Blue Creek

Blue Creek is the largest Lower Klamath River tributary and provides approximately 40 miles of anadromous habitat for chinook, coho, steelhead, coastal cutthroat trout, and multiple lamprey species (Figures 1 – 2). Blue Creek contains the highest quality habitat of all Lower Klamath River tributaries and therefore was identified as the number one priority watershed for restoration in the LKRSB (Gale and Randolph 2000). Priority restoration objectives identified included reducing sediment delivery rates throughout the watershed and reestablishing healthy, native conifer and hardwood riparian forests in the lower valley. Field investigations conducted by the Yurok Tribal Fisheries Program (YTFP) over the last decade have documented moderate channel instability and substantial riparian dysfunction occurring in lower Blue Creek. A logical approach to remediate channel and riparian dysfunction is to understand how the watershed has responded to various magnitudes of disturbance over different time scales.

From 1996 to 1998 YTFP conducted Level IV habitat surveys and large wood inventories in Blue Creek and all of the major tributaries as part of the initial sub-basin restoration planning effort (Tables 1 – 2). YTFP has conducted salmonid spawning surveys in the watershed since 1994, monitored juvenile salmonid outmigrantion since 1995, and collected juvenile coho abundance data in the upper reaches from 2001 – 2004 (Figure 66). These efforts have provided critical information regarding factors limiting each salmonid species and age class in this watershed. To address upslope sediment concerns, the YTWRP completed a road inventory of Blue Creek in 1999 and has since implemented limited road decommissioning and upgrading activities in the watershed. YTEP currently operates a stream gage in the watershed to document long-term hydrologic patterns and statistics. Blue Creek stream gage data can be accessed along with other Tribal operated water quantity and quality stations at: http://exchange.yuroktribe.nsn.us/lrgsclient/stations/stations.html.

YTFP conducted an assessment of the fluvial corridor of lower Blue Creek to document changes in channel pattern, valley morphology, and riparian vegetation over time. This assessment is based on geomorphic mapping, aerial photograph analysis, topographic surveys, other field evidence, and a compilation of information from previous studies and written accounts. This process allowed YTFP to identify factors currently limiting channel stability and riparian vegetation; and to evaluate stresses and resiliency of channel and riparian habitats from natural or anthropogenic disturbances. This level of assessment was needed to address cumulative effects resulting from land management practices, large flood events, and feral cattle grazing occurring over the last 150 years. The goal was to develop restoration prescriptions for lower Blue Creek that would result in short- and long-term benefits to Klamath Basin fish, wildlife, and riparian forests.

This study focused on investigating changes in valley landforms over time, and the relationship between riparian vegetation types, topographic position and base flow elevations. Critical questions addressed included: how did flood events and management activities affect valley landforms; what were the common mechanisms for floodplain revegetation following large-scale flood events; and what plants historically dominated the

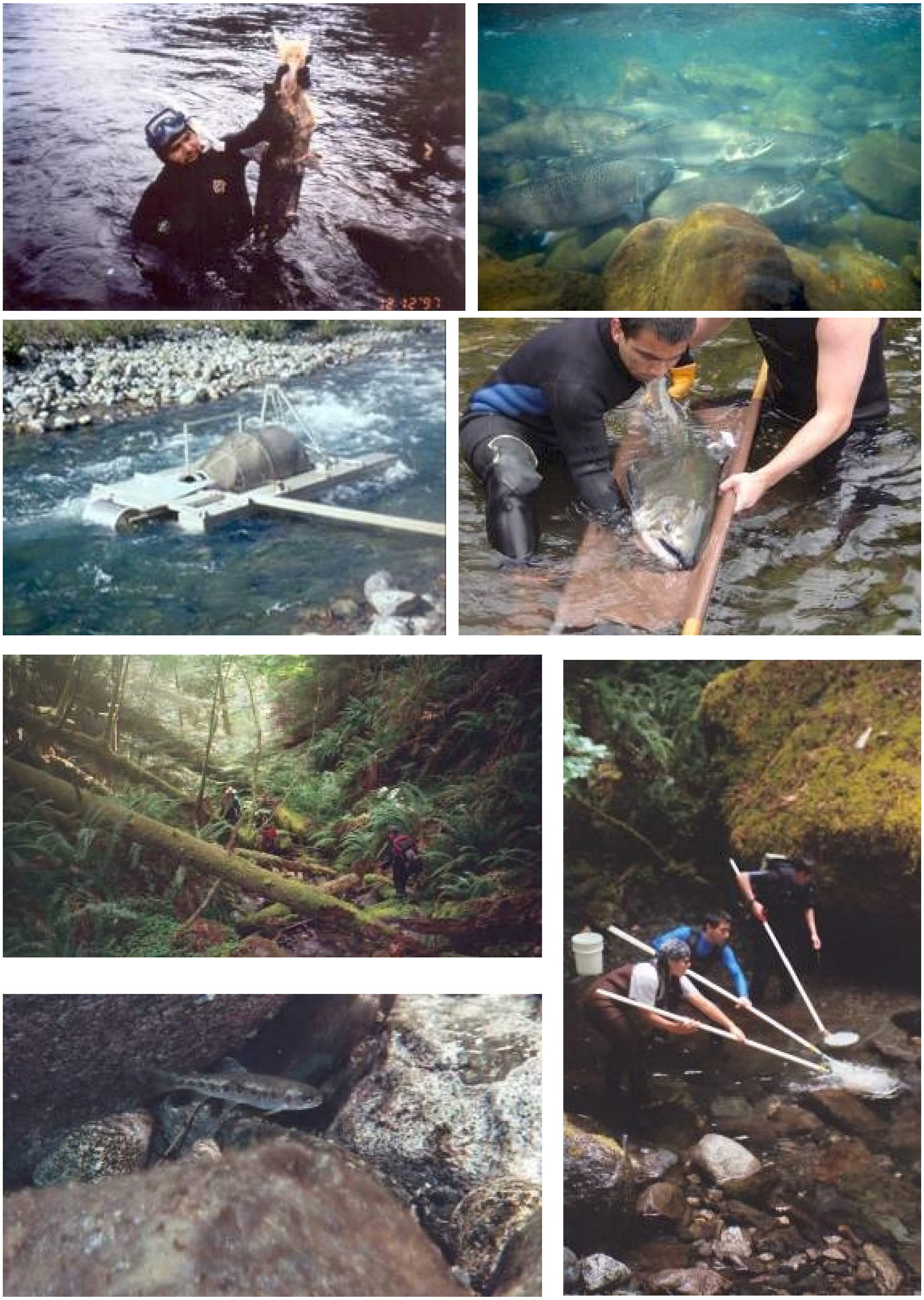


Figure 66. Yurok Tribal Fisheries Program conducting adult and juvenile salmonid monitoring activities in Blue Creek, Klamath River Sub-basin, California (1996 – 2008).

riparian versus modern plant assemblages. This approach assisted the development of restoration treatment alternatives that account for natural and anthropogenic disturbances currently and historically affecting the fluvial corridor of lower Blue Creek; and the natural resiliency of the riparian forests and floodplains located within the project area. A primary goal was to begin developing treatment concepts and strategies that provide long-term biological and geomorphic solutions to identified limiting factors.

Blue Creek Study Area

The Blue Creek watershed is contained within the Lower Klamath River Sub-basin in northern California and drains 120 mi^2 of moderate to well dissected, high relief topography of the Klamath Mountains in the Coast Range Geomorphic Province (Figure 1). The confluence of Blue Creek and the Klamath River is located within the Yurok Indian Reservation on the north side of the river 15.9 river miles upstream of the Pacific Ocean (Figure 2). Elevations range between 40 and 5,685 ft. The region has a Mediterranean climate, receiving as much as 90 inches of precipitation each year. Temperatures are moderated by the proximity to the Pacific Ocean, yet snow can accumulate above 2,400 feet.

Lower Blue Creek is privately owned and managed for industrial timber harvest (Figure 1). Upper Blue Creek, including the four largest tributaries, are located in the Six Rivers National Forest (SRNF) (Figures 1 and 67). The majority of SRNF ownership is contained within the Siskiyou Wilderness Area or is classified as Late Successional Reserve (FEMAT 1993). Timber harvest, road construction, and other related land management activities have been moderate in the SRNF portion of Blue Creek relative to the privately owned portion.

Blue Creek watershed occupies portions of two parallel but distinct geologic provinces: the Coast Ranges Province and the Klamath Mountains Province. The lower third of the watershed is comprised of sandstones, shales, metagreywacke, schist, and other rocks of the Franciscan Complex. Part of the Coast Ranges of northern California, the Franciscan Complex, represents recent and contemporary accretion and uplift of geologic materials associated with the development of the Cascadia Subduction Zone. The majority of the upper watershed overlies an assemblage of older metamorphic and igneous intrusive rocks of the Western Jurassic and Western Paleozoic and Triassic Belts or terranes that form the western edge of the Klamath Mountains Province. These terranes were successively accreted against the western margin of North America over an approximately 300-million-year period of convergent motion of lithospheric plates.

Quaternary terraces and younger floodplains occur throughout the watershed. Some of the older alluvial deposits, located at higher topographic positions, were uplifted since the time of their deposition. Glacial landforms, including cirques and moraines, also occur within a small region at the highest elevations in the watershed. Concordant ridgelines that form the western and eastern watershed divides are part of the Klamath peneplain of Diller (1902) (see also Irwin 1997 and Aalto 2006). Several older faults also bisect the watershed. The difference in rock strength and resistance to erosion is generally expressed by the steep

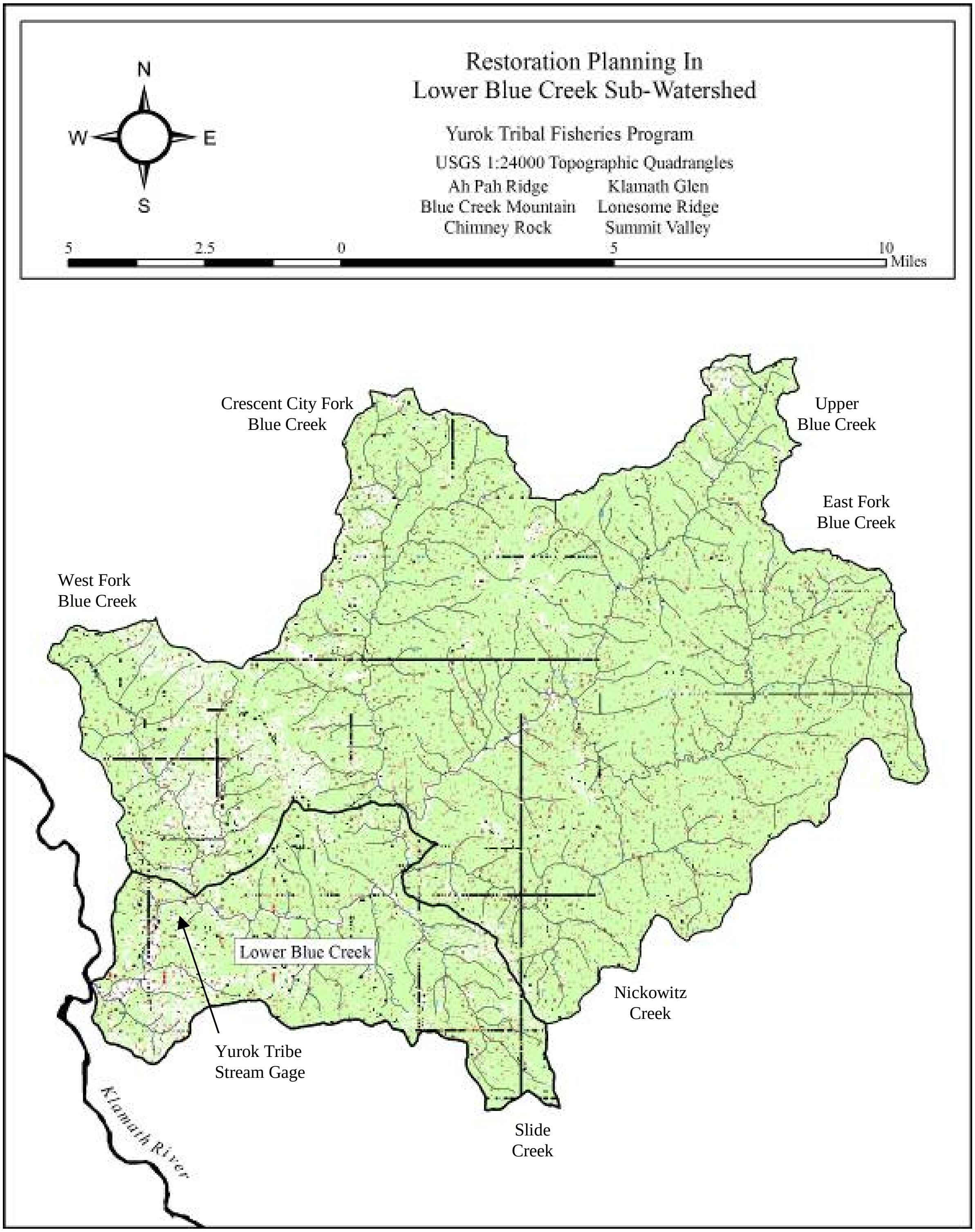


Figure 67. Map depicting the Lower Blue Creek Sub-watershed and location of the Yurok Tribe Environmental Program's stream gage, Lower Klamath River Sub-basin, California.

bedrock canyons and strath terraces that characterize the middle and upper watershed verses the more moderate slopes and wider bedrock-alluvial valley that forms the lower watershed.

The project area consisted of riparian habitats and stream reaches located from the mouth of Blue Creek (41.426 Latitude; 123.928 Longitude) to approximately 2.1 miles upstream of the Yurok Tribe Environmental Program's stream gage (Figure 67). The study area was separated into an upper and lower reach, based on the degree of valley confinement (Jain et al. 2007). The upper reach is located within a steep narrow bedrock valley that limits lateral channel migration and the formation of extensive floodplains. The lower reach extended from where the valley widens and a series of discontinuous floodplains have formed, down to the confluence with the Klamath River (Figure 68).

Blue Creek Assessment Methods

Detailed field and GIS based mapping of valley landforms and riparian habitats was supplemented with stratigraphic and substrate descriptions, cross section surveys, radiocarbon dates from buried woody materials, and dendrochronological samples to inform the preparation of restoration prescriptions presented herein. In addition, information from previous studies by Helley (1968), Helley and LaMarche (1969), and Helley and LaMarche (1973), newspaper reports compiled by Suzy VanKirk (VanKirk 2005), and other written materials and oral histories were also collected. This information provided an understanding of the social and bio-geologic framework of the area, assisted the identification of limiting factors, and improved our ability to develop restoration strategies for lower Blue Creek.

Sequential aerial imagery included aerial photographs, USGS Digital Orthophoto Quadrangles (DOQs), and 2005 NAIP satellite mosaics for Humboldt and Del Norte Counties (Appendix A). Aerial photographs of lower Blue Creek from 1948 – 2004 were scanned as high resolution TIFF files and rectified to the 1993 DOQs using ArcMap. The 2005 NAIP satellite imagery for lower Blue Creek was also incorporated in the GIS project for analysis. After reviewing the image library, ArcMap tiles depicting lower Blue Creek and UTM gridlines were created using the 2005 NAIP imagery as the photo base. Maps were printed on 11x17 inch paper, laminated, and then overlaid with mylar film. In the field, channel patterns, floodplain and terrace surfaces, riparian habitats, and other geomorphic features were mapped onto the mylar overlays. Geomorphic information collected during these investigations was documented on the field maps or in notebooks and transferred into the project database. A hand-held GPS unit (sub-meter accuracy) was also used to assist field mapping efforts by documenting the location of the active channel, floodplain features, riparian vegetation, and prominent landmarks.

The 2005 NAIP imagery, the field generated maps, and collected GPS data were then used to prepare a GIS based hydro-geomorphic map for lower Blue Creek. This map and associated GIS database containing the geomorphic attributes classified during field investigations served as the baseline for assessing conditions present in the aerial imagery. Channel patterns, floodplain and terrace surfaces, and riparian habitats were mapped and classified by reviewing the aerial imagery and the hydro-geomorphic map and heads-up digitizing features

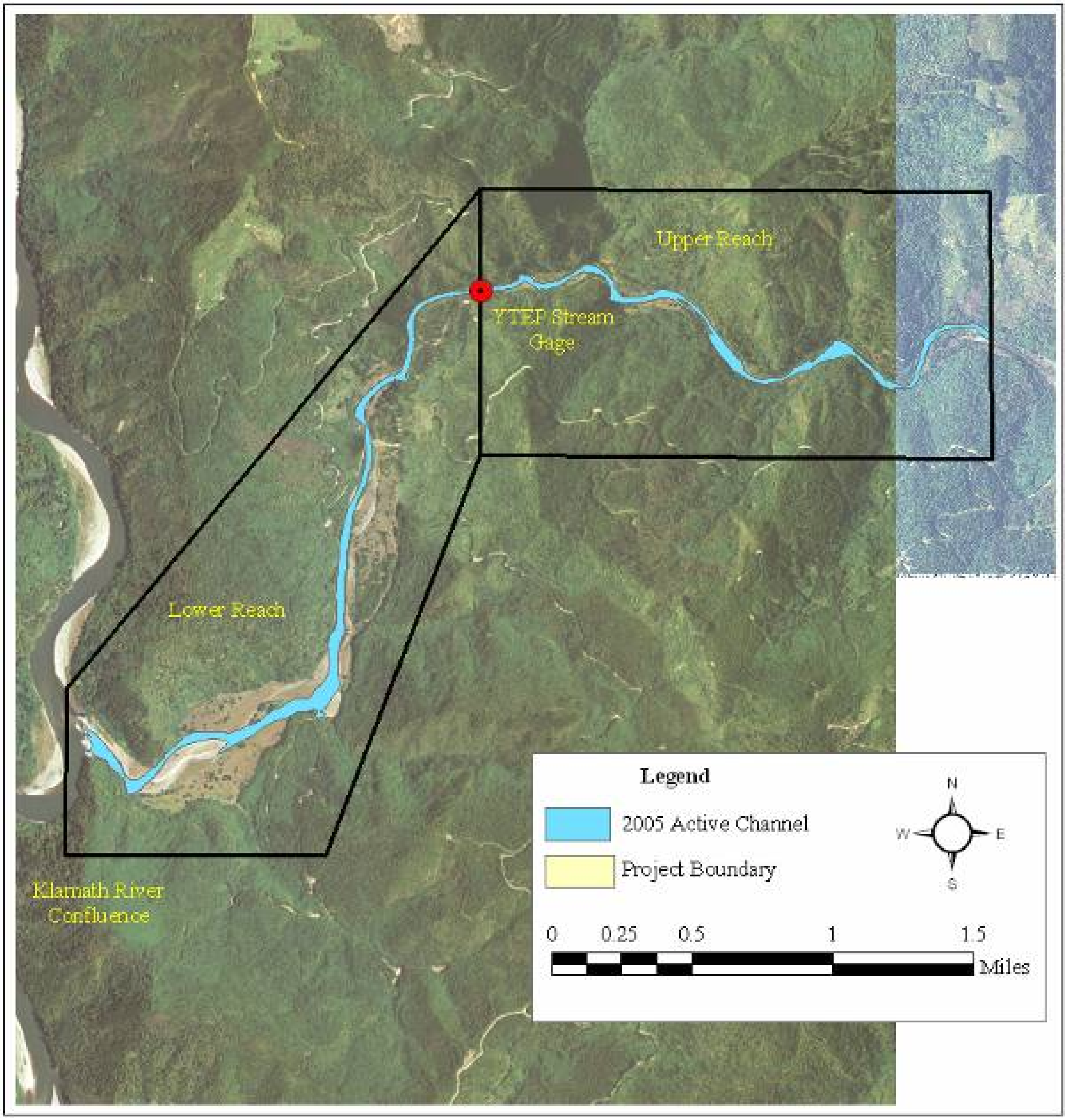


Figure 68. Map depicting two assessment areas in lower Blue Creek, Lower Klamath River Sub-basin, California. Base image: portions of the 2005 NAIP imagery, 1 meter resolution.

into the GIS project. Aerial image mapping was calibrated with ground based observations made during the initial field mapping efforts and subsequent surveys.

Valley landform classifications of Nanson and Croke (1992), Reinfelds and Nanson (1993), Nanson and Knighton (1996), Abbe and Montgomery (1996), Poole et al. (2002), and Beechie et al. (2006) were reviewed to develop the Level I classification system used in this study (Table 3). The Level I system was used to classify meso- to mega-scale landforms

Table 3. Valley landform classification system developed for lower Blue Creek, Lower Klamath River Sub-basin, California.

Type	Classification	Description	Flood Flow Regime	Age Range (years)
1	Active Channel	No vegetation. Includes active bars and other streambed forms.	Frequent	Active
2	Incipient Floodplain	Actively eroding and depositional floodplain features. Includes higher order surfaces where vegetation was removed or severely disturbed by recent flood events.	Frequent	1 – 5
3	Established Floodplain	Depositional features with vegetation usually dominated by hardwood species. Includes semi-stable surfaces dominated by grasslands.	Infrequent	5 – 10
4	Mature Floodplain	Depositional feature with vegetation usually comprised of mixed hardwood and conifer species. Includes stable surfaces dominated by grasslands.	Infrequent	10 – 100
5a	Sand and Silt Dominated Terraces	Depositional feature with significant fine grain (sand, silts, & clay) component formed in backwater or overbank flow environments. Vegetation usually consists of mature hardwood and conifers species.	Infrequent	10 – 300
5b	Gravel & Coble Dominated Terraces	Depositional feature generally comprised of coarse grained sediments (gravel, cobble, boulders with sands). Vegetation usually dominated by conifer species and mature cottonwood.	Rare	>60

from sequential imagery in the project GIS and includes six types of landform development: 1) active channel; 2) incipient floodplain; 3) established floodplain; 4) mature floodplain; 5a) sand and silt dominated terraces; and 5b) gravel and coble dominated stream terraces.

The classification used in this study most closely followed that of Reinfelds and Nanson (1993), which was created to describe the formation of floodplains in the high energy and sediment rich Waimakariri River in New Zealand. The stratigraphy and morphology of Waimakariri River, described by Reinfelds and Nanson (1993), was similar to some of the features observed within the Blue Creek study area. A more detailed Level II classification was used for field and GIS mapping, those results will be provided in a subsequent report.

Permanent survey benchmarks were established in lower Blue Creek using a GPS total station tied to National Geodetic Survey (NGS) benchmarks with a 1988 North American Vertical Datum (NAVD88) and 1983 North American Datum (NAD83) for horizontal coordinates. Several reference cross sections were established in the project area to characterize valley floor topography, to assess bed materials, and to monitor long-term changes in the study area (Figure 69). Topographic surveys were conducted using an optical total station during fall 2006 and fall 2007 to take advantage of low flow conditions. Limited surveying of floodplain and terrace features also occurred in winter 2007. Wolman pebble counts (Wolman 1954) were used to characterize surface particle size distributions at riffle crests at several of the surveyed cross sections.

Survey data was imported into Microsoft Excel to generate plots and imported into ArcView 3.2 for spatial analysis and further characterize existing riparian conditions. Surveyed cross sections were draped over the 2005 NAIP imagery to assess relationships between vegetation composition and the height of existing riparian surfaces above base flow elevations. We defined five vegetation classes for lower Blue Creek based on initial field mapping efforts: 1) Mature Conifer; 2) Conifer Regeneration; 3) Mature Cottonwood; 4) Upper Mixed Mesophytic; and 5) Lower Mixed Mesophytic. Mesophytic species include willows, red alder, and other species that require relatively shallow water tables to survive. Vegetation classes and height above base flow elevations were then determined for every surveyed location along each of the cross sections (Figure 70). Vegetation and elevation relationships were assessed and statistics were generated using Microsoft Excel data analysis tools.

Surface particle data were converted to cumulative percent finer than for each fraction size class and size distribution curves were plotted using Microsoft Excel. 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 surface 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). Field investigations conducted during this study also included characterization of exposed terrace and floodplain soil profiles and radiocarbon dating from two floodplain units. One site contained a buried redwood tree and the other site contained peat material within a charcoal rich horizon.

Blue Creek Assessment Results

Valley Landform Dynamics

Measurements from this and previous studies show that four phases of valley landform evolution can be identified: Phase I) 1860 to 1948 – Geomorphic Equilibrium; Phase II) 1948 to 1975 – Instability and Valley Aggradation; Phase III) 1975 to 1988 – Sediment Transport

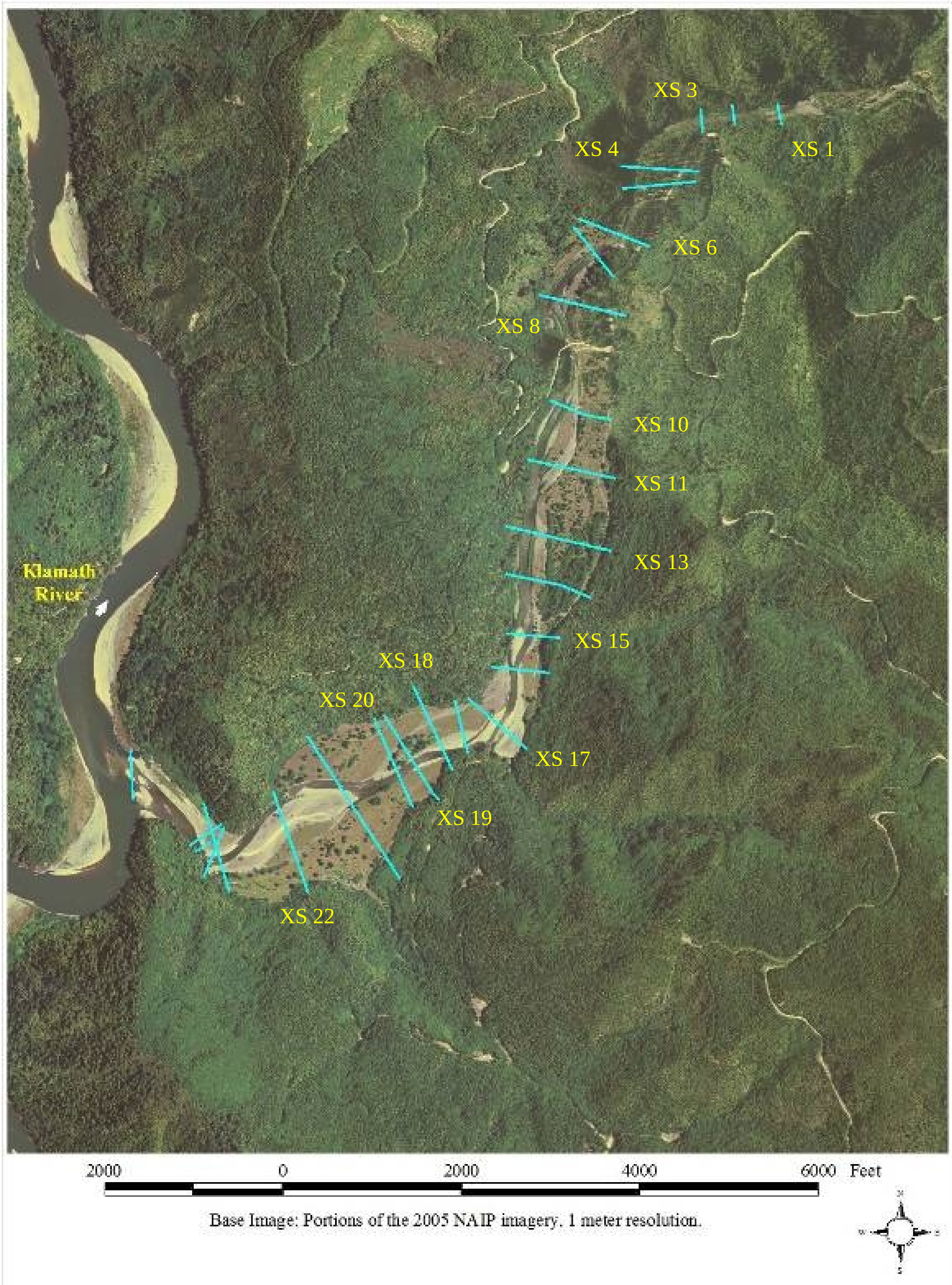


Figure 69. Map depicting permanent reference cross sections established in Blue Creek by the Yurok Tribal Fisheries Program, Lower Klamath River Sub-basin, California (2007 – 2008).

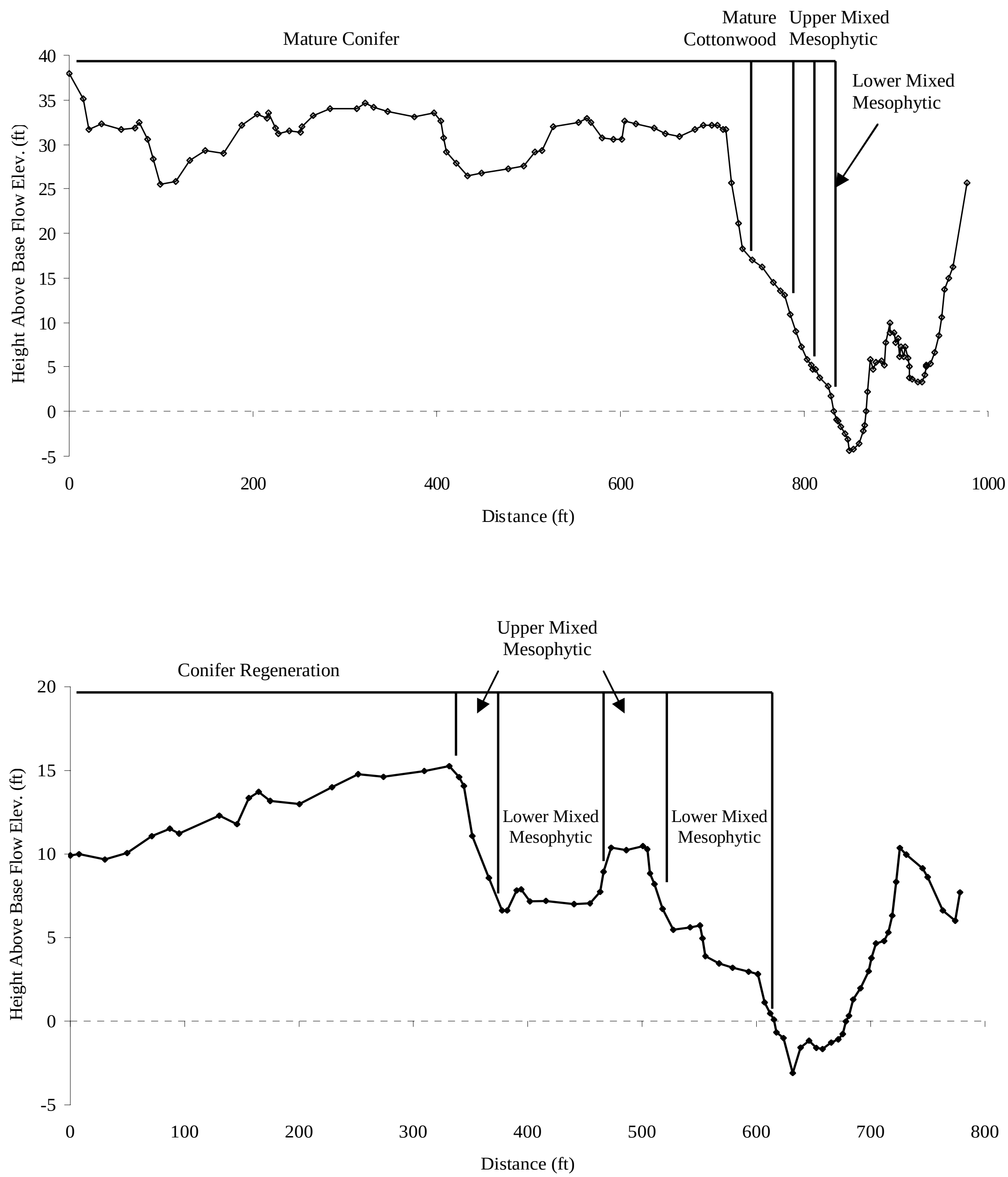


Figure 70. Cross section plots depicting riparian vegetation classes and elevations of riparian surfaces relative to base flow elevations in lower Blue Creek, Lower Klamath River Sub-basin, California (2007 – 2008).

and Channel Degradation; and Phase IV) 1988 to 2008 – Channel Incision and Floodplain Abandonment.

Phase I) 1860 to 1948 – Geomorphic Equilibrium

The geomorphic map produced from the1948 images show valley landforms in apparent equilibrium with the existing sediment and flood regime (Figure 71). The channel exhibited a sinuous planform and the majority of the valley landforms supported vegetation. Forested debris fan deposits were mapped at the mouths of Pularvasar Creek and at the un-named tributary at the Washout Pool (Figure 71). The gravel and coble dominated terraces (type 5b) in the lower and upper reaches were covered by mature stands of mixed conifers, similar to the stands that remain at the campground flat and on the remnant patch terraces located upstream of West Fork Blue Creek.

Phase II) 1948 to 1975 – Instability and Valley Aggradation

The geomorphic map from the 1958 images includes details of the changes in channel and valley landforms two years following the large magnitude flood event in 1955 (Figure 71). This map shows a wider channel with a side channel that reoccupied an abandoned floodplain channel adjacent to One Mile Creek. Areas with incipient floodplains formed near where the bridge is now located and within the next downstream meander bend. Measurements of landform change in the lower reach show the proportional area of active channel planform and incipient floodplain increased by 30 and 24 percent, respectively compared to measurements from the 1948 images (Figure 72). Concurrent with an increase in the more active features, the proportional area of established and mature floodplains decreased by 10 and 24 percent, respectively (Figure 72).

Mapping and measurements from the 1965 images show significant changes in channel and valley landforms following the 1965 flood (Figure 73). In the lower reach, the area of active channel planform and incipient floodplain increased by 26 and 129 percent, respectively (Figure 72). These changes were exhibited by significant areas of vegetation loss, channel avulsion, aggradation and channel straightening in the reach below One Mile Creek. While major changes were recorded in the lower reach, the first appearance of channel instability also occurred in the upper reach just upstream of West Fork Blue Creek during this mapping period (Figure 73).

Analysis of the 1970 images shows the near complete degradation of key valley landforms in the lower reach (Figure 73). A large mature floodplain on the right bank was completely stripped and its area occupied by the straightening active channel. It could not be determined from the available images if the old growth stand visible on earlier images was harvested from this surface prior to the 1970 image date. Remnant sand and silt dominated terraces (type 5a), which supported old growth forest stands, were also reduced and the active channel planform area increased slightly. The 92 percent increase in established floodplain since the 1970 mapping period (Figure 72) was likely in association with rapid recovery of grasses and cottonwoods that re-sprouted on the undissected portions of Black Bear and Pularvasar Flats.

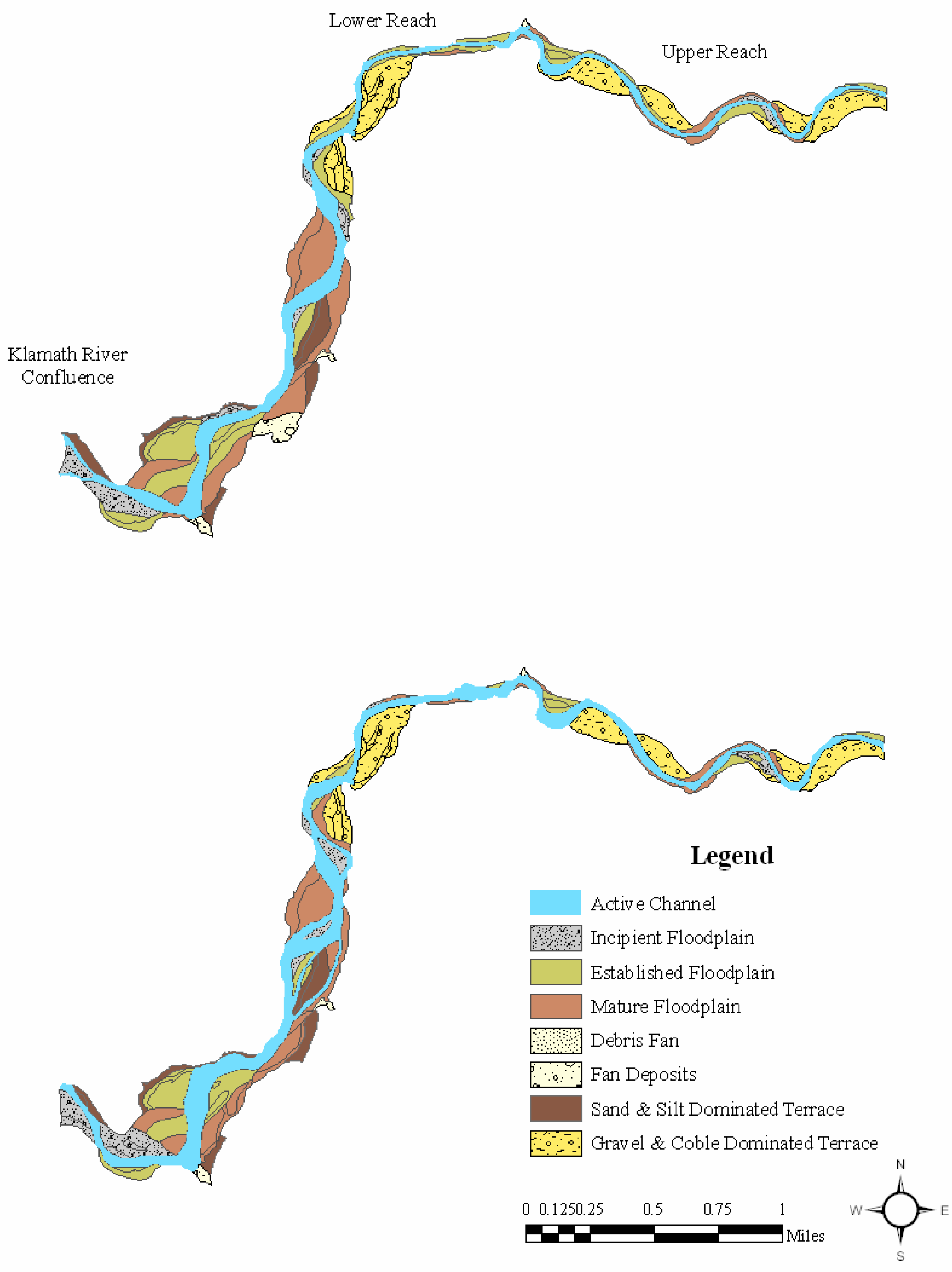


Figure 71. Geomorphic map of the Blue Creek valley floor for 1948 (top image) and 1958 (bottom image), Lower Klamath River Sub-basin, California.

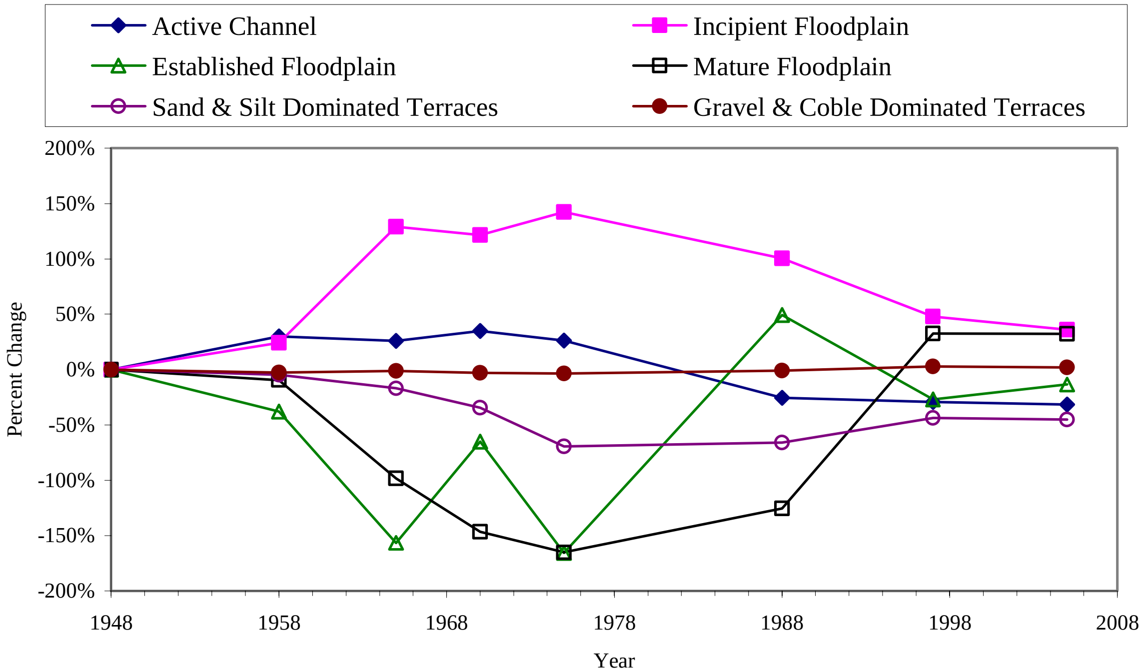


Figure 72. Measured percent change in valley landform area for the period 1948 - 2005, lower Blue Creek, Lower Klamath River Sub-basin, California. Percent change was calculated as the change in the landform area compared to its area mapped from 1948 images.

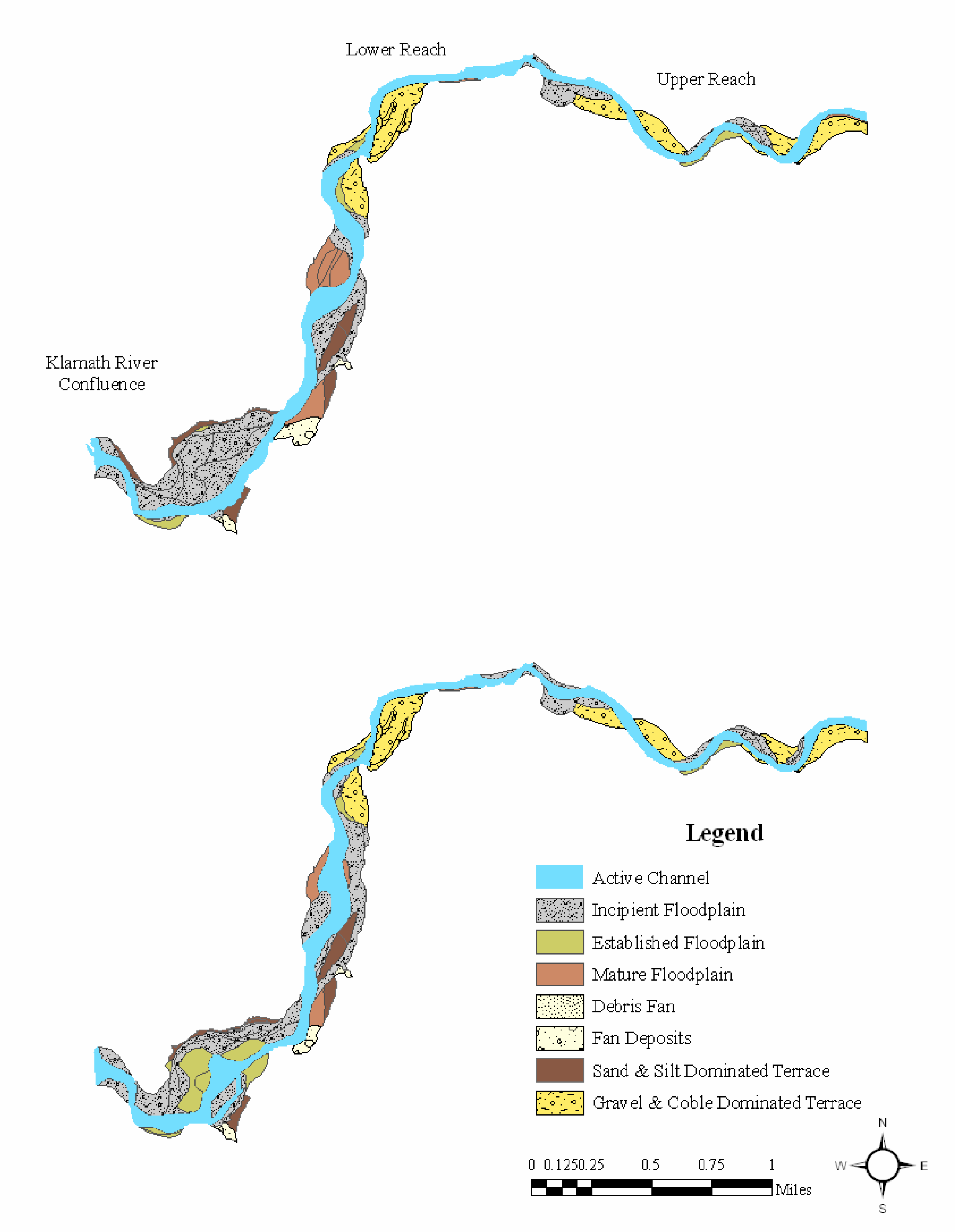


Figure 73. Geomorphic map of the Blue Creek valley floor for 1965 (top image) and 1970 (bottom image), Lower Klamath River Sub-basin, California.

Map analysis of the 1975 images show the flow path in the lower reach of Blue Creek had nearly straightened and shifted to the right side the valley since the 1970 images (Figure 74). The greatest decrease in the more stable landforms (types 3, 4 and 5a) accompanied by the greatest increase in incipient floodplain area occurred during this mapping period (Figure 72). The remnant type 5a terraces along western margin of Black Bear Flat were mapped in the field. Several of these features supported residual old growth redwood and second growth from redwood stump sprouts. The conditions observed at the type 5a terraces in the lower reach indicate a period of long-term stability for these surfaces.

Phase III) 1975 to 1988 – Sediment Transport and Channel Incision

Mapping and measurements from the 1988 images showed a 42 and 52 percent decrease in incipient floodplain and active channel planform areas compared to the previous mapping period (Figure 74). A 215 percent increase in established floodplain area also occurred since the 1975 mapping period. The dramatic increase in established floodplain area, coupled with the decrease in active channel planform and incipient floodplain area, indicate a change in channel and floodplain behavior. This change becomes more evident in the 1997 and 2005 map periods.

Phase IV) 1988 to 2008 – Channel Degradation and Floodplain Abandonment

Analysis of the maps from the 1997, and 2005 aerial images (Figure 75), combined with the 2007 geomorphic mapping and other recent evidence showed the active channel is degrading and becoming isolated from its floodplain. Although, analysis presented in the next section showed floodplain occupancy rates did increase following the 1988 map period, surveyed cross sections and field observations of flood peaks in 2008, had limited capacity to deposit or erode floodplain surfaces. These data indicated flood peaks above 17,000 cfs, that were formerly capable of significant geomorphic work, appeared to be generally contained within a narrowing and deeper channel, with the stream power focused on the channel bed.

Since the 1988 map period the planform area of the active channel has dropped below the area mapped in 1948 (Figure 72). The area of incipient floodplain has also steadily decreased but has not yet reached levels mapped prior to 1958. The area of mature floodplain and type 5a terraces increased over the Phase IV period. However, poor soil and vegetation development on the new 5a terrace deposits leaves them vulnerable to erosion.

Discharge information is often used to provide a measure of the geomorphic energy available to effect changes in valley landforms. Because a continuous record of discharge was not collected in Blue Creek during the years 1979 – 2003, the instantaneous annual flood peaks from gages on the Smith River and Redwood Creek were used as surrogates for the missing records in Blue Creek. The instantaneous annual flood peaks from these gages were scaled by their drainage area ratio with Blue Creek. This provided a reasonable estimate of the annual flood peaks for the missing records (Figure 76).

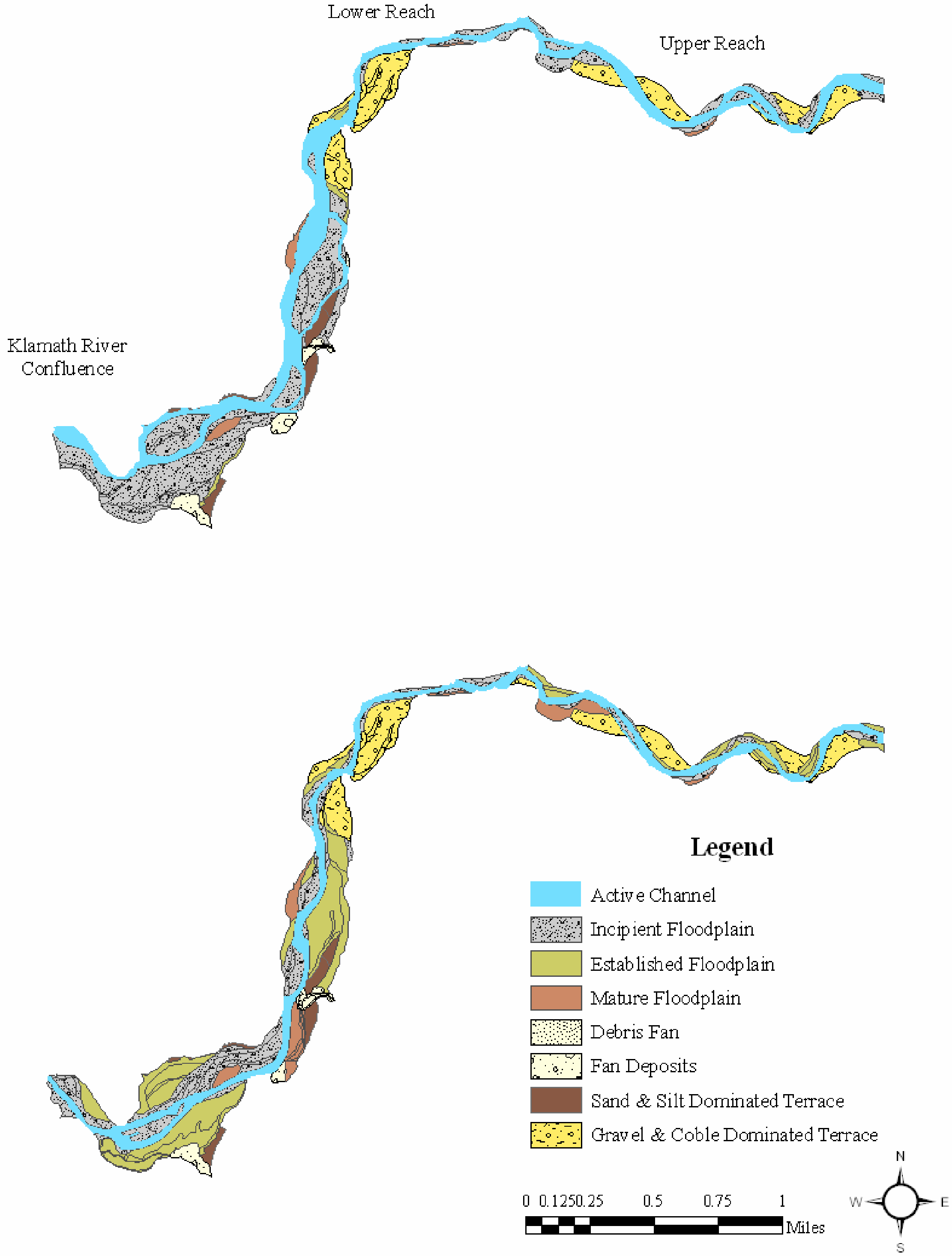


Figure 74. Geomorphic map of the Blue Creek valley floor for 1975 (top image) and 1988 (bottom image), Lower Klamath River Sub-basin, California.

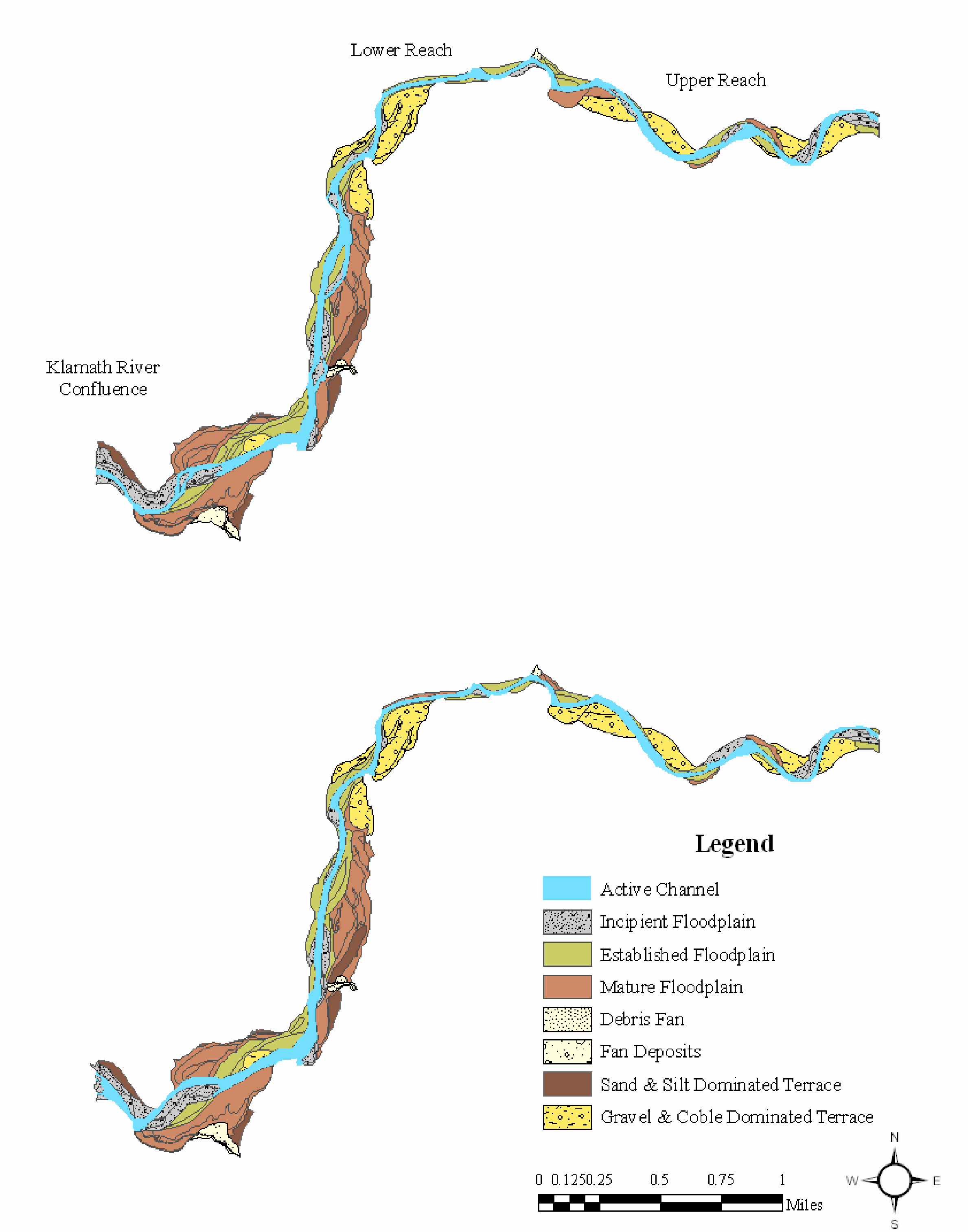


Figure 75. Geomorphic map of the Blue Creek valley floor for 1997 (top image) and 2005 (bottom image), Lower Klamath River Sub-basin, California.

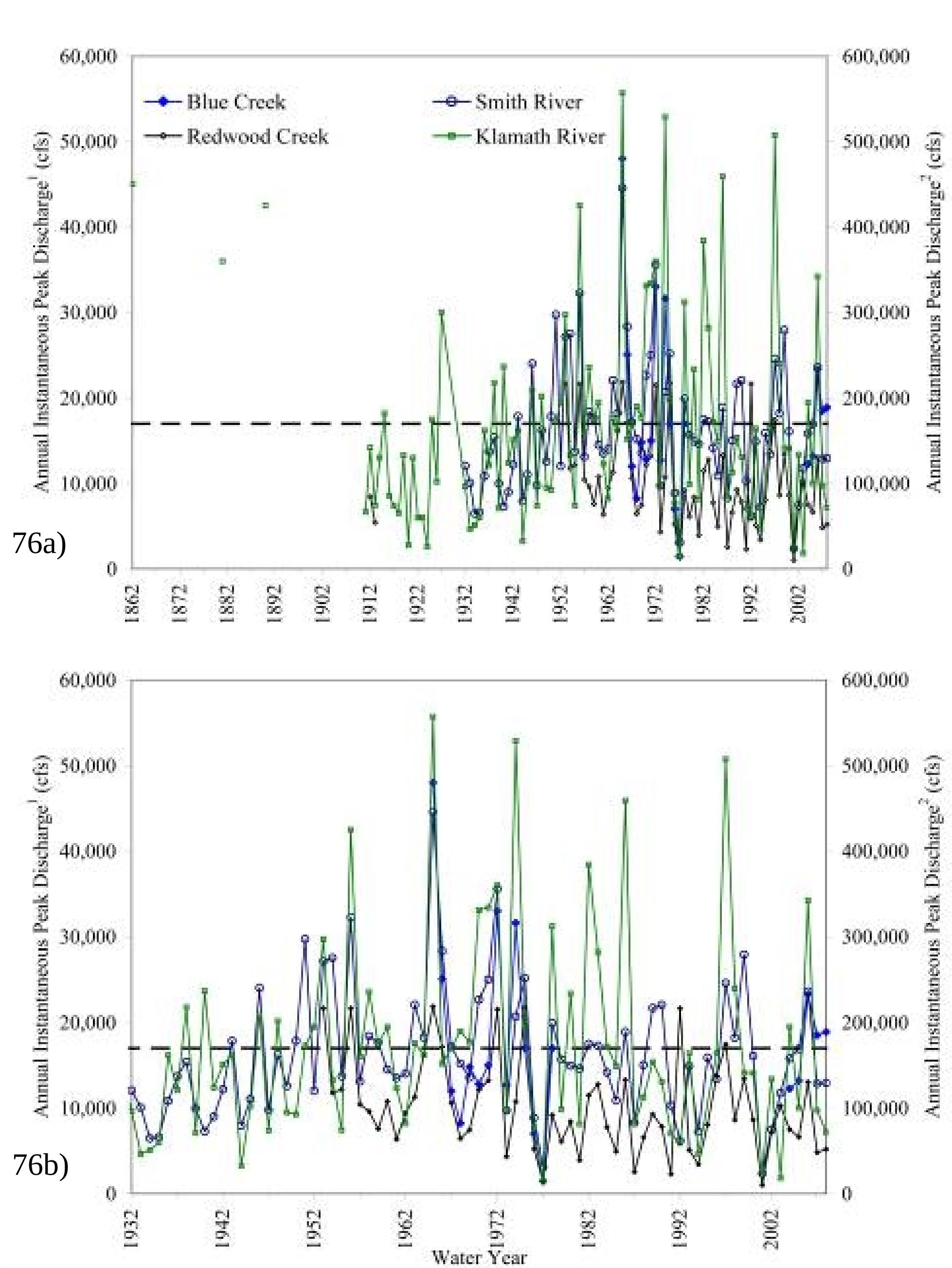


Figure 76. 76a) Annual instantaneous peak discharges for Blue Creek near Klamath (BCK), Smith River near Crescent City (JED), Redwood Creek at Orick (ORK), and Klamath River near Klamath (KNK), period of record. 76b) Annual instantaneous peak discharges for BCK, JED, ORK and KNK, for the period 1932 to 2008. All data is from USGS, except Blue Creek – 2004 to 2008, from Yurok Tribe Environmental Program. Notes: 1) Discharge for Smith River and Redwood Creek scaled by drainage area ratio with Blue Creek; 2) KNK discharge is not scaled and corresponds to the right axis. Dashed line at 17,000 cfs represents the apparent magnitude where discharge becomes geomorphically effective in Blue Creek.

The Smith River near Crescent City, and Redwood Creek at Orick have drainage areas of 614 and 277 mi^2, respectively. Peak flood data for the Klamath River (12,100 mi^2 drainage area) were included for context and the long period of record that includes the historic floods of 1861, 1880, and 1890. However, these data are not scaled because the basic requirement of similar drainage area was not met. The period of record for these gage stations were as follows: Blue Creek near Klamath (BCK) – 1965 to 1978 and 2004 to 2008; Smith River near Crescent City (JED) – 1932 to 2008; Redwood Creek at Orick (ORK) – 1912, 1913, and 1953 to 2008; and Klamath River near Klamath (KNK) – 1862, 1881, 1890, and 1911 to 2008. The annual peak flood data from JED and ORK gages correspond reasonably well with the available record for Blue Creek (Figure 76). While stream power would be the preferable measure, compared to flood peaks (Costa and O'Conner 1995; Bull 1979), the necessary data was not available for this report phase.

Channel migration for the upper and lower reaches, and the apparent degradation rate of valley landforms at cross section 19 (Figure 69), were measured to characterize the temporal pattern and rates associated with these processes. Channel migration rates were calculated as the percent valley landforms were occupied by the active channel per year (O'Conner et al. 2003) (Figure 76a). Apparent valley landform degradation rates were calculated as the difference between successive landform surface elevations divided by the surface age estimated at cross section 19 (Figure 76b). The 1860 date for the highest alluvial surface at cross section 19 was estimated based on a radiocarbon dated peat sample for a concordant surface located at cross section 13. The 1860 date for this surface was also supported by the size range of redwood stumps occupying both sites and radiocarbon dates for the flood deposits studied by Helley and LaMarche (1973). The remaining surface ages were estimated from aerial images that show when a surface at the cross section was last occupied by the stream channel or flood deposit and supported by geomorphic mapping.

Mapping and related measurements showed distinct changes over time (Figures 77 – 78). The occupancy rate increased from 1.9 and 1.6 percent per year prior to 1958 to a maximum of 10.4 and 10.5 percent per year by 1975, for the upper and lower reaches respectively (Figure 76a). For this same period the degradation rate was calculated as -0.13 to 0.49 and -0.34 ft/yr for the years 1948, 1965 and 1975, respectively (Figure 76b). Since positive values indicate aggradation, this analysis shows the period between 1948 and 1975 included phases of aggradation and degradation. The 1948 degradation rate is conservative because of the uncertainty in landform change between 1860 and 1942 (1942 was the earliest aerial images available). The period between 1958 and 1975 was associated with intensive timber harvest activities and several flood events that equaled or exceeded 17,000 cfs (Table 4).

For the period 1975 to 1988, occupancy rates for the upper and lower reaches, decreased to 4.0 and 4.4 percent per year, coincident with a period of lower flood peaks (Figures 76 – 77). During this same period the valley floor continued to degrade, however, the rate decreased to -0.14 ft/yr, compared to the -0.34 ft/yr calculated for the previous period. During the 1997 map period, occupancy rate increased to 5.8 and 6.6 percent per year for the upper and lower reaches and increased again by 2005 to 6.6 and 7.6 percent per year, respectively. Calculated degradation rates were greatest, -0.64 and -0.54 ft/yr, in 1997 and 2007, compared to all previous estimates.

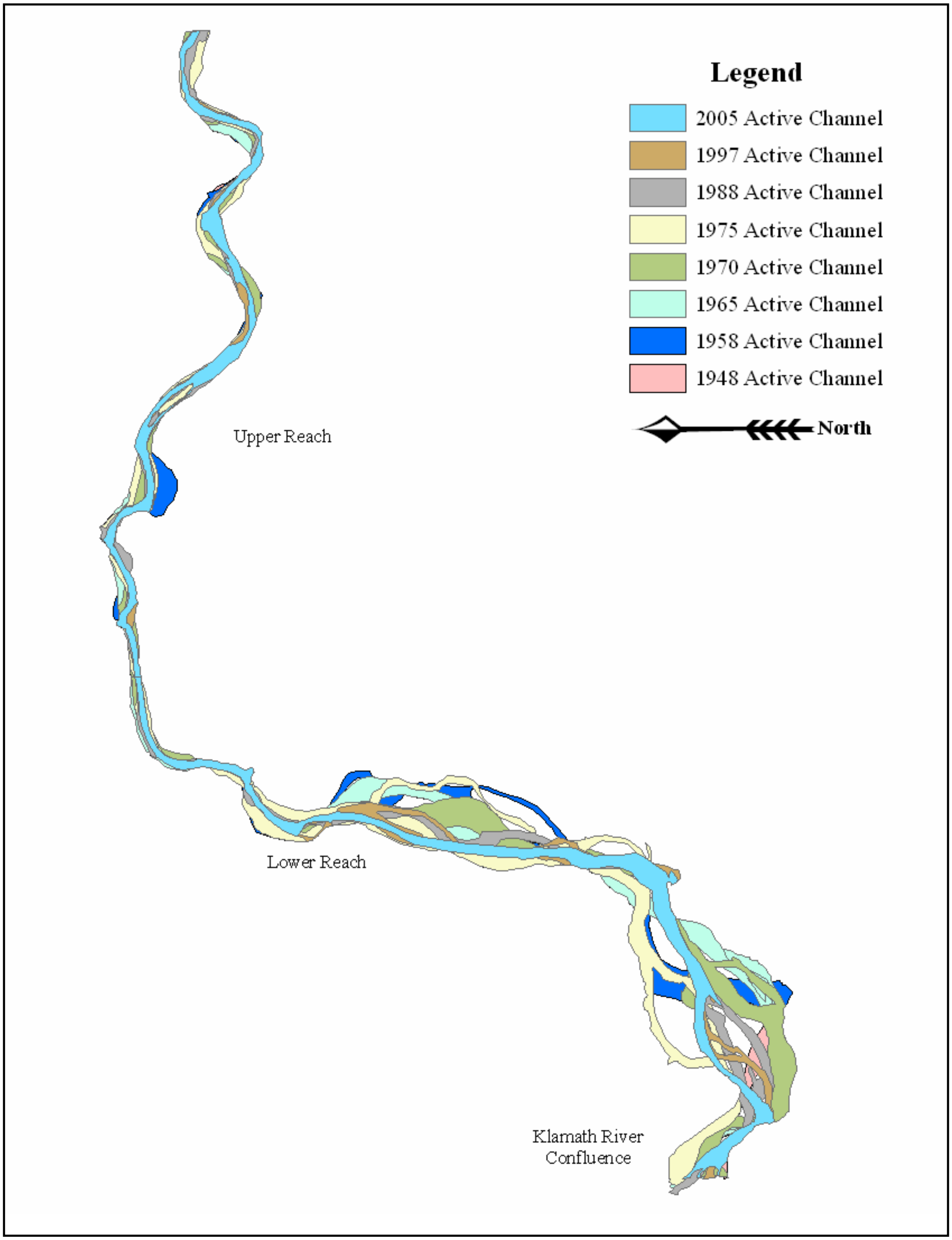


Figure 77. Geomorphic map of the active channel of lower Blue Creek (1948 – 2005), Lower Klamath River Sub-basin, California.

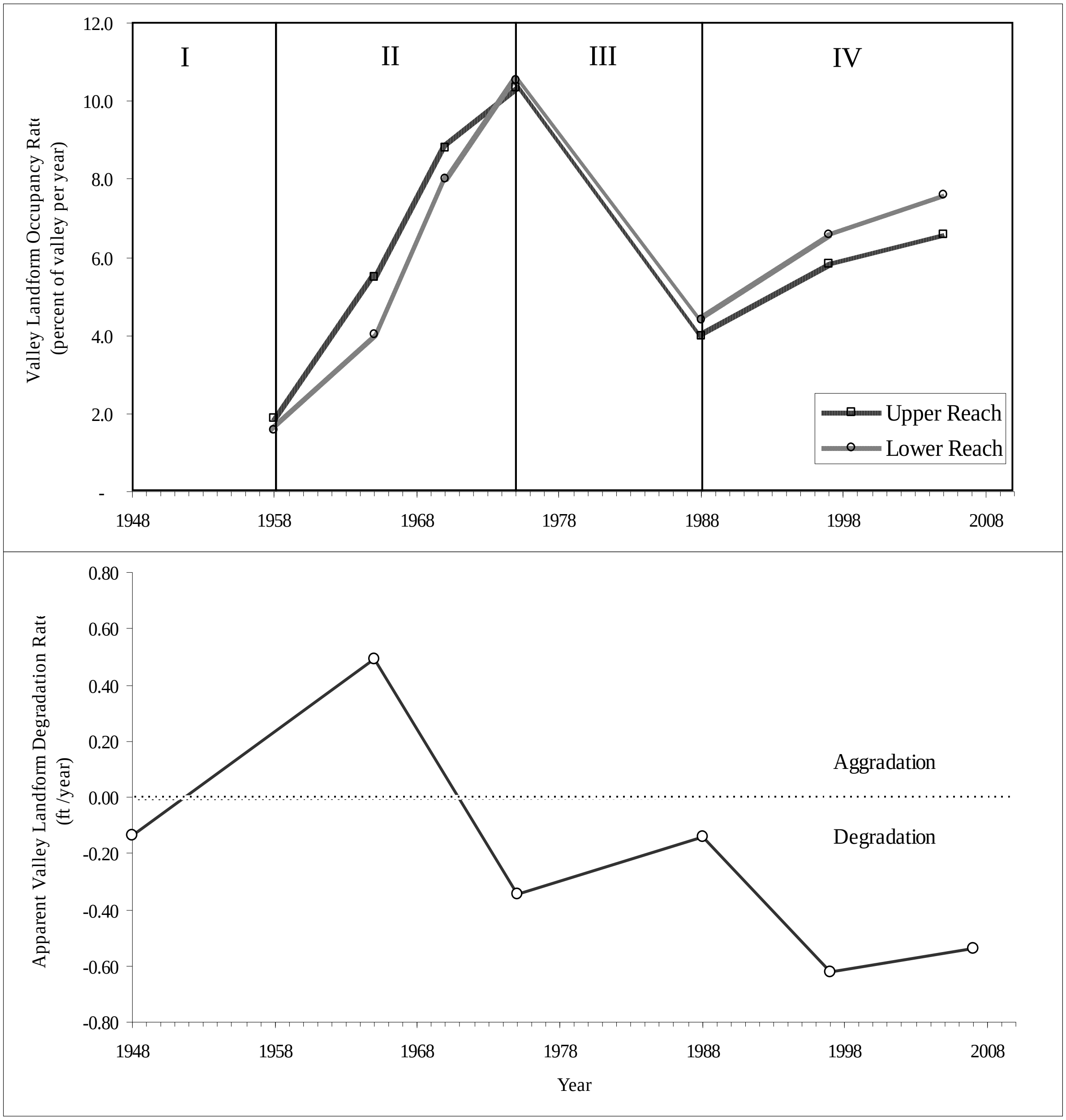


Figure 78. Temporal variation in mean annual erosion of valley landforms by the active channel (top plot), and apparent valley landform degradation rate (bottom plot). Occupancy rate is calculated on the basis of annual percent area of channel movement into formerly unoccupied areas of mapped valley landforms. Roman numerals indicate different phases of valley landform evolution. Degradation rate estimated at cross section 19, where positive values show aggradation.

Table 4. Annual instantaneous peak discharges for the Blue Creek gage near Klamath, California. Data is from United States Geologic Survey (USGS) for the 1965 to 1978 record and Yurok Tribal Environmental Program (YTEP) for the 2004 to 2008 record.

Data Source	Water Year	Day of Flood	Stage (ft)	Discharge (cfs)
USGS	1965	12/22/1964	21.55	48,000
USGS	1966	1/6/1966	15.97	25,100
USGS	1967	1/27/1967		12,000
USGS	1968	2/23/1968	10.65	8,230
USGS	1969	12/24/1968		14,800
USGS	1970	1/22/1970		12,800
USGS	1971	11/24/1970	12.59	15,000
USGS	1972	3/2/1972	18.1	33,000
USGS	1973	12/17/1972	13.86	12,700
USGS	1974	1/15/1974	17.77	31,600
USGS	1975	3/18/1975	14.01	17,000
USGS	1976	2/26/1976	12.2	7,000
USGS	1977	3/9/1977	9.5	1,450
USGS	1978	12/14/1977		17,000
YTEP	2004	12/13/03	8.48	12,273
YTEP	2005	12/8/2004	9.99	13,212
YTEP	2006	12/30/2005	13.18	23,317
YTEP	2007	12/13/2006	11.77	18,513
YTEP	2008	10/19/2007	11.85	18,906

Channel migration rates can usually be estimated in river systems where floodplains form in a series of point bars and overbank sediments deposited behind the slow lateral migration of the channel across the valley bottom. This process of channel migration creates geomorphic patterns that can be mapped and dated by several techniques. However, in fluvial systems where channel migration occurs in a sequence of sudden and catastrophic events, valley landform half-life can be calculated to estimate the floodplain turnover rate.

Valley landform half-life was calculated by fitting exponential decay curves to the cumulative erosion of the mapped 1948 valley landforms (the area outside the 1948 mapped active channel) over the three time periods: i) 1948 to 1975 (27 years); ii) 1975 to 2005 (30 years); and iii) 1948 to 2005 (57 years) (Figure 79). The method used here follows the approach of O'Conner et al. (2003).

In Blue Creek, during the 1948 to 1975 period, the half-life for valley landforms in the upper and lower reaches was calculated as 9.6 and 11.8 years, respectively. The turnover rate decreased during the 1975 to 2005 period, with the rate was calculated as 31.5 and 32.2 years, for the respective reaches. The long term turnover rate for the 1948 to 2005 period was 15.3 and 14.6 years.

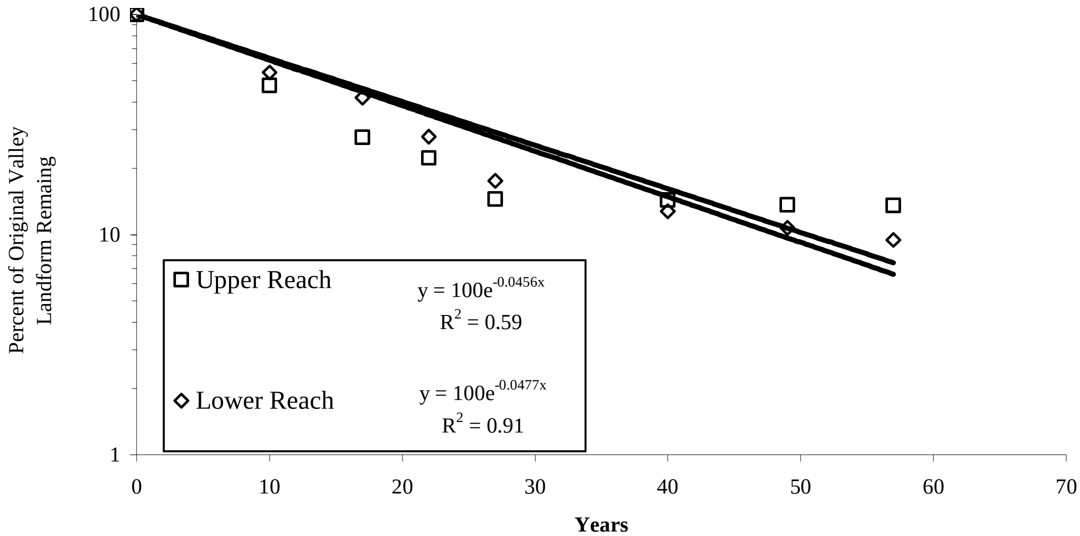


Figure 79. Long-term average (1948 to 2005) exponential decay curves fit to the cumulative erosion of the portion of formerly unoccupied areas of mapped valley landforms.

O'Conner et al. (2003) calculated the half-life for the upper Quinalt River, a watershed with a similar drainage area, geology and climate as Blue Creek. They reported the floodplain half-life for the upper Quinault River was 277 $\pm$ 53 years. The upper Quinault River drains a 170 mi^2 area of the rugged Olympic Mountains within Olympic National Park in Washington State. The watershed is underlain by Tertiary marine sedimentary and volcanic rocks that have undergone rapid Cenozoic uplift and the climate is Pacific maritime with a mean annual precipitation of 141 inches.

Topography, Vegetation, and Sediment Characterization

A total of 22 permanent and an additional four cross sections were established and surveyed in lower Blue Creek (Figure 69). Cross sections were established in various habitat types (i.e. pools, riffles, and runs) to better characterize the range of topographic conditions present in the lower valley. The Mature Conifer vegetation class was located on surfaces that were on average 29 feet above base flow elevations (Table 5; Figure 80). Both the Conifer Regeneration and Mature Cottonwood vegetation classes were located on surfaces that were on average 15 feet above base flow elevations (Table 5; Figure 80). The Upper Mesophytic vegetation class was present on surfaces that were on average 10 feet above base flow elevations; while the lower Mesophytic Class was located on surfaces that were on average 4.7 feet above base flow elevations (Table 5; Figure 80).

Particles were mainly collected at riffle crests from ten of the lower Blue Creek cross sections (Table 6; Figures 69 and 81). The sediment size distributions for lower Blue Creek were relatively similar (Figure 81) even though the data was collected from a reach that was just over two miles in length (Figure 69). The D_{50} at these locations ranged from 75 mm at

Table 5. Summary statistics for vegetation information collected in lower Blue Creek, Lower Klamath River Sub-basin, California (2007 – 2008).

	Mature Conifer	Conifer Regeneration	Mature Cottonwood	Upper Mesophytic	Lower Mesophytic
Mean	29.6	15.7	15.6	10.2	4.7
Median	31.5	15.1	14.9	10.3	4.7
Std Error	0.5	0.6	0.4	0.2	0.1
Std Dev.	4.5	4.0	2.3	1.8	1.6
Lower 95%CL	28.5	14.6	14.8	9.9	4.4
Upper 95%CL	30.7	16.9	16.5	10.6	5.0
25th Percentile	27.4	13.2	14.3	8.6	3.5
75th Percentile	32.4	16.5	17.4	11.6	6.1
Minimum	16.6	9.7	10.3	6.6	1.3
Maximum	38.0	23.5	20.2	14.6	7.9
Count	72.0	47.0	30.0	125.0	132.0

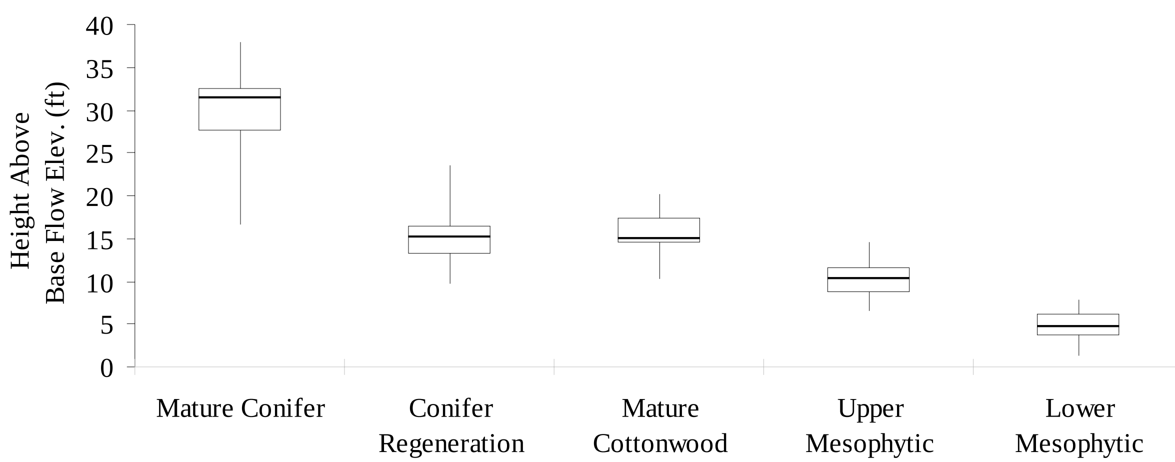


Figure 80. Box plots depicting summary statistics for vegetation information collected in lower Blue Creek, Lower Klamath River Sub-basin, California (2007 – 2008).

Table 6. Surface particle size data from samples collected in lower Blue Creek, Lower Klamath River Sub-basin, California.

Site	D_{16} mm	D_{50} mm	D_{84} mm	Geometric Mean (dg)	Graphic Mean (mg)	Sorting Index (sg)	Skewness (sk)
XS 1	60	150	280	129.6	135.4	2.160	-0.190
XS 3	18	120	310	74.7	87.1	4.150	-0.333
XS 4	35	150	320	105.8	118.3	3.024	-0.315
XS 6	20	100	240	69.3	78.0	3.464	-0.295
XS 8	40	150	320	113.1	123.7	2.828	-0.271
XS 10	13	100	300	62.4	72.7	4.804	-0.300
XS 15	25	95	200	70.7	77.7	2.828	-0.284
XS 17	37	110	230	92.2	97.4	2.493	-0.193
XS 19	28	95	300	91.7	92.3	3.273	-0.030
XS 20	17	75	170	53.8	59.8	3.162	-0.289

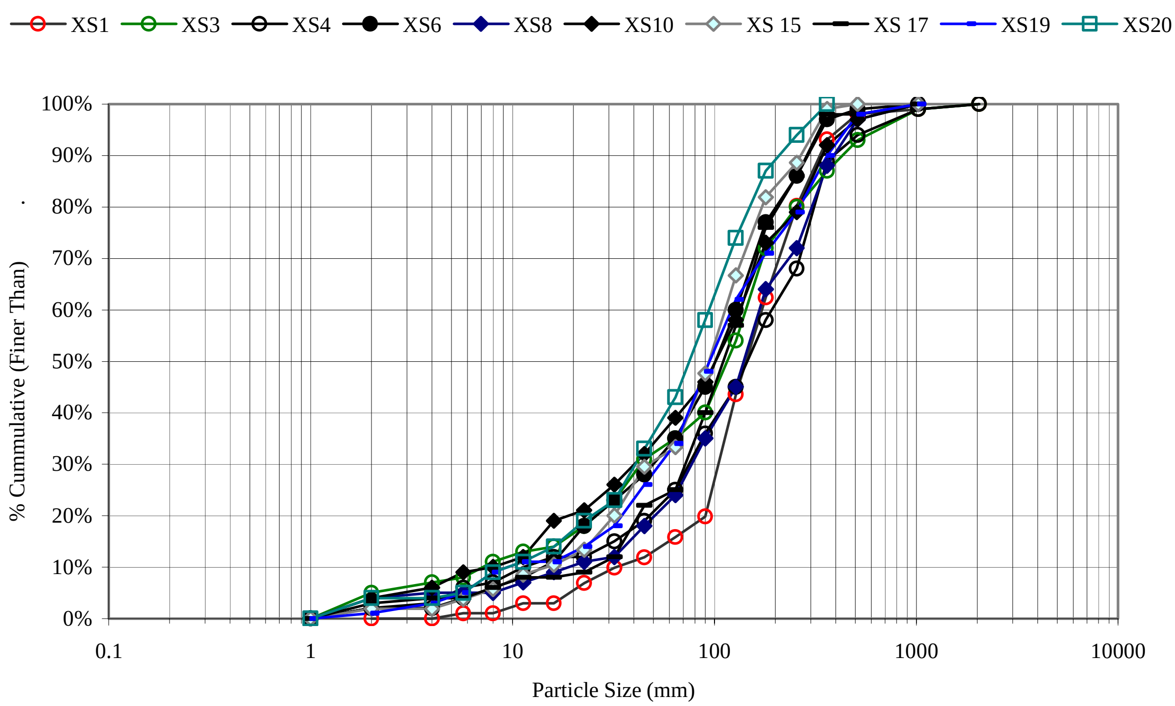


Figure 81. Surface particle size distribution for samples collected in lower Blue Creek, Lower Klamath River Sub-basin, California (2007 – 2008).

the lower-most cross section examined (XS 20) to 150 mm at cross sections located in the middle (XS 8 and XS 4) and the top of the reach (XS 1) (Table 6; Figures 69 and 81).

Kondolf and Wolman (1993) reviewed published and original size distribution data from salmonid spawning gravels (Table 7). They reported median diameters (D_{50}) for spawning gravels ranged from 5.4 – 78 mm with 50 percent of the median diameters ranging from 14.5 – 35 mm. Median diameters (D_{50}, dg, and mg) calculated from the surface sediment samples collected in lower Blue were large relative to those values presented by Kondolf and Wolman (1993) for chinook, coho, and steelhead spawning gravels (Tables 6 – 7). Seventy to ninety percent of the particles measured at riffle crests in lower Blue Creek were larger than the preferred size range (14.5 – 35 mm) presented by Kondolf and Wolman (1993) for salmonid spawning gravels (Figure 81).

Table 7. Published size distribution data from salmonid spawning gravels adapted from Kondolf and Wolman (1993); and surface particle size data from lower Blue Creek, Lower Klamath River Sub-basin, California.

Salmonid Species	n	Fish Length Range (cm)	D_{50} mm Range	Geometric Mean (dg) Range	Graphic Mean (mg) Range	Sorting Index (sg) Range	Skewness (sk) Range
steelhead	71	75 - 76	31 - 46	19.1 - 25.7	25.5 - 30.2	3.9 - 5.8	-0.2 - -0.5
coho	15	65	16.5 - 35	15.2 - 21	15.6 - 24.3	3.2 - 3.4	-0.07 - -0.44
chinook	24	81 - 101	16 - 54	12.7 - 39.5	13.6 - 43.7	2.2 - 3.9	-0.07 - -0.42
Blue Creek Data			75 - 150	53.8 - 129.6	59.8 - 123.7	2.16 - 4.80	-0.03 - -0.33

Key Limiting Factors in Lower Blue Creek

This study was part of the first phase of a larger-scale effort by YTFP to conduct comprehensive, multi-disciplined assessments and research in Blue Creek. The goal of these efforts is to develop and implement a prioritized watershed enhancement plan. The first phase allowed us to begin characterizing historic and existing physical and biological conditions in lower Blue Creek. The aerial image analysis, field mapping, and topographic surveys conducted in this phase allowed us to identify several factors that currently limit salmonid and riparian forest productivity in lower Blue Creek. Characterizing factors that limit Tribal Trust fish and wildlife resources and improving our understanding of how watershed processes and landscape disturbances influence these factors was critical for developing meaningful, restoration strategies in this dynamic system. The following is a discussion of the priority issues identified during this study.

Feral Cattle Populations

Based on the research conducted during this study, cattle were likely brought into the Blue Creek watershed during the mid-1800s to support the gold rush and homesteaders. Currently, several feral populations inhabit Blue Creek and many other Lower Klamath River watersheds (Figure 82) (Gale and Randolph 2000). Feral herds inhabiting lower Blue Creek have caused severe riparian degradation over the past several decades. Cows inhibit riparian plant survival and recruitment by browsing or trampling young trees and shrubs (i.e. 1 – 15 years) (Figure 83). A majority of young trees in the valley had evidence of cattle browse or trampling and were stunted in their development (Figure 84).

The lower Blue Creek herds have also caused substantial impacts to floodplain and terrace soils. The herds have developed extensive trail networks and compacted large areas of the valley floor through long-term, unmanaged grazing activities. The cows have also disturbed riparian soils by digging depressions for sleeping or to search for mineral deposits. These actions, carried out over several decades, have resulted in fairly degraded conditions for native riparian trees and shrubs and inhibited critical soil forming processes. Other long-term consequences of these unmanaged herds include degraded water quality at springs and ephemeral wetlands, reduced recruitment of wood and other organic materials to stream and floodplain habitats, diminished riparian canopy coverage and shade relief for stream habitats.

Stream and Floodplain Stored Wood

Industrial timber harvest has been occurring in the Blue Creek watershed since the mid-1950s. A majority of old growth conifers have been removed from lower Blue Creek and the area continues to be managed for industrial timber harvest (Figure 85). Although most of the upper watershed has various levels of protective status, timber harvest has occurred on the SRNF property. Harvested units remain in various states of recovery and would benefit from management activities such as thinning overcrowded stands, reducing brush and fuel loads to decrease fire hazards, and upgrading and decommissioning roads.

Field surveys conducted in the Blue Creek valley revealed a significant absence of small and large wood in the stream and on floodplain surfaces. This is likely a result of limited recruitment rates following large-scale timber harvest; and impacts associated with long-term, unmanaged grazing by feral cattle and firewood collection activities. Downed wood serves many different and critically important functions in a watershed. Channel stored wood can dramatically alter sediment storage and delivery dynamics, facilitate the formation and maintenance of critical salmonid habitats (i.e. spawning beds and pools), and provide cover for fish and other aquatic dependent species. Hillslope derived and channel stored wood plays a crucial role in floodplain forming processes. Accumulations of large wood were observed projecting from floodplain and terrace deposits at several locations. In many cases the trees growing at the surface had regenerated from the buried wood (Figure 86).

At three locations, radiocarbon dating of wood buried within floodplain and terrace deposits and dendrochronological evidence, indicated these features were formed in association with the major floods of the late 1800's (Helley and LaMarche 1969). Buried wood linked together by a network of live roots may be a key stabilizing element adding to the resiliency of valley landforms during and after flood events. Floodplain stored wood absorbs moisture during the wet season, releases it to the soil and nearby plants in the dry season, thereby improving growing conditions for seedlings and young trees. Floodplain stored wood eventually breaks down to form productive riparian soils. Field observations in lower Blue

Figure 82. Photographs of feral cattle on floodplains of lower Blue Creek, Lower Klamath River Sub-basin, California (2008).

Figure 83. Photographs of riparian vegetation trampled and damaged by feral cattle, Blue Creek, Lower Klamath River Sub-basin, California (2008).

Figure 84. Photographs of young cedar (top photographs) and cottonwood (bottom photographs) that have been damaged and stunted by feral cattle, Blue Creek, Lower Klamath River Sub-basin, California (2007).

Figure 85. Photographs of past harvest units in Blue Creek, Lower Klamath River Sub-basin, California (2008) (Note the old growth redwood located in the middle of the top photograph).

Figure 86. Photograph of buried wood and regenerated redwoods and associated conifers located in lower blue Creek, Lower Klamath River Sub-basin, California (2008).

Creek revealed that many of the native riparian trees were capable of regenerating from downed segments or from stumps (i.e. coastal redwood, big leaf maple, California bay, cottonwood, and willow) (Figure 87).

Valley Floor Evolution and Channel Degradation

The primary mode of instability and conversion of valley landforms was through channel avulsions that dissected floodplains and deposited coarse sediment onto low elevation surfaces (Slingerland and Smith 2004). Coarse sediment deposition (avulsion splays) generally occurred downstream of valley constrictions, and in the lower reach in areas where backwater effects from the Klamath River reduced the tractive force necessary to maintain sediment transport. The avulsion and deposition processes occurred repeatedly from 1958 – 1975, until an apparent reduction in sediment supply and a hiatus in geomorphically effective floods (Costa and O'Conner 1995) occurred from 1976 – 1988 (Figures 71, 73 – 74). The spate of floods between 1970 and 1975 resulted in a significant reduction in the proportion of established and mature floodplains and an increase in active channel planform area and

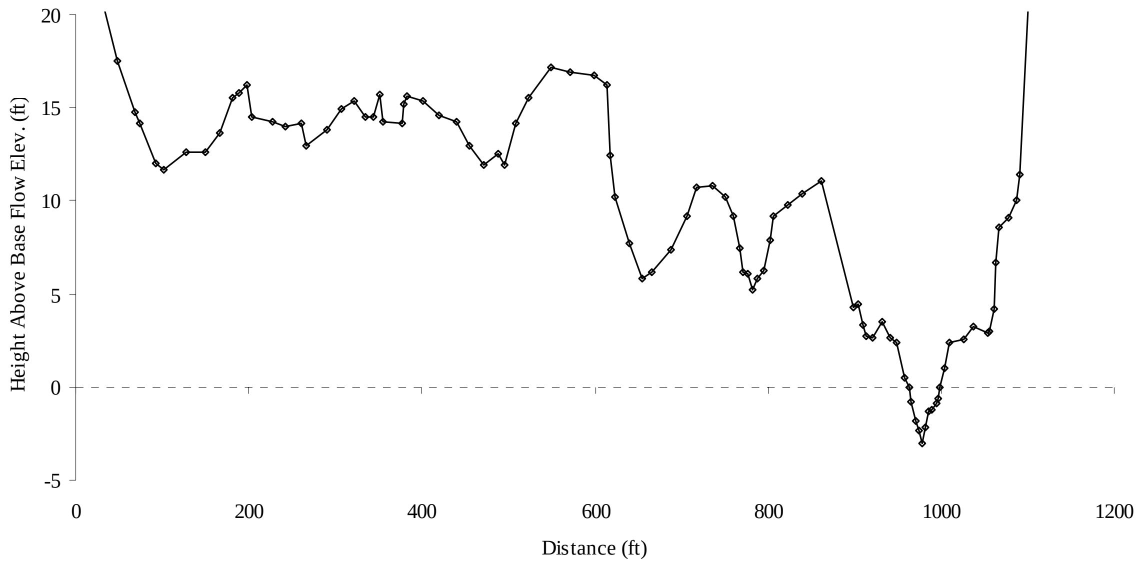
Figure 87. Photographs of young trees sprouting from downed cottonwood nurse logs (top photographs) and a redwood sprout growing from an old growth stump (bottom photograph), lower Blue Creek, Lower Klamath River Sub-basin, California (2007 – 2008).

incipient floodplain surfaces (Figures 72 and 76). From 1976 – 1988, the proportion of active channel planform and incipient floodplain area decreased while the proportional area of established and mature floodplains increased. This trend has continued through the duration of this study. The average long term turnover rates calculated for valley landforms in the Blue Creek study area (15 years) were 18 times greater than O'Conner et al. (2003) determined for the upper Quinalt River (277 years). The average recent (1975 to 2005) period rates in Blue Creek (32 years), while lower, were nearly 9 times greater compared with the upper Quinalt River.

Floodplain instability and channel degradation occurring in lower Blue Creek over the last decade resulted from a combination of watershed processes, land management activities, and large flood events occurring over the last 150 years. The channel has now incised into the coarse sediment deposits that filled the valley during the 1960s and 1970s. Long-term channel degradation will result in substantial reduction in floodplain connectivity with ever increasing flow magnitudes required to inundate adjacent floodprone surfaces (Figures 88 – 89). At cross section 19, the channel has degraded approximately 16.0 ft, since the end of the aggradational phase in 1975 (Figures 69 and 89). This cross section spans the upper ends of Black Bear and Pularvasar Flats, illustrating the sequential aggradation and degradation that has occurred, and the current separation between the baseflow water surface elevation and the ground surface. As the separation distance increases the water holding capacity of the coarse sediments will not be able to support a viable riparian. Mapping and other analysis indicate existing riparian habitats occur at three basic locations: 1) on 5a and 5b surfaces with mature cottonwood and conifers; 2) along preferential subsurface flow paths (buried channels) that include large woody debris; and 3) along the baseflow channel.

Long-term channel incision has resulted in coarsening of bed materials and likely reduced the amount of suitable salmonid spawning gravels in this reach. This was evident from the surface particle size analysis (Table 6; Figure 81). Results of the particle size analysis suggested that spawning gravels may also be limited in upstream reaches. Channel degradation and subsequent reductions in floodplain connectivity concentrates surface and subsurface flow paths, results in increased stream velocities, stream power, and sediment transport capacity and has several significant implications for salmonid and riparian productivity. Concentrated flows and high water velocities require adult and juvenile fish to expend more energy to sustain their position in the water column or to migrate upstream. During high flow events adult and juvenile salmonids migrate to areas protected from high velocity currents (i.e. backwaters, alcoves, or inundated floodplains) to conserve energy. These types of habitats become increasingly limited and hydrologically disconnected during periods of long-term channel incision.

The reduction in large wood recruitment to the fluvial corridor; and the changes in run-off regime (as a result of road building and timber harvest activities); have altered floodplain formation processes in lower Blue Creek. Repeated channel avulsion and valley mobilizing events occurring in lower Blue Creek and subsequent long-term channel incision has resulted in coarsening of floodplain sediments and decreased floodplain hydrologic connectivity. With rapid floodplain turnover rates the time required to i) re-establish robust riparian forests, that can, ii) recruit the size and quantity of woody material needed to decrease the



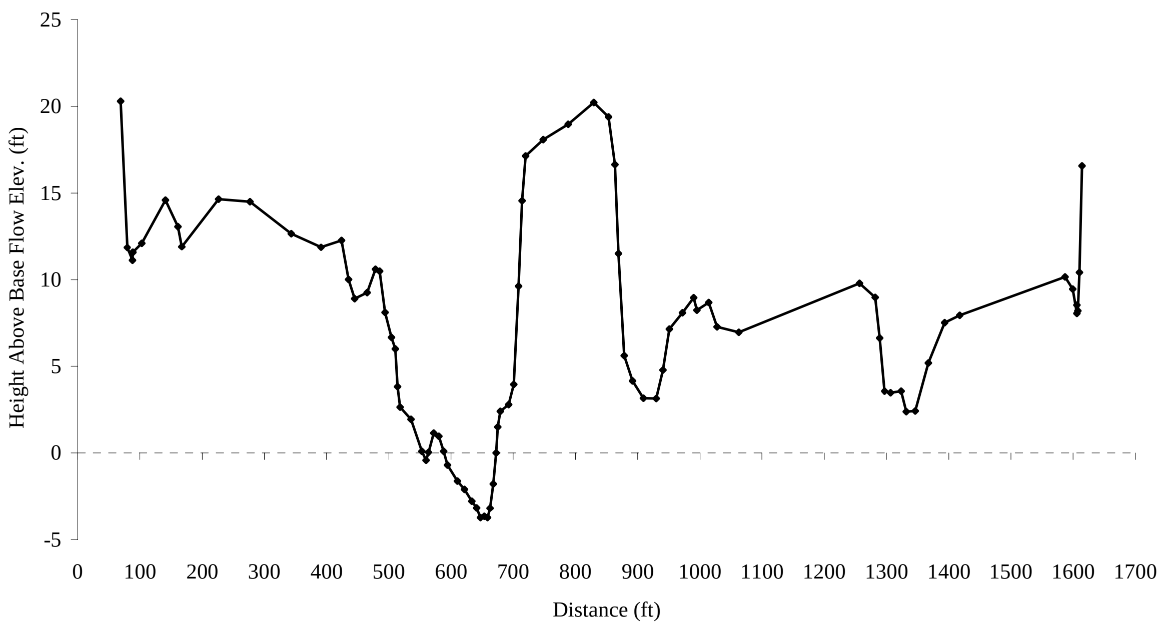


Figure 88. Cross section plots depicting elevations of floodprone surfaces relative to base flow elevations in lower Blue Creek, Lower Klamath River Sub-basin, California (2007 – 2008).

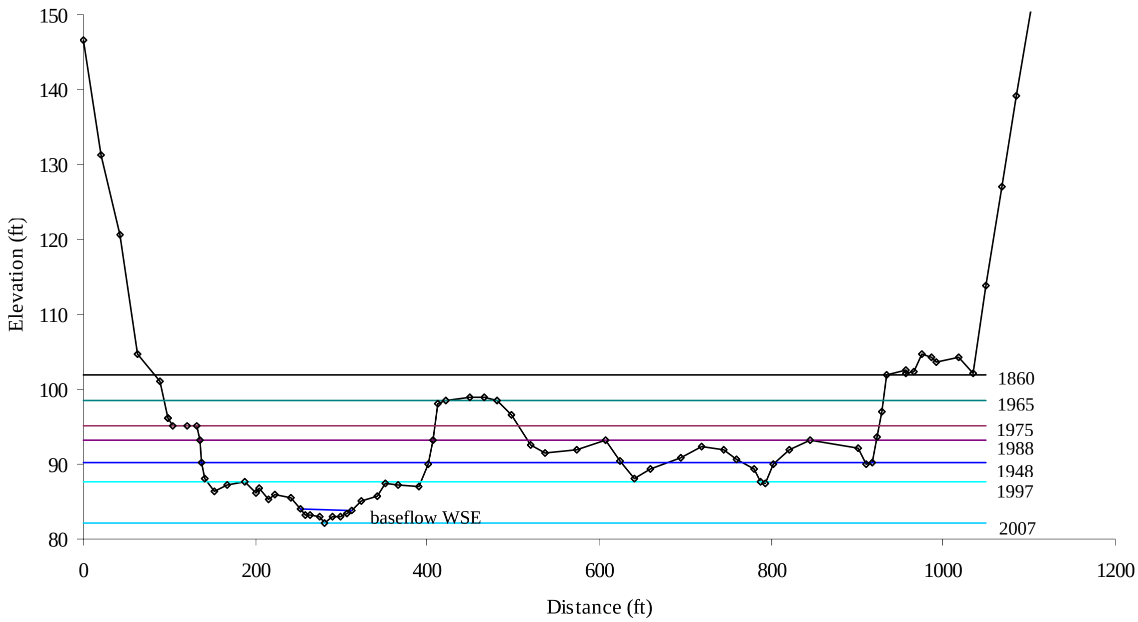


Figure 89. Sequential valley landform surface elevations at cross section 19 in lower Blue Creek, Lower Klamath River Sub-basin, California (2007 – 2008).

channel degradation rate is improbable. Rebuilding floodplain resiliency to floods and other disturbances will require a substantial re-introduction of large and small wood material into the fluvial corridor from hillslope sources until riparian supplies become available. The current floodplain and riparian dysfunction are clearly related to the depletion of large and small woody material and result in un-quantified impacts to Tribal Trust fish and wildlife resources of Blue Creek.

Blue Creek Recommendations

Blue Creek is a dynamic system that has undergone substantial impacts related to natural and anthropogenic disturbances. Yet, Blue Creek still provides the highest quality habitat for Tribal Trust fish and wildlife in the Lower Klamath River. Therefore, implementing watershed enhancement activities that promote processes that facilitate long-term benefits to the natural and cultural resources of this watershed is a top priority of YTFP. This first phase resulted in the development of several site specific treatment alternatives for lower Blue Creek. Restoration treatments primarily focused on floodplain habitats and riparian forests of lower Blue Creek. Strategies were developed in a manner that built on observed natural resilience and potential of treatment areas. The intended goals include promoting the geomorphic and biological conditions that facilitate complex, self-maintaining riparian forests and result in improved conditions for native fish and wildlife.

Flood events occurring over the last 150 years have resulted in extensive mobilization of valley floor sediments, led to substantial channel aggradation and widening, and removed critical streamside forests. Studies conducted throughout northern California suggest reestablishment of riparian forests in these widened systems is critical to restoring channel form and function. However, rehabilitating riparian forests in this type of setting is usually difficult given the harsh growing conditions and specialized methods are often required to reestablish robust forests. Therefore, treatment alternatives presented in this study were intended to function within existing constraints identified in lower Blue Creek.

Blue Creek is located in the Klamath Glen hydrologic sub-area (HSA), which was given the highest priority rating in the California Department of Fish and Game's *Recovery Strategy for California Coho Salmon* (CDFG 2004). Priority coho recovery task numbers addressed by this project included: KR-KG-06, KR-KG-14, and KR-KG-17. The restoration recommendations presented most closely addressed coho recovery task KR-KG-04. This task stated the need to develop a plan that would maintain Blue Creek and its major tributaries as key thermal refugia. Blue Creek provides the most significant thermal refugia areas for migrating adult and juvenile salmonids in the Lower Klamath River (Strange 2005; Beesley and Fiori 2007b). Task KR-KG-04 also stated that any plan developed for Blue Creek should emphasize the importance of continuing upslope stabilization and restoration activities, including road assessment and treatment, to reduce sediment impacts to critical thermal refugia; and implementing large-scale channel and riparian restoration efforts, including eradicating the feral cattle that currently inhabit the watershed (CDFG 2004).

For this study, we defined five potential treatment areas in lower Blue Creek: 1) the Campground Flat, 2) the Rain Gage Flat, 3) Black Bear Flat, 4) Pularvasar Flat, and 5) the Confluence Reach (Figure 90). These designations were based on existing geomorphic and hydrologic conditions, topography, and riparian vegetation. We also developed various restoration related recommendations to address watershed-level concerns.

Watershed Recommendations

Feral Cattle Populations

Eradicating the feral cattle populations in Blue Creek and adjacent watersheds is a priority restorative measure. This would entail developing a comprehensive plan and permission from GDRC and coordination with other pertinent stakeholders. Potential strategies include wide-spread hunting of local herds and using baited cattle pens with automated gate closing mechanisms to trap and remove individuals or small herds over time. Long-term observations of the cattle and knowledge of the terrain lead us to believe that attempts to round up or herd the cattle into large pens would likely fail. These cows tend to spook easily and scatter into dense riparian stands or cross Blue Creek. Eradication of the Blue Creek herd is not that likely given the number of successfully reproducing feral herds inhabiting the sub-basin. Therefore, eradicating feral cattle should be considered a long-term maintenance effort to ensure sustained resource protection. Implementing any riparian enhancement in lower Blue Creek prior to employing measures that would result in a substantial reduction to the feral herds is not recommended. The only other option would be to construct cattle

Figure 90. Map depicting designated restoration areas in Blue Creek, Lower Klamath River Sub-basin, California.

exclusion areas using fencing. This type of effort is labor intensive, aesthetically unpleasing, and likely difficult to maintain given the flood history of the valley.

Stream and Floodplain Stored Wood

Increasing recruitment of wood to stream and floodplain habitats throughout the watershed is another priority restorative measure. Adding large wood and constructing complex wood accumulations in priority mainstem and tributary habitats is also a priority restorative measure. Since the upper watershed remains relatively protected, efforts should mostly focus on mainstem and tributary habitats located downstream of the confluence of upper Blue Creek and the Crescent City Fork of Blue Creek (Figure 67). This type of activity should also be considered a long-term effort until natural recruitment rates increase as a result of watershed protection and improved timber harvest practices. GDRC is in the process of finalizing a Habitat Conservation Plan that calls for use of harvest practices that would allow increased recruitment and retention of wood to stream and floodplains.

As part of this initial planning phase we identified several sources of downed wood along the roads above the Blue Creek valley. Most of the wood was relatively small (i.e. < 1- 2 feet diameter and ≤ 20 feet in length) but many pieces had intact rootwads. This type of wood is great for use in riparian planting islands and for incorporating into instream large wood structures. Locating and securing the wood sources required to accomplish the restoration goals set forth in this document would be huge effort. Given the need for instream and floodplain wood through the watershed, more planning is required to prioritize all of the potential areas. The priority should focus on loading the anadromous reaches of Slide Creek and West Fork Blue Creek as mentioned previously. Feral cattle eradication efforts and future riparian enhancement of lower Blue Creek should facilitate increased wood recruitment to floodplain habitats and as long as those sources remain protected from wood gathering, the process should become self-maintaining. Employing this type of strategy would ultimately reduce the amount of wood required to meet watershed objectives. Complex wood accumulations comprised of large key logs interlinked with small woody debris facilitate the formation and maintenance of critical stream and floodplain habitats; improve growing conditions for newly recruited riparian vegetation; and can significantly alter sediment storage and delivery dynamics, thereby improving spawning and rearing conditions for native fish populations.

Upslope Enhancement

There is a critical need to increase the amount of upslope restoration that occurs annually in the Lower Klamath River Sub-basin. The Yurok Tribe will need to continue to work with GDRC, SRNF, and other stakeholders to address all high and medium priority roads identified in past and future upslope assessments of Blue Creek. Upslope road assessments should be updated in priority areas of Blue Creek to ensure future implementation programs are based on the best information possible. A sediment budget should also be constructed to quantify the dominant hillslope sediment sources in the watershed and improve on-going restoration planning and monitoring efforts. Assessing historic and current rates of sediment delivery to the fluvial corridor of lower Blue Creek is a priority restoration measure to allow informed management and restoration of the riparian forests of lower Blue Creek.

Landuse Status

Given the unique physical setting of Blue Creek, the quantity of salmonid habitat the watershed provides, and the cultural significance of the watershed to the Yurok People; the entire watershed should be protected from further timber harvest and road building activities. This would require a huge financial commitment to ensure the land would be managed in a way that resulted in improved watershed conditions and facilitated the biological and physical processes necessary for maintaining robust riparian forests and complex stream habitats. Increased watershed protection may be the only feasible way to generate enough recruited wood to begin reforming geomorphically effective wood accumulations throughout the watershed.

Treatment Area Recommendations

Campground Flat

In general, the Campground Flat is comprised of relatively high elevation surfaces that are not typically inundated during high flow events. The dominant vegetation classes of this area include Mature Conifer, Conifer Regeneration, and Mature Cottonwood (Figure 91). The primary restoration recommendations for this area include 1) protecting standing trees and downed wood sources; and 2) planting native conifers and cottonwoods to promote future wood recruitment and improved riparian forest conditions. The Campground Flat is used every summer by timber industry staff that work in the Blue Creek watershed. This land use activity results in a significant loss of downed wood sources to fuel campfires (Figure 92) and the accumulation of a substantial amount of trash each year. This activity should be more closely managed and campers should bring in firewood from approved sources to protect wood sources located in lower Blue Creek.

The most dynamic areas of the Campground Flat are the lower elevation floodplains located upstream of the Blue Creek bridge. The most effective restorative measure to address these floodplains would be to change the road and bridge configuration. The road and bridge significantly constrict the channel and concentrate the flow through an area that would naturally allow overbank flows to spread onto adjacent floodplains (Figure 93). To address this issue, YTFP obtained funding from the Bureau of Reclamation to conduct more detailed topographic surveys in the vicinity of the bridge to develop topographic and hydrologic models that will allow us to investigate potential designs that would result in improved floodplain connectivity and reduced channel incision.

Until the road related impacts are addressed, the lower elevation floodplains and associated riparian forests of the Campground Flat will likely remain in poor condition. An attempt could be made to plant these areas with native conifers, cottonwood, California bay, and willows. Trees should be planted in areas with good soil conditions (i.e. comprised mostly of

Figure 91. Photographs of terrace surfaces in lower Blue Creek, Lower Klamath River Sub-basin, California (2008).

Figure 92. Photographs of downed wood cut for firewood, lower Blue Creek, Lower Klamath River Sub-basin, California (2008).

Figure 93. Photographs of the habitats located adjacent to the Blue Creek bridge, Lower Klamath River Sub-basin, California (October 2007) (Flood flow at time of photographs approximately 10,000 cfs, following the 2008 water year peak flow of 18, 908 cfs).

sand and fine grained sediments) within existing riparian stands and/or directly downstream of wood accumulations. The adjacent riparian trees and downed wood provide the saplings with increased shade, nutrients, and soil moisture. Field observations conducted in many

Lower Klamath River tributaries revealed that riparian vegetation often establishes in the vicinity of roughness elements such as floodplain stored wood or established vegetation (Figure 94). We refer to this type of feature as a natural vegetation island or as a riparian planting island.

As a test, a limited number of trees could also be planted in the more open areas of the lower elevation floodplains. This would allow YTFP to assess the survival of planted trees to determine what methods and species achieved the best results. Other techniques to test include bending over young cottonwood, maple, bay, and willow trees or larger branches and burying them in shallow depressions comprised of mostly fine grained materials. This type of vegetation recruitment method was observed fairly often during field surveys of lower Blue Creek (Figure 87). As previously mentioned, the herds of feral cattle should be greatly reduced or eradicated prior to implementing large-scale riparian enhancement on floodplains and terraces of lower Blue Creek.

Rain Gage Flat

The Rain Gage Flat is comprised mainly of moderate to low elevation floodplains and limited higher elevation surfaces. Dominant vegetation classes included Upper and Lower Mixed Mesophytic and Mature Cottonwood (Figure 95). However, all of the vegetation classes identified in this study were found in the area. A few of the higher elevation surfaces located on the Rain Gage Flat support mature cottonwood and conifers. The type 5a terraces should protected from future harvest activities and forest improvement measures should be employed to promote conifer regeneration on these critically important surfaces.

A priority restorative measure for the Rain Gage Flat is to further characterize topographic and hydrologic conditions associated with the Blue Creek bridge and haul road. These data will be critical for developing hydrologic and topographic models for the site and potential design improvements. The current configuration results in substantial channel and flow path constriction, thereby causing a significant loss in floodplain connectivity (Figures 93 and 95).

Necessary improvements to the structure include 1) installing a bridge with a wider span to increase flow conveyance; and 2) incorporating multiple, oversized elliptical culverts in the road bed at or just above bankfull stage to improve hydrologic function in the reach and increase floodplain connectivity during moderate to high flows. These improvements would also likely reduce future flood related damage to the road and bridge due to the increased flow conveyance and improved hydrologic function at the site. This type of construction would be expensive but the long-term benefits to fish and riparian forests associated with the project would likely outweigh the costs.

Black Bear Flat

Priority restorative measures for this area include wood loading of the flat; constructing multiple, complex riparian planting islands in select areas, and increasing floodplain connectivity in certain areas to increase the amount of quality over-winter habitat available to native fish. Increasing the amount of wood rich, slow-velocity habitats for juvenile coho

Figure 94. Photographs of natural vegetation islands in riparian habitats of Terwer Creek (top photographs 2004) and Blue Creek (bottom photograph 2008), Lower Klamath River Sub-basin, California.

Figure 95. Photograph of lower Blue Creek, Lower Klamath River Sub-basin, California (October 2007) (Flood flow at time of photograph approximately 6,000 cfs, following the 2008 water year peak flow of 18, 908 cfs).

salmon is a high priority task identified in the Recovery Strategy for California Coho Salmon (CDFG 2004). More detailed topographic surveys and additional geomorphic and hydrologic assessments would be required to better determine the feasibility and cost effectiveness of this type of effort. Habitats that provide salmonids refuge from excessive velocities associated with high flow events are critical given the intensive channel incision occurring in lower Blue Creek. Increasing seasonal access to shallow, nutrient rich floodplain habitats will likely result in improved survival and growth of juvenile salmonids.

Access to Black Bear Flat by heavy equipment is more limited relative to the Campground Flat and the Rain Gage Flat. The most direct access to this area requires crossing the creek; however, YTFP will investigate alternative access options via abandoned logging roads on the west side of the valley during the next phase of planning.

Pularvasar Flat

The Pularvasar Flat has sustained considerable damage from natural and anthropogenic disturbances and long-term unmanaged grazing by feral cattle. Young trees in the area are severely stunted or damaged and recruitment of new trees in minimal, especially in the open grasslands (Figure 83). Cattle tend to occupy this surface in greater numbers relative to the other areas due to the increased seclusion and protection (i.e. forested escape routes) offered at this site. This is a high priority area for employing cattle eradication methods given the relatively high density of cows present in this area. Once the populations are greatly reduced, riparian enhancement measures should be employed in select areas on this flat. An effective strategy for reestablishing riparian forests in systems degraded by multiple valley floor mobilization events is to work from the valley side wall towards the more active surfaces. This would likely be a successful strategy to employ on the Pularvasar Flat given that the best growing conditions (i.e. fine grained, organic rich soils and established vegetation to provide shade and moisture) existed along the base of the valley side wall.

Planting areas should be selected based on local soil composition and moisture conditions and proximity to established vegetation and/or wood accumulations. A variety of native conifers and deciduous trees should be planted in these areas to assess survival and growth in this setting. Burying select cottonwood, maple, bay, and willow nurse trees and limbs would be the other primary technique to employ in these areas. The type 5a terraces located on Pularvasar Flat should be protected from future harvest activities and forest improvement measures should be employed to promote conifer regeneration on these critically important surfaces. Riparian growing conditions for mesophytic species appeared very favorable at the terrace bases relative to conditions in the adjacent open grasslands.

Constructing complex, wood rich planting islands in the more open areas located near the valley side walls may also prove effective in very select areas. The critical limiting factor for these more open canopy plantings will likely be the ability of the root systems to keep pace with groundwater recession during the low flow season. Access to this site by heavy equipment is difficult but could likely be accomplished using the existing and partially decommissioned road network located in the area. The road network would need to be winterized each year following summer restoration activities (i.e. constructing the planting islands). Once the use of heavy equipment becomes unnecessary, the road segments opened to access the site should be decommissioned. Road removal projects conducted in lower Blue Creek should employ full recontouring techniques where slope stability allows. This method provides both sediment reduction and hydrologic recovery of the groundwater system while other less intensive treatments only provide sediment reduction. Increasing hydrologic connectivity in coastal watersheds has become increasingly more important due to the effects related to global climate change (i.e. increased air temperatures, reduced annual snow accumulation, and decreased summer snow melt runoff events).

The Pularvasar Flat may be another place to implement strategies to increase floodplain connectivity and create higher quality over-winter habitats for native fish and other aquatic dependent species. The area to employ such strategies includes the confluence reach of Pularvasar Creek and Blue Creek. The area currently supports mature cottonwood, young conifers, and mesophytic vegetation. Potential strategies include enhancing the lower reach of Pularvasar Creek by improving channel form and function and creating complex, wood rich pools, alcoves, and backwater habitats. Increasing floodplain connectivity would also require lowering of adjacent aggraded surfaces.

Confluence Reach

The confluence of Blue Creek and the Klamath River is an extremely dynamic area and the channel occupying this reach is prone to high rates of lateral migration and braiding (Figures 77 and 90). The Confluence Reach has been actively eroding and a substantial amount of fine grained materials have been mobilized over the last few years (Figures 96 – 97). This area was designated as the lowest priority treatment area given the dynamic hydrologic processes and high rates of channel instability occurring in this reach. YTFP is hopeful that large-scale restorative actions implemented upstream of the Confluence Reach will result in improved hydrologic and geomorphic conditions at the mouth of Blue Creek. Blue Creek provides the most significant thermal refugia for migrating adult and juvenile salmonids in the Lower Klamath River (Strange 2005; Beesley and Fiori 2007b).

Figure 96. Photographs looking downstream towards the Klamath River (top photograph) and looking upstream at actively eroding banks (bottom photograph), lower Blue Creek, Lower Klamath River Sub-basin, California (2007).

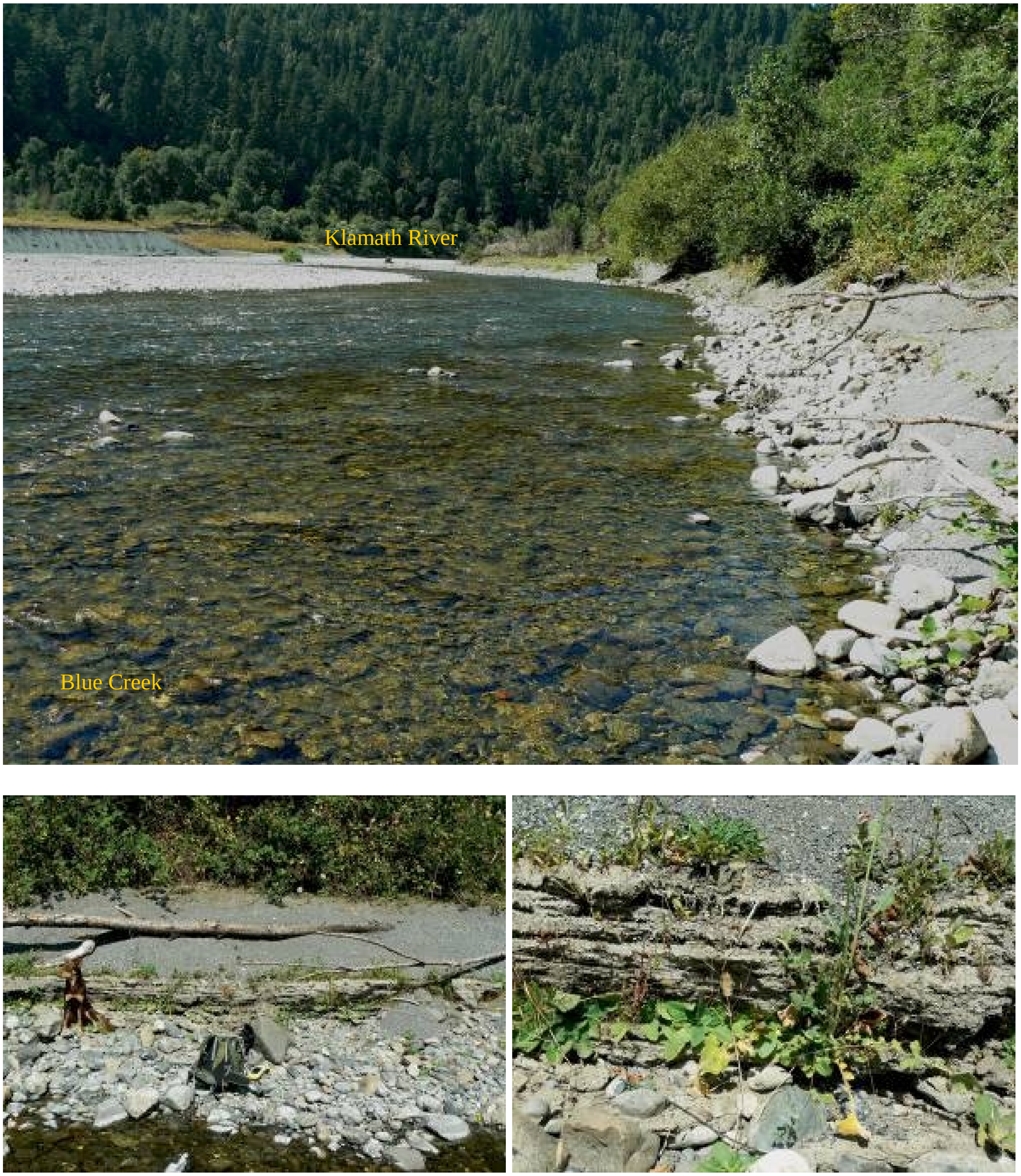


Figure 97. Photographs looking downstream towards the Klamath River (top photograph) and looking at the actively eroding banks (bottom photograph), lower Blue Creek, Lower Klamath River Sub-basin, California (2007).

References Cited

Abbe, T. and D.R. Montgomery. 1996. Large woody debris jams, channel hydraulics and Habitat formation in large rivers. Regulated Rivers: Research & Management. 12: 201-221.

Aalto, K.R. 2006. The Klamath peneplain: A review of J.S. Diller's classic erosion surface. In: Snoke, A.W. and C.G. Barnes (editors). Geological studies in the Klamath Mountains province, California and Oregon: A volume in honor of William P. Irwin: Geological Society of America Special Paper 410. Pp. 451-463.

Beechie, T.J., M. Leirmann, M.M. Pollock, S. Baker, and J. Davies. 2006. The dynamics of channel patterns and floodplains in forested mountain river systems. Geomorpology. 78: 124-141.

Beesley, S. and R.A. Fiori. 2004. Habitat Assessment and Restoration Planning in the Salt Creek Watershed, Lower Klamath River Sub-Basin, California. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Beesley, S. and R. Fiori. 2007a. Geomorphic and hydrologic assessment and restoration planning in the Salt Creek watershed, Lower Klamath River Sub-basin, California. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Beesley, S. and R. Fiori. 2007b. Lower Klamath River Tributary Delta and Subsurface Flow Study, Lower Klamath River Sub-basin, California. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Bull, W.B. 1979. Threshold of critical power in streams. Geological Society of America Bulletin. v.90, no. 5, p. 453 – 464.

CDFG (California Department of Fish and Game). 2004. Recovery Strategy for California Coho Salmon. Prepared for: California Fish and Game Commission. Prepared by: California Department of Fish and Game. Native Anadromous Fish and Watershed Branch. 1416 9th Street; Sacramento, California 95814.

Costa, J.E. and J.E., O'Conner. 1995. Geomophically effective floods. In: Costa, J.E., A.J. Miller, K.W. Potter, and P.R. Wilcock (editors). Natural and Anthropogenic Influences in Fluvial Geomorphology. American Geophysical Union. Geophysical Monograph 89. Pp. 45-56.

Diller, J.S. 1902. Topographic development of the Klamath Mountains. Washington, D.C., U.S. Geological Survey Bulletin 196.

FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem manangement: an ecological, economic, and social assessment. U.S. Department of Agriculture, U.S. Department of Commerce, U.S. Department of the Interior, and the U.S. Environmental Protection Agency, Portland, Oregon.

Gale, D.B. 2006a. Lower Terwer Creek Emergency Streambank Stabilization Project. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Gale, D.B. 2006b. Lower Terwer Creek Bioengineering Project. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Gale, D.B. 2007a. Lower Terwer Creek Riparian Restoration Project (Phase II). Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Gale, D.B. 2007b. Terwer Creek Bank Stabilization & Riparian Restoration Project. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Gale, D.B. 2007c. Terwer Creek Riparian Restoration Project. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Gale, D.B. 2008. Lower Terwer Creek Riparian Restoration Project (Phase III). Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Gale, D.B. and S.S. Beesley. 2006. Lower Terwer Creek Riparian Restoration Project (Phase I). Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Gale, D.B. and D.B. Randolph. 2000. Lower Klamath River sub-basin watershed restoration plan. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Graham Matthews and Associates. 2006. Hydrology, geomorphology, and stream channel changes in Hunter Creek, Del Norte County, California. Prepared for: Green Diamond Resources Company. Prepared by: Graham Mathews & Associates. P.O. Box 1516, Weaverville, California, 96093.

Helley, E.J. 1968. Field measurement of the initiation of large bed particle motion in Blue Creek near Klamath, California. U.S. Geological Survey Professional Paper 562-G.

Helley, E.J. and V.C. La Marche. 1969. December 1964 – A 400 year flood in northern California. U.S. Geological Survey Professional Paper 600-D. Pp. D34-D37.

Helley, E.J. and V.C. La Marche. 1973. Historic flood information for in northern California streams from geologic and botanical evidence. U.S. Geological Survey Professional Paper 485-E.

Hiner, M. 2008. Yurok Tribal Fisheries Program, Klamath, CA.

Hiner, M. and A. Brown. 2004. Monitoring and Evaluation of Current and Historical Physical Habitat Conditions, Water Quality, and Juvenile Salmonid Use of the Klamath River Estuary. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Irwin, W.P. 1997. Preliminary map of selected post-Nevadan geologic features of the Klamath Mountains and adjacent areas, California and Oregon. Reston, Virginia, U.S. Geological Survey Open-File Report 97-465.

Jain, V., K. Fryirs, and G. Brierley. 2007. Where do floodplains begin? The role of total stream power and longitudinal profile form on floodplain initiation processes. Geological Society of America Bulletin. 120(1/2): 127-141.

Kondolf, G.M. and M.G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research. 29(7): 2275-2285.

Laird, A. 2008. Historical planform study of the Klamath River estuary. Prepared for: Yurok Tribal Fisheries Program. Prepared by: Aldaron Laird. 980 7th Street, Suite K, Arcata, California 95521.

Nanson, G.C. and J.C. Croke. 1992. A genetic classification of floodplains. Geomorphology. 4: 459-486.

Nanson, G.C. and A.D. Knighton. 1996. Anabranching rivers: Their cause, character and classification. Earth Surface Processes and Landforms. 21: 217-239.

Nicholas, J.W. and D.G. Hankin. 1989. Chinook salmon populations in Oregon coastal river basins: descriptions of life histories and assessment of recent trends in run strengths. Oregon Department of Fish and Wildlife. No. EM 8402, March 1989. Oregon State University Extension Service, Corvallis, Oregon.

O'Connor, J.E., M.A. Jones, and T.L. Haluska. 2002. Flood plain and channel dynamics of the Quinault and Queets Rivers, Washington, USA. Geomorphology. 51: 31-59.

Poole, G.C., J.A. Stanford, C.A. Frissell, and S.W. Running. 2002. Three-dimensional mapping of geomorphic controls on flood-plain hydrology and connectivity from aerial photos. Geomorphology. 48: 329-347.

Reinfelds, I. and G.C. Nanson. 1993. Formation of braided river floodplains, Waimakariri River, New Zealand. Sedimentology. 40: 1113-1127.

Slingerland, R. and N.D. Smith. 2004. River avulsions and their deposits. Annual Review of Earth and Planetary Science. 32: 257-285.

Strange, J. 2005. Adult chinook salmon migration on the Klamath River Basin: 2005 sonic telemetry study final report. Yurok Tribal Fisheries Program. Weitchpec, California.

Taylor, D.W. 1982. Ecological survey of the Yurok Research Natural Area, California. Report to: Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

VanKirk, S. 2005. Transcription and summaries of historic newspaper articles regarding the Klamath River region: 1854 to 1954. Arcata, California.

Wolman, M.G. 1954. A method of sampling coarse river bed material. EOS Transactions of American Geophysical Union. 35(6): 951-956.

Wallace, M. 1995. The emigration timing of juvenile salmonids through the Klamath River estuary. In T.J. Hassler (Editor). Proceedings of the Klamath Basin Fisheries Symposium. March 23-24, 1994. Eureka, CA.

Wallace, M. 1998. Seasonal water quality monitoring in the Klamath River Estuary, 1991-1994. Administrative Report No. 98-9, Inland Fisheries Division, California Department of Fish and Game, Arcata, California.

Wallace, M. 2000. Length of residency of juvenile chinook salmon in the Klamath River estuary. Final Performance Report. Federal Aid in Sport Fish Restoration Act. Project F-51-R-7; Project No. 32; Job No. 5.

YTFP. In Progress. Investigations of juvenile salmonid use of Lower Klamath River and tributary habitats 2007 - 2008. Yurok Tribal Fisheries Program. PO Box 339; Klamath, California 95548.

Appendix A

Appendix A. List of aerial imagery used in by the Yurok Tribal Fisheries to assess lower Blue Creek, Lower Klamath River Sub-basin, California (1942 – 1948).

Date	Type	Comments
9/15/1942	B&W Image	Available images were rectified and reviewed but did not provide full coverage of study area.
6/22/1948	B&W Image	Available images were rectified to map study area.
7/25/1954	B&W Image	Available images were rectified and reviewed but did not provide full coverage of study area.
6/11/1956	B&W Image	Available images were rectified and reviewed but did not provide full coverage of study area.
9/18/1958	B&W Image	Available images were rectified to map study area.
8/30/1965	B&W Image	Available images were rectified to map study area.
9/13/1970	B&W Image	Available images were rectified to map study area.
~ Sept 1974	B&W Image	Available images were rectified and reviewed but did not provide full coverage of study area.
5/24/1975	B&W Image	Available images were rectified to map study area.
6/17/1985	Color Image	Available images were rectified and reviewed but did not provide full coverage of study area.
7/8/1988	Color Image	Available images were rectified to map study area.
6/12/1993	B&W DOQ	Available images were reviewed to map the study area.
5/8/1997	Color Image	Available images were rectified to map study area.
8/12/1998	B&W DOQ	Available images were reviewed to map the study area.
7/6/2004	Color Image	Available images were rectified to map study area.
6/23/2005	Color NAIP Mosaic	Available images were used to map study area.