforts would be incorporated in the Tribal nursery database and considered for future propagation. The final restoration plan would include a comprehensive revegetation plan for rehabilitating disturbed areas. This plan would need to include: species and age class information for the plants to be used, planting densities and percent vegetation cover, planting times and methods, expected survival rates, and a monitoring plan to assess project effectiveness and direct future revegetation efforts.

- **Water Diversion, Isolating Work Areas, De-Watering**

Most of the treatment options would require dewatering or isolating the work area from surface water. Although, lower High Prairie Creek generally experiences periods of subsurface flow in the reach upstream of the U.S. Highway 101 Bridge, water table elevations downstream of the bridge are consistently high during the low flow hydro-period. Water diversion measures would need to be tailored specifically to the preferred treatment alternative. YTFP would take great care to rescue any stranded fish and amphibians from the project area and re-locate them to other habitats in the watershed.

- **Excavation and Grading**

Most of the treatment options would require excavation and grading of ground surfaces in the project area. Rough estimates of cut and fill volumes and areas were developed for specific treatment alternatives presented. However, additional three-dimensional topographic surveys would be required prior to implementing any of the proposed treatment alternatives to better describe pre-treatment topography and monitor post-treatment topography. Three-dimensional topographic survey data provides critical information for assessing project effectiveness and directing future efforts.

- **Stockpiling**

Pre-treatment topographic surveys would provide the means to estimate the area required for stockpiling any material excavated. YTFP would take great care to locate stockpile

sites outside of designated flood zones and would employ erosion control measures to ensure that stockpiled sediments did not discharge to any waters of the state.

- **Monitoring**

YTFP is dedicated to monitoring restoration effectiveness in the Lower Klamath River Sub-basin. Therefore, a comprehensive, long-term monitoring program would be established based on the specific treatment alternative. The monitoring program would be developed in a manner that allowed YTFP to adapt on-going and future treatment activities to continue to improve conditions for Klamath Basin fish populations.

Environmental Assessments

Although YTFP has compiled a fairly large body of information for the Salt Creek watershed, additional environmental surveys or studies would likely be required to obtain any necessary project permits. Potential surveys/studies that may be required to describe the project area and analyze potential environmental impacts include:

Surveys

- Vegetation cover/habitat and sensitive plant species;
- Wetland survey;
- Sensitive wildlife species and critical habitat;
- Fish species and habitat;
- Topographic;
- Hydrology;
- Cultural resources and record search; and
- Underground utilities and record search.

Studies

- Noise;
- Traffic; and
- Hydrologic-tidal/hydraulic-modeling.

Following the completion of all environmental surveys/studies, an environmental planner would assist YTFP in developing a regulatory constraint analysis and designing a compliance strategy. During this step, an environmental planner would meet with YTFP and other affected landowners and/or stakeholders to explore project design modifications and mitigation measures to avoid any regulatory constraints and reduce any adverse impacts. This step would ensure the proposed project had a high probability of receiving all required permits while meeting proposed restoration objectives.

When the final project description has been developed, YTFP would work with an environmental planner to prepare necessary environmental documents and permit applications. The final project description and all survey/study data would be used to prepare one of the following environmental impact assessment documents listed below.

Impact Assessments

- California Environmental Quality Act: Initial Study/Mitigated Negative Declaration or Environmental Impact Report;
- National Environmental Policy Act: Environmental Assessment, FONSI, or Environmental Impact Statement; and
- Endangered Species Act: Biological Assessment.

Permitting agencies may need to consult with one or more resource agencies depending on the environmental setting and the proposed project. Additional information may be required at this point to allow permitting agencies to complete their analysis of the proposed project. Acquiring the necessary project permits requires concurrent preparation of Environmental Reviews, submitting permit applications/fees, seeking consultations, and actively engaging the permitting and resource agencies to ensure successful permit review.

Draft Treatment Alternatives

Several treatment alternatives were developed based on the findings of this study and the initial watershed assessment conducted by Beesley and Fiori (2004). Treatment alternatives ranged from taking no action to developing large-scale wetlands and re-aligning lower High Prairie Creek. The wide range of alternatives allows YTFP to account for multiple factors including existing infrastructure, private property concerns, permitting requirements, and potential outcomes versus cost effectiveness. Due to the amount of data required to develop as built treatment designs for this particular area, alternatives were presented as concepts to be considered during the peer review process. Estimated project costs for proposed alternatives were not developed for this preliminary report given the uncertainties and complexities involved. However, alternatives were presented from least expensive (Alternative I) to most expensive (Alternative IV).

Alternative I: No Restoration Alternative.

Restoration alternative I would be to take no restorative action within the project area. There would be no costs or permits associated with this alternative. Conditions appear to be declining rapidly and therefore this option is not likely the path that will be selected.

Alternative II: Rehabilitate Existing Channel

Alternative II would involve the removal of 8,000 to 12,000 yds^3 of sediment that has reduced channel conveyance capacity and limits salmonid use of High Prairie Creek (Figure 23). Levees would be adjusted to improve channel function and increased connectivity with adjacent wetlands. Sediment removal would be accompanied by construction of large wood structures needed to improve stream habitat, maintain grade, and improve sediment transport and storage dynamics.

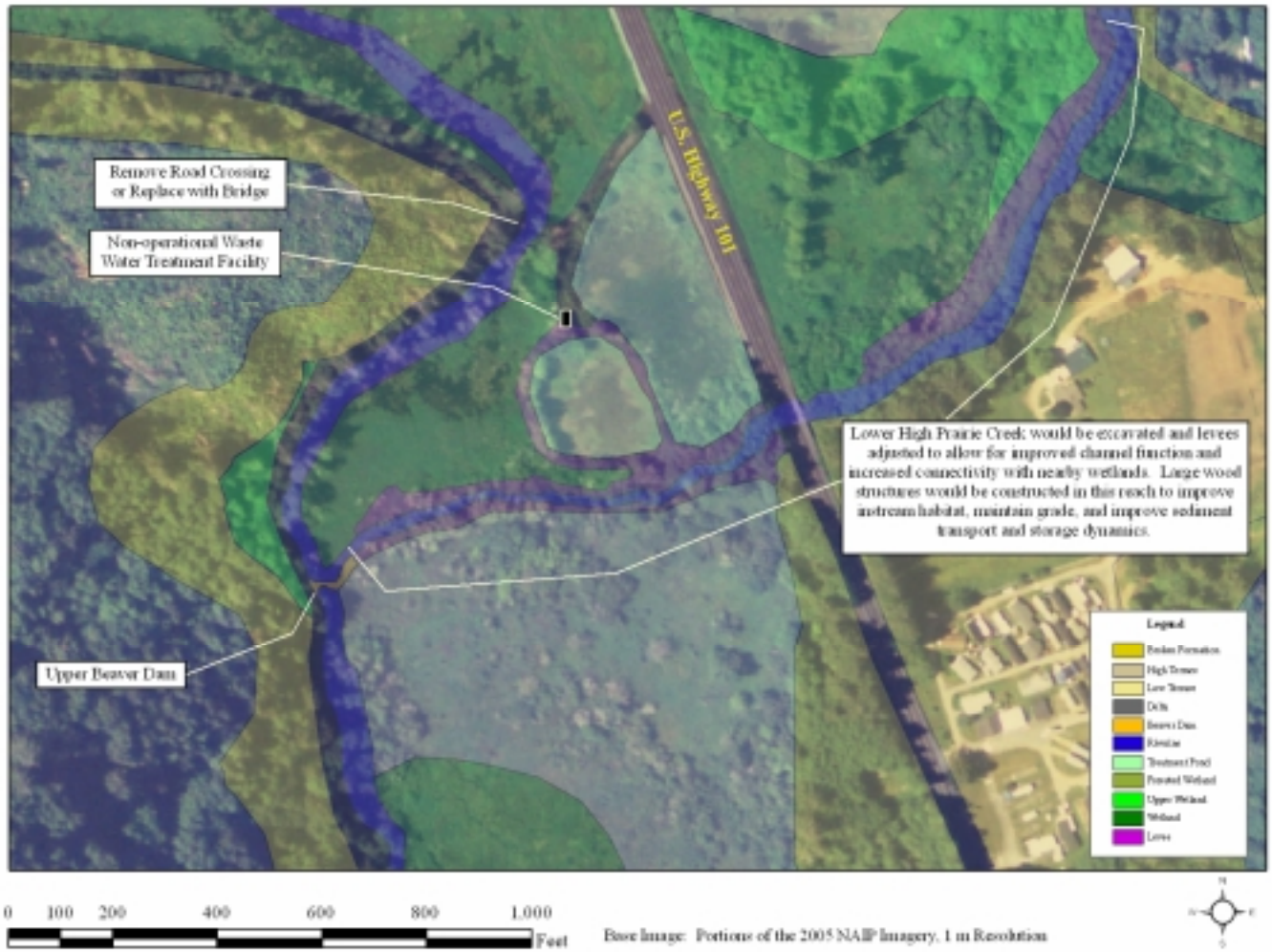


Figure 23. Proposed restoration Alternative II for the confluence reach of High Prairie Creek and Salt Creek.

This restorative alternative would require the least amount of disturbance to existing vegetation, soils, and private land. The permits required for this option would include a CDFG stream alteration permit, CEQA documentation, Army Corps permits and other permits. YTFP should be able to obtain these permits given the low impacts associated with this alternative and the environmental conditions typical during the implementation season.

Rehabilitating the lower reaches of High Prairie Creek would improve adult and juvenile salmonid access. However, this alternative would not likely result in a substantial increase in the amount of habitat available for juvenile and adult salmonids. Due to relatively high sediment loads in High Prairie Creek, alternative II has the shortest design life relative to the larger-scale restorative alternatives presented. Therefore, this alternative would only be implemented if it was impossible to obtain landowner consent or acquire the necessary permits for Alternatives III and IV.

Alternative III: Deepen High Prairie Creek Delta

Alternative III would include excavating sediments from the lower reaches and the delta of High Prairie Creek in a manner that would result in an increase in wetland habitat, improved juvenile and adult salmonid access, and increased habitat quality, especially for juvenile coho salmon (Figure 24). Other advantages of Alternative III include the increased storage area for sediment emanating from High Prairie Creek and water. Increased water storage at this site may help attenuate downstream flood peaks. Alternative III would require a revegetation component designed by YTFP, a professional geologist, and wetland vegetation specialists. Perceived outcomes of revegetation efforts include reducing the presence of invasive species, especially reed canary grass, promoting native wetland and riparian species, and improving wetland function.

Possible disadvantages to Alternative III included the larger restoration footprint on existing vegetation, soils, and private land associated with this plan. This alternative would require substantial landowner consent and project success may depend on the ability to provide affected landowners with beneficial conservation easement strategies. Permitting for this alternative would be more extensive relative to Alternatives II. Specialized excavation techniques would be required due to the existing soil saturation conditions and the presence of reed canary grass. Disposal of the extracted material would require careful planning with the pertinent permitting agencies. The design life of Alternative III would be intermediate relative to Alternatives II and IV.

Alternative IV: Large-scale Wetland and Channel Improvement

Alternative V would expand on the objectives of Alternative IV by 1) excavating sediments from lower High Prairie Creek and from critical areas in Salt Creek, 2) removing or modifying existing levees and infrastructure to improve channel and wetland function, 3) providing juvenile and adult salmonid access, and 4) increasing the quality of salmonid habitats in a fairly large area (Figure 25). This alternative would provide the longest design life relative to Alternatives II – III and would greatly improve the

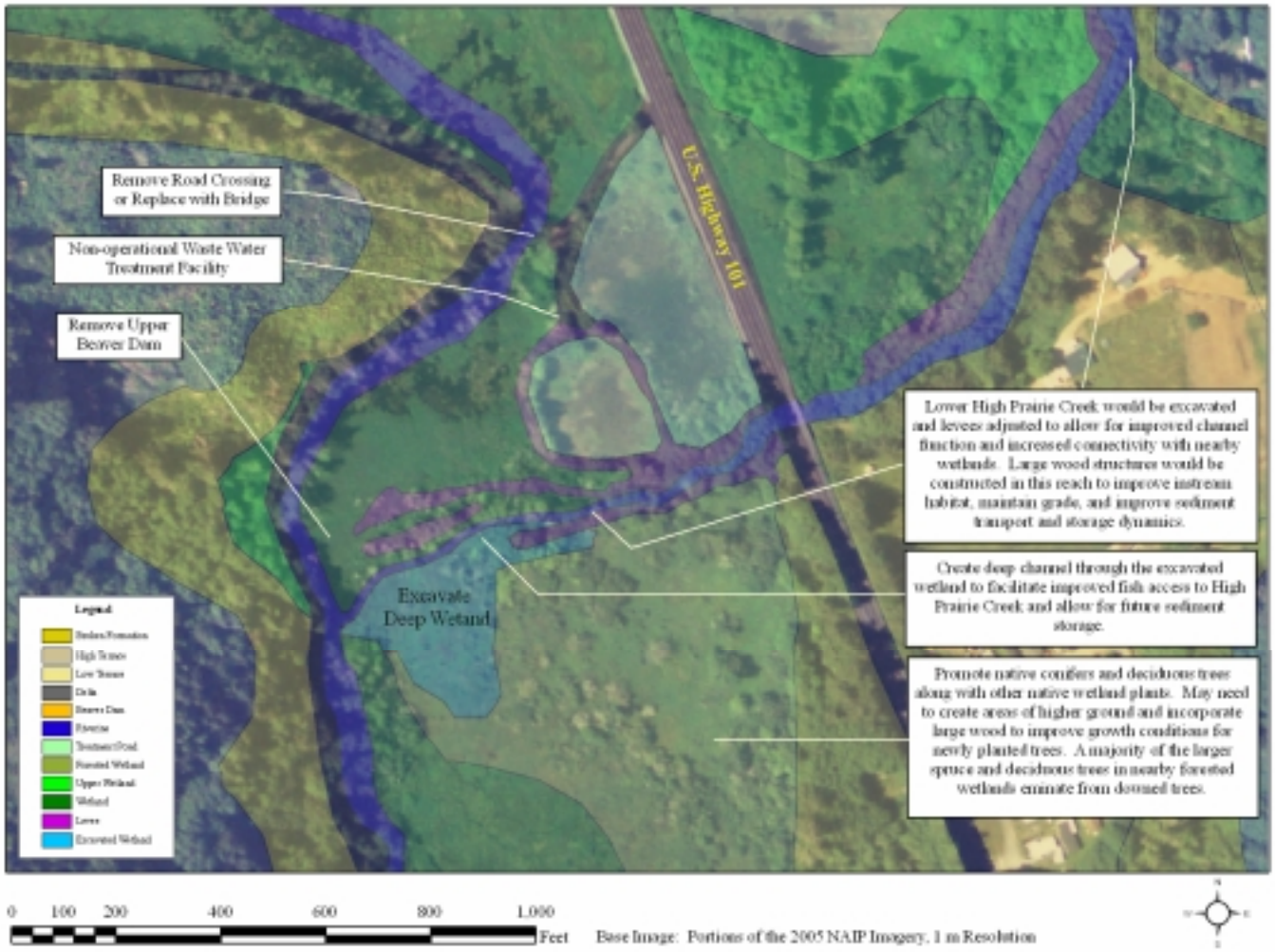


Figure 24. Proposed restoration Alternative III for the confluence reach of High Prairie Creek and Salt Creek.

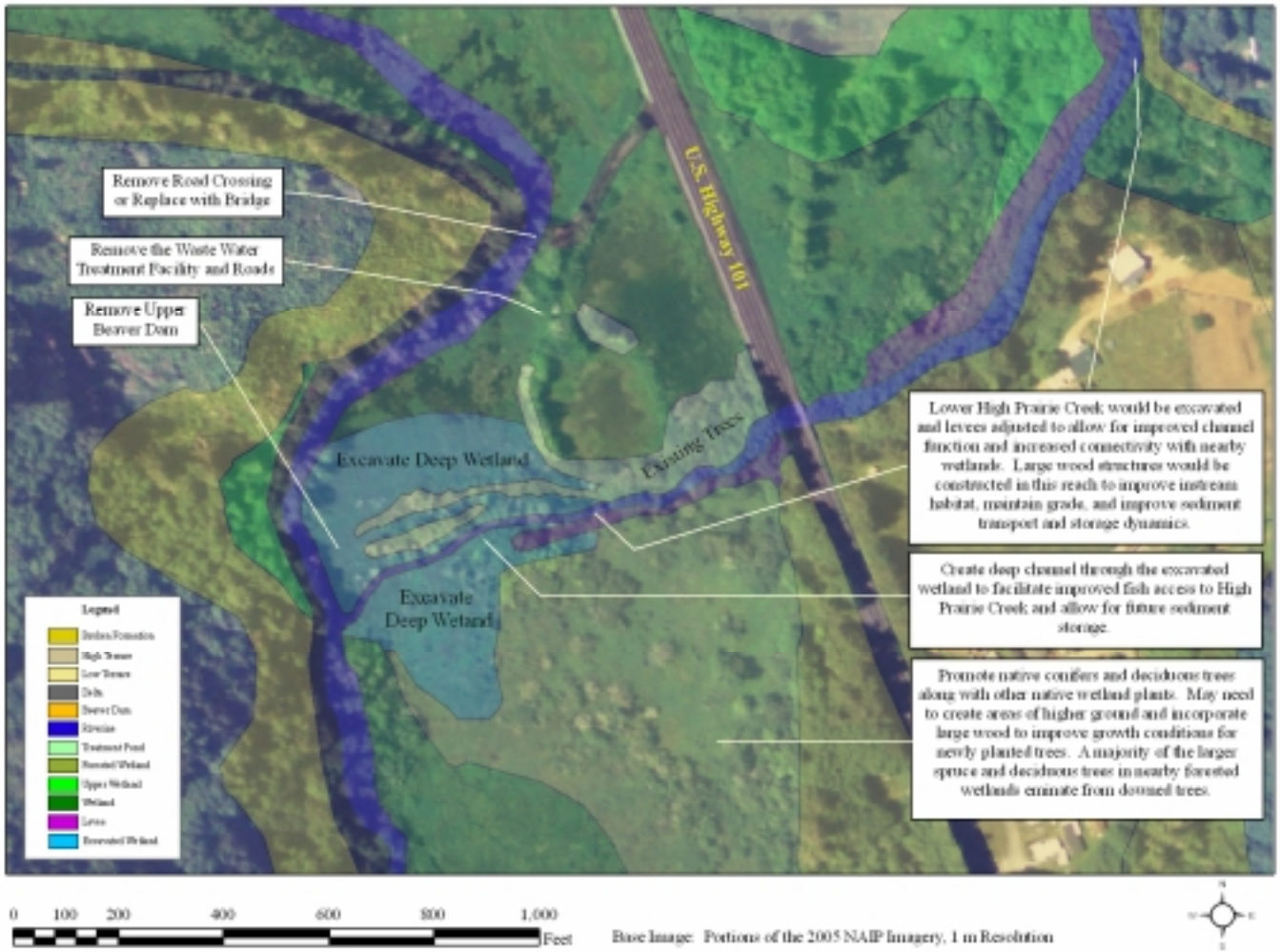


Figure 25. Proposed restoration Alternative IV for the confluence reach of High Prairie Creek and Salt Creek.

aesthetics of the area by naturalizing defunct infrastructure associated with the wastewater treatment facility (WTF). Permitting for this alternative would be similar those presented for Alternative IV but for a larger area.

Alternative IV requires the largest restoration footprint of the alternatives presented, therefore, landowners would have to consent to using a greater portion of their lands for conservation purposes. Developing beneficial conservation easement strategies and landowner partnerships would be critical to developing this alternative. This alternative would require additional studies to assess and develop a strategy to deal with potential contaminants that may be associated with the defunct WTF. As was presented for Alternative IV, a re-vegetation plan would be developed for this alternative to ensure restorative measures were aimed at promoting native wetland and riparian vegetation assemblages. Long-term objectives of this alternative include implementing process based restoration strategies that would be adaptive in nature to allow for modifications based on comprehensive, multi-disciplined, effectiveness monitoring. Through this project, YTFP has developed strong partnerships with several resource agencies that have offered to assist with developing this alternative and have programs that could assist with implementation and effectiveness monitoring. The Yurok Tribe Environmental Program (YTEP) is currently expanding their wetland program and coordinating with YTFP to assess off-estuary tributaries, wetlands, and sloughs of the Klamath River and develop large-scale restoration strategies for these critical habitats.

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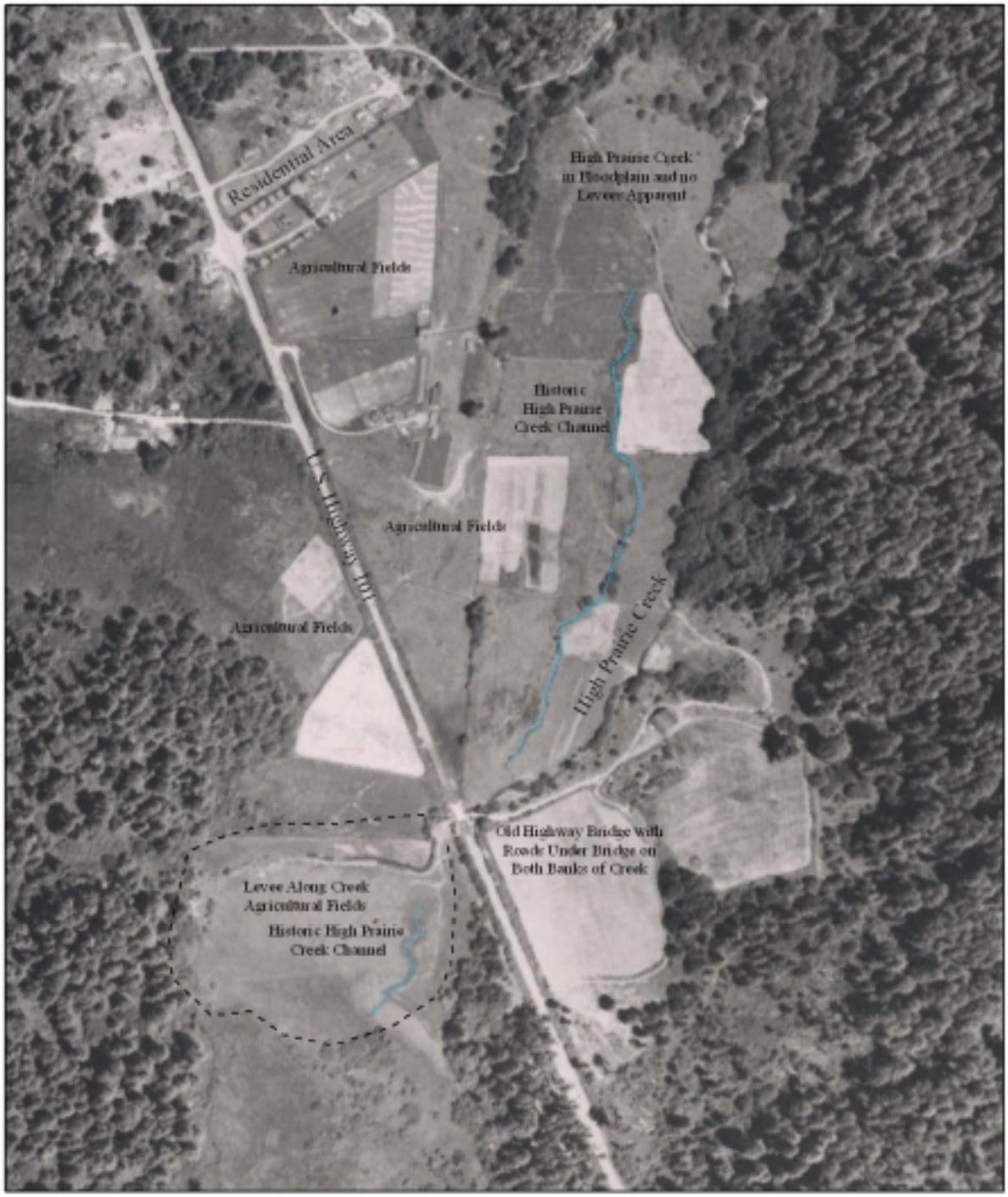
APPENDIX A

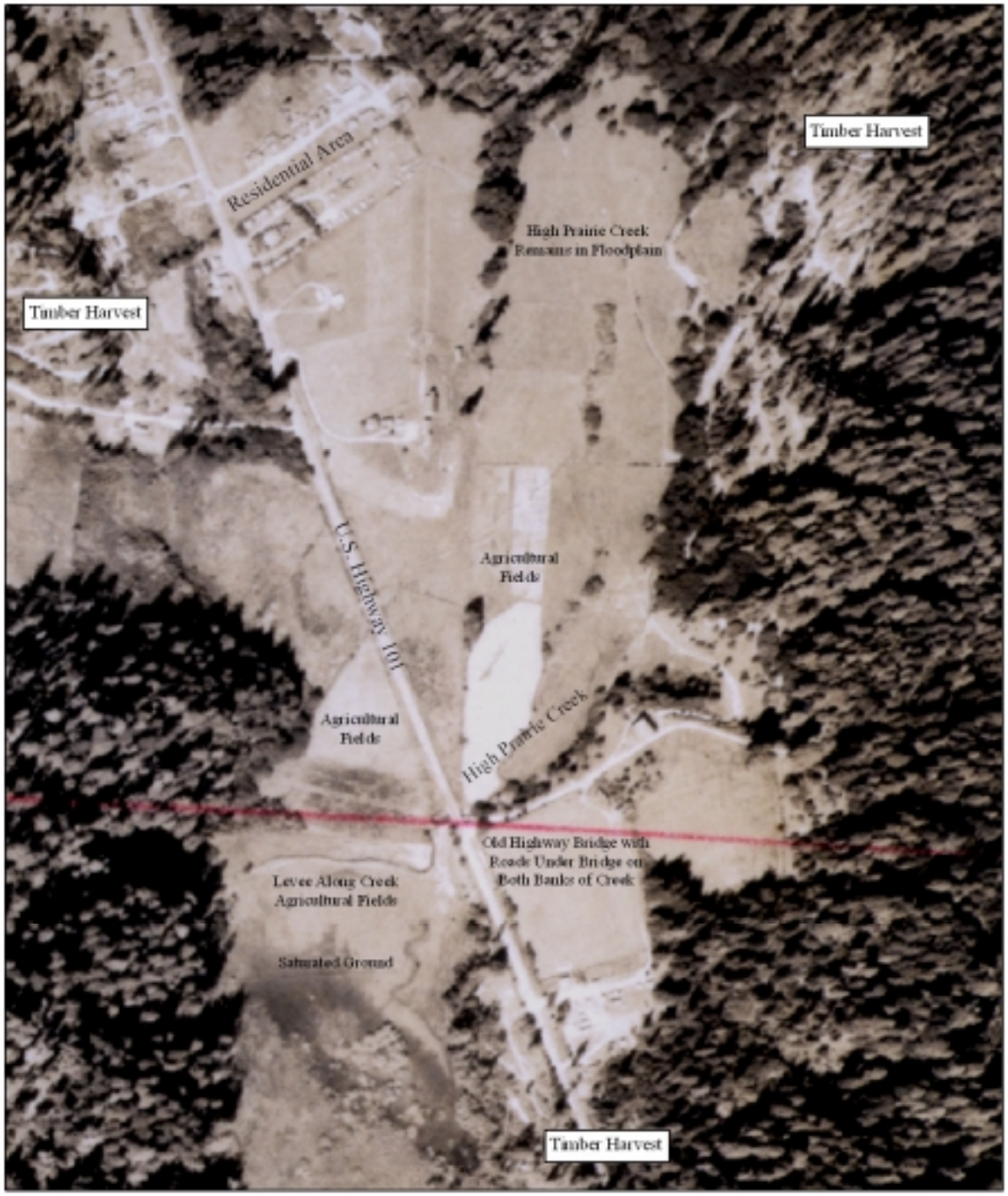
Appendix A. Image library for the confluence reach of High Prairie Creek and Salt Creek, Lower Klamath River Sub-basin, California (Period: 1948 – 2005).



0 250 500 1,000 1,500 2,000 Feet

N W E S

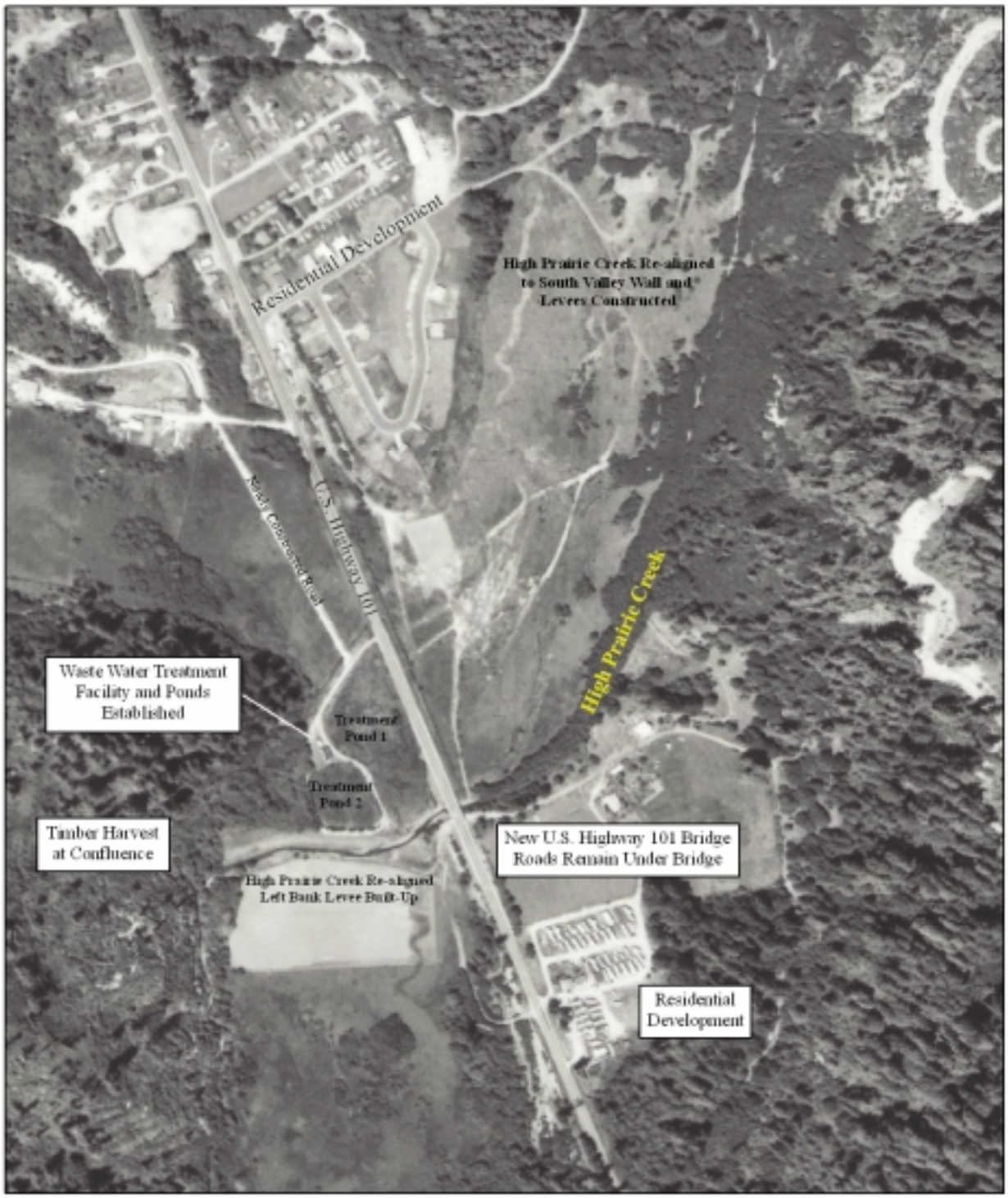
1948 Salt Creek - High Prairie Creek Confluence
Base Image: 1948 Rectified Aerial Photograph (Flight Date: 06/23/48)



0 250 500 1,000 1,500 2,000 Feet

N W E S

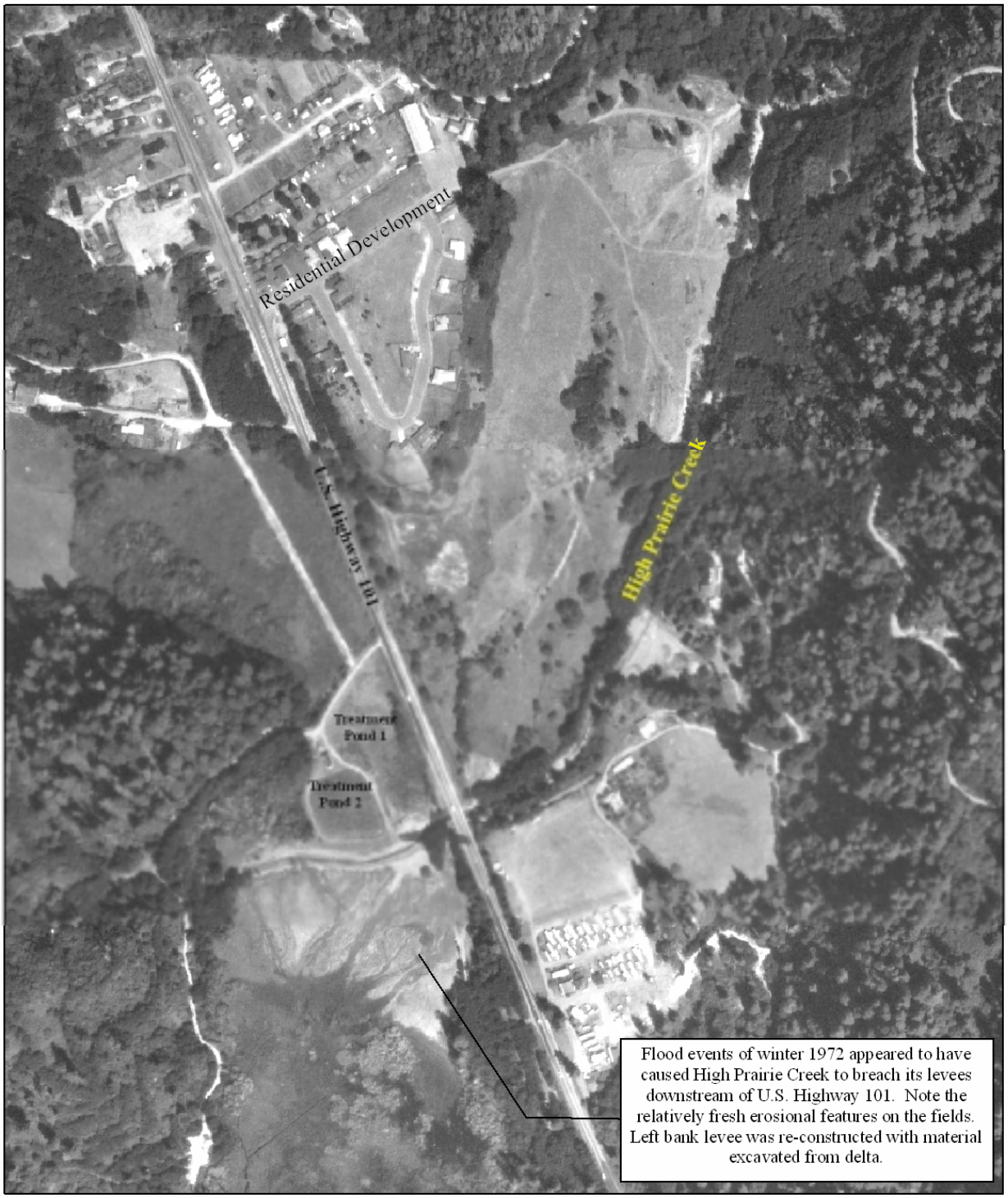
1954 Salt Creek - High Prairie Creek Confluence
Base Image: 1954 Rectified Aerial Photograph (Flight Date: 09/28/54)



0 250 500 1,000 1,500 2,000 Feet

N W E S

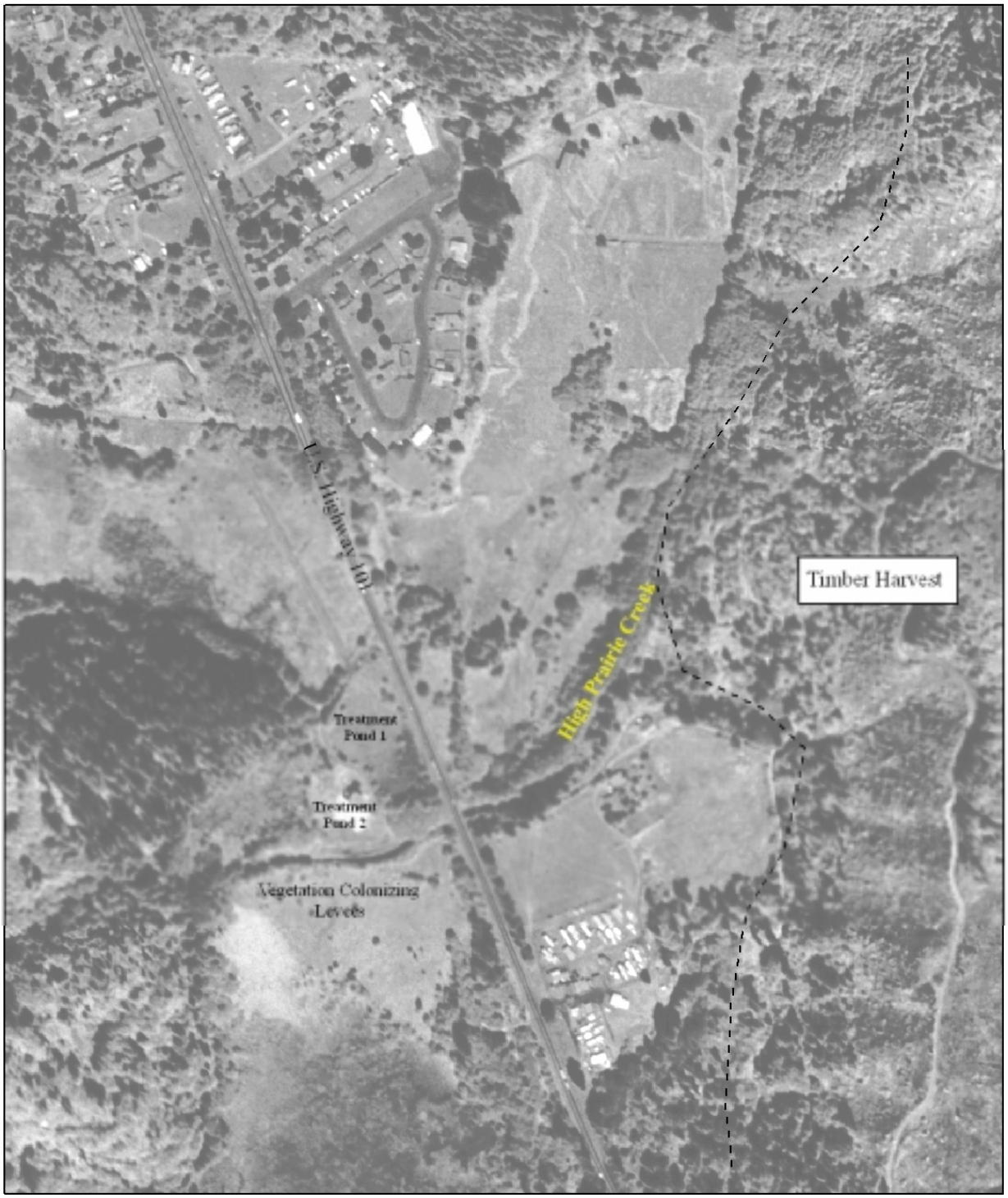
1965 Salt Creek - High Prairie Creek Confluence
Base Image: 1965 Rectified Aerial Photograph (Flight Date: 07/08/65)



0 250 500 1,000 1,500 2,000 Feet

N W E S

1972 Salt Creek - High Prairie Creek Confluence
Base Image: 1972 Rectified Aerial Photograph (Flight Date: 09/22/72)



0 250 500 1,000 1,500 2,000 Feet

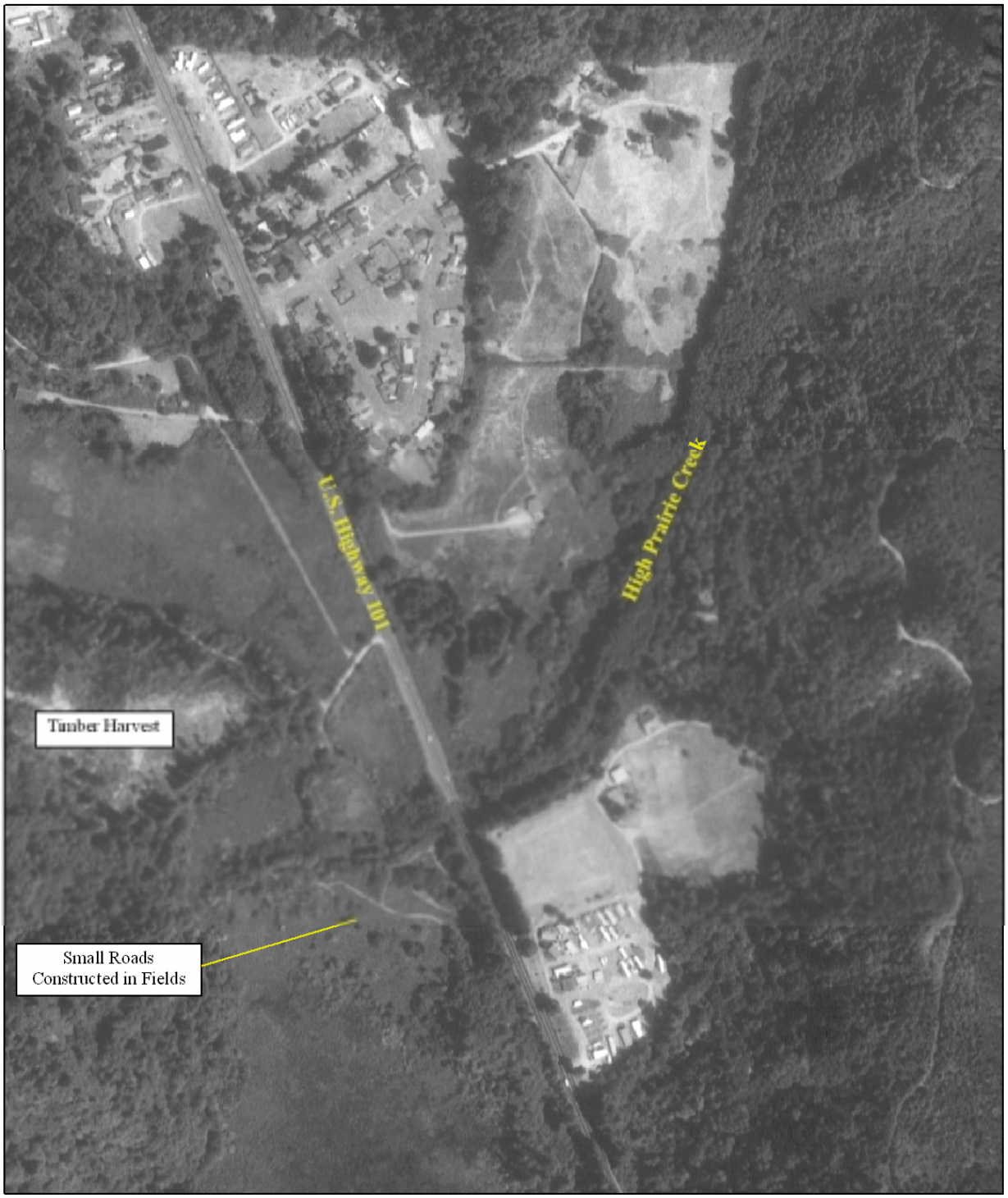
N W E S

1988 Salt Creek - High Prairie Creek Confluence
Base Image: Portions of 1988 Requa USGS Digital Orthophoto Quad

0 250 500 1,000 1,500 2,000 Feet

N W E S

1993 Salt Creek - High Prairie Creek Confluence
Base Image: Portions of 1993 Requa USGS Digital Orthophoto Quad (Flight Date: 06/12/93)



0 250 500 1,000 1,500 2,000 Feet

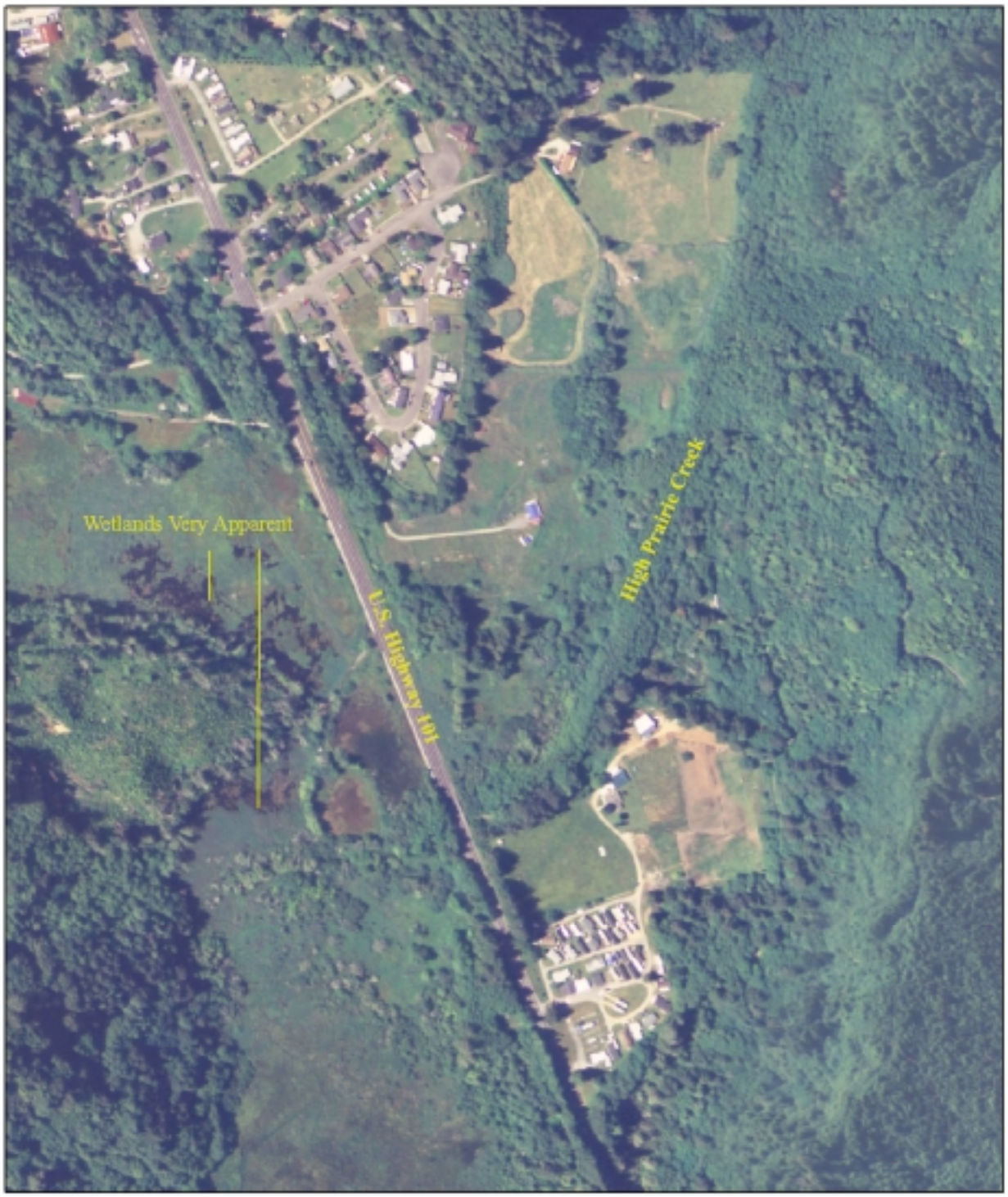
N
W E
S

1998 Salt Creek - High Prairie Creek Confluence
Base Image: Portions of 1998 Requa USGS Digital Orthophoto Quad

0 250 500 1,000 1,500 2,000 Feet

N W E S

2004 Salt Creek - High Prairie Creek Confluence
Base Image: 2004 Rectified Aerial Photograph (Flight Date:



0 250 500 1,000 1,500 2,000 Feet

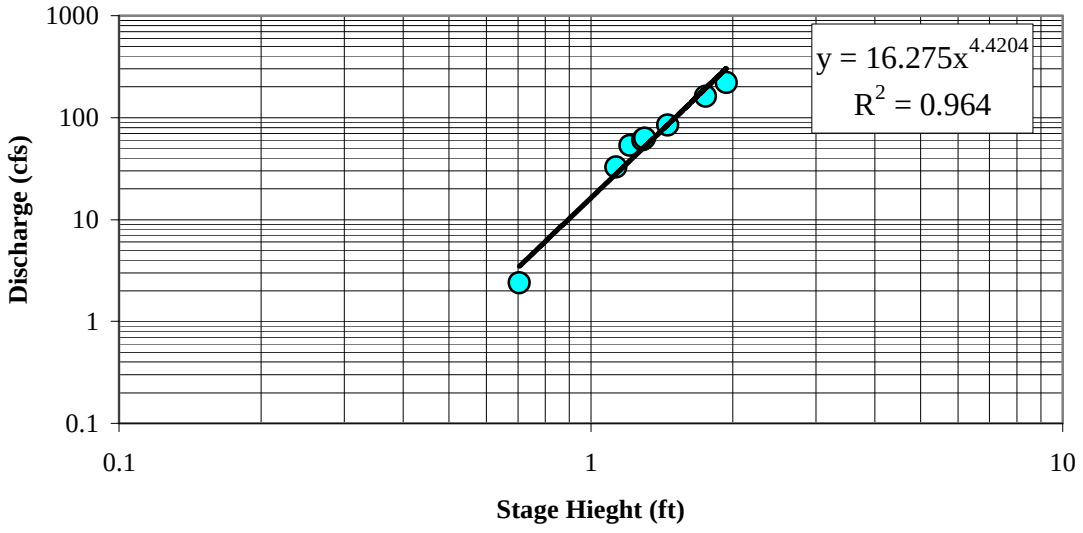
N W E S

2005 Salt Creek - High Prairie Creek Confluence
Base Image: Portions of the 2005 NAIP Imagery, 1 m Resolution

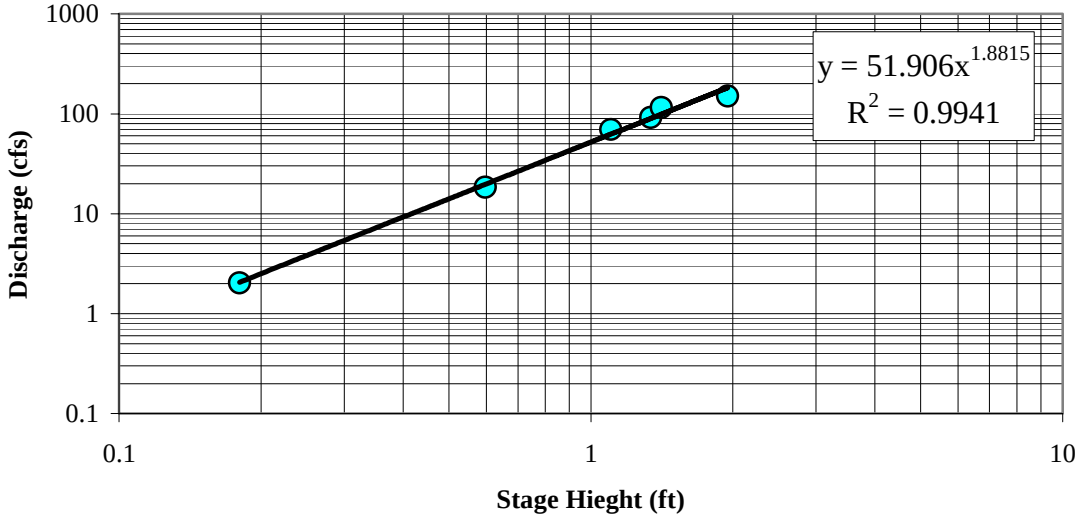
APPENDIX B

Appendix B1. Stage rating curves developed for the period 1 December 2005 – 25 February 2007 for two stream gages located in the Salt Creek watershed, Lower Klamath River Sub-basin, California.

a. High Prairie Creek Gage (HP 1)

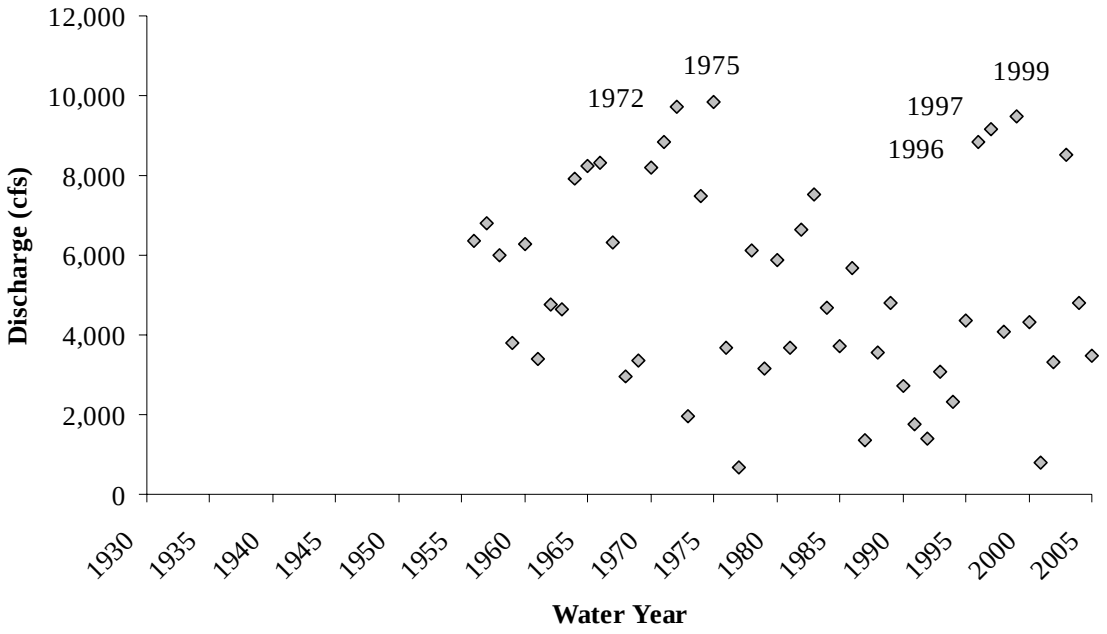


b. Lower Salt Creek Gage (Salt 1)

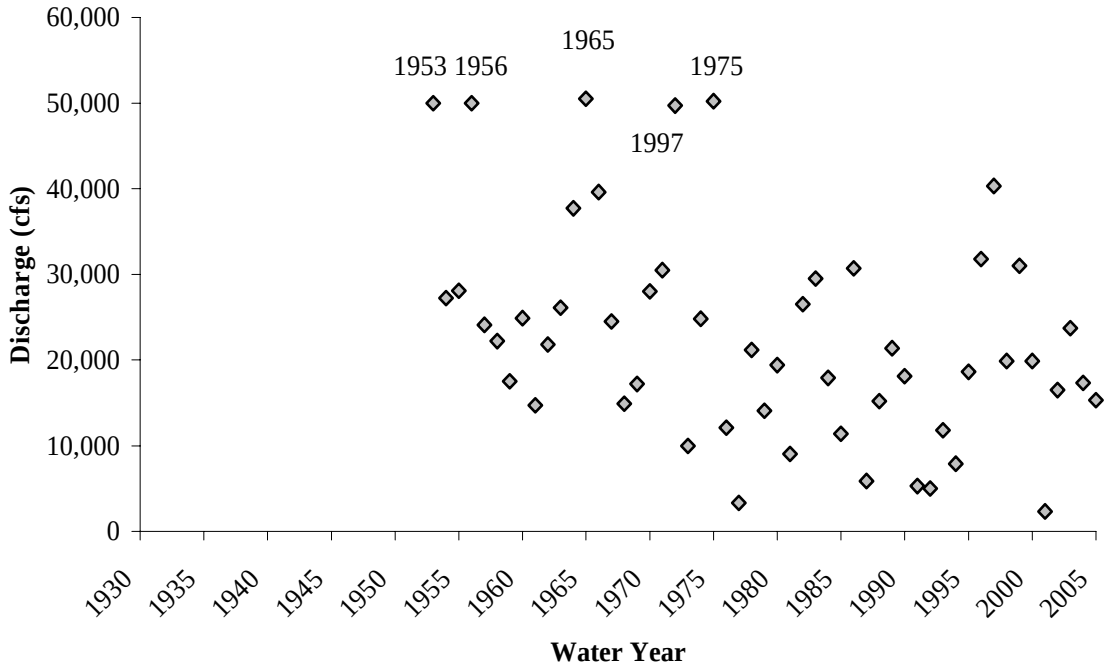


Appendix B2. Peak flood event data for northern California coastal streams obtained from USGS stream data (CDEC 2007).

a. Little River Stream Gage Data

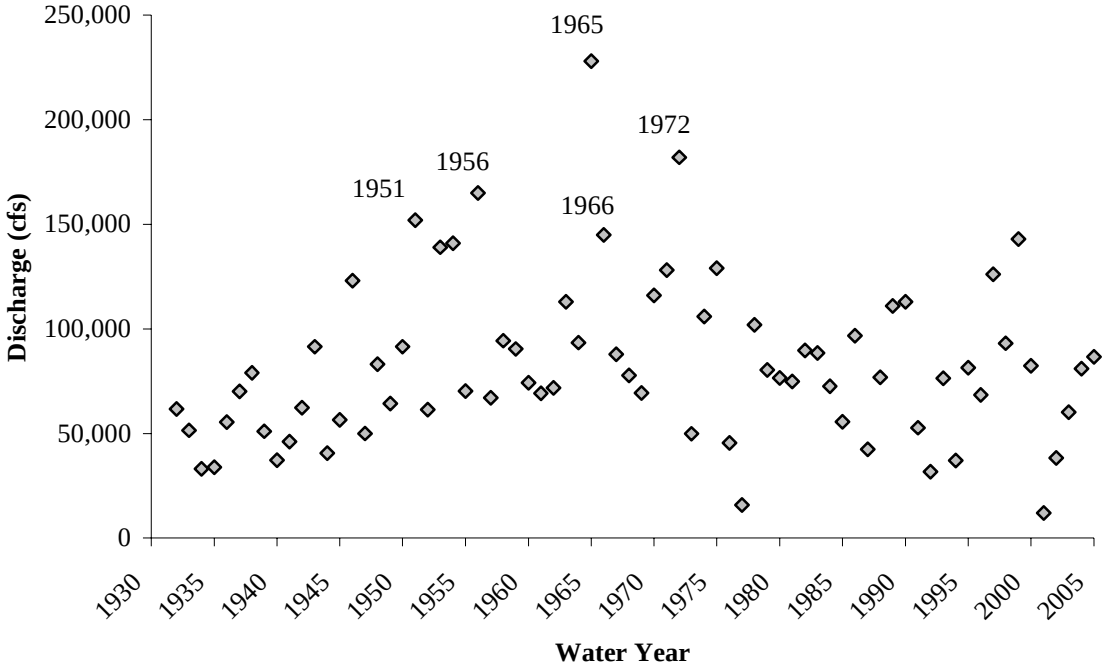


b. Redwood Creek Stream Gage Data

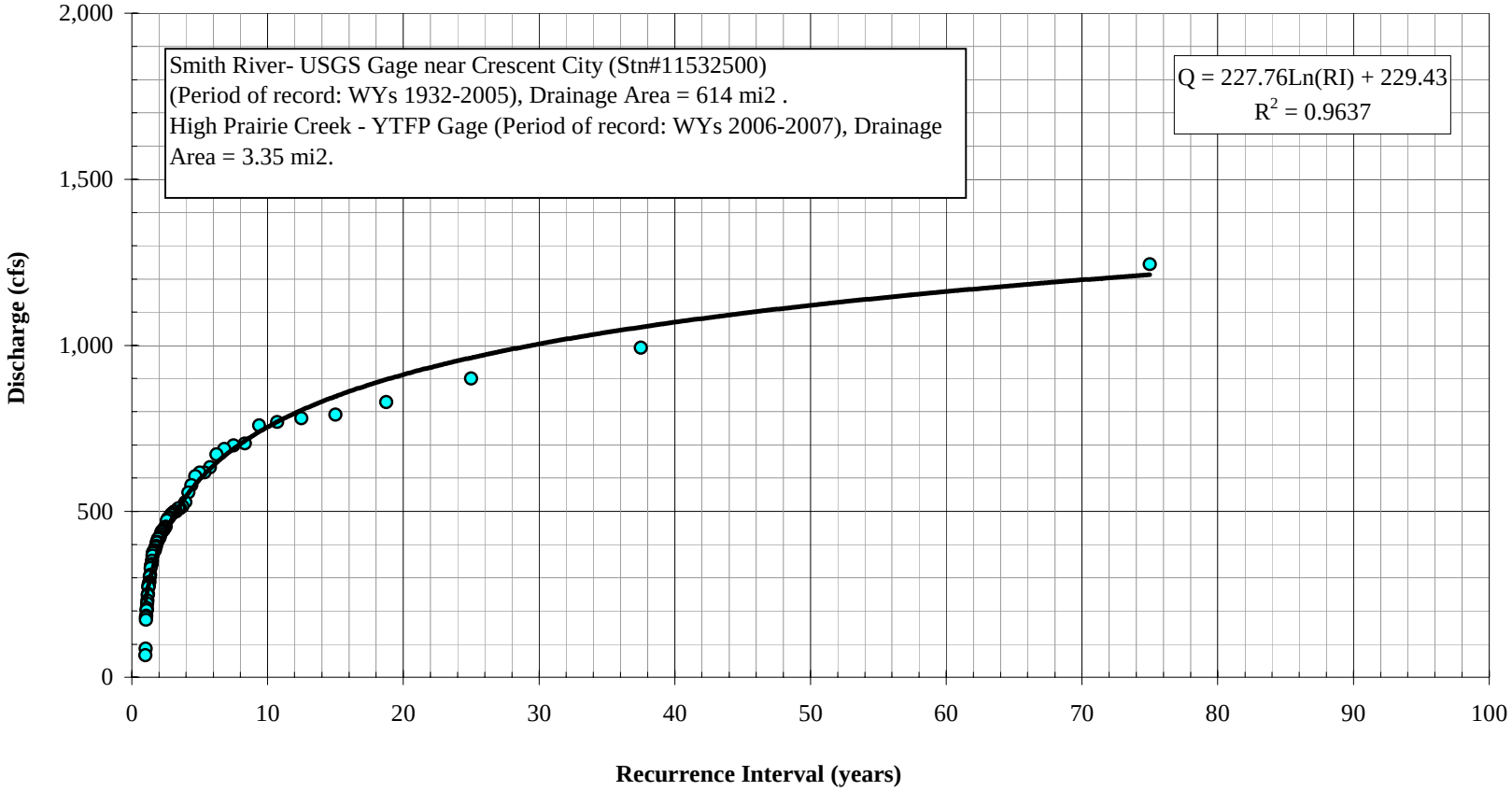


Appendix B2. Continued.

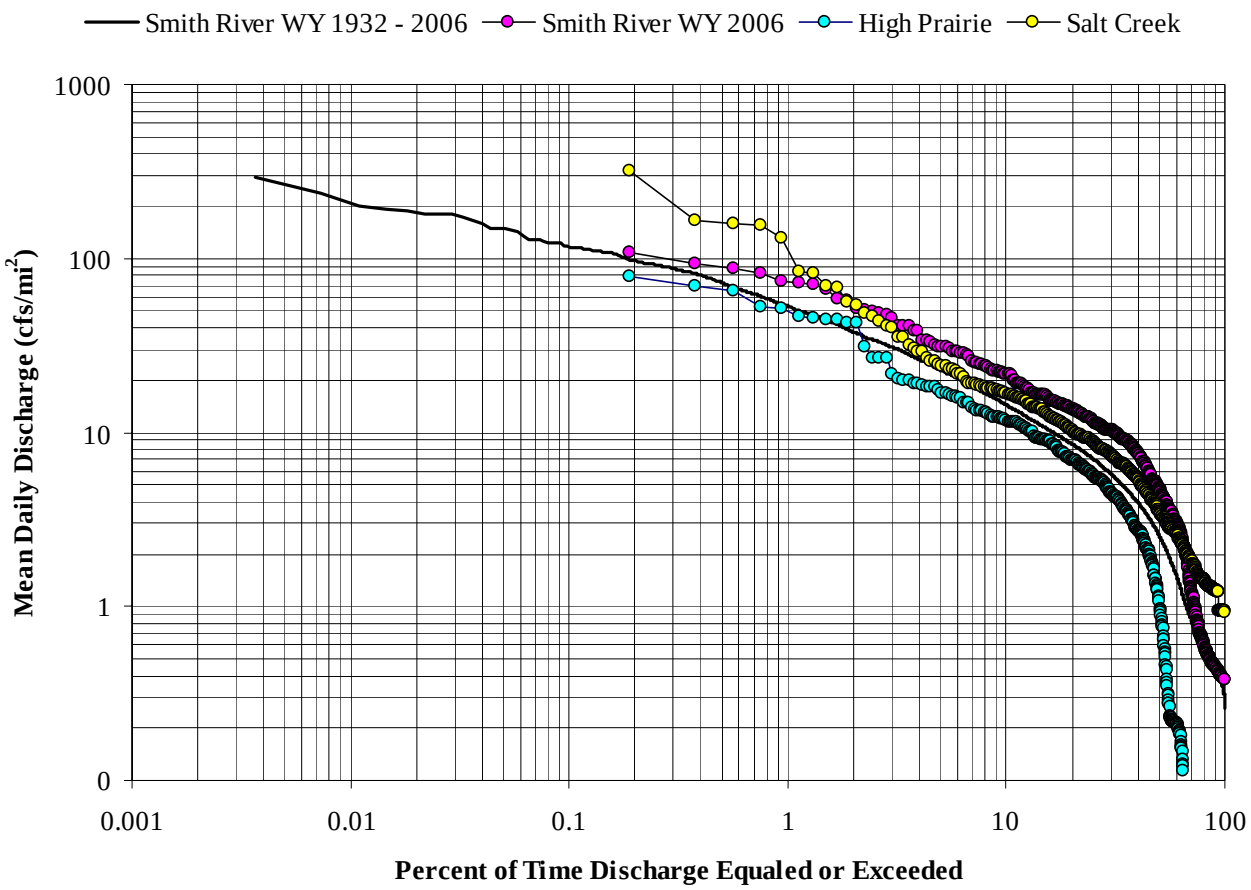
c. Smith River near Crescent City, California



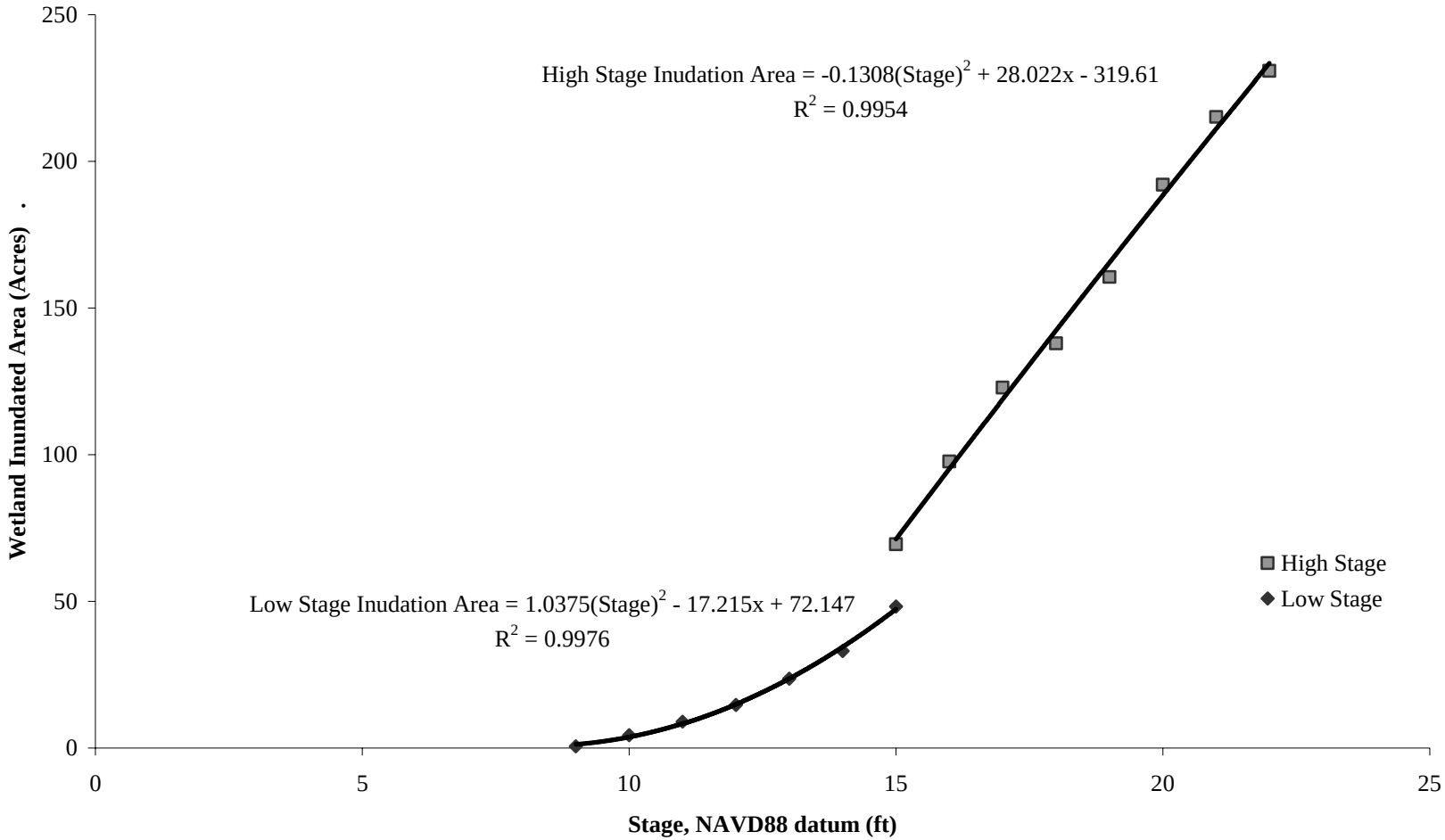
Appendix B3. Flood frequency curve for High Prairie Creek based on the drainage area ratio for the Smith River Gage, northern California.



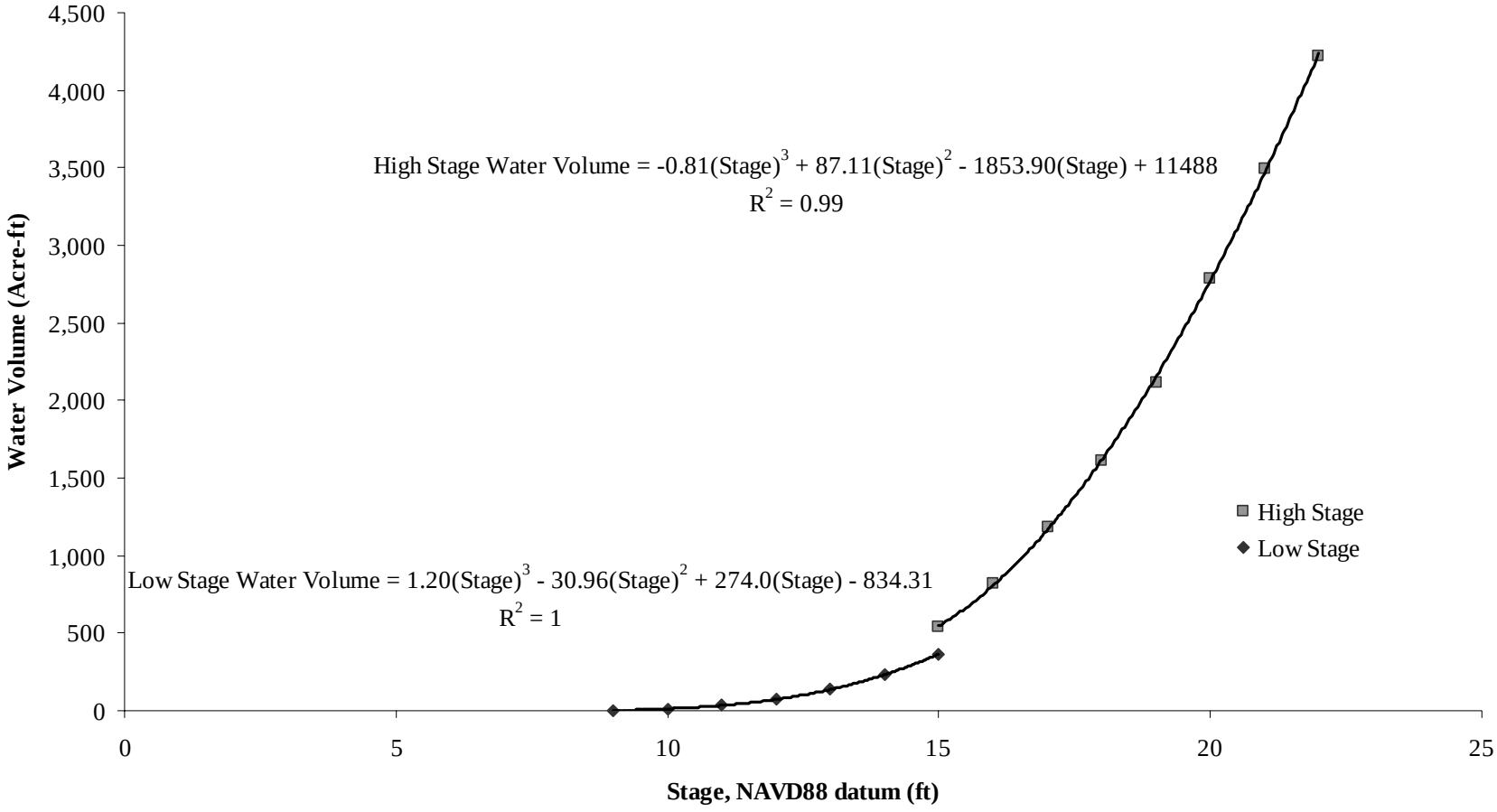
Appendix B4. Flow duration curves for several northern California streams. Smith River - USGS Gage near Crescent City (Stn#11532500) (Drainage Area of 614 sq mi), Period of record: WYs 1932 – 2006 (27,394 days) and 01 October 2005 - 14 March 2007 (529 days). High Prairie Creek (Drainage Area of 3.35 sq mi) and Lower Salt Creek (Drainage Area of 5.64 sq mi) – YTFP Gages (Period of record: 01 October 2005 - 14 March 2007 (529 days).



Appendix B5. Wetland stage to area relationships for low and high stage conditions in Salt Creek, Lower Klamath River Sub-basin, California.

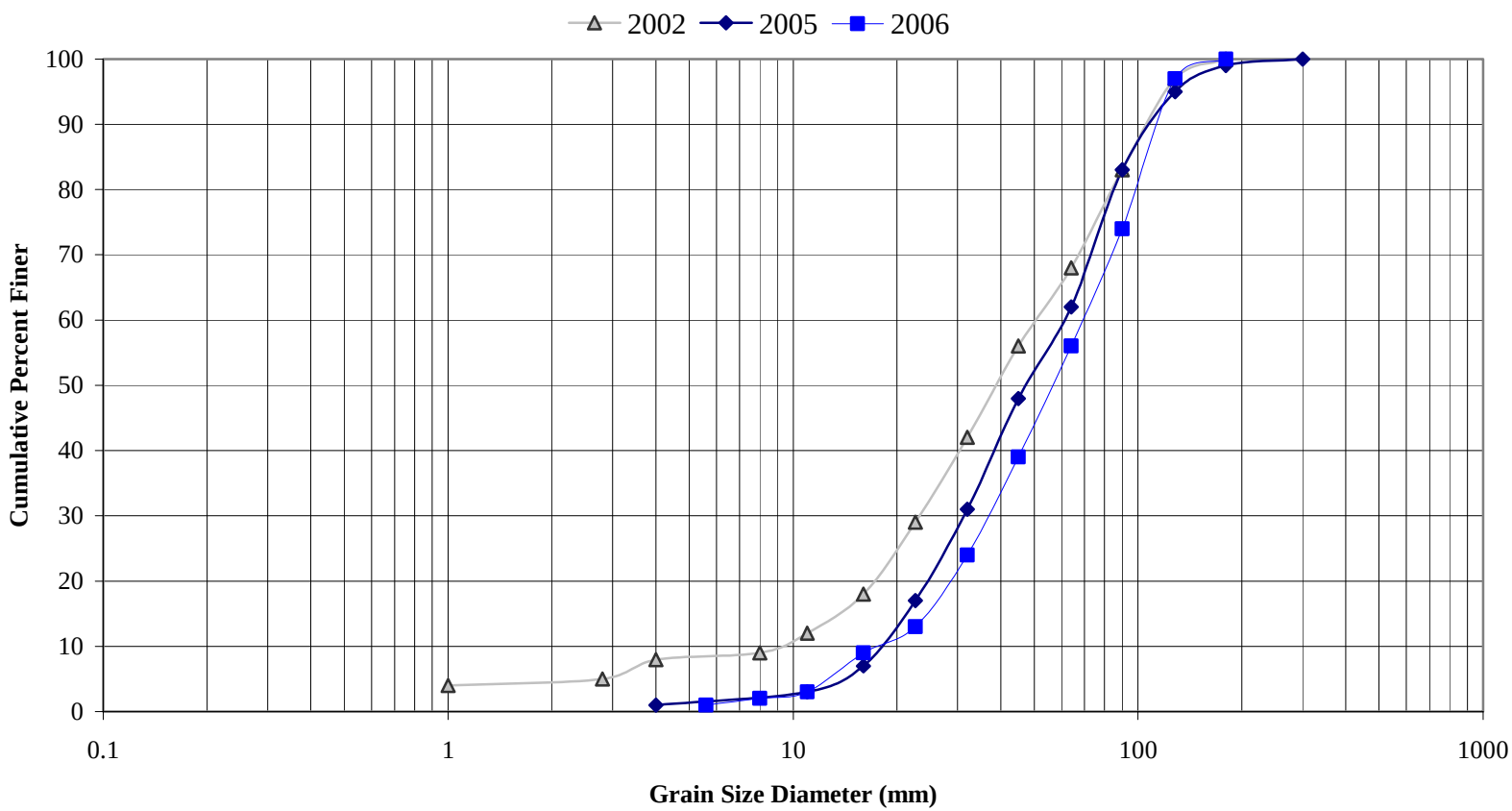


Appendix B6. Wetland stage to volume relationships for low and high stage conditions in Salt Creek, Lower Klamath River Sub-basin, California.

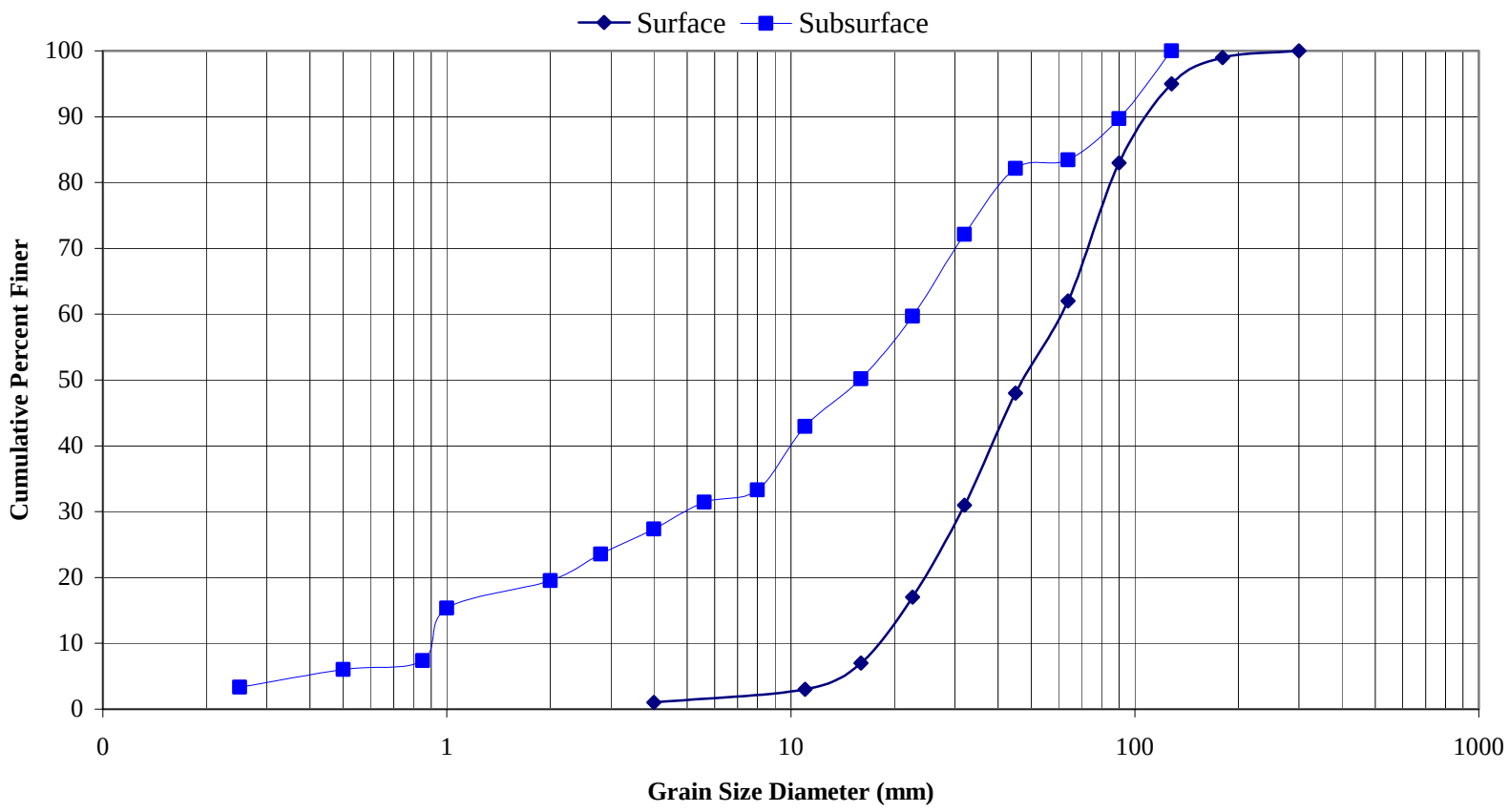


APPENDIX C

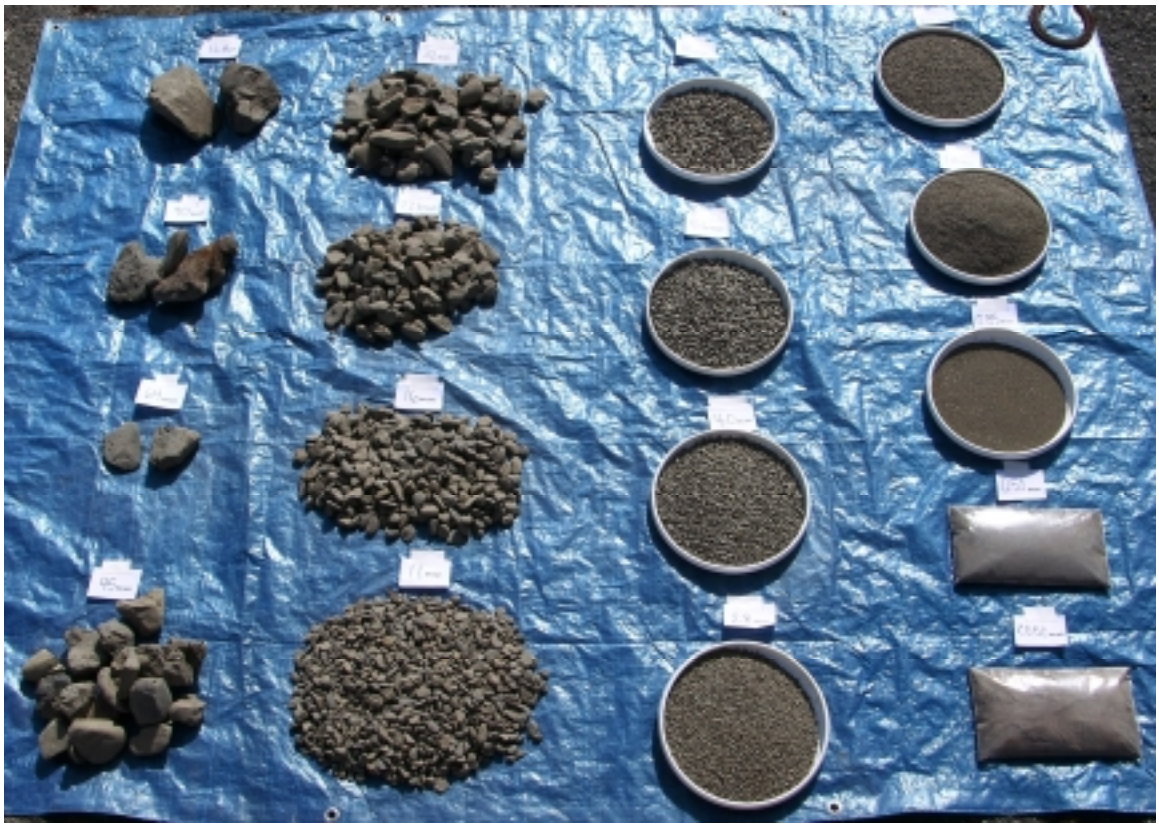
Appendix C1. Size distribution of surface channel sediment at a monitoring cross section in upper High Prairie Creek (HP XS 3).



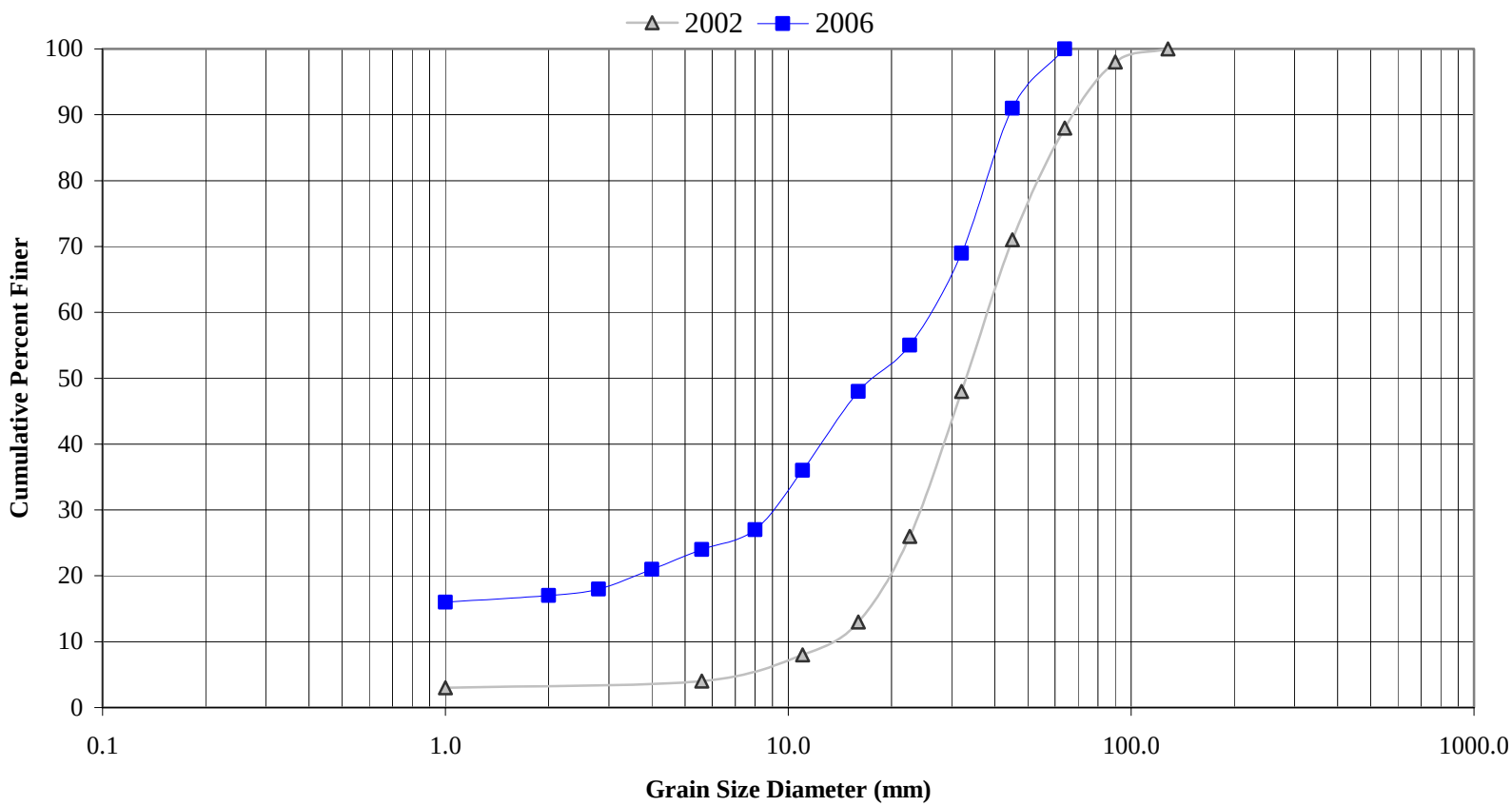
Appendix C2. Size distribution of channel sediment at a monitoring cross section in upper High Prairie Creek (HP XS 3) (Fall 2005).



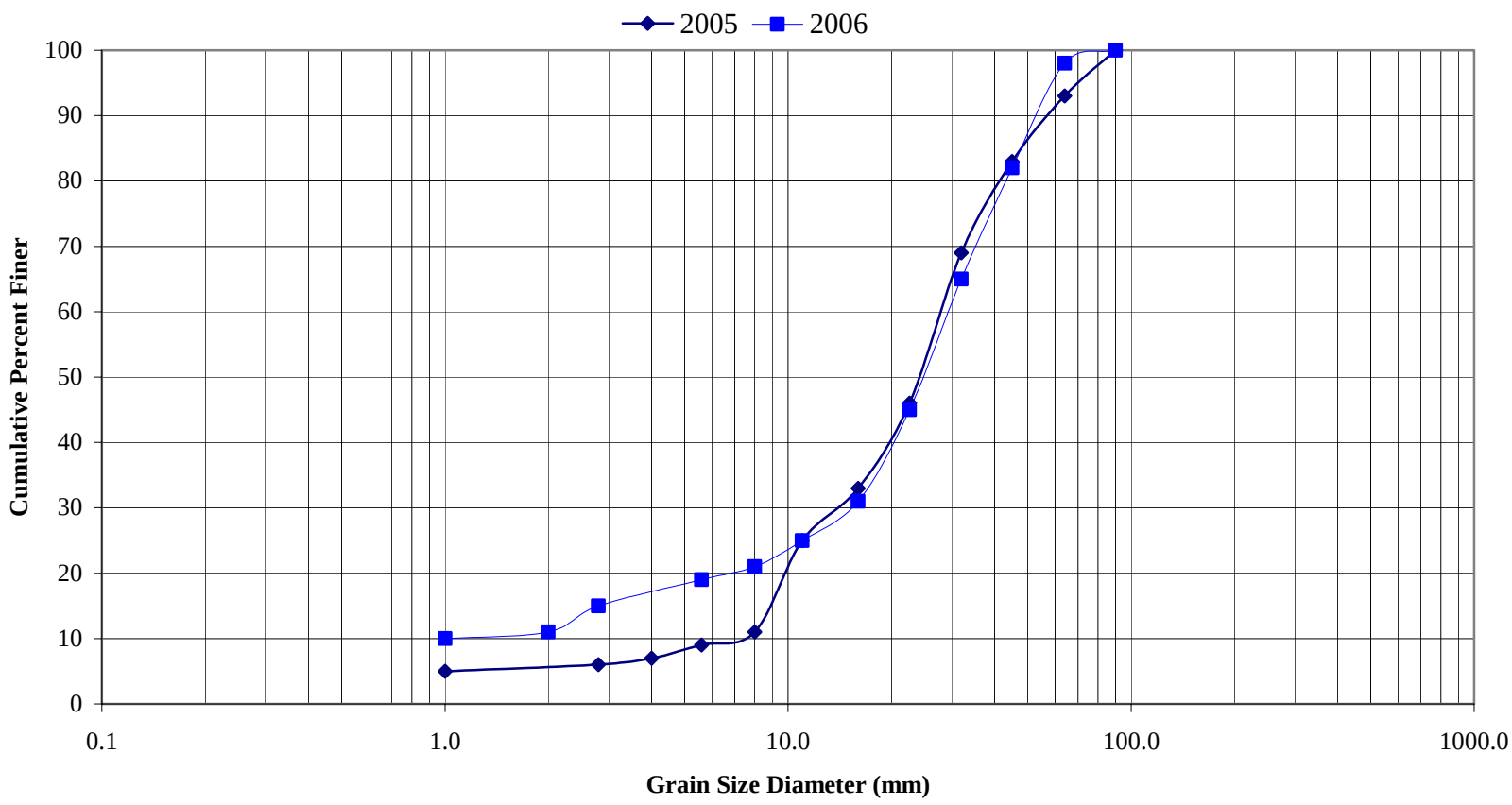
Appendix C3. Photograph of subsurface sediments collected at a monitoring cross section in upper High Prairie Creek (HP XS 3) (Fall 2005).



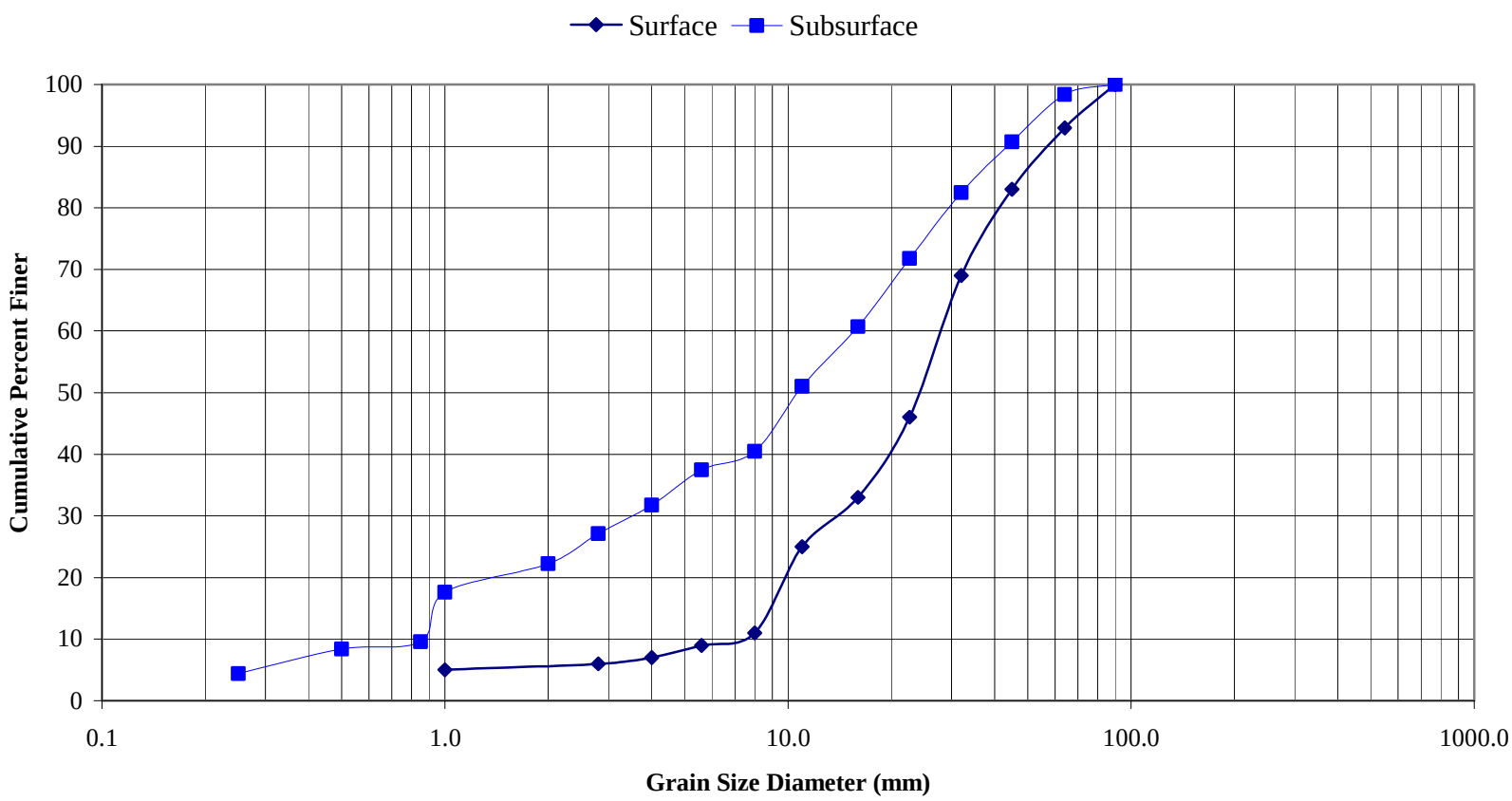
Appendix C4. Size distribution of surface channel sediment at a monitoring cross section in High Prairie Creek (HP XS 2).



Appendix C5. Size distribution of surface channel sediment at a monitoring cross section in High Prairie Creek (HP Gage 1).

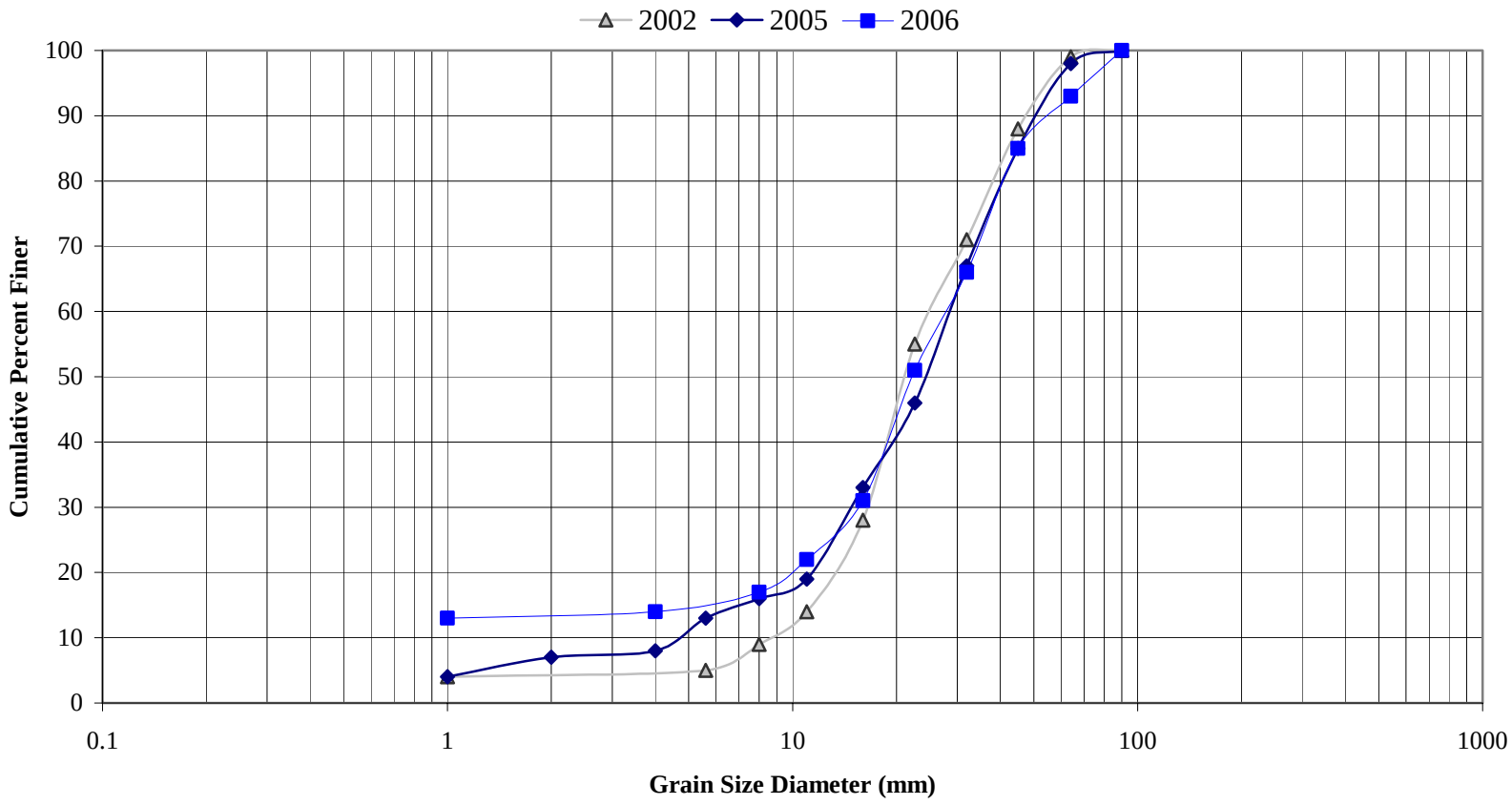


Appendix C6. Size distribution of channel sediment at a monitoring cross section in High Prairie Creek (HP Gage 1).



Appendix C7. Photograph of subsurface sediments collected at a monitoring cross section in High Prairie Creek (HP Gage 1) (Fall 2005).

Appendix C8. Size distribution of surface channel sediment at a monitoring cross section in lower High Prairie Creek (HP XS 1).



Appendix C9. Size distribution of channel sediment at a monitoring cross section in lower High Prairie Creek (HP XS 1).
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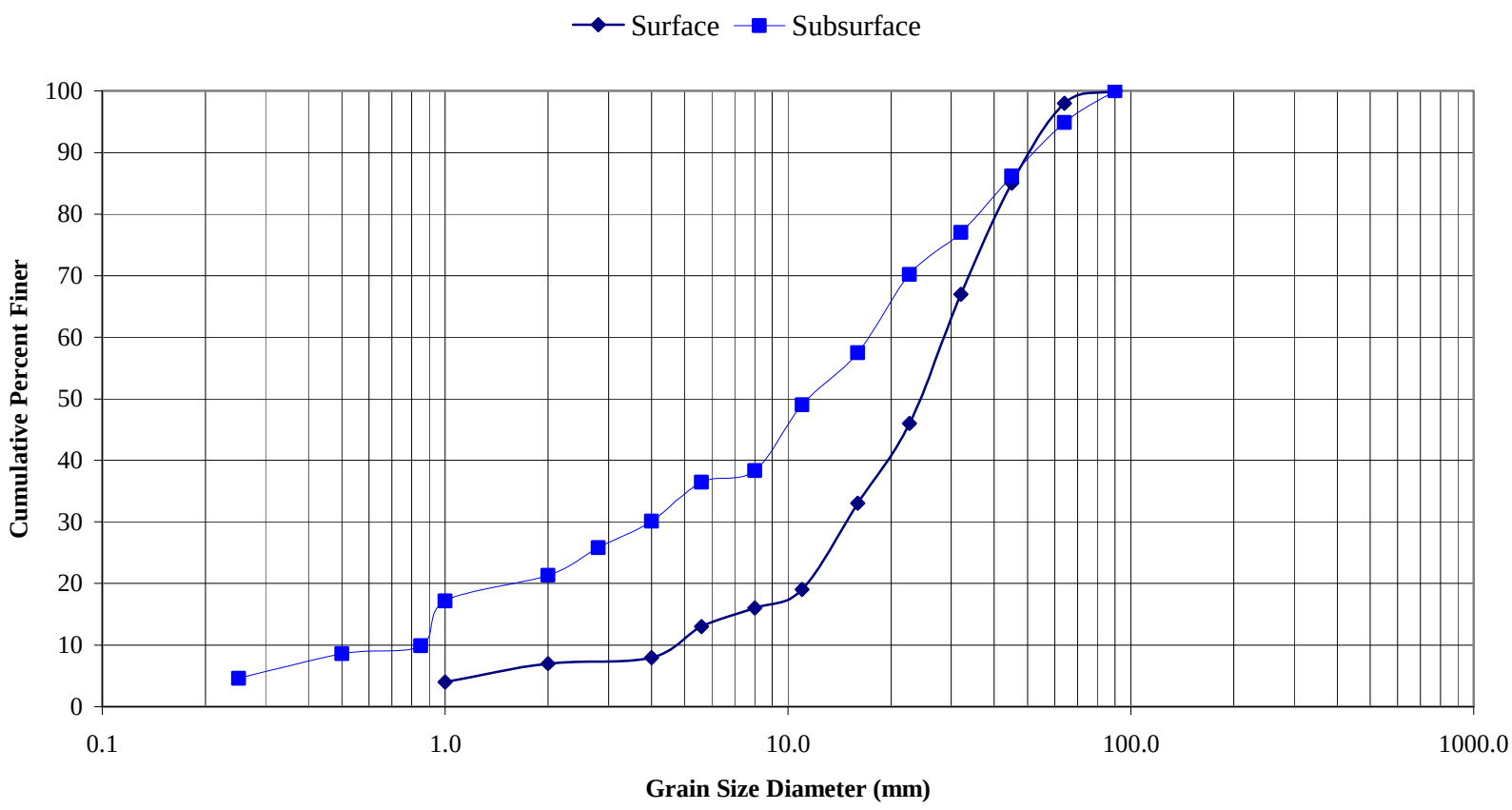
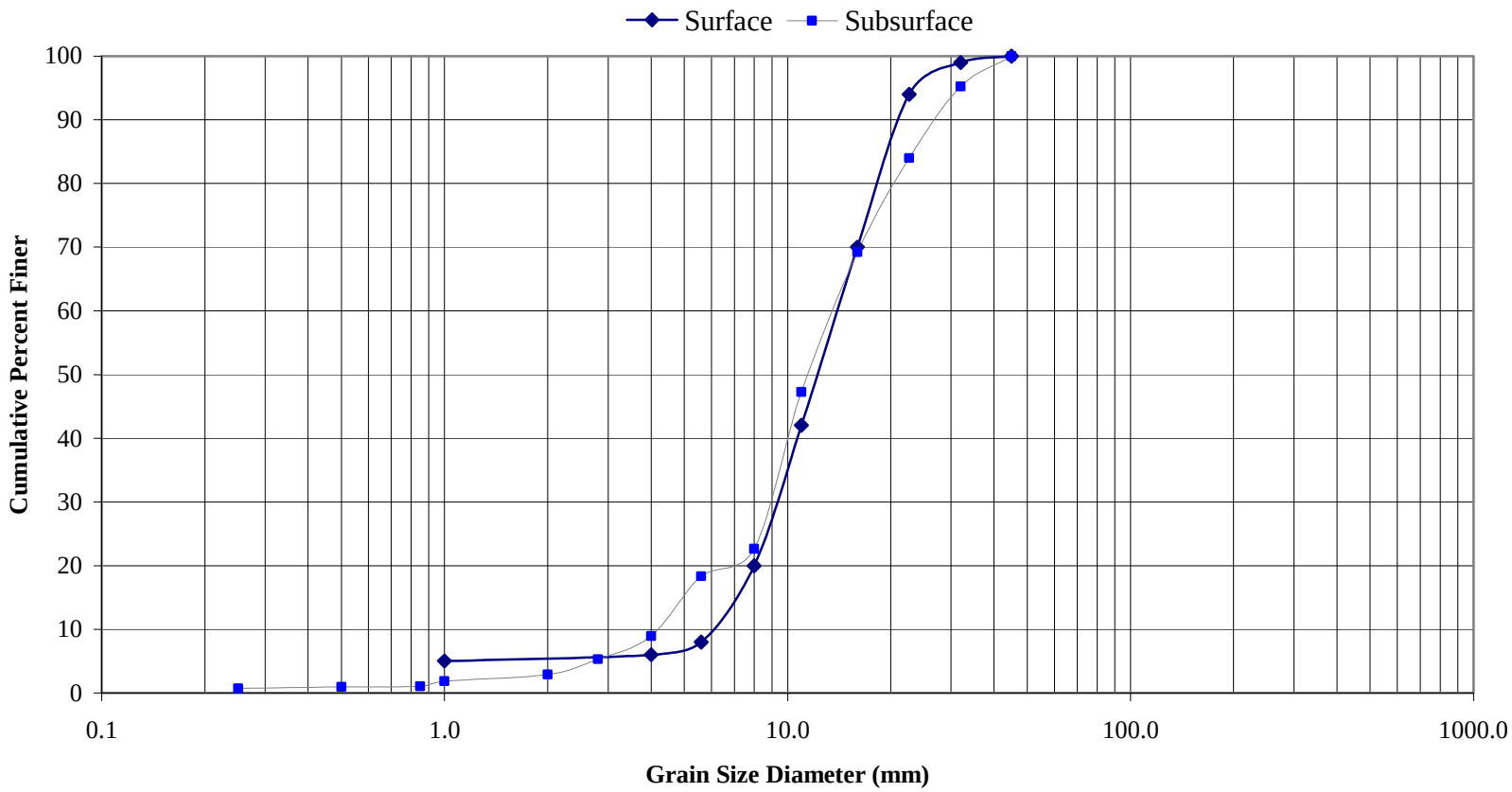
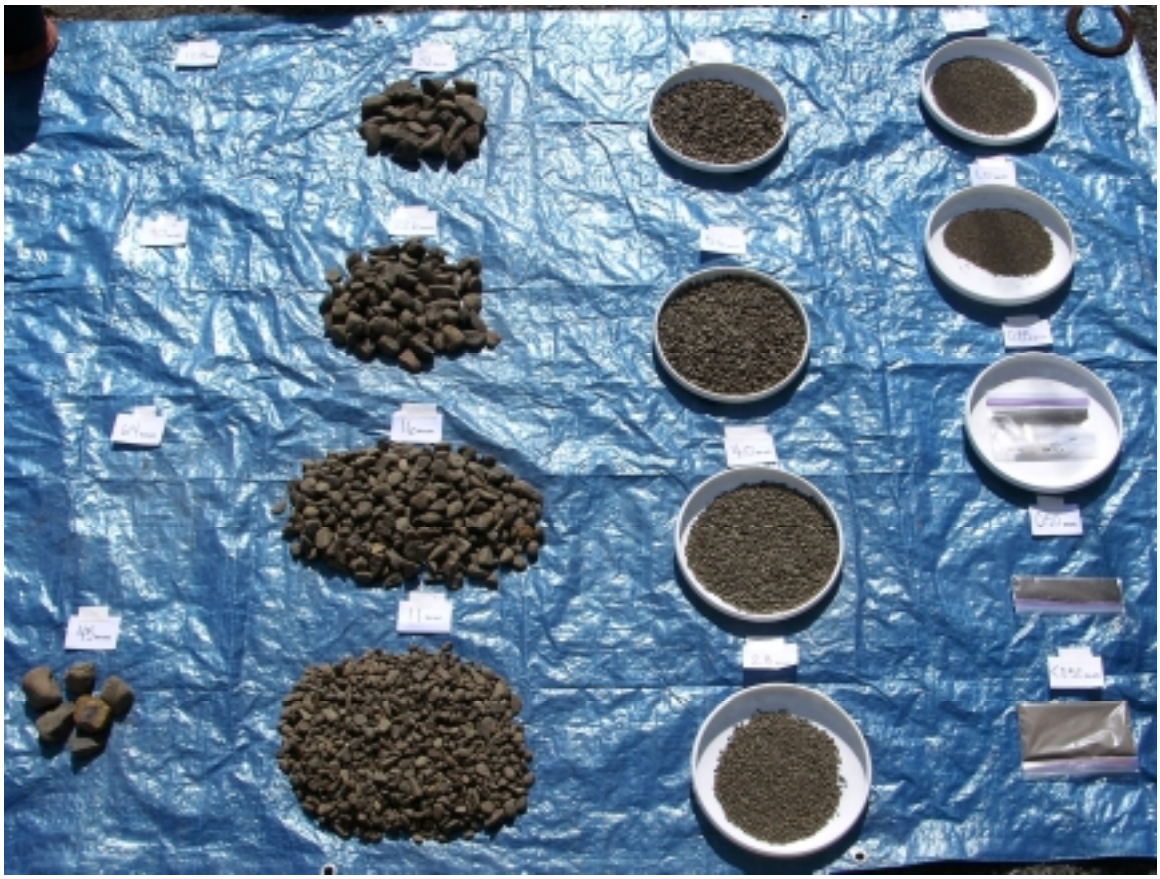


Appendix C10. Photograph of subsurface sediments collected at a monitoring cross section in High Prairie Creek (HP XS 1) (Fall 2005).

Appendix C11. Size distribution of channel sediment at a monitoring cross section downstream of the High Prairie and Salt Creeks (Fall 2006).



Appendix C12. Photograph of subsurface sediments collected at a monitoring cross section downstream of the High Prairie and Salt Creeks (Fall 2006).