Lower Klamath River Tributary Delta and Subsurface Flow Study, Lower Klamath River Sub-basin, California

Prepared by:

Sarah Beesley

Yurok Tribal Fisheries Program
PO Box 339
Klamath, CA 95548

And

Rocco Fiori
Fiori GeoSciences
PO Box 387
Klamath, CA 95548

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Captain Scott Gibson installing a well in lower Terwer Creek, 2005.

SCOTT CHARLES GIBSON 1978 – 2008

This report is dedicated to Scott Charles Gibson, who passed away unexpectedly on June 14, 2008. Scott worked for the Yurok Tribal Fisheries Program for nearly a decade. He was very passionate about his culture, the Klamath River, and the fish and wildlife of the area. He grew up in Mynot Creek near the Klamath River estuary and explored every inch of the lower river. Scott always shared his passion for the river and his knowledge of the area to anyone interested. It was such a pleasure and honor to be his field partner! Scott shared so much about his life on the river, he never got you lost, he always figured a way to rig the jet boat after breaking down upriver, and his smile was contagious. We miss him dearly and we'll carry him in our hearts always! AHOOO – Captain Scotty G!!

Introduction

Yurok People inhabiting the Lower Klamath have relied on the areas resources for their subsistence, cultural, and economic livelihood since time immemorial. The Yurok Tribe is the largest aboriginal tribe in the state of California and the Yurok people are amongst the few aboriginal inhabitants in California with a land base. What is now the Yurok Indian Reservation was created by federal actions between 1853 and 1891. The Reservation encompasses a strip of land one mile wide on each side of the Klamath River from just upstream of the confluence with the Trinity River at Weitchpec, California, to the confluence with the Pacific Ocean (Figure 1). Central to Yurok culture is the harvest of anadromous Klamath Basin fish populations.

Anthropogenic activities over the past century have resulted in substantial declines to Klamath Basin fish runs and have dramatically altered or degraded associated habitats. 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. Investigations conducted in many Lower Klamath River tributaries have documented substantial channel aggradation, channel widening, and loss of riparian forests due to historic logging and mining practices, large floods, and livestock grazing (Gale and Randolph 2000).

While surface flows usually provide adequate fish access to many Lower Klamath River tributaries during winter months, periods of subsurface flow often occur during the remainder of the year. Subsurface conditions are largely due to interactions of several natural and anthropogenic factors: timing of rainfall and river/tributary flows, excessive sedimentation emanating from tributaries, and the combination of sediment transport and backwater interactions between tributaries and mainstem Klamath. These interactions have resulted in the formation of large persistent gravel deltas at the mouths of many Lower Klamath River tributaries. Subsurface conditions and delta formation interrupt successful juvenile emigration in the spring, block adult immigration in the fall, inhibit immigration of non-natal juvenile salmonids in fall and spring, limit the quality and quantity of rearing habitat, increase competition and predation, alter composition of available food organisms, thereby reducing overall survival of salmonids from spawning to emigration.

Study objectives included:

- examining how rainfall events and river flows affect spatial and temporal patterns of surface flow, groundwater tables, and fish access conditions in Lower Klamath River tributaries;
- expanding on the Payne and Associates (1989) tributary delta study that estimated extent and causes of delta formation over the period 1936 – 1989 in Bear Creek, Tectah Creek, and Roaches Creek; and
- assessing summer water quality conditions at Lower Klamath River stations located in the vicinity of select tributary confluences to examine how surface flows and thermal patterns affect quality and quantity of mainstem habitats.

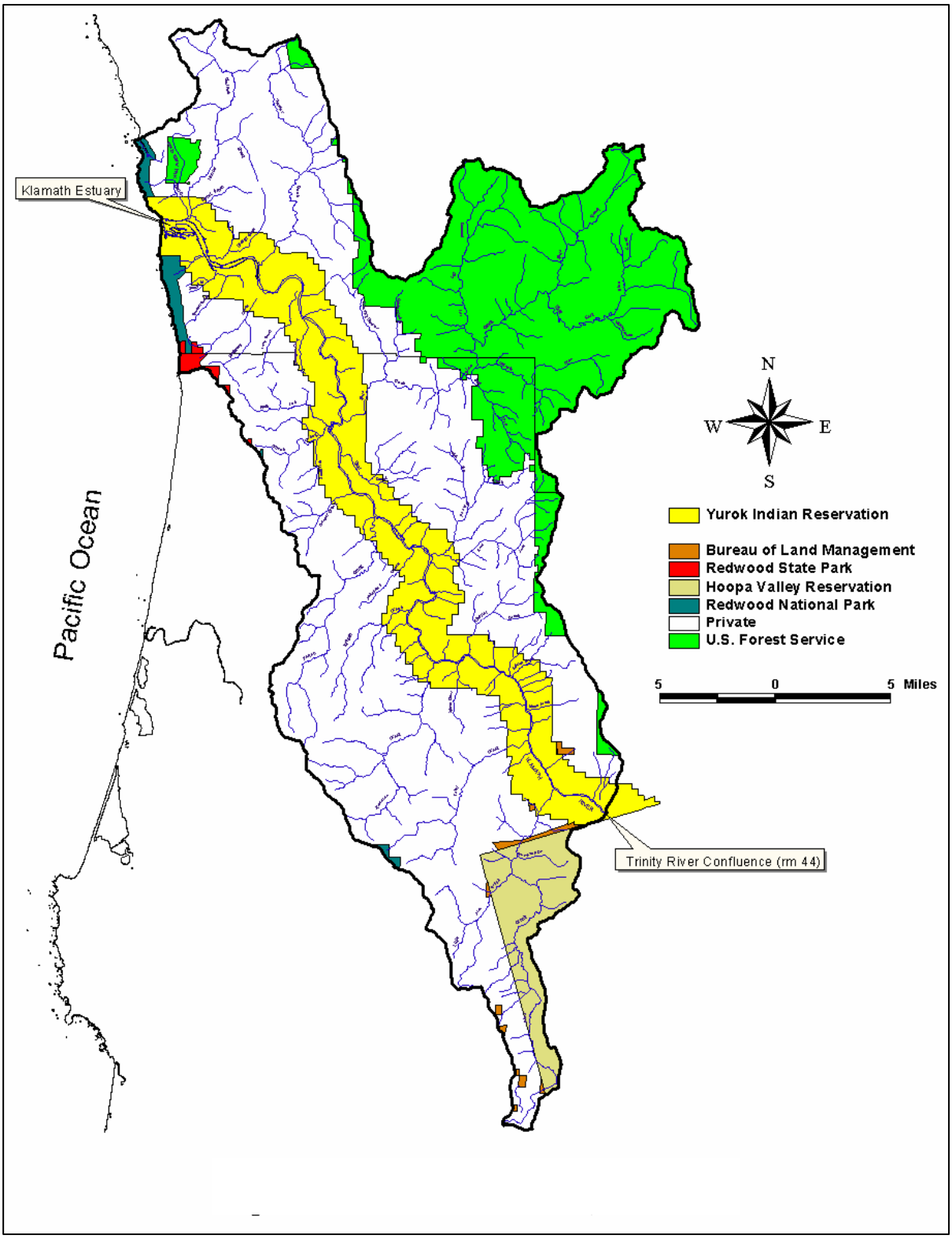


Figure 1. Map of the Lower Klamath River Sub-basin, California.

The primary goal was to use collected and historical data to begin developing water management and restoration related recommendations aimed at reducing impacts to Klamath Basin anadromous fish populations.

Study Area

The study area consisted of the lower reaches of 19 tributaries draining to the Lower Klamath River Sub-basin, California (Figure 1). Intensive surveys were conducted in Hunter Creek, Terwer Creek, McGarvey Creek, Blue Creek, Bear Creek, Tectah Creek, and Roaches Creek (Table 1; Figure 2). Refer to Gale and Randolph (2000) for a comprehensive overview of Lower Klamath River tributary habitats, fish presence and distribution, and land use history.

Table 1. Physical parameters for seven tributaries of the Lower Klamath River Sub-basin, California.

Watershed Name	Watershed Area Mi^2	Enters Klamath at River Mile	Stream Order	Dominant Channel Type	Average Canopy Closure
Hunter Creek	25.74	0.80	4th	C-4	81
Terwer Creek	31.84	5.63	4th	B-4	66
McGarvey Creek	8.85	6.38	3rd	C-4	92
Blue Creek	128.30	15.90	5th	C-2	68
Bear Creek	9.18	18.21	3rd	A-2	75
Tectah Creek	19.84	21.78	3rd	B-3	86
Roaches Creek	29.34	31.54	4th	B-2	78

Hydrology

Precipitation data for the study area was obtained from the California Department of Water Resources (CDWR) for the station: Klamath River near Klamath. This station is located on the north side of the Klamath River just upstream of the Terwer Creek confluence. A total of 72.92 inches of precipitation was recorded for water year (WY) 2004 (Figure 3). Precipitation began accumulating in early November with a fairly large event occurring in December 2003. Precipitation steadily accumulated from early December 2003 through mid April 2004. Very little precipitation was recorded from May – September 2004 (Figure 3).

A total of 64.72 inches of precipitation was recorded during WY 2005 (Figure 3). The temporal pattern of precipitation in WY 2005 was quite different relative to WY 2004. Rainfall events occurred in mid October and in December 2004 with very little precipitation occurring from mid January through late March 2005 (Figure 3). Storm events in late March – early April 2004 resulted in substantial precipitation. Very little precipitation was recorded from late June – September 2005 (Figure 3). Precipitation began in early October 2005 and continued steadily until February 2006 (Figure 3).

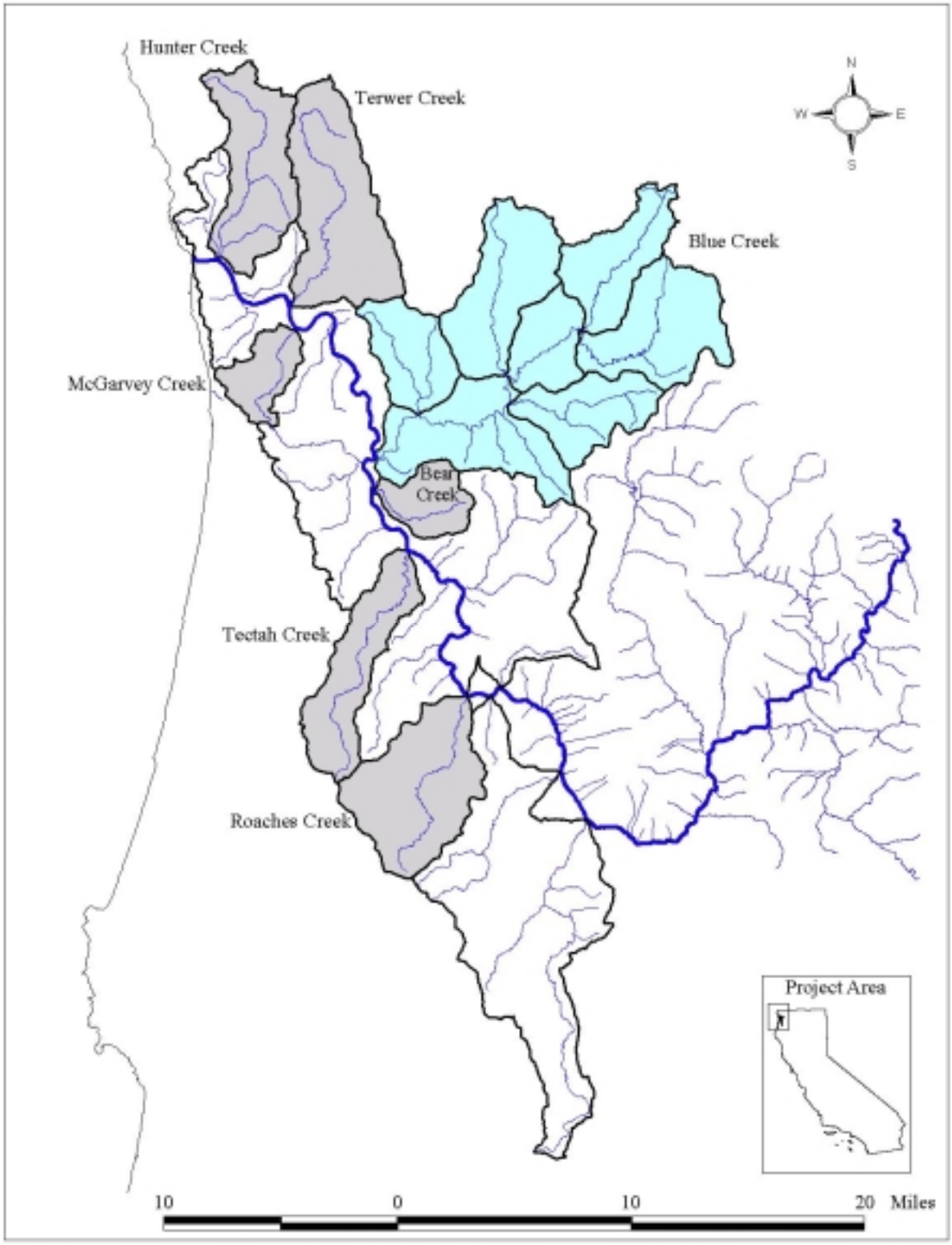


Figure 2. Map of the tributaries selected for intensive monitoring, Lower Klamath River Sub-basin, California.

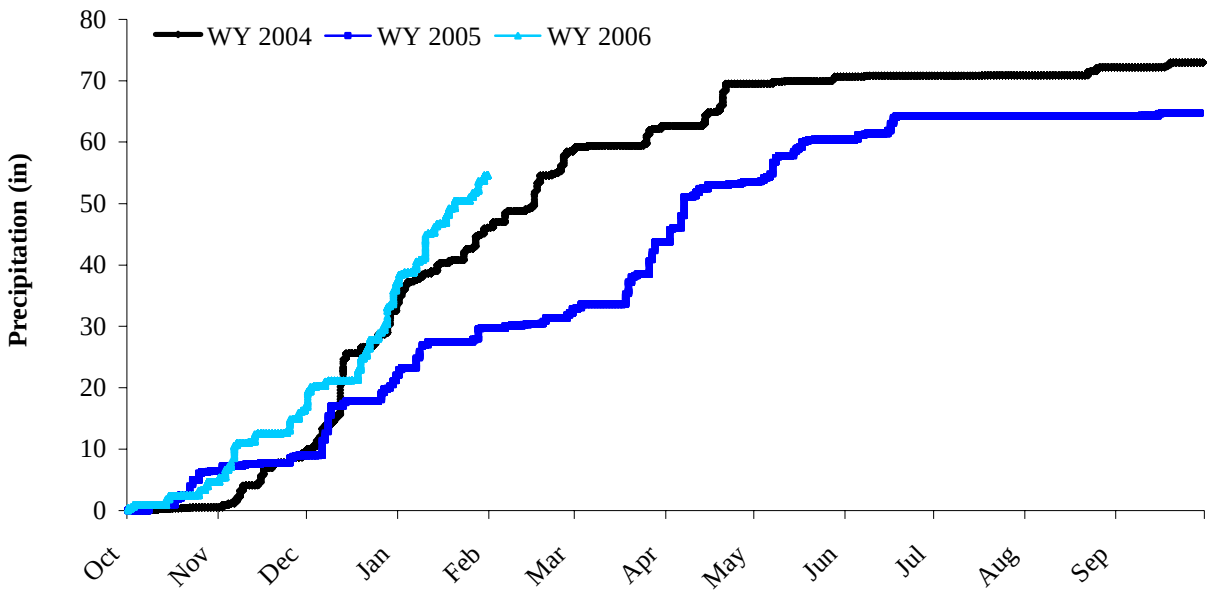


Figure 3. Cumulative precipitation data obtained from the California Department of Water Resources precipitation station: Klamath River near Klamath, for water years 2004 – 2005 and a portion of water year 2006.

Klamath River discharge data collected at the United States Geological Survey (USGS) gage station Klamath River near Klamath was obtained from both USGS and CDWR. Daily mean discharge data for WY 2004 was obtained from USGS (Figure 4). Daily mean discharge ranged from 2910 – 5210 cfs from October through late November 2003. Several moderate peaks occurred in mid December 2003 – mid February 2004 (Figure 6). The largest event of WY 2004 occurred on 18 February 2004 with a daily mean discharge of 174,000 cfs (Figure 4). One more moderate event occurred in late February 2004 but flows declined slowly from this point until early June 2004. Flows declined steadily after early June 2004 with a minimum daily mean of 2,440 cfs on 22 August 2004 (Figure 4). The peak in late August – early September 2004 resulted from rainfall and a managed flow release in the Trinity River for the Hoopa Valley Tribe's ceremonial Boat Dance.

Hourly Klamath River discharge data for the period 1 October 2004 – 30 June 2006 was obtained from CDWR (Figure 5). A small peak of 9,520 cfs occurred on 24 October 2004 but low flow conditions resumed until early December 2004 when storm events resulted in increased river flows. The early December storm event resulted in the largest flow of WY 2005 with a peak hourly discharge of 119,000 cfs (Figure 5). River flows dropped steadily after this event and although several small peaks occurred during January – mid March 2005, flows remained near 10,000 cfs. Several moderate peaks occurred and flows remained fairly high from mid March – June 2005 (Figure 5). Flows dramatically decreased through July 2005 and remained relatively low, ranging from ~3,500 – 2,500 cfs, through September 2005.

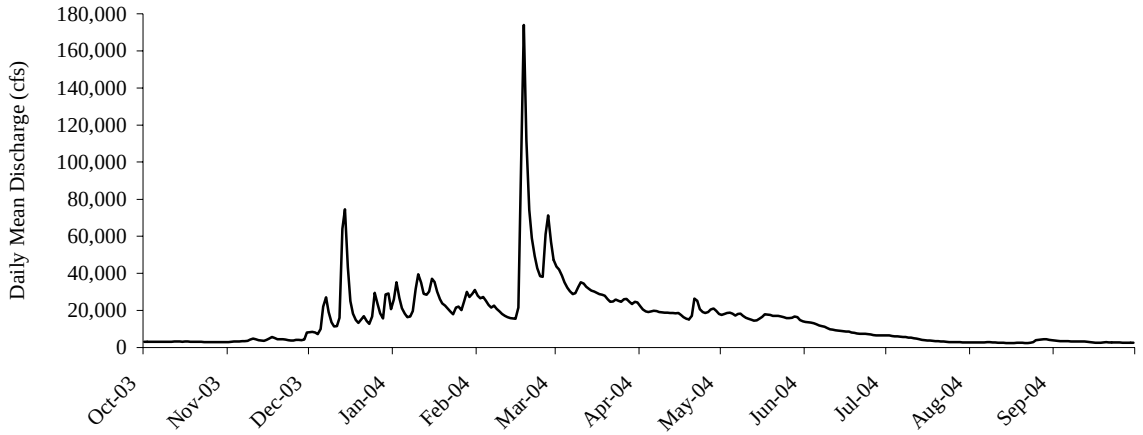


Figure 4. Daily mean discharge as reported by the U.S. Geological Survey for the Klamath River near Klamath gage for water year 2004.

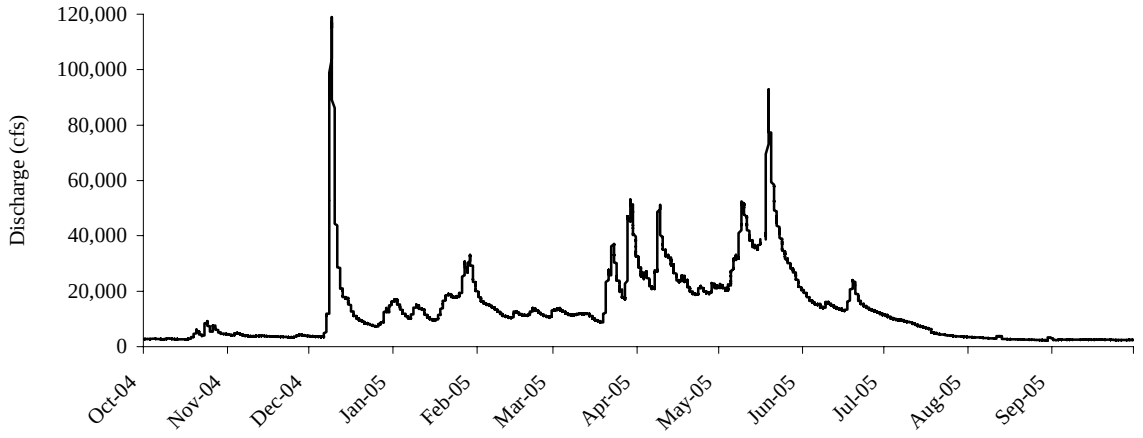


Figure 5. Klamath River discharge as reported by the California Department of Water Resources for the U.S. Geological Survey gage station: Klamath River near Klamath, for water year 2005.

Two small peaks occurring in mid and late August 2005 with the peak in late August resulting from a managed flow release in the Trinity River for the Hoopa Valley Tribe's ceremonial Boat Dance (Figure 5).

The first discharge peaks of WY 2006 occurred in early November with a maximum hourly discharge of 33,300 cfs occurring on 7 November 2005 (Figure 6). After this peak, flows declined and remained low until storm events in late November resulted in a peak discharge of 117,000 cfs on 2 December 2005 (Figure 6). Persistent rainfall resulted in several large magnitude flow events during December 2005 – January 2006 including the flood event estimated at over 470,000 cfs on 31 December 2005 (Figure 6).

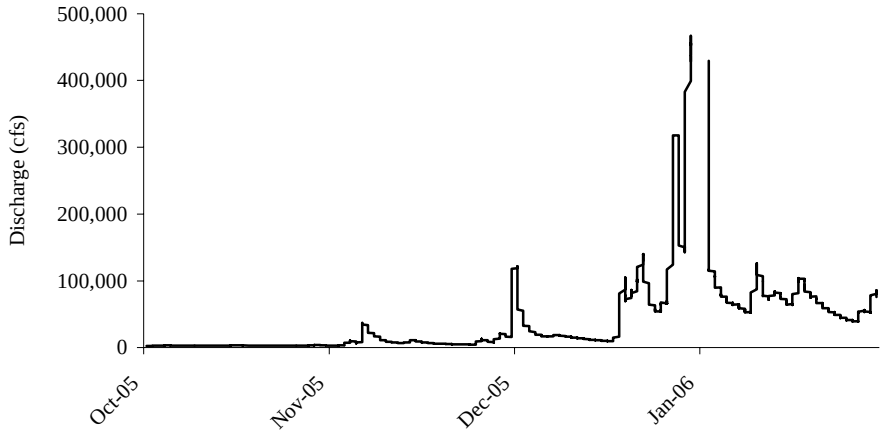


Figure 6. Klamath River discharge as reported by the California Department of Water Resources for the U.S. Geological Survey gage station: Klamath River near Klamath, for the period 1 October 2005 – 31 January 2006.

Methods

Tributary Delta Study: 1936 to 2004

In 1989, Payne and Associates examined causes of delta formation and changes in delta size through time for three Lower Klamath River tributaries: Bear Creek, Tectah Creek, and Roaches Creek. They assessed timing and magnitude of watershed disturbance and estimated the extent and causes of delta formation over the period 1936 – 1989 using aerial photographs and topographic survey data. They attributed delta formation and changes in size to interactions between watershed disturbance, tributary erosion rates, and the timing and magnitude of tributary watershed flood peaks relative to those of the Klamath River. They also estimated Klamath River discharges capable of inundating study deltas and reviewed USGS stream gage records (1967 to 1987) to estimate earliest fall season dates where fish access through deltas may have been facilitated by river inundation.

To better understand existing tributary delta and fish passage conditions at Lower Klamath River tributaries, we employed similar methodologies presented in Payne and Associates (1989) for Bear Creek, Tectah Creek, and Roaches Creek (Figure 7). Unfortunately, the exact set of aerial photographs used in the 1989 study could not be obtained for this study. Aerial photographs from 1948 – 2004 were used to estimate tributary delta extent in Tectah Creek and Roaches Creek to expand on the work of Payne and Associates (1989). We were unable to repeat aerial photograph analysis in Bear Creek. Poor image resolution, contrast, and river flow elevations made it difficult to consistently distinguish tributary delta deposits from Klamath River bar deposits.

Aerial photographs were scanned as high resolution TIFF files and rectified to the 1993 Digital Orthophoto Quarter Quadrangles (DOQQs) using ArcView GIS. Tributary delta features and channel patterns were mapped by reviewing the series of aerial photographs and

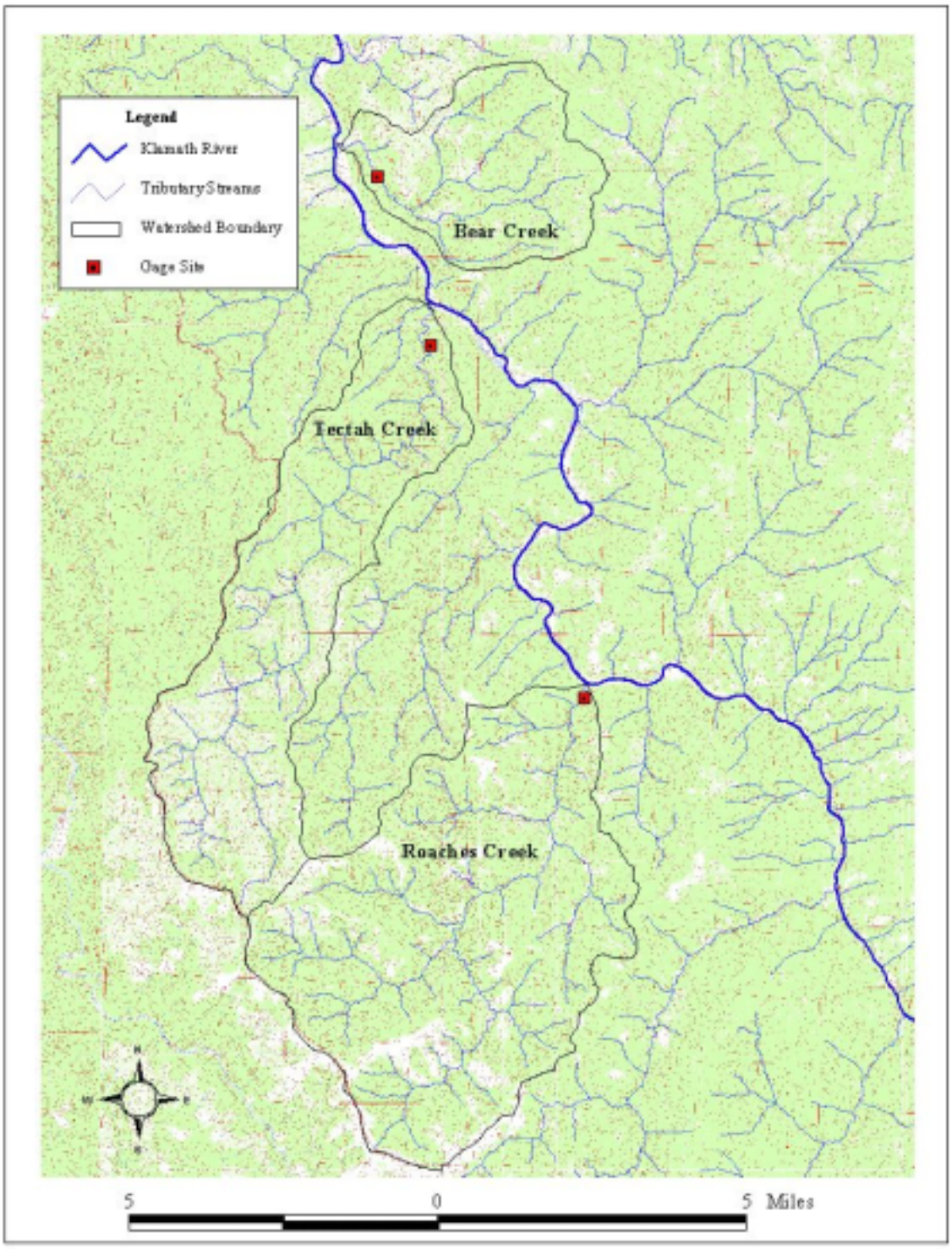


Figure 7. Map of the streams selected for monitoring tributary delta formation and extent in the Lower Klamath River Sub-basin, California.

DOQQs and heads-up digitizing features into an ArcView GIS project. Discrepancies in spatial accuracy were improved by mapping on the rectified aerial photographs (RAPs) and adjusting the delineation to the 1993 DOQQs. We defined the upper boundary of each delta as the location where the distance between the tributary valley side walls expanded in the vicinity of the Klamath River confluence.

Three-dimensional topographic surveys of critical tributary delta features and stream channel long profiles were conducted in Bear Creek, Tectah Creek, and Roaches Creek in summer 2004. Surveys were conducted with a Nikon optic total station to develop topographic and tributary delta inundation models and to calibrate aerial image mapping with ground based observations. To relate topographic data collected on multiple surveys, reference benchmarks were established at each tributary confluence on 18 May 2004 and mapped using a high precision GPS unit. Survey data was imported into ArcView 3.2 for spatial analysis. Stream cross sections and longitudinal profiles were plotted using Microsoft Excel.

Klamath River water surface elevations through the delta reaches of Bear Creek, Tectah Creek, and Roaches Creek were surveyed periodically during May – June 2004 and in April 2005 using a survey level and rod. All surveys were tied to the reference benchmarks established at each tributary. Plots of water surface elevation to daily mean discharge (obtained from the USGS gage site: Klamath near Klamath) were generated for each tributary using Microsoft Excel. Least-squares regression was used to determine the line of best fit relating Klamath River water surface elevation at each tributary delta and daily mean discharge for the Klamath River. These relationships were used to develop delta inundation models to assess times of year when mainstem flows facilitated fish access to tributary habitats. For each tributary, water surface elevations at specific Klamath River flow magnitudes were plotted along with the surveyed delta profiles from 2004 using Microsoft Excel. The 2004 plots were then compared with the flow inundation models presented in Payne and Associates (1989).

Tributary Connectivity Monitoring

Assessments of river/tributary connectivity and fish passage conditions for all salmonid life history stages were conducted at the mouths of 18 Lower Klamath River tributaries (Figures 1 and 8). Crews observed tributary confluences via jet boat to document flow conditions (a qualitative observation of high, medium, low, or dry), and assess the feasibility of adult and juvenile salmonid passage. Surface flows persist year round at the mouth of Hunter Creek, therefore assessment of flow and fish passage conditions were assessed at a location upstream of U.S. Highway 101.

Objectives of this component included documenting times of the year when fish access was questionable or prevented and when tributary flows went subsurface at the mouth. While there was some subjectivity as to when fish access was hindered under low flow conditions, the staff involved in this project had several years experience in the Lower Klamath assessing adult and juvenile salmonid passage at tributary barriers and culverts. As a result, our professional judgment was assumed to adequately reflect when access was hindered or prevented due to low flows.

McGarvey Creek Mouth RM 6.3

Tarup Creek Mouth RM 9.0

Omagaar Creek Dry Mouth RM 10.5

Blue Creek Mouth 15.9

Ah Pah Creek Mouth RM 17.2

Bear Creek Mouth RM 18.2

Figure 8. Photographs of select Lower Klamath River tributary confluences monitored for fish passage by the Yurok Tribal Fisheries Program, California (19 March 2004).

Surpur Creek Mouth RM 20.2

Little Surpur Creek Mouth RM ~21
Mouth at willows in center of Photograph

Tectah Creek Mouth RM 21.7

Johnson's Creek Mouth RM 24.0

Pecwan Creek Main Channel Mouth
RM 24.9

Mettah Creek Mouth RM 28.5

Figure 8. Continued.

Roaches Creek Mouth RM 31.5

Morek Creek Mouth RM ~32

Ka'pel Creek Mouth RM 33.0

Figure 8. Continued.

Surveys were conducted bi-weekly from December 2003 – March 2004 and weekly from April – December 2004. The same sampling protocol was followed during the period January – December 2005. Surveys were conducted in a similar manner by YTFP during the period 1996 - 1999. Little Surpur Creek was not assessed in 1996. Tully Creek and Pine Creek were assessed during 1996 – 1999 but were not assessed in 2003 – 2005 due to difficulties navigating a rapid located on the Klamath River downstream of Tully Creek.

Intensive Subsurface Flow Monitoring

Select Lower Klamath River tributaries were intensively monitored to document the temporal and spatial pattern of subsurface flows occurring in these streams. Study tributaries included: Hunter Creek, Terwer Creek, McGarvey Creek, and Tectah Creek (Figure 2). These streams were selected to represent a range of stream types existing in the Lower Klamath. Crews conducted foot surveys of channel reaches known to experience subsurface flow and documented locations of flowing and dry reaches in each tributary using a high precision GPS unit and USGS topographic maps. Surveys were generally conducted from May

through late fall (Table 2). However, crews also surveyed the streams outside of this period when tributary and/or mainstem flows were considered low or questionable. A GIS database documenting subsurface conditions was developed from collected GPS and survey data and imported into ArcView 3.2 for spatial analysis.

Table 2. Schedule of intensive subsurface flow surveys in the lower reaches of select Lower Klamath River tributaries, California (2004 - 2005).

Time Frame	Watershed	Survey Schedule
April	Hunter Creek, Terwer Creek	Bi-Weekly
May - Mid July	Hunter Creek, Terwer Creek	Weekly
Mid July - September	Hunter Creek, Terwer Creek	Bi-Weekly
October - November	Hunter Creek, Terwer Creek	Weekly
May	Tectah Creek	Bi-Weekly
June - July	Tectah Creek	Weekly
August - September	Tectah Creek	Bi-Weekly
October - November	Tectah Creek	Weekly
July	McGarvey Creek	Bi-Weekly
August - October	McGarvey Creek	Weekly
November	McGarvey Creek	Bi-Weekly

Tributary Water Table Monitoring

Groundwater elevations were monitored in Terwer Creek, McGarvey Creek, and Tectah Creek to examine the interaction of rainfall and Klamath River flow levels with local tributary water tables and surface flows. Wells consisted of sections of inch and a quarter diameter, galvanized metal pipe attached to a perforated well point (inch and a quarter diameter by three feet long) (Figure 9). At each well location, a starter hole was excavated and the well point with one section of pipe was inserted. A drive cap was placed on the last pipe section and driven into the ground using a steel post driver or a sledge hammer (Figure 9). Care was taken to keep the first sections of the well as vertical as possible. Sections of pipe were added and driven into the ground until the desired depth was achieved. A section of two-inch diameter pipe connected to a metal security box was added to select wells to house water level loggers. Galvanized end caps were used to secure the remaining wells (Figure 10).

Wells were established at five locations in Terwer Creek in early May 2005 and water stage was monitored weekly using a hand-held water level indicator (Figure 11). Water level loggers were placed in two of the wells (TC Well 1, TC Well 4) in late May after tributary and mainstem Klamath River flows subsided enough to allow access. A third logger was placed at the upper most well (TC Well 5) in Terwer Creek on 17 June 2005. Unfortunately,

Figure 9. Supplies used to construct and install monitoring wells and Wiley (Left) and a well installation in Terwer Creek (Right), tributary to the Lower Klamath River Sub-basin, California.

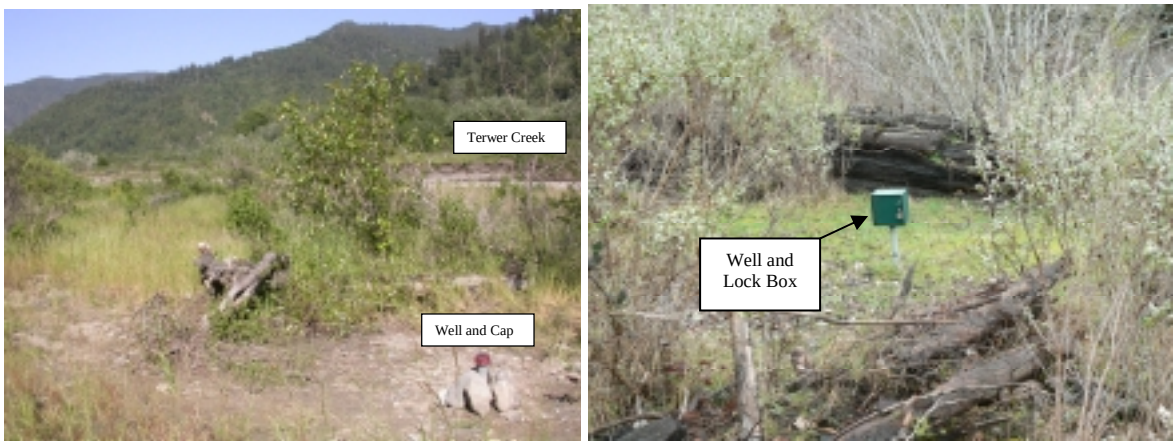


Figure 10. Photographs of groundwater monitoring wells located in Terwer Creek, tributary to the Lower Klamath River Sub-basin, California.

Figure 11. Location of groundwater monitoring wells in Terwer Creek, Lower Klamath River Sub-basin, California. Base image: portions of the 2005 NAIP imagery, 1 meter resolution.

the lower most well (TC Well 1) was vandalized and the logger was stolen in July 2005. The well was repaired on 3 August 2005 and water stage was monitored weekly using the hand-held indicator. Terwer Creek and Klamath River water surface elevations were surveyed near each well during spring and summer using a precision laser level. A longitudinal profile of the channel from the upper most well to the junction with the Klamath River was surveyed on 31 October 2005. The loggers at TC Well 5 and TC Well 4 were retrieved on 6 November 2005 after substantial rainfall and increased tributary flows.

Two wells (MG Well 1, MG Well 2) were installed near the mouth of McGarvey Creek on 8 June 2005 and a water level logger was placed in the lower well (MG Well 1) on 24 June 2005 (Figure 12). Two additional wells (MG Well 3, MG Well 4) were installed upstream of MG Well 1 and MG Well 2 in July 2005 (Figure 12). McGarvey Creek and Klamath River water surface elevations along with well and water table elevations were surveyed in early summer using a precision laser level. The logger at MG Well 1 was retrieved on 6 November 2005 and the well was capped to avoid flooding by the Klamath River.

Two wells (Tectah Well 1, Tectah Well 2) with water level loggers were also installed near the mouth of Tectah Creek in late June 2005 (Figure 13). Tectah Creek and Klamath River water surface elevations were surveyed during spring and summer using a precision laser level. Loggers were retrieved from Tectah Creek wells on 9 November 2005 after substantial rainfall had occurred and tributary flow was moderately high.

Tributary Confluence Water Quality Monitoring

Water quality conditions were monitored at four priority Lower Klamath River tributary confluences: McGarvey Creek (Figure 14), Blue Creek (Figure 15), Tectah Creek (Figure 16), and Roaches Creek (Figure 17) from July – early October 2005 to document conditions available for migrating salmonids. Sampling stations were established in the Klamath River in the vicinity of each tributary confluence in July 2005 and monitored ~monthly for water temperature and dissolved oxygen using a hand-held YSI 85 Meter. Measurements at a given station were taken just below the water surface and at select depth intervals to the river bottom. A precision GPS unit (<0.5 meter resolution) was used to record station locations and to navigate to the same monitoring stations on every survey.

Water Temperature Monitoring

Water temperature was monitored every half hour at several locations in the Klamath River to document thermal conditions during summer 2005. Continuously recording temperature loggers were placed in the Klamath River downstream of the Coon Creek confluence; at the Roaches Creek confluence and downstream of Roaches Creek; and upstream of the Tectah Creek confluence, at two locations near the tributary confluence, and downstream of Tectah Creek. Water temperature was also monitored every hour in lower Roaches Creek and lower Tectah Creek during summer 2005 to document tributary thermal conditions. Daily mean water temperatures for each monitoring site were calculated from the continuous data.

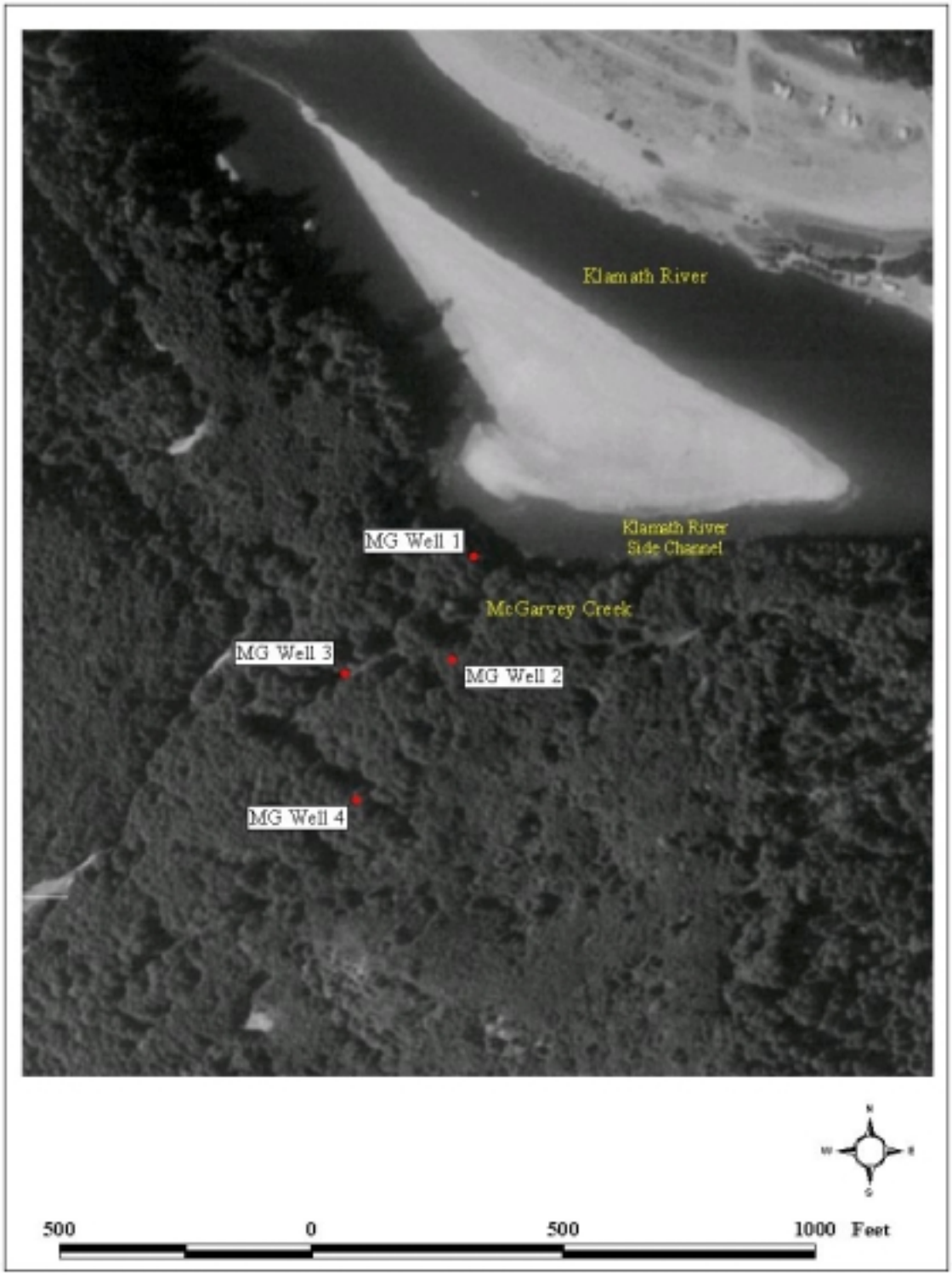


Figure 12. Location of groundwater monitoring wells in McGarvey Creek, Lower Klamath River Sub-basin, California. Base image: portions of the 1998 U.S. Geological Survey Fern Canyon and Ah Pah Ridge digital orthophoto quarter quadrangles.

Figure 13. Location of groundwater monitoring wells in Tectah Creek, Lower Klamath River Sub-basin, California. Base image: rectified aerial photograph, flight date 6 July 6 2004.

Figure 14. Location of Klamath River water quality monitoring transects established in the vicinity of the confluence with McGarvey Creek, Lower Klamath River Sub-basin, California. Base image: portions of the 1998 U.S. Geological Survey Fern Canyon and Ah Pah Ridge digital orthophoto quarter quadrangles.

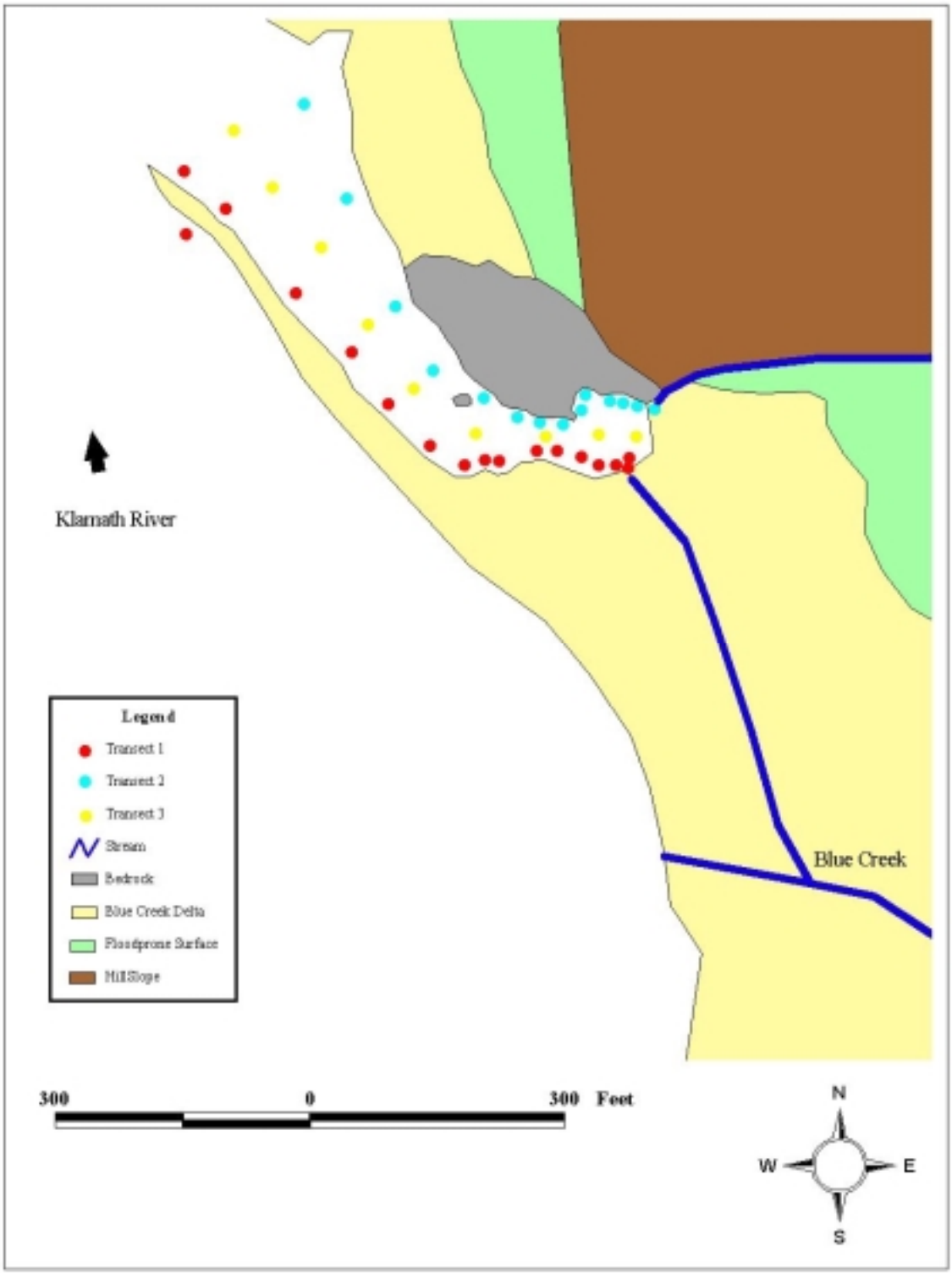


Figure 15. Location of Klamath River water quality monitoring transects established in the vicinity of the confluence with Blue Creek, Lower Klamath River Sub-basin, California.

Figure 16. Location of Klamath River water quality monitoring transects established in the vicinity of the confluence with Tectah Creek, Lower Klamath River Sub-basin, California. Base image: rectified aerial photograph, flight date July 6, 2004.

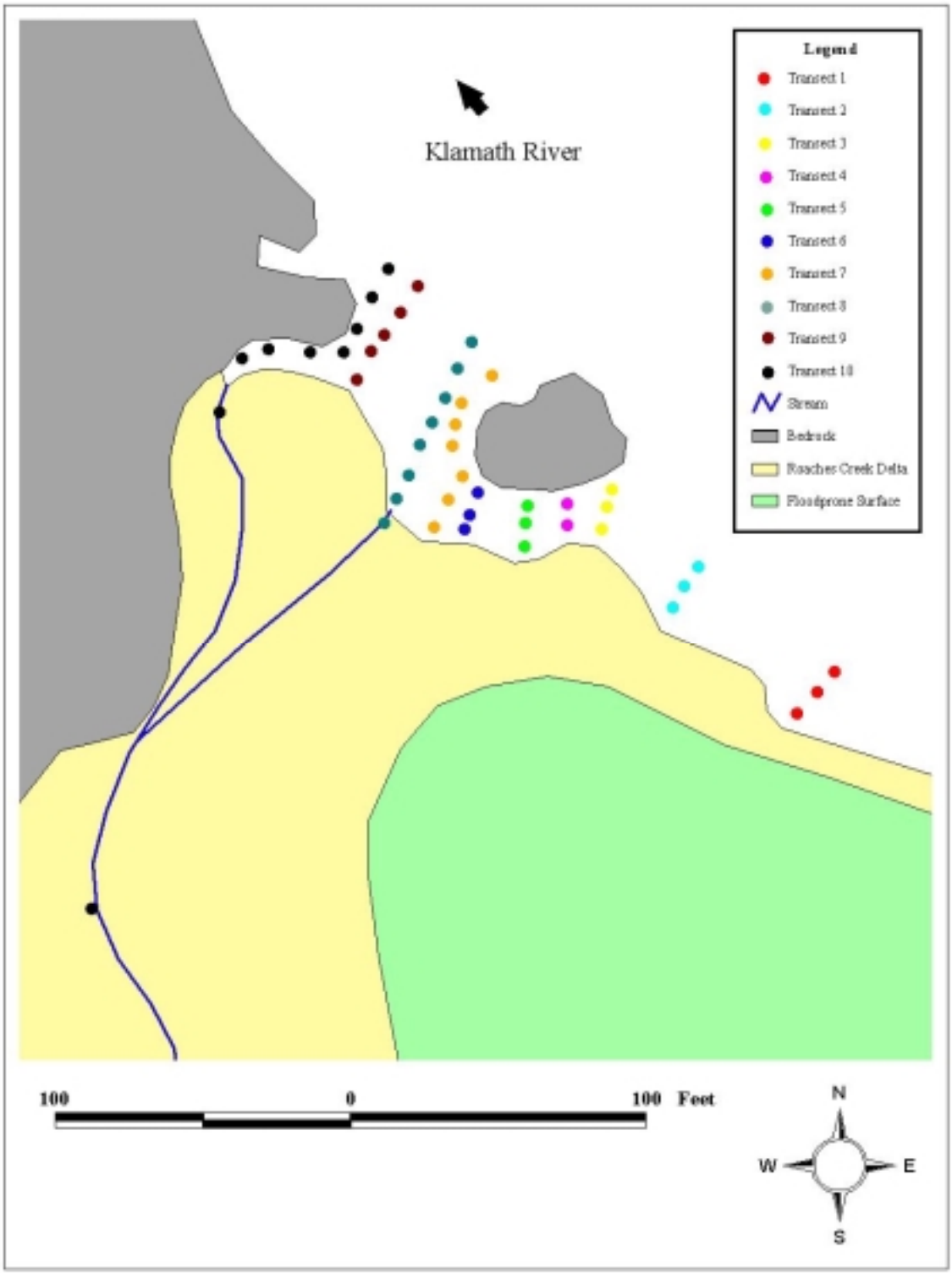


Figure 17. Location of Klamath River water quality monitoring transects established in the vicinity of the confluence with Roaches Creek, Lower Klamath River Sub-basin, California.

Results

Tributary Delta Study

Bear Creek

Although we did not estimate historical delta extent for Bear Creek, we did rectify and examine aerial photographs from 1948 – 2004 (Figure 18). Lower Bear Creek was confined by old growth conifers and little evidence of channel stored aggregate was observed in 1948 (Figure 18). Lower Bear Creek experienced substantial channel widening from 1949 – 1975 presumably a result of land management activities and large flood events occurring during this time. The channel remained fairly wide with substantial channel stored aggregate from 1975 – 2004 (Figure 18). The slope of the 2004 Bear Creek delta was very steep at the distal edge and bed elevations through the rest of the profile were high relative to the Klamath River profiles (Figure 19). According to our model, Klamath River flows greater than 20,000 cfs were required to inundate the Bear Creek delta.

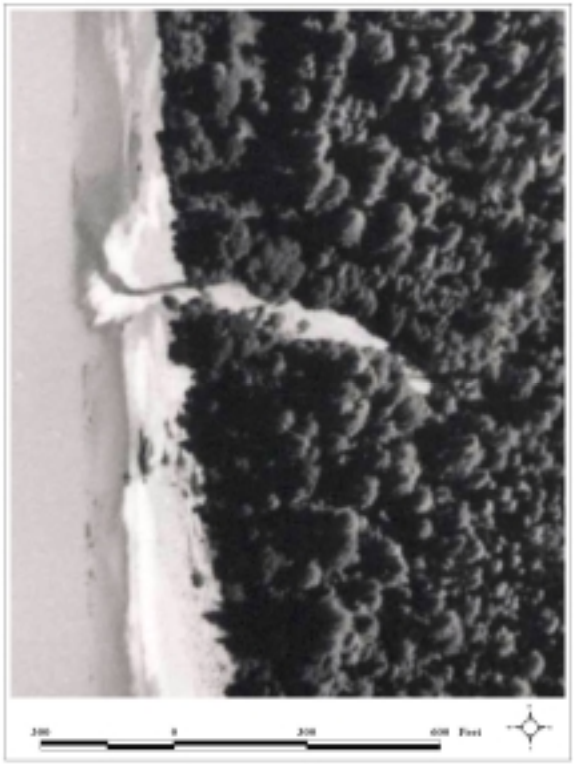
Tectah Creek

Aerial extent of the Tectah Creek delta measured in 1948 was 0.43 acres (Figures 20 – 21). The delta more than doubled in extent from 1948 – 1965. Tectah Creek delta remained relatively stable from 1965 – 2004 ranging in extent from 1.18 – 1.55 acres during this period (Figures 20 – 21). The distal edge of the 2004 delta profile in Tectah Creek was relatively flat with a few small pools and a large bedrock corner pool located ~ 500 ft upstream of the Klamath River (Figure 22). Bed elevations increased a few feet in height just upstream of the corner pool (Figure 22). The 2004 inundation model for Tectah Creek delta predicted that Klamath River flows of 10,000 cfs or less would not facilitate fish access at Tectah Creek (Figure 22). A Klamath River flow of 15,000 cfs was predicted to inundate the bedrock corner pool and facilitate fish access to spawning and rearing habitats located in Tectah Creek (Figure 22).

Roaches Creek

Roaches Creek delta extent was measured at 0.24 acres in 1948 and increased in extent to 1.07 acres by 1958 (Figures 23 – 24). A dramatic increase in delta extent occurred from 1958 – 1970 with a maximum of 5.56 acres measured from the 1970 image. Roaches Creek delta decreased in extent from the peak observed in 1970 to 2.56 acres measured from the 2004 image (Figures 23 – 24). The slope of the 2004 profile for Roaches Creek delta was fairly low through a majority of the reach (Figure 25). However, both the proximal edge and the distal edge of the profile were quite steep. Several small pools were surveyed through the delta reach, unfortunately, the steep distal edge of the profile precluded Klamath River flows of 10,000 cfs or less from inundating the delta (Figure 25). A Klamath River flow of 15,000 cfs was predicted to inundate the delta and facilitate fish access to spawning and rearing habitats located in Roaches Creek (Figure 25).

1948



1958

1969

1975

Figure 18. Rectified aerial photographs of the Bear Creek confluence with the Klamath River, California.

1988

1994

2004

Figure 18. Continued.

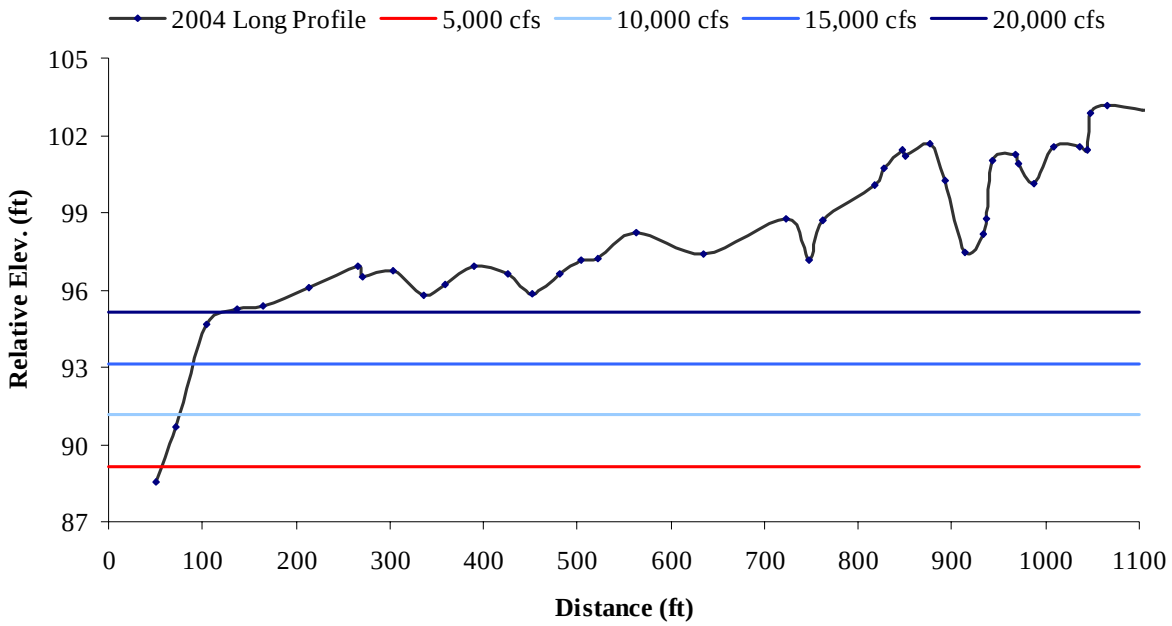


Figure 19. Klamath River inundation elevations on the 2004 Bear Creek delta profile, Lower Klamath River Sub-basin, California.

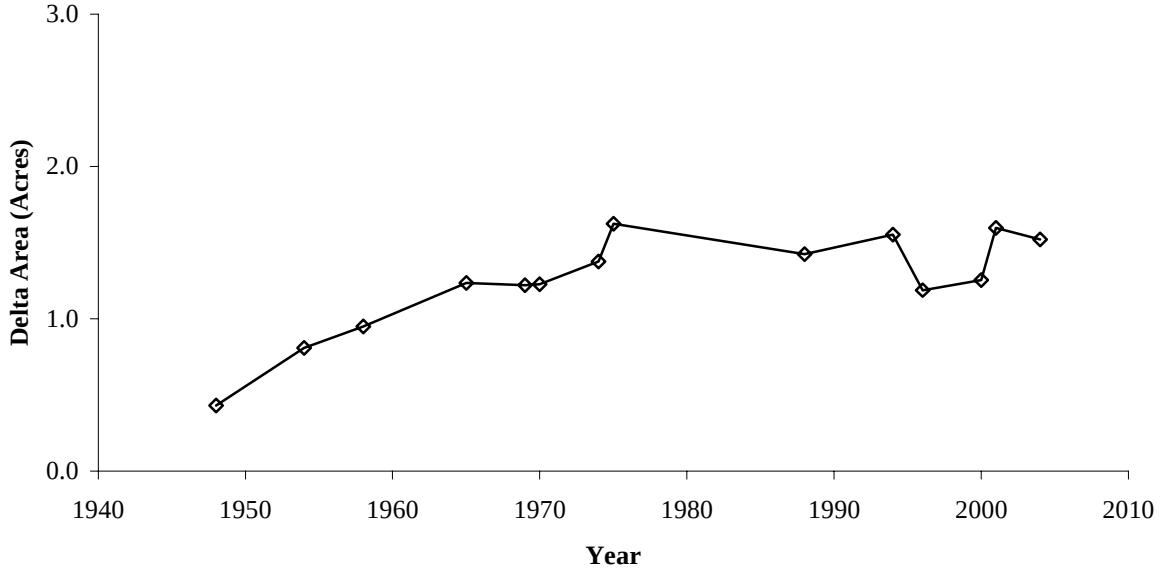
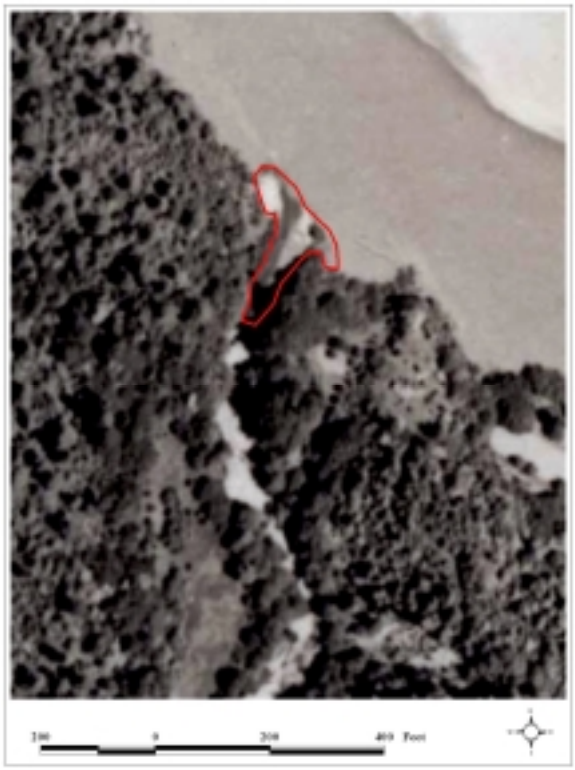
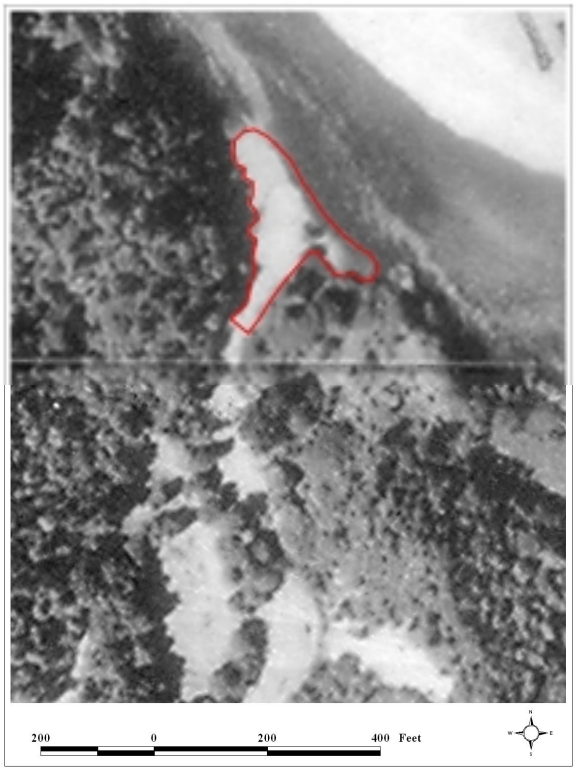


Figure 20. Historical changes in tributary delta extent for Tectah Creek, Lower Klamath River Sub-basin, California (1948 – 2004).

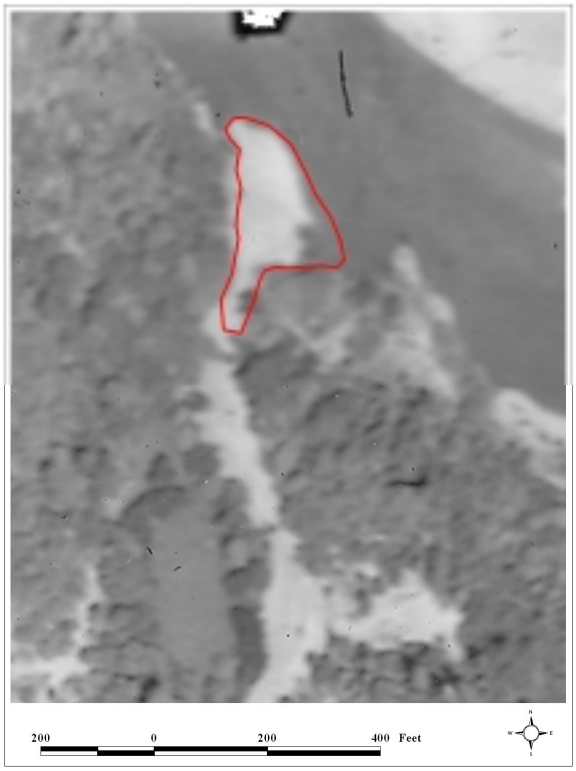
1948



1954



1958

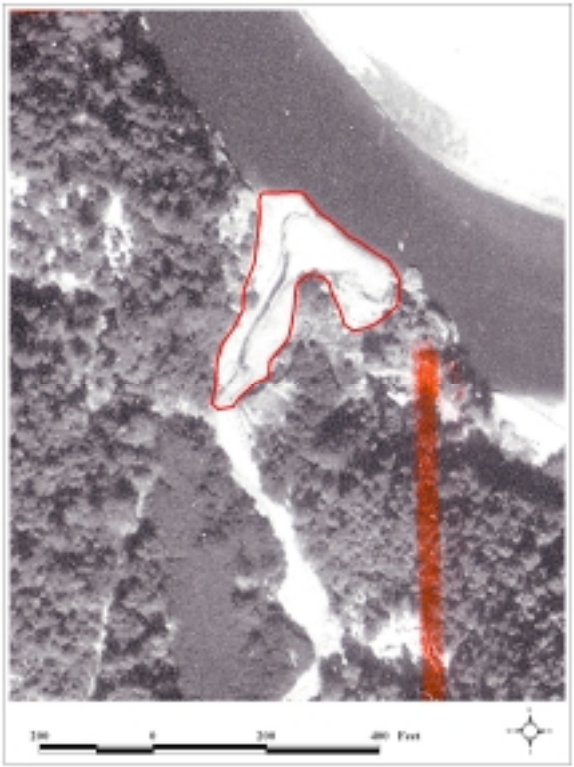


1965

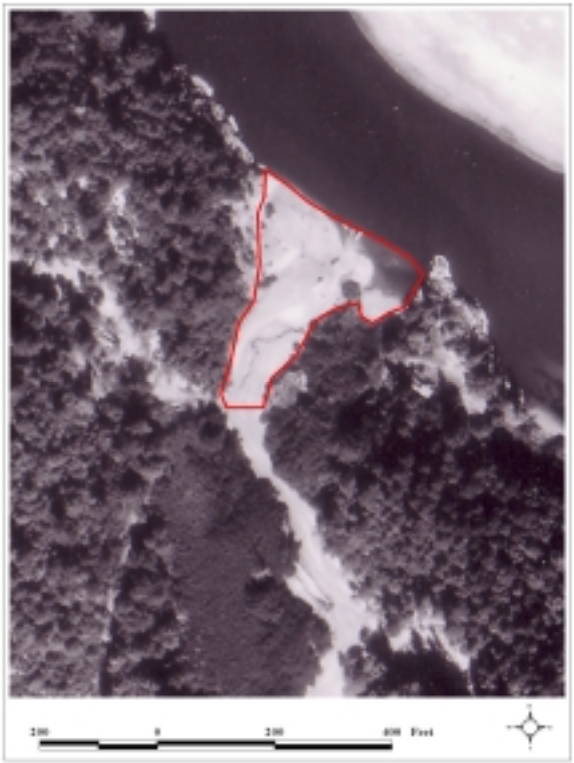
Figure 21. Rectified aerial photographs of the Tectah Creek confluence with the Klamath River, California. The red boundary depicts the aerial extent of the tributary delta.

1969

1970



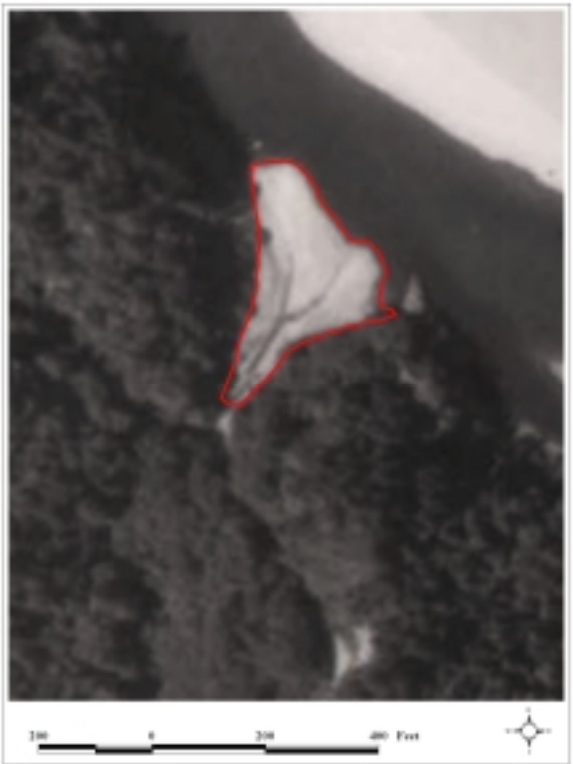
1974



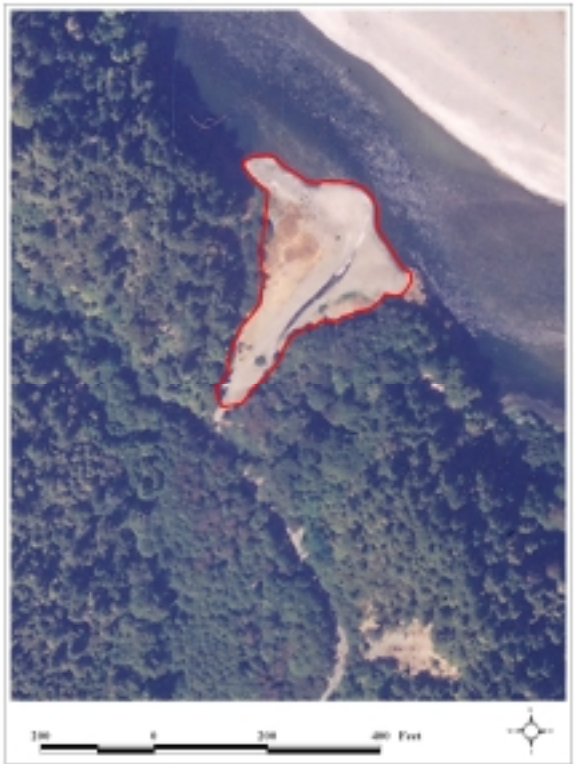
1975

Figure 21. Continued.

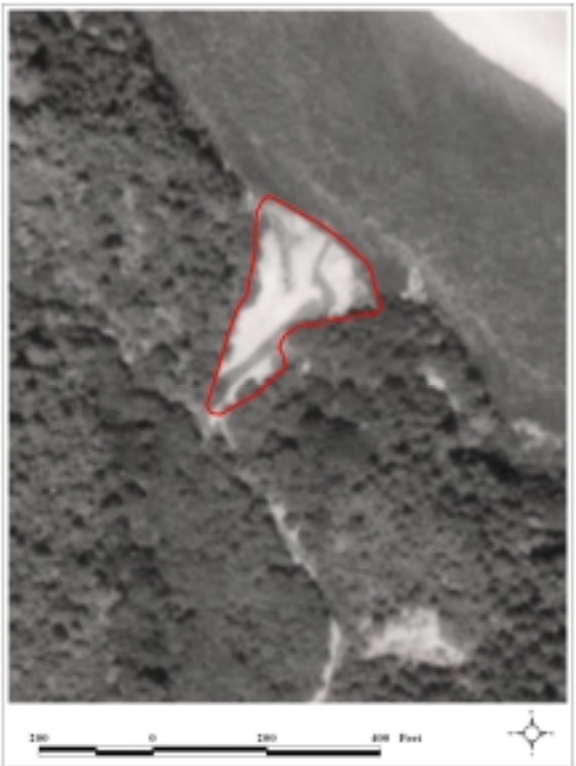
1988



1994



1996



2000

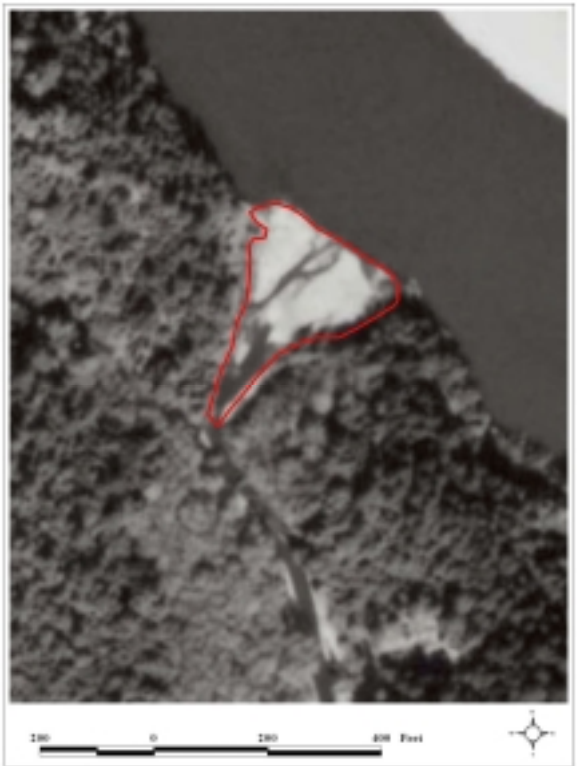
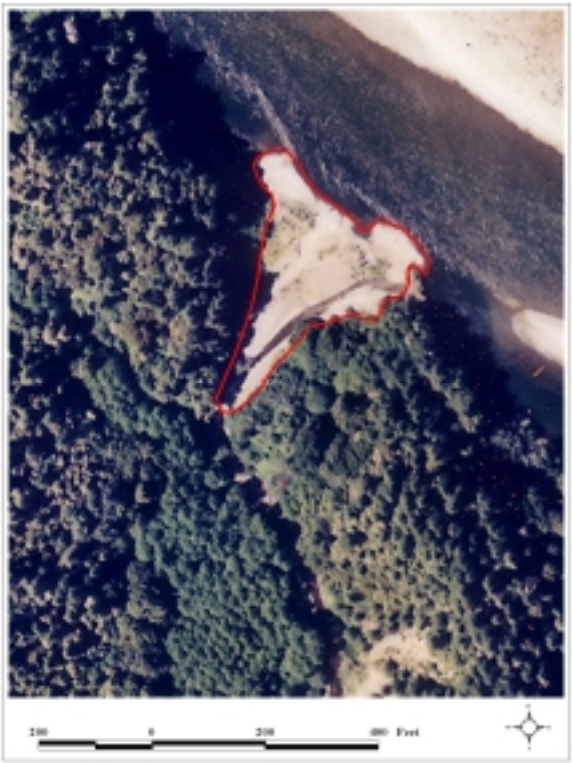


Figure 21. Continued.

2001



2004

Figure 21. Continued.

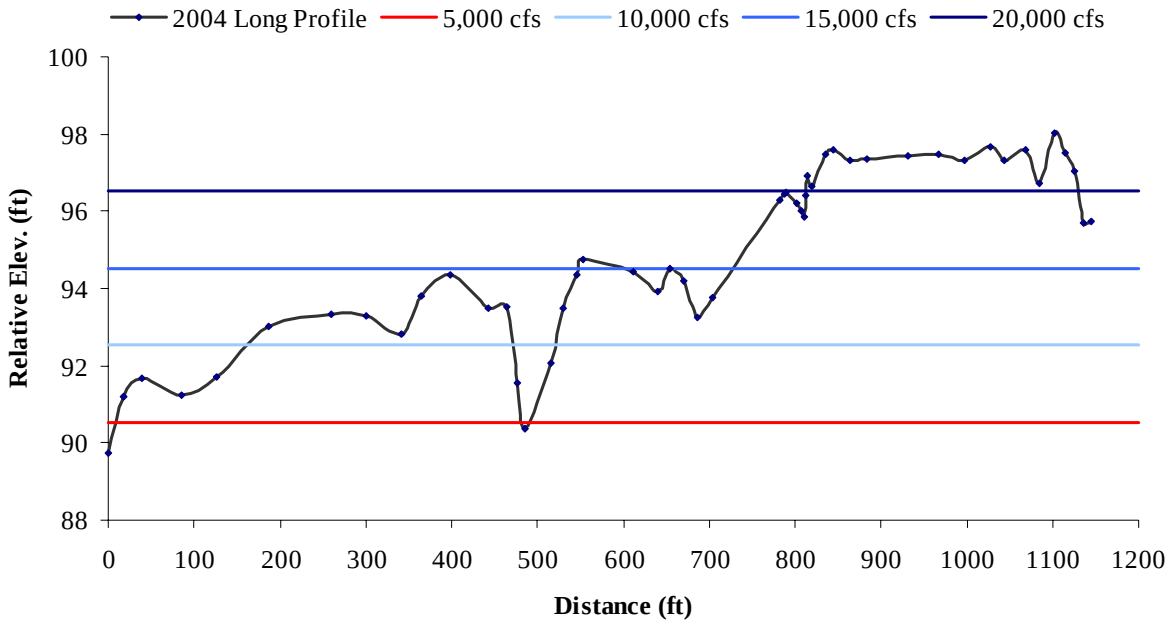


Figure 22. Klamath River inundation elevations on the 2004 Tectah Creek delta profile, Lower Klamath River Sub-basin, California.

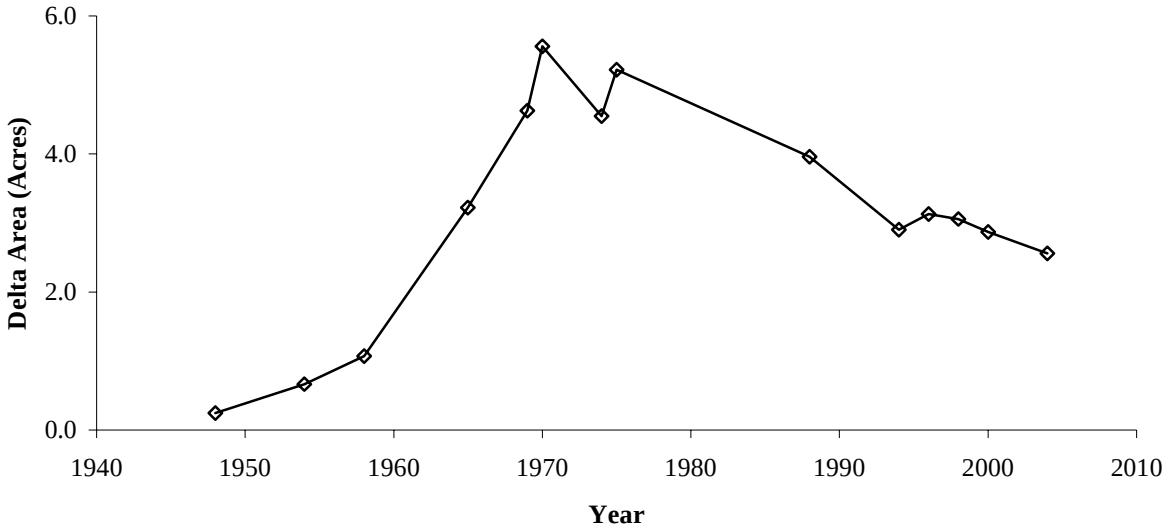


Figure 23. Historical changes in tributary delta extent for Roaches Creek, Lower Klamath River Sub-basin, California (1948 – 2004).

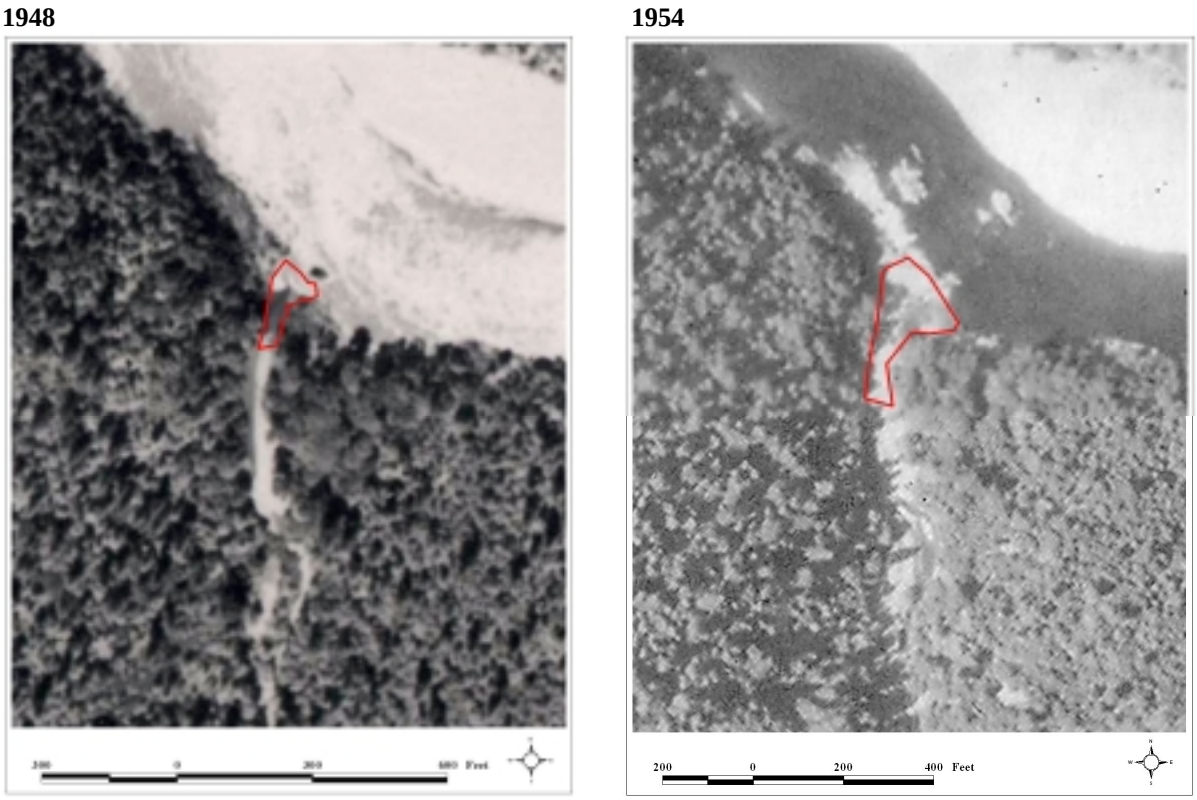
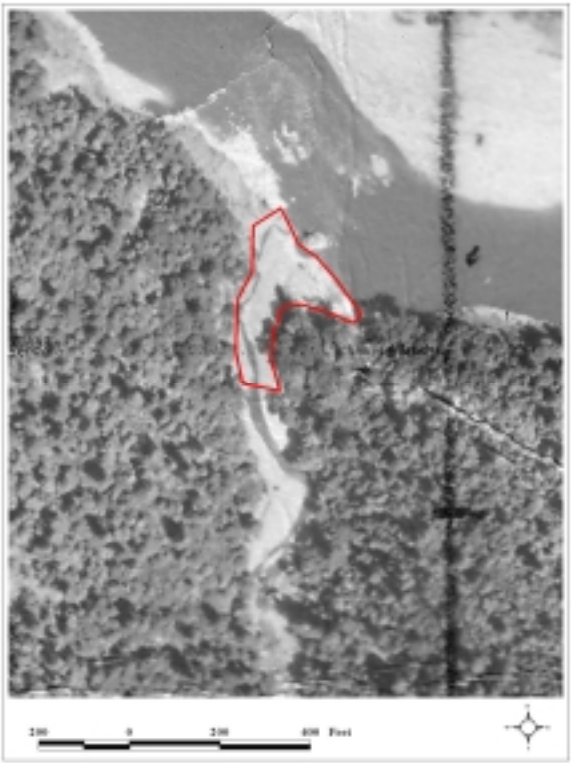
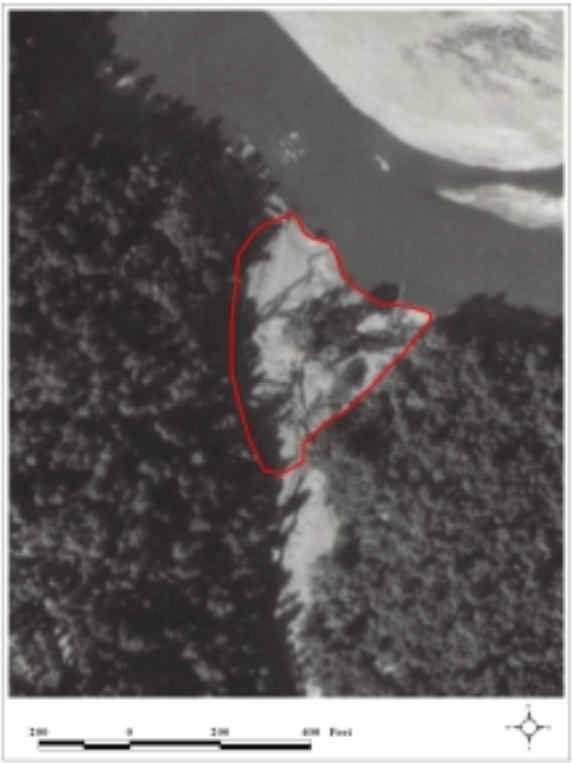


Figure 24. Rectified aerial photographs of the Roaches Creek confluence with the Klamath River, California. The red boundary depicts the aerial extent of the tributary delta.

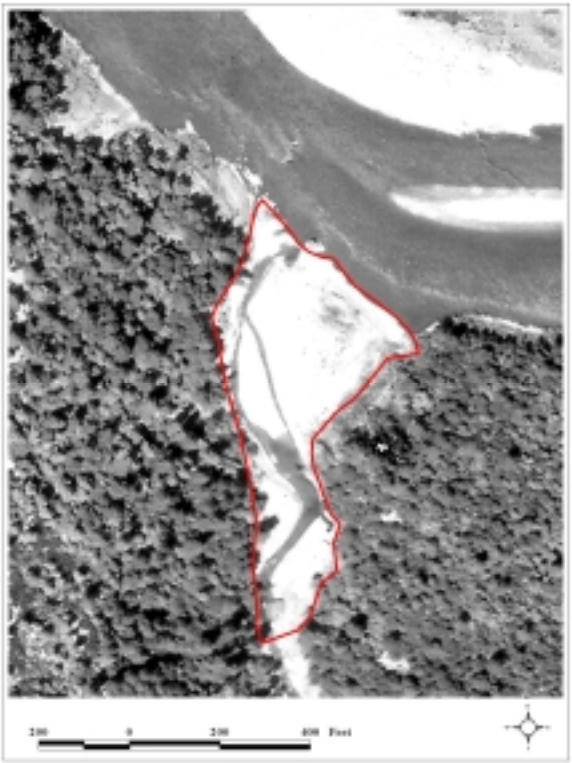
1958



1965



1969



1970

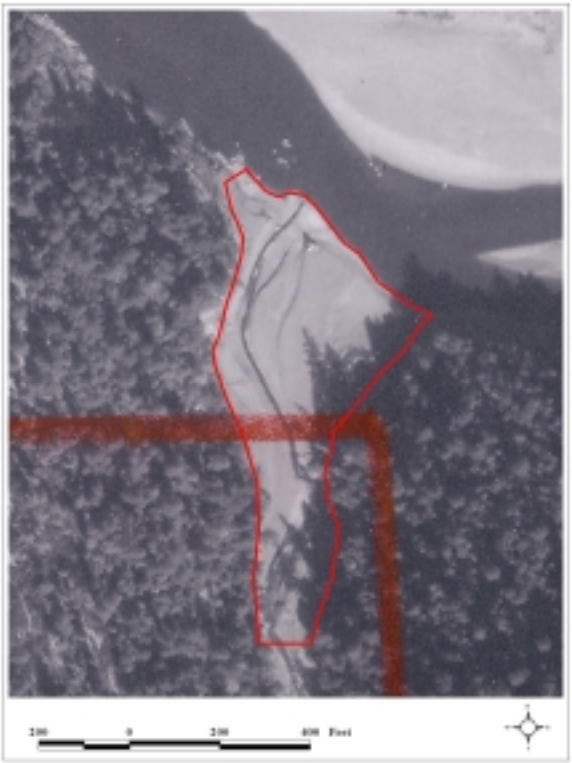
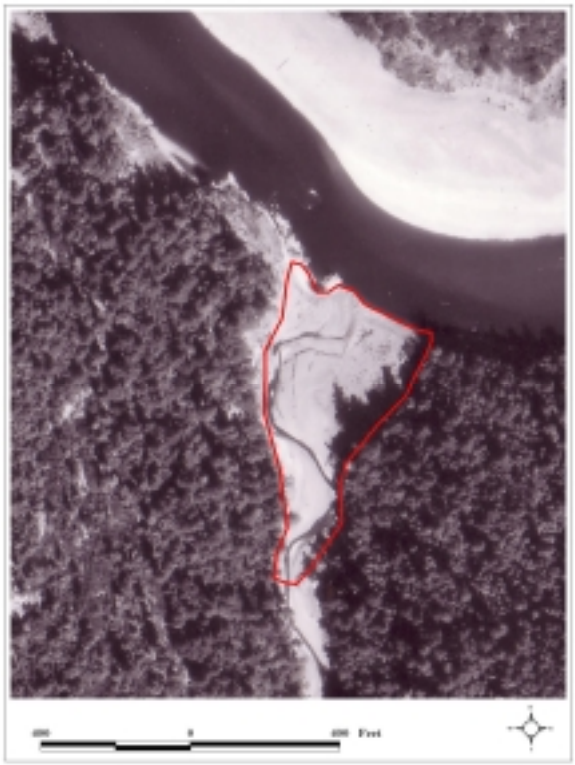


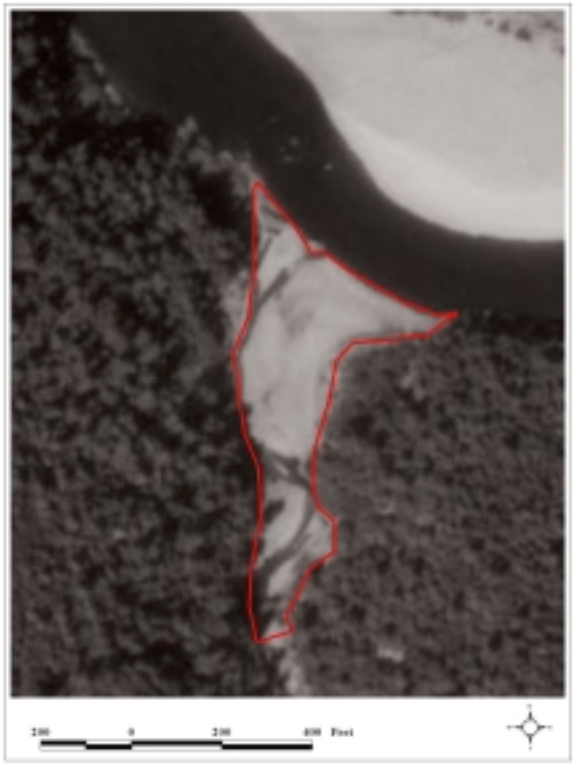
Figure 24. Continued.

1974



1975

1988



1994

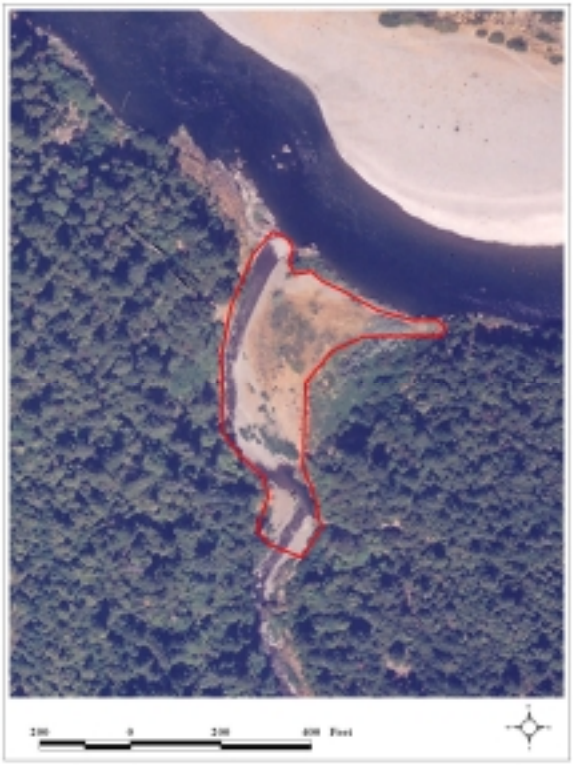
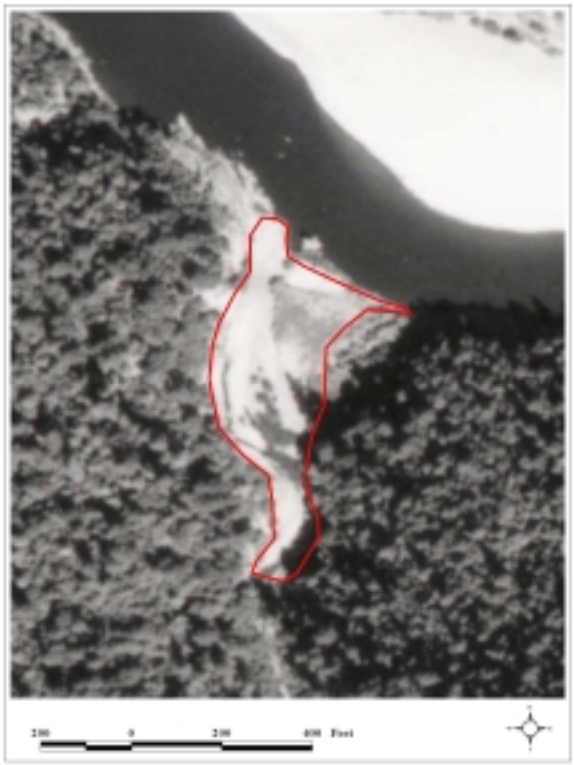


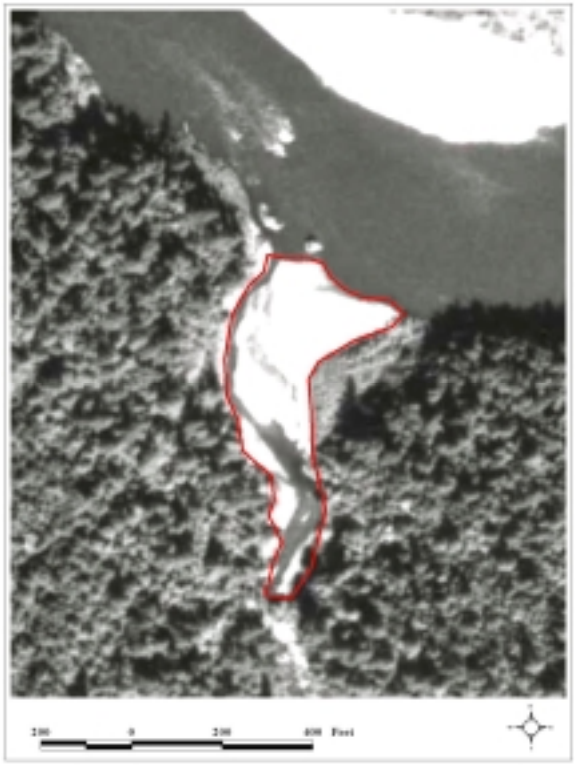
Figure 24. Continued.

1996



1998

2000



2004

Figure 24. Continued.

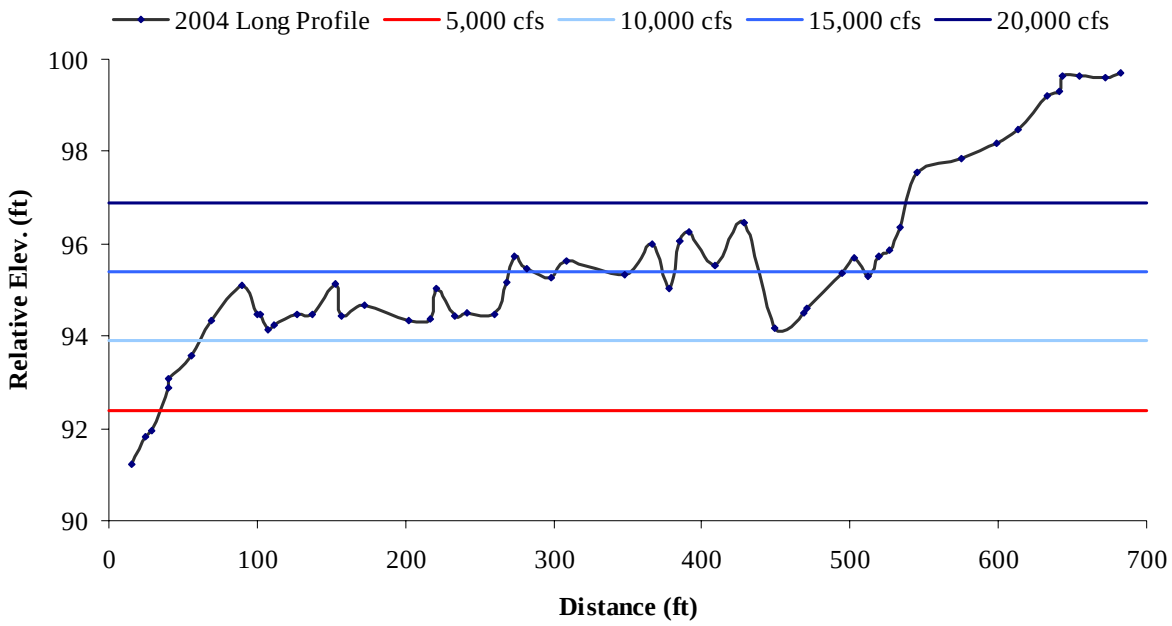


Figure 25. Klamath River inundation elevations on the 2004 Roaches Creek delta profile Lower Klamath River Sub-basin, California.

Tributary Connectivity Monitoring

Twelve of the 19 tributaries assessed in 1996 experienced periods of subsurface flow (Figure 26). Seventeen tributaries had periods where fish access was questionable due to low flows. Periods of subsurface flow and hindered access generally occurred from May through November 1996 (Figure 26). Conditions were similar in 1997 with 14 of the 19 tributaries assessed experiencing periods of subsurface flow (Figure 26). Fish access was questionable in 18 of the tributaries from May through November 1997 due to low flows. Several tributaries also experienced subsurface flow and conditions that hindered access from February through late April 1997. Blue Creek was the only tributary that provided year round access during 1996 – 1997 (Figure 26).

Sixteen of the 19 tributaries assessed in 1998 experienced periods of subsurface flow (Figure 27). Eighteen tributaries had periods where fish access was questionable due to low flows during May through November 1998. Omagaar Creek also experienced subsurface flow and conditions that hindered access from February through late March when a rain event increased flows for only a short period. Seventeen of the 19 tributaries assessed in 1999 experienced periods of subsurface flow (Figure 27). Eighteen tributaries had periods where fish access was questionable due to low flows. Subsurface flow conditions and hindered access generally occurred from May through November as in 1996 – 1998. Four tributaries experienced subsurface flow and hindered access during winter months when rainfall was limited (Figure 27).

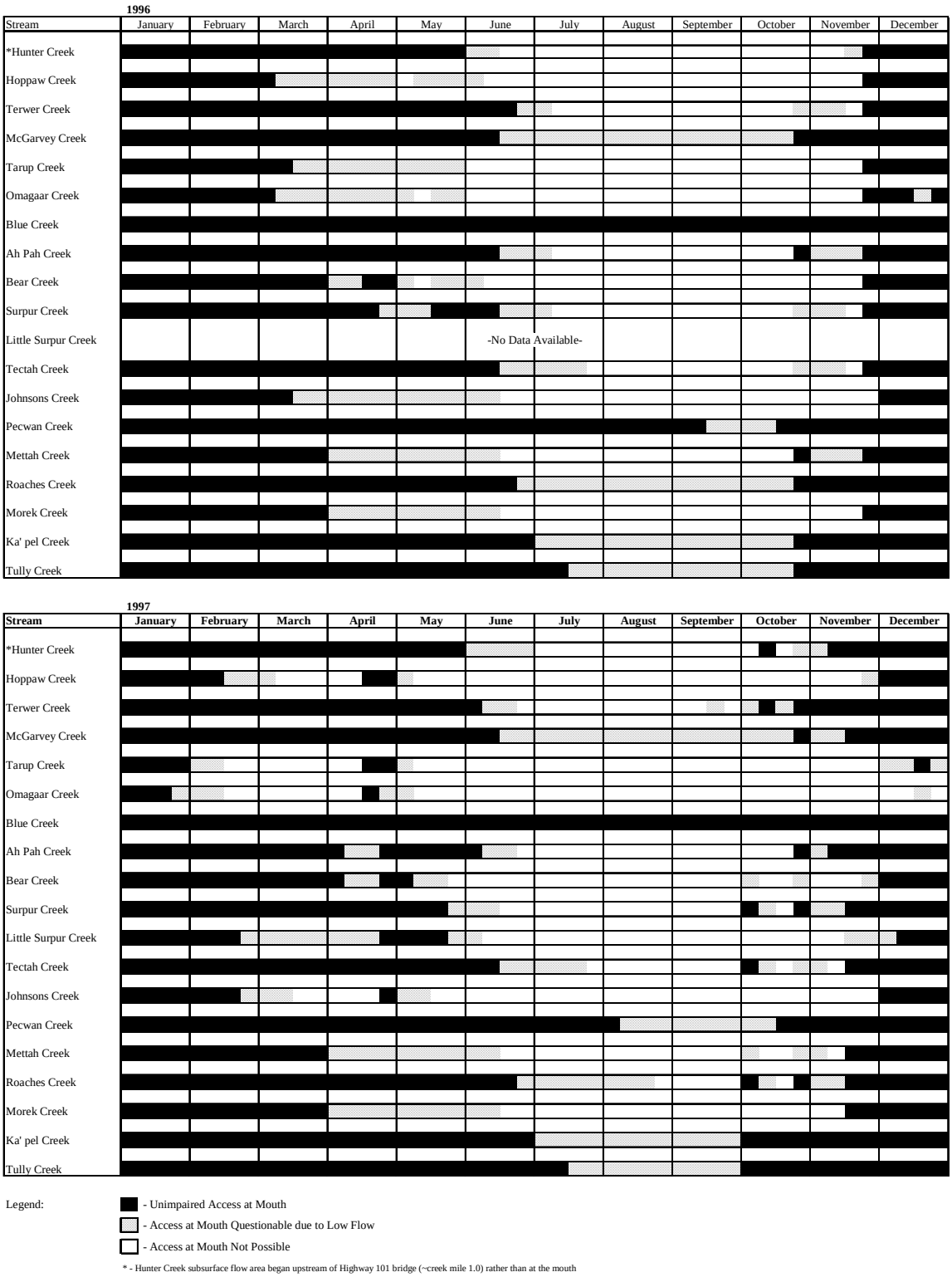


Figure 26. Fish access periodicity for 1996 – 1997 at select Lower Klamath River tributary confluences, California.

Figure 27. Fish access periodicity for 1998 – 1999 at select Lower Klamath River tributary confluences, California.

Sixteen of the 18 tributaries assessed in 2003 – 2004 experienced periods of subsurface flow and/or conditions that hindered access due to low flows (Figure 28). As in previous years, subsurface flow and hindered access generally occurred from May through November. Omagaar Creek was dry at the mouth for a majority of the year with only one observation of flow in February 2004. Tarup Creek and Little Surpur Creek also experienced prolonged periods of subsurface flow and hindered access. Blue Creek and Ka'pel Creek were the only tributaries to maintain year round fish access during this period (Figure 28).

Blue Creek was the only tributary to provide year round fish access during 2005 (Figure 28). Subsurface flow and hindered access generally occurred in the remaining tributaries from June through October 2005. There were also periods in late winter and early spring where access was limited in a number of the tributaries (Figure 28). Two substantial storms occurred in late October – early November 2005 that re-established surface flows to a majority of the tributaries. Although we were unable to survey tributary junctions during peak flow events, we observed no evidence that Omagaar Creek had surface flow at the mouth during any part of the year. Tarup Creek, Little Surpur Creek, Johnson's Creek and Morek Creek also experienced prolonged periods of hindered access (Figure 28).

Intensive Subsurface Flow Monitoring

Hunter Creek

Subsurface flow first occurred in Hunter Creek on 5 May 2004 in the vicinity of the Hunter Creek subdivision (Figure 29). Dry channel reaches steadily increased over the summer with a maximum of 26,281 ft of dry channel documented on 29 November 2004 (Figures 29 and 30). Surface flows resumed through the Hunter Creek study reach on 8 December 2004 after a significant storm event (Figures 3 and 30). However, a lack of precipitation (Figure 3) in conjunction with unusually warm air temperatures likely caused additional periods of subsurface flow in February 2005 (Figure 31). On 17 February 2005, YTFP staff encountered three adult steelhead (large male and two females) trapped in an isolated pool located upstream of the subdivision. The fish were captured, transported upstream in a large storage tank, and released into a flowing reach of Hunter Creek to spawn.

Surface flows resumed on 2 March 2005 and persisted until mid March 2005. A total of 4,601 ft of dry channel was observed on 15 March 2005 (Figure 31). On this date, YTFP staff observed at least five adult steelhead spawning just upstream of the dry channel reach. Surface flows resumed through the study reach on 21 March 2005 and persisted until early July 2005. A total of 4,218 ft of dry channel was observed in Hunter Creek on 6 July 2005 (Figure 31). Subsurface reaches steadily increased over summer and early fall 2005 with a maximum of 23,522 ft of dry channel observed on 26 September 2005 (Figures 29 and 31). Surface flows resumed in Hunter Creek after a significant storm event in late October (Figure 3). Isolated pools were again observed on 24 November 2005, however, surface flows resumed that night after a small storm event (Figure 3).

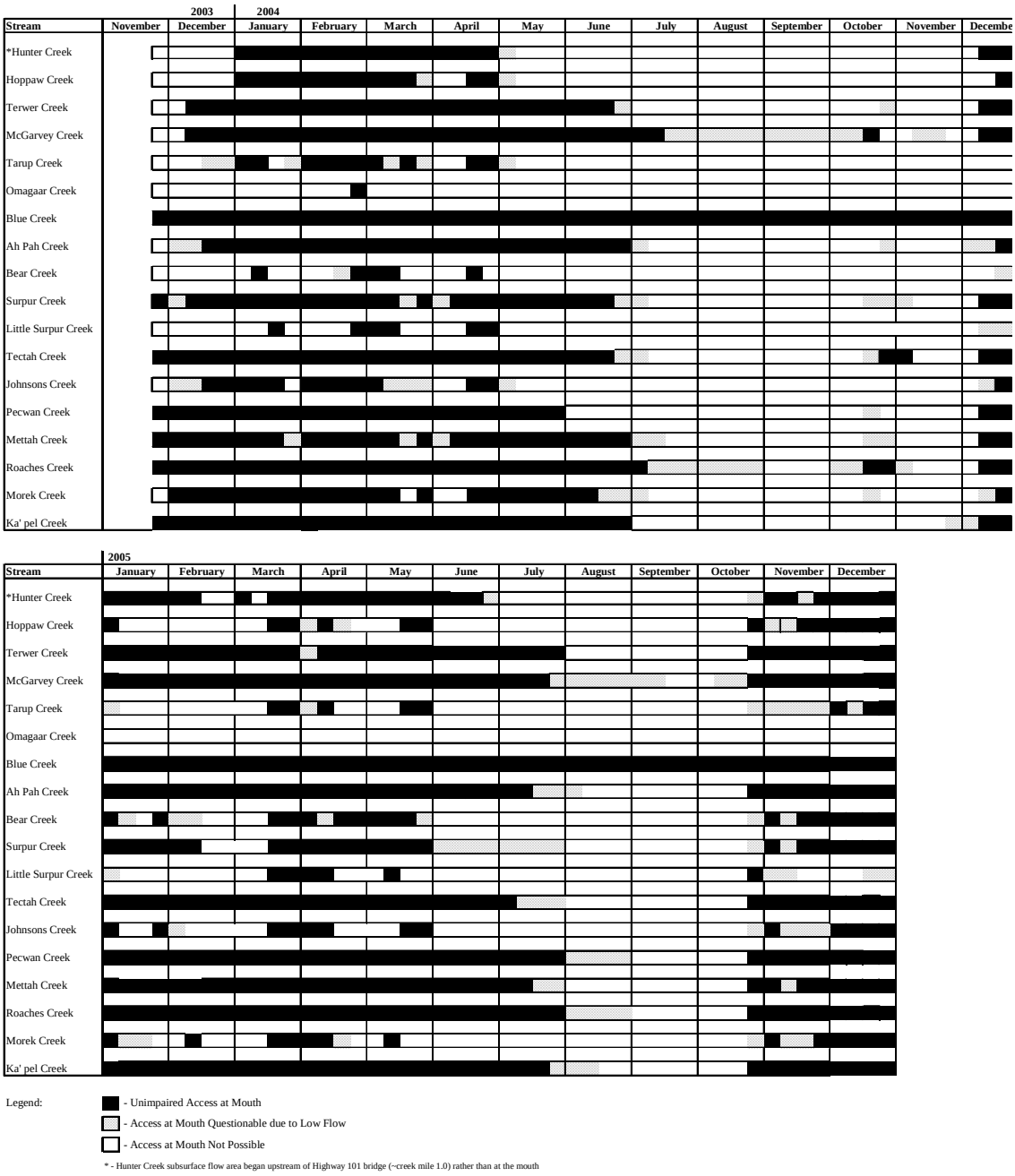


Figure 28. Fish access periodicity for the period November 2003 – December 2005 at select Lower Klamath River tributary confluences, California.

Figure 29. Map depicting the Hunter Creek channel and the reach surveyed for subsurface flow for the period 1 April 2004 – 31 December 2005, Lower Klamath River Sub-basin, California.

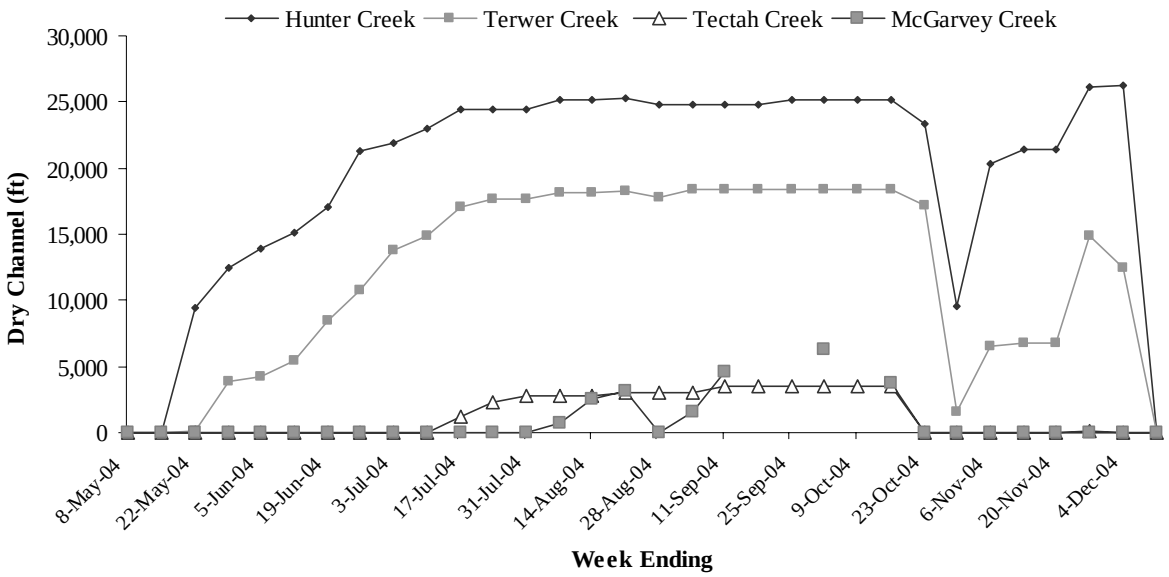


Figure 30. Length of subsurface flow documented during 2004 in the lower reaches of several Lower Klamath River tributaries, California.

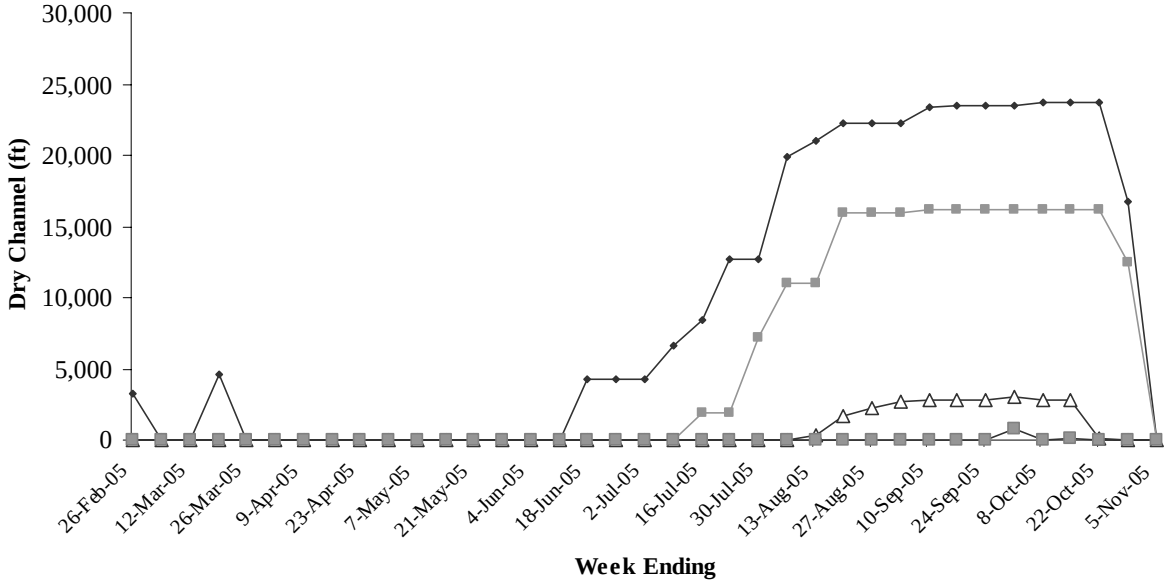


Figure 31. Length of subsurface flow documented during 2005 in the lower reaches of several Lower Klamath River tributaries, California.

Terwer Creek

Terwer Creek flows first went subsurface through the lower valley on 14 May 2004 (Figures 30 and 32). A maximum of 18,335 ft of dry channel was observed through the study reach from 1 September – 18 October 2004 (Figures 30 and 32). Storm events occurring in late October (Figure 3) caused surface flows to resume through the study reach on 26 October 2004 (Figures 30 and 32). Lower Terwer Creek began drying again on 1 November 2004 and continued to dry until an early December storm event caused surface flows to resume (Figures 3 and 30). Surface flows persisted in Terwer Creek through winter and spring 2005. The first dry channel reaches of the year were documented on 11 July 2005 (Figures 31 – 32). Surface flows steadily decreased through summer and early fall 2005 with a maximum of 16,155 ft of dry channel observed from 6 September – 28 October 2005 (Figures 31 – 32). Surface flows resumed in Terwer Creek in late October 2005 after multiple storm events (Figures 3 and 31).

McGarvey Creek

Subsurface conditions were first observed in McGarvey Creek on 7 August 2004 with a maximum of 6,231 ft of dry channel documented on 2 October 2004 (Figures 30 and 33). Surface flows resumed through the study reach in late October 2004. Surface flows persisted in McGarvey Creek through winter and spring 2005. Dry channel reaches were not observed until late September 2005 with a maximum of 815 ft of dry channel observed on 28 September 2005 (Figure 31). Storm events in October caused surface flows to resume on 3 October 2005. However, 120 ft of dry channel was observed in McGarvey Creek on 12 October 2005 (Figures 31 and 33). Flows resumed through the study reach on 18 October 2005 (Figure 31).

Tectah Creek

In 2004, Tectah Creek flows went subsurface through the delta on 17 July 2004 (Figures 30 and 34). Subsurface conditions progressed from this point with a maximum of 3,520 ft of dry channel observed from 11 September to 16 October 2004 when flows resumed (Figure 30). Surface flows persisted in Tectah Creek until the delta reach lost surface flow in mid August 2005 (Figures 31 and 34). Tectah Creek steadily dried from this date with a maximum of 2,999 ft of dry channel observed on 30 September 2005 (Figures 31 and 34). An early October 2005 storm event increased surface flows through the study reach with complete connectivity occurring in late October 2005 after substantial rainfall (Figures 3 and 31).

Tributary Water Table Monitoring

Terwer Creek

Water tables in Terwer Creek declined slowly from June through early July 2005 when the rate of decline began increasing (Figure 35). This higher rate of decline continued until late

Figure 32. Map depicting the Terwer Creek channel and the reach surveyed for subsurface flow for the period 1 April 2004 – 31 December 2005, Lower Klamath River Sub-basin, California.

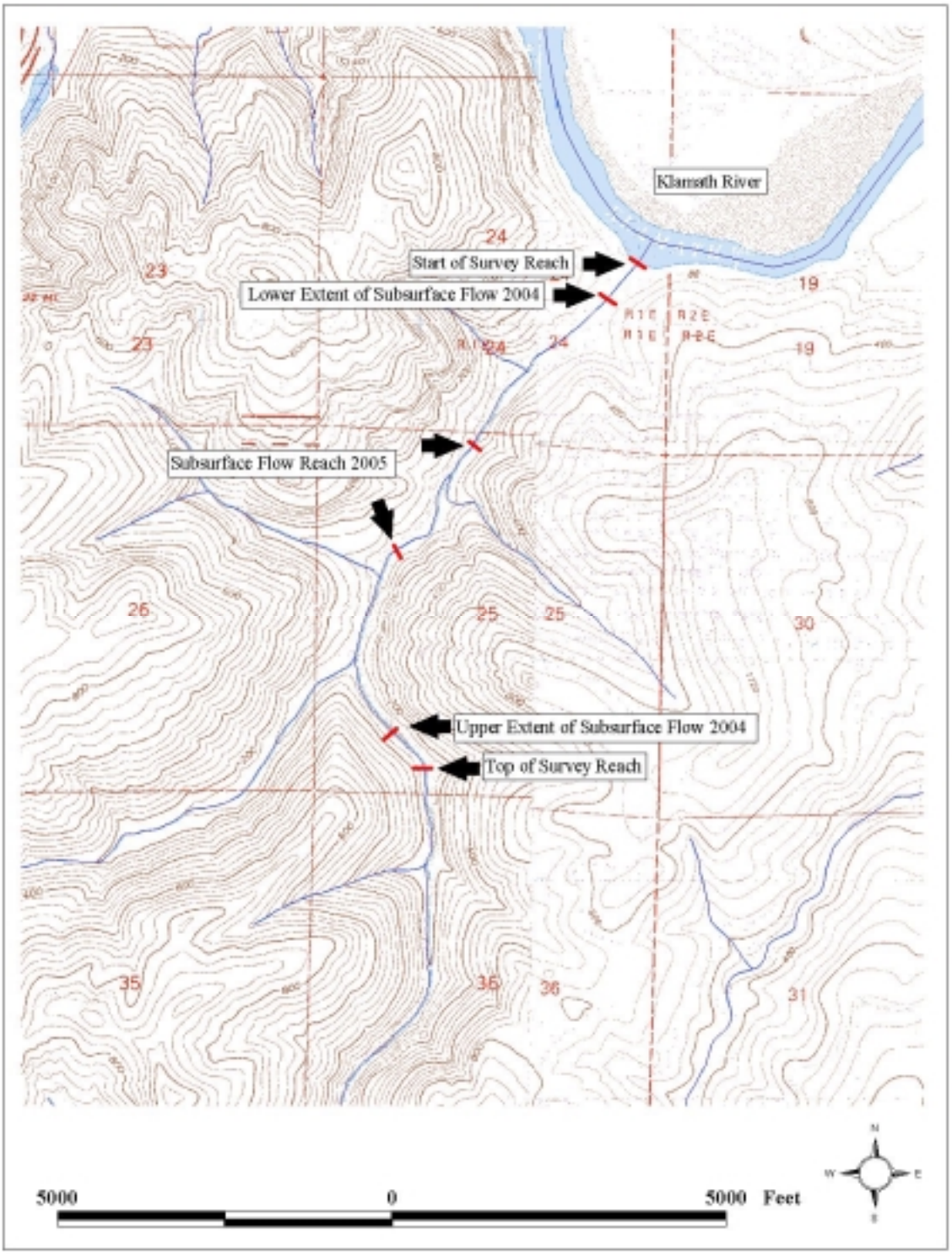


Figure 33. Map depicting the reach in McGarvey Creek surveyed for subsurface flow for the period 1 July 2004 – 31 December 2005, Lower Klamath River Sub-basin, California.

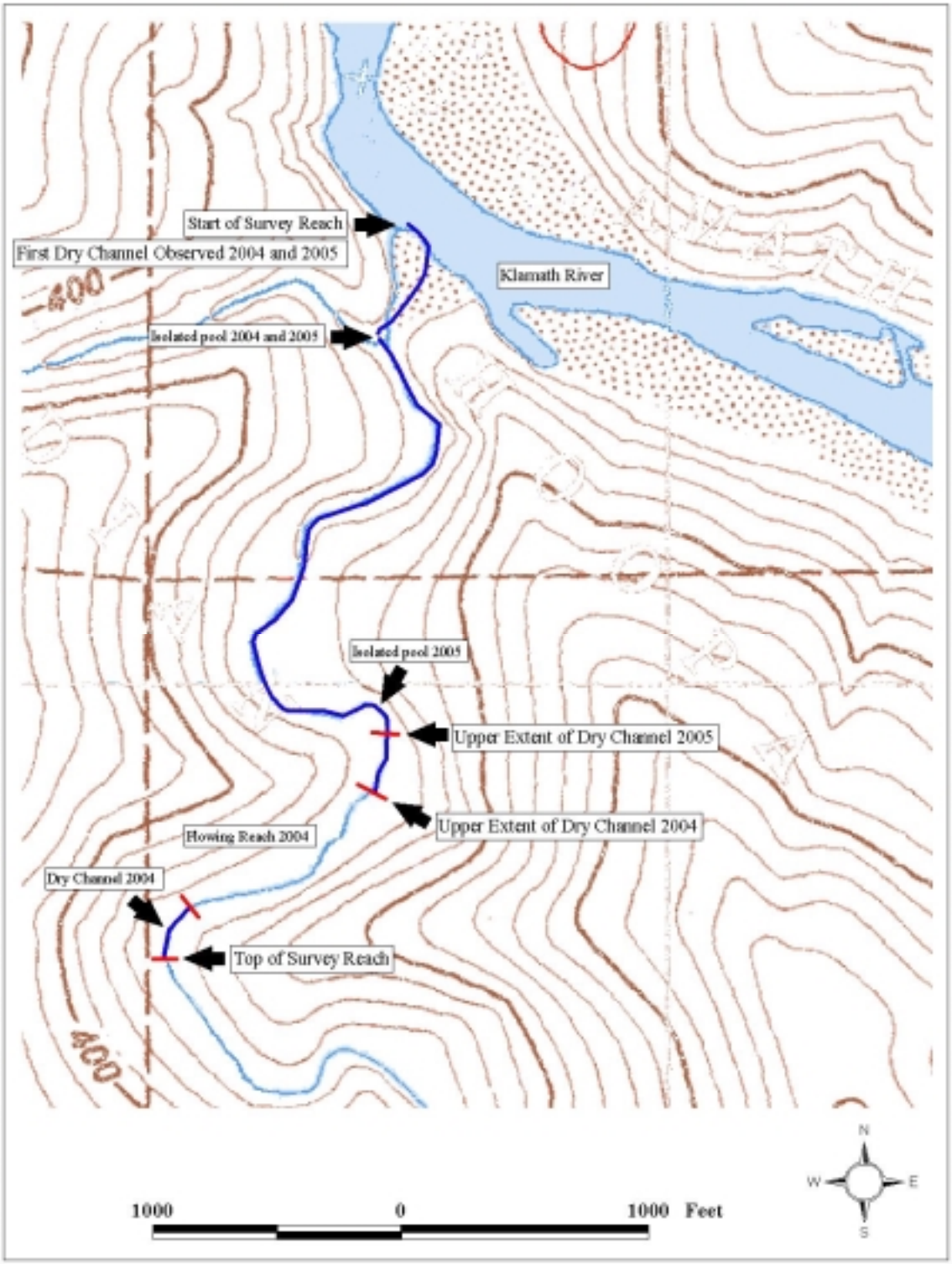


Figure 34. Map depicting the Tectah Creek channel and the reach surveyed for subsurface flow for the period 30 April 2004 – 31 December 2005, Lower Klamath River Sub-basin, California.

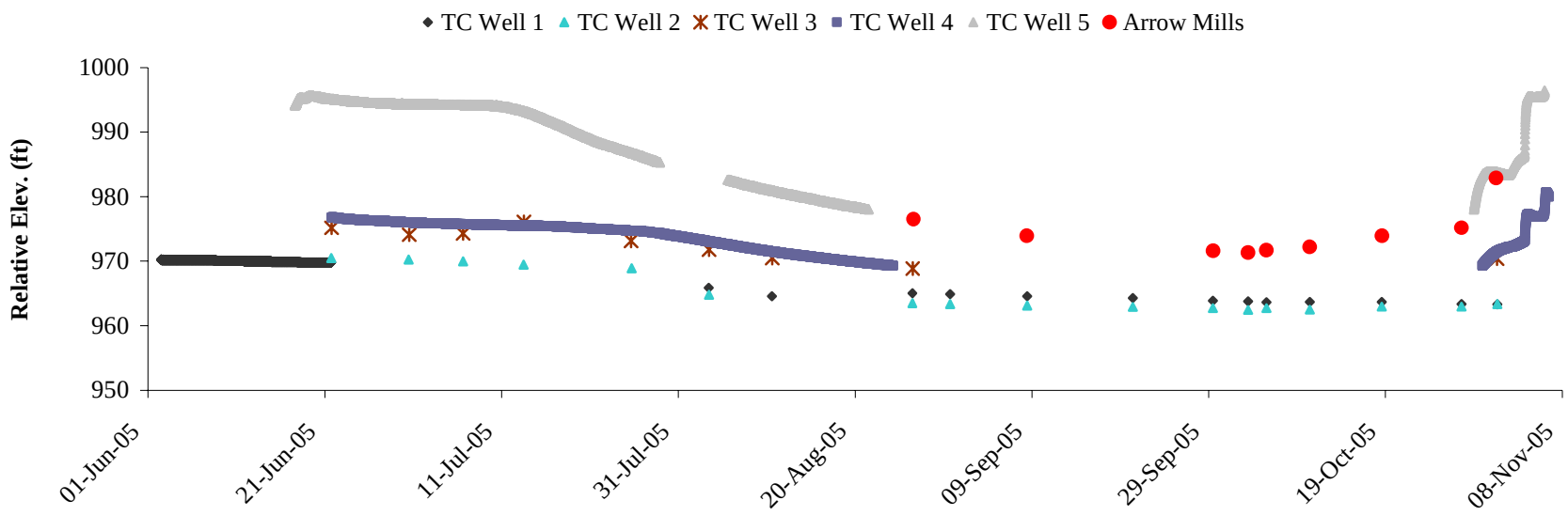


Figure 35. Relative groundwater elevations measured at six monitoring wells located in lower Terwer Creek, Lower Klamath River Sub-basin, California.

August 2005 when the water table began to stabilize. On 5 August 2005, a five-foot section of pipe was added to TC Well 5 to increase the well depth to 21 ft. However, the well went dry again on 21 August 2005 (Figure 35). At this time, crews began measuring the depth to water in an abandoned well (Arrow Mills Well) located near TC Well 5 (Figure 11). The maximum depth to water at the Arrow Mills Well was 28 ft measured on 3 October 2005 (Figure 35). The maximum depth to water was 9.38 ft at TC Well 1 on 31 October 2005. The water table in the vicinity of the upper most wells began recharging a few days later and gradually increased until 29 October 2005 (Figure 35). The longitudinal survey was conducted just prior to rainfall events that caused rapid recharge of the water table and increased surface flows at these sites (Figure 36).

McGarvey Creek

The water table in the vicinity of MG Well 1 declined from late June through early August 2005 (Figure 37). Surface flows persisted year round in this reach of McGarvey Creek and therefore water tables were very stable from August through late October 2005. During this time, the managed flow release in the Trinity River for the Hoopa Valley Tribe's ceremonial Boat Dance resulted in a small peak in the water table in late August 2005 (Figure 38) and rainfall events caused two other small peaks (Figure 37). The maximum depth to water at MG Well 1 was 9.0 ft on 2 – 3 September 2005 (Figure 37). The maximum depths to water observed at the monitoring wells were 5.32 ft at MG Well 2 (12 October 2005), 2.89 ft at MG Well (3 October 2005), and 1.65 ft at MG Well 4 (24 October 2005) (Figure 37). Several rainfall events occurred and surface flows increased during late October 2005 resulting in approximately three peaks in the water table. Results of the longitudinal surveys suggested that surface water elevations were directly related to local water tables of lower McGarvey Creek (Figure 39). Continued rainfall and rising surface flows in early November 2005 resulted in rapid recharge of the water table at MG Well 1 (Figure 37).

Tectah Creek

The water table at Tectah Well 1 held steady from late June through late August 2005 (Figure 40). The rate of decline increased from late August through early September 2005 with one very small peak on 30 August 2005 resulting from the managed flow release in the Trinity River for the Boat Dance. The water table at Tectah Well 2 declined slowly from late June through mid-September 2005 relative to Tectah Well 1 (Figure 40). The influence of increased mainstem flows associated with the Hoopa Valley Tribe's Boat Dance was more pronounced at Tectah Well 2 due to the well's proximity to the Klamath River (Figures 40 – 41). The water table at both wells continued to decline through late September 2005 when a small peak resulted from a rainfall event (Figure 40). The maximum depth to water at Tectah Well was 8.3 ft and occurred from 29 September – 1 October 2005 (Figure 40). Surface water persisted in the bedrock corner pool located at Tectah Well 1 during the study period. Water surface elevations in this pool appeared directly related to the local water table. The maximum depth to water at Tectah Well 2 was 10.66 ft on 30 September – 1 October 2005. Rainfall events and increased surface flows in October and early November 2005 recharged local water tables and resulted in several peaks over this period (Figures 3 and 40).

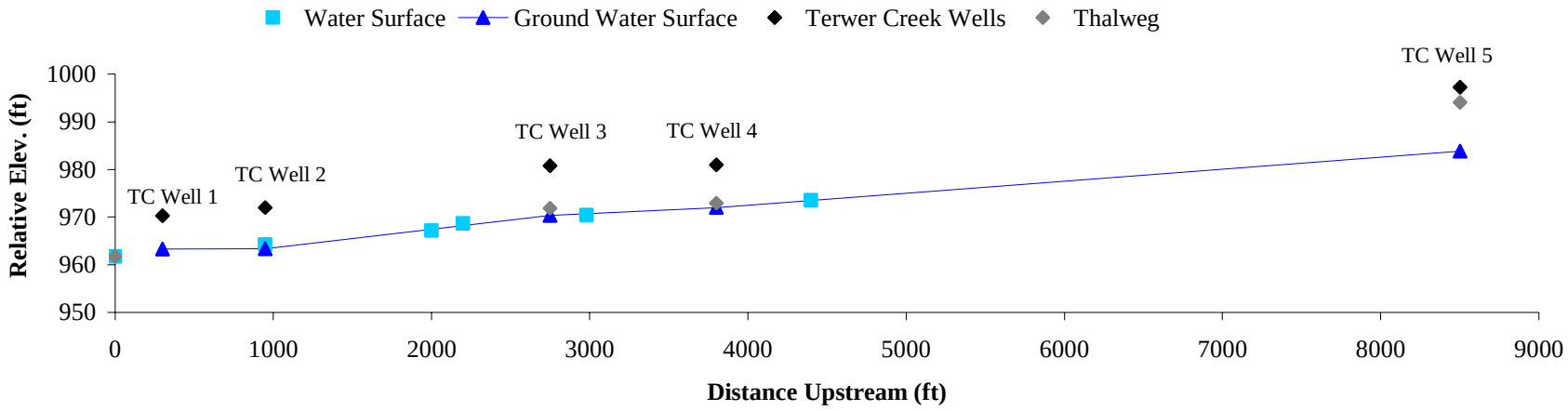


Figure 36. Longitudinal profile survey conducted on 31 October 2005 to document relative elevations of the channel, five monitoring wells, and relative water surface elevations in Terwer Creek, Lower Klamath River Sub-basin, California.

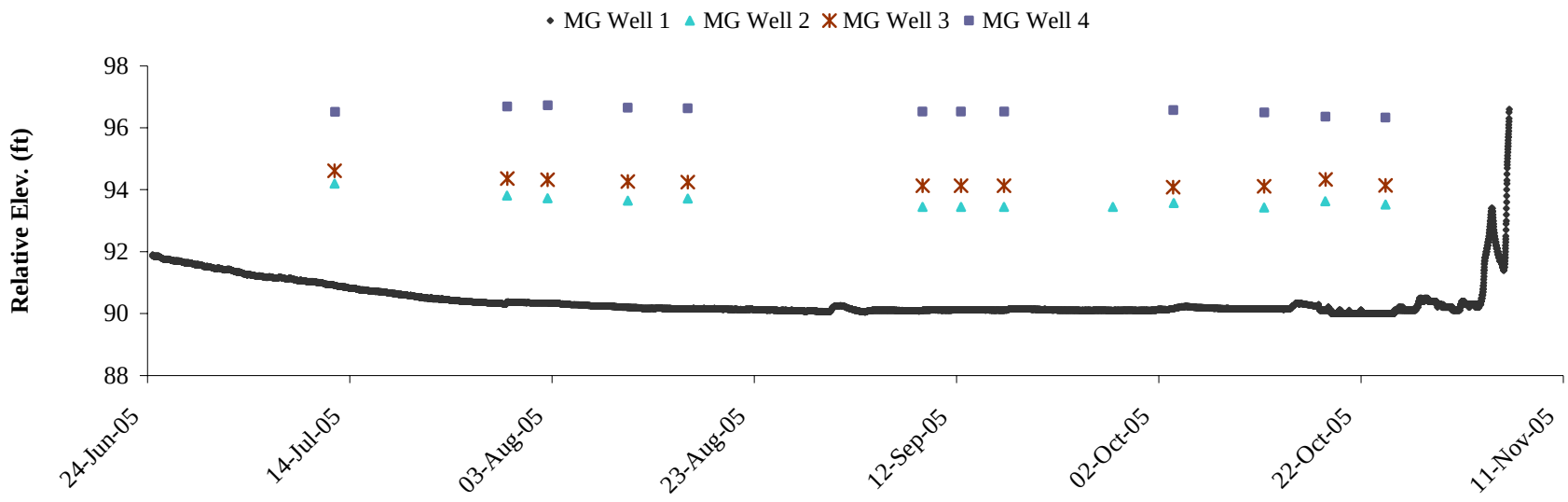


Figure 37. Relative groundwater elevations measured at six monitoring wells located in lower McGarvey Creek, Lower Klamath River Sub-basin, California.

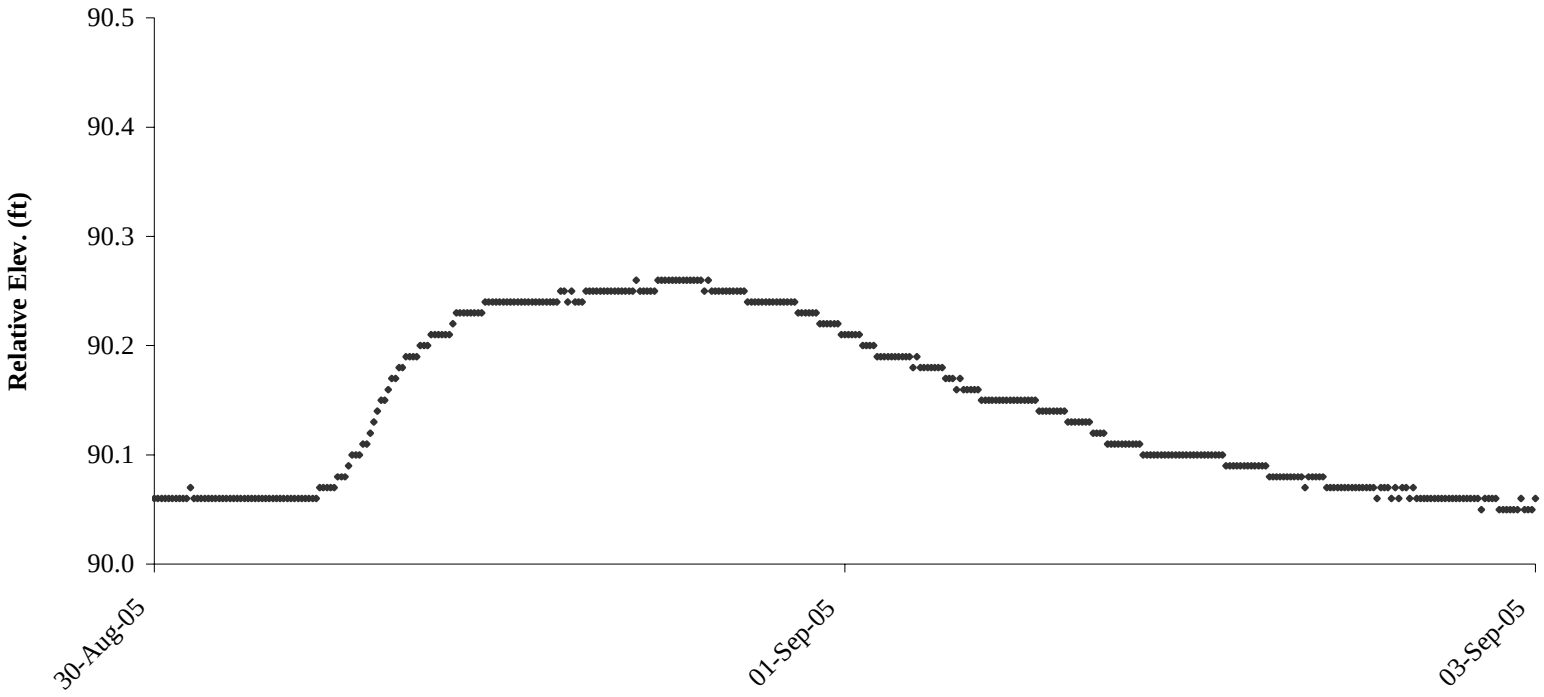
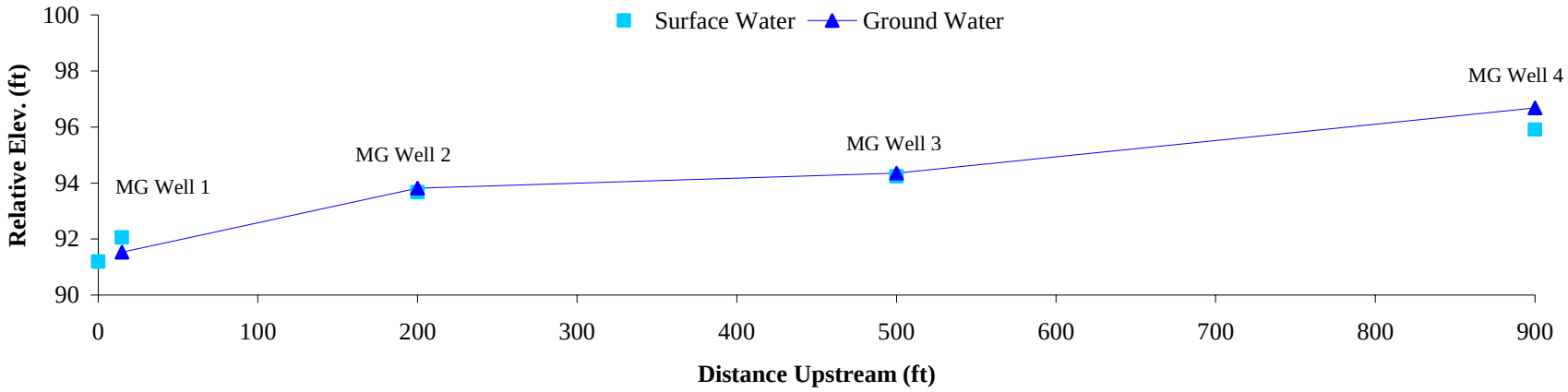


Figure 38. Relative groundwater elevations measured at a monitoring well located at the mouth of McGarvey Creek, Lower Klamath River Sub-basin, California. Note the small peak associated with the managed flow release in the Trinity River for the Hoopa Valley Tribe's ceremonial Boat Dance.



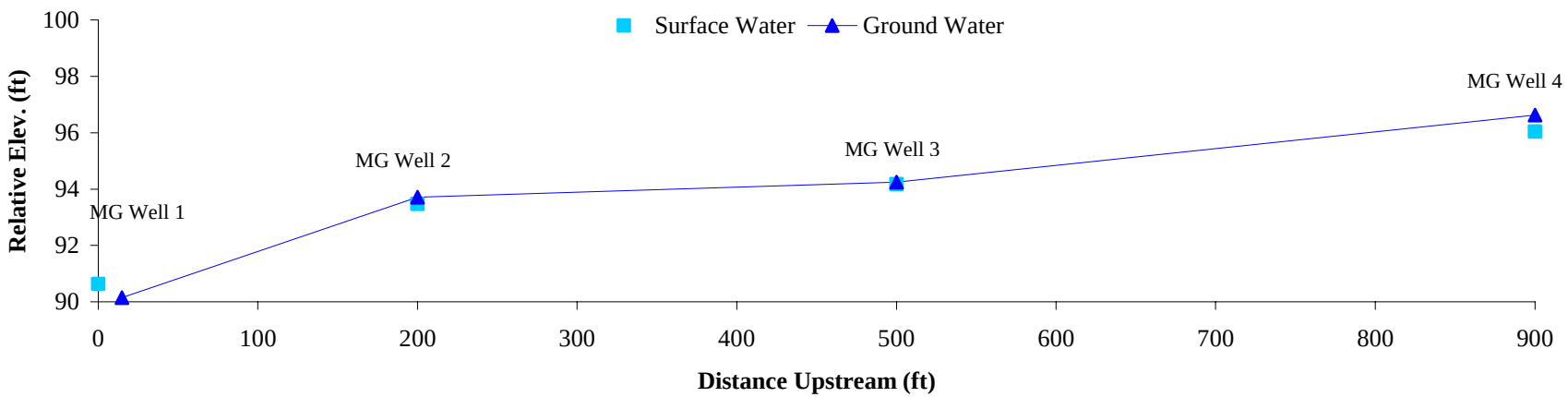


Figure 39. Longitudinal profile surveys conducted on 29 July 2005 (Top Plot) and 16 August 2005 (Bottom Plot) to document relative elevations of tributary and groundwater levels in McGarvey Creek, Lower Klamath River Sub-basin, California.

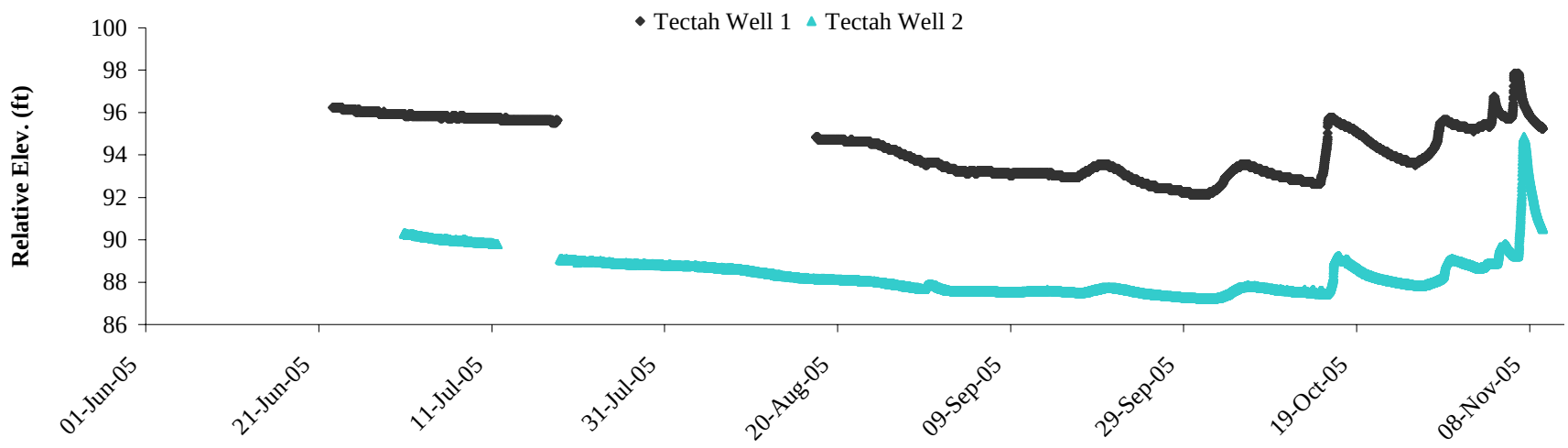


Figure 40. Relative groundwater elevations measured at six monitoring wells located in lower Tectah Creek, Lower Klamath River Sub-basin, California.

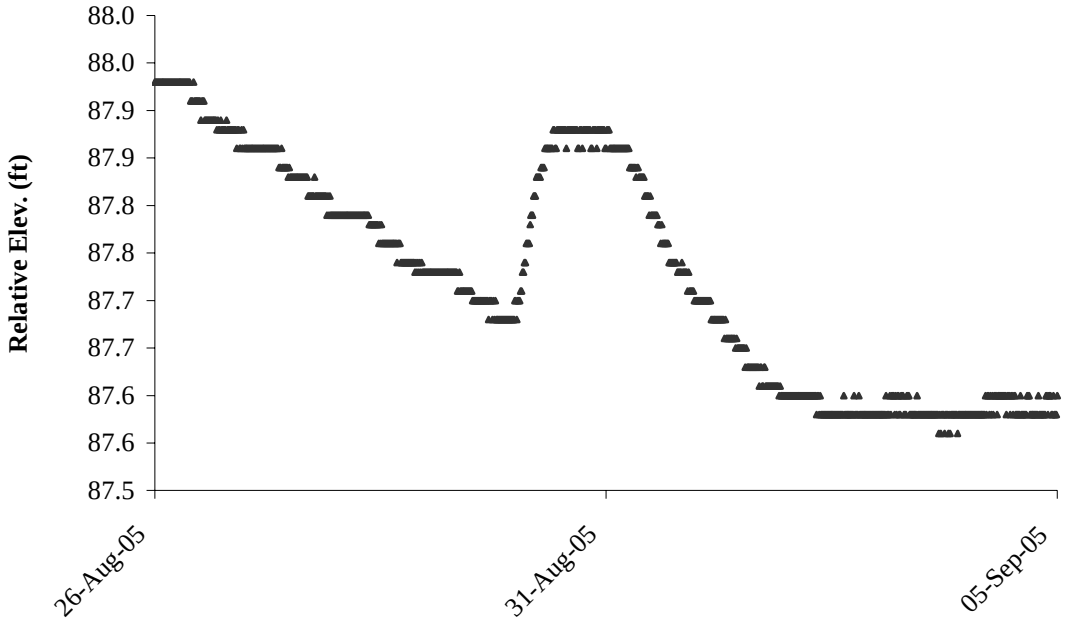


Figure 41. Relative groundwater elevations measured at a monitoring well located at the mouth of Tectah Creek, Lower Klamath River Sub-basin, California. Note the small peak associated with the managed flow release in the Trinity River for the Hoopa Valley Tribe's ceremonial Boat Dance.

Tributary Confluence Water Quality Monitoring

McGarvey Creek

Water quality sampling began at the McGarvey Creek confluence on 2 August 2005 (Figure 14). Water temperatures at the most upstream transect were fairly high ranging from 21.9 – 22.2 ºC (Figure 42). Water temperatures in McGarvey Creek were considerably lower with 15.2 ºC measured at a site located in a flowing reach upstream of Transect 2 (Figure 42). Surface flows from McGarvey Creek were responsible for the lower water temperatures measured at the first few sites in Transect 2 (Figure 42). A few sites located nearest the shore along Transects 3 – 4 were also influenced by the cooler water inputs of McGarvey Creek but to a lesser extent. Water temperatures along Transect 5 appeared unaffected by tributary inputs and ranged from 22.2 – 22.4 ºC. Dissolved oxygen conditions at all sites were generally near 8 mg/l and ranged from 6.87 – 9.53 mg/l (Figure 42).

Water quality sampling occurred again at McGarvey Creek confluence on 22 August 2005. The water column at Transects 1 and 4 – 5 were well mixed with water temperatures fluctuating from 21.6 – 22.2 ºC (Figure 43). Surface and subsurface flow inputs from McGarvey Creek affected two sites nearest the stream mouth in Transect 2 and at locations near the river bottom in Transect 3 (Figure 43). Dissolved oxygen conditions were fairly consistent among all sites with values ranging from 7.73 – 9.23 mg/l (Figure 43).

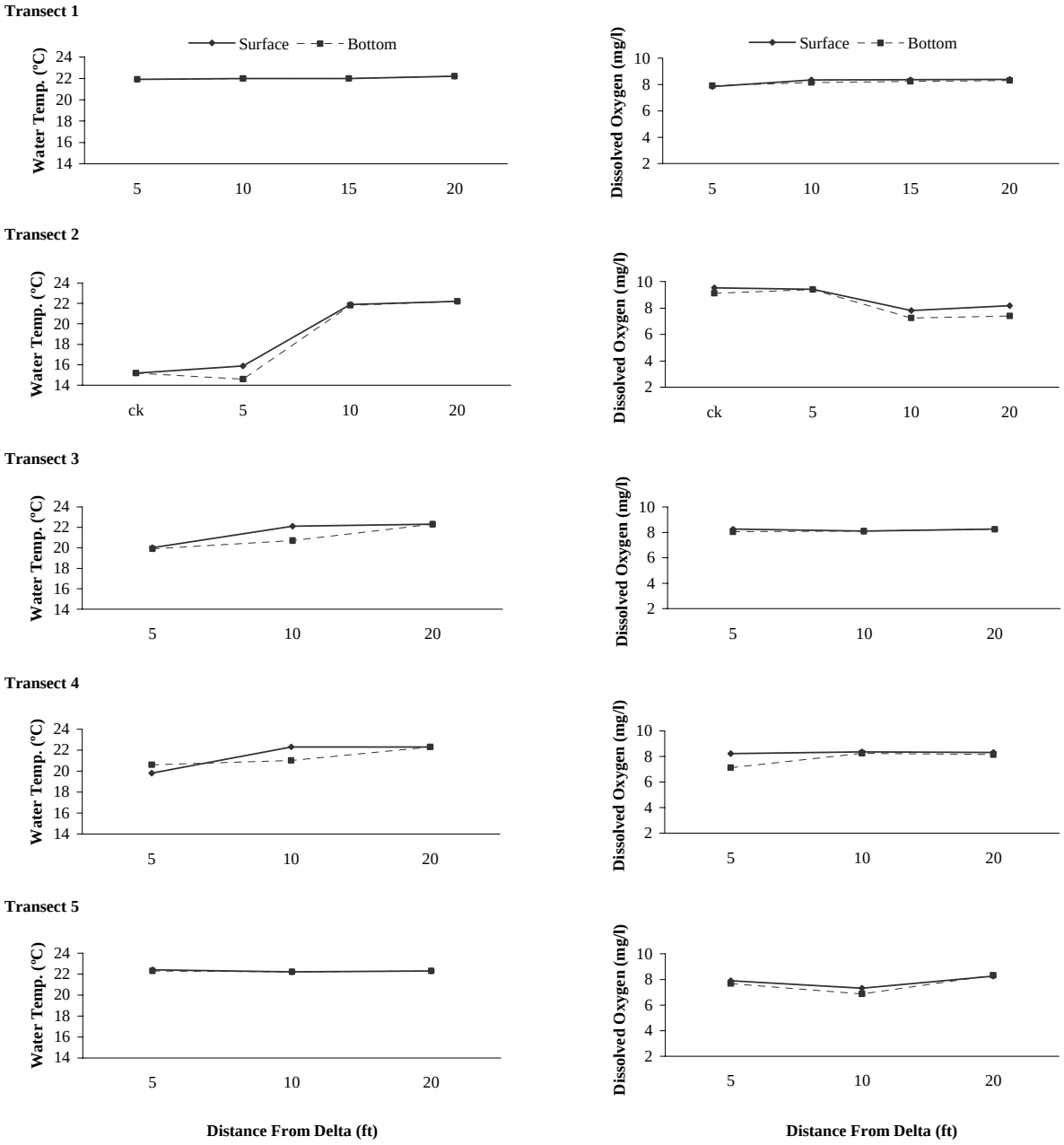


Figure 42. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with McGarvey Creek on 2 August 2005.

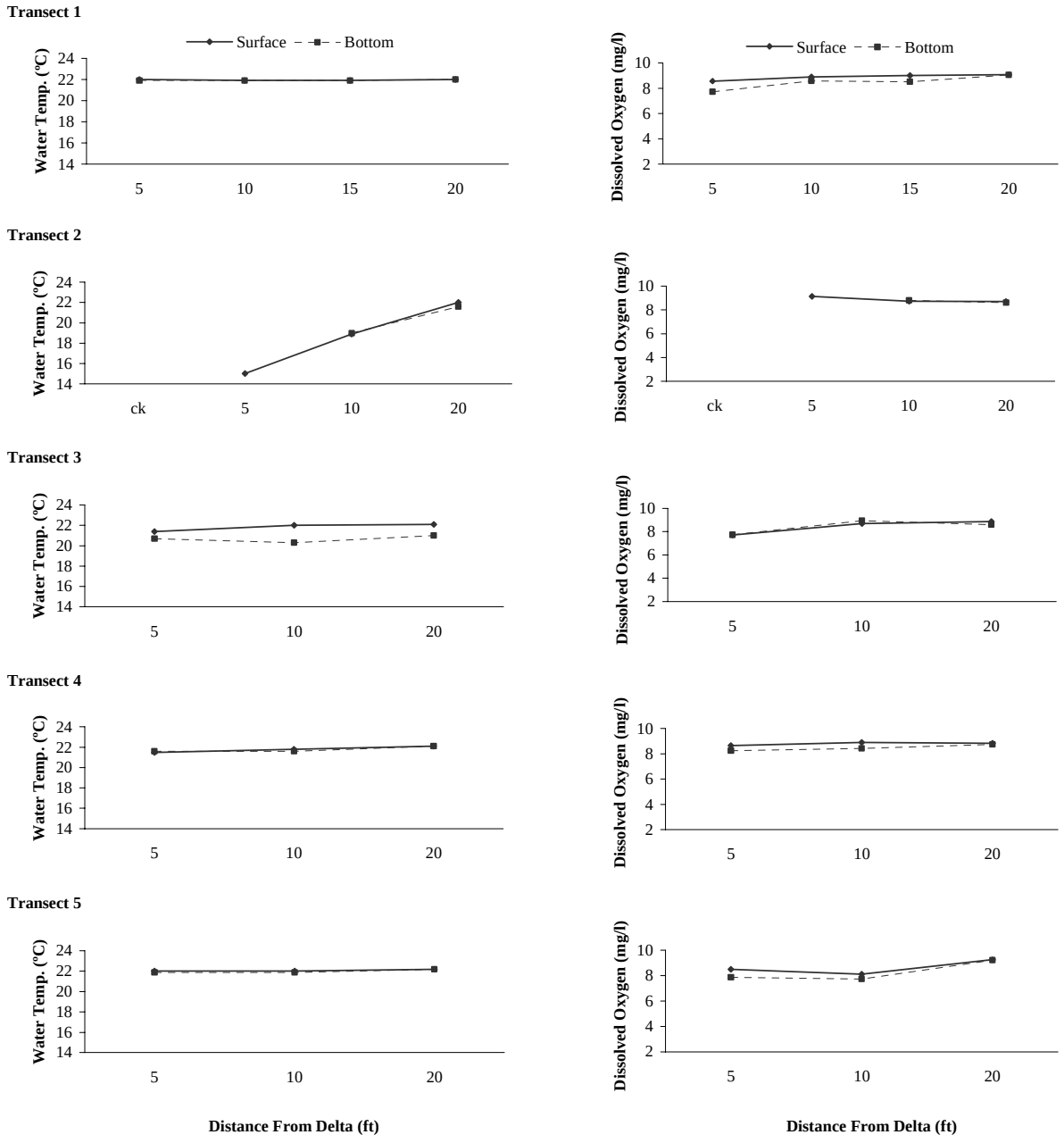


Figure 43. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with McGarvey Creek on 22 August 2005.

Water temperatures in the Klamath River had dropped substantially by the time of the last sampling effort at the McGarvey Creek confluence. Water temperatures measured at Transects 1 and 2 – 5 were all near 16 ºC (Figure 44). McGarvey Creek inputs appeared to affect water temperature at the first site in Transect 2 (Figure 44). Interestingly, water temperature measured at the McGarvey Creek site was 14.1 ºC and 12.6 ºC at the interface of McGarvey Creek and the Klamath River (Figure 14). This discrepancy was likely the result of cooler subsurface flow inputs form McGarvey Creek affecting mainstem water temperatures. Subsurface flows from McGarvey Creek were likely responsible for the difference in temperature at these sites. The water column in Transects 3 – 5 appeared well mixed with water temperatures ranging from 16.0 – 16.3 ºC (Figure 44). Dissolved oxygen was lowest in McGarvey Creek measuring 7.29 mg/l near the stream bottom. Dissolved oxygen values at all other sites were from 8.47 – 10.73 mg/l (Figure 44).

Blue Creek

The first water quality sampling at the Blue Creek confluence occurred on 27 July 2005 and consisted of three transects (Figure 15). The furthest site in Transect 1 was located in a flowing reach of the Klamath River adjacent to the area sampled (Figure 15). Water temperature was highest during this sampling period at this site with surface water measuring 20.7 ºC (Figure 45). Two small flowing channels and one seep emanating from Blue Creek provided surface flows to the area sampled. Water temperatures at these sites were from 12.0 – 16.6 ºC (Figure 45). Cool water inputs from Blue Creek appeared to substantially affect water temperatures along all three transects. Water temperatures varied slightly among sites with values ranging from 13.2 – 18.6 ºC (Figure 45). Transects 2 – 3 were located in relatively deep water that at the time of the survey was stratified with the coolest temperatures observed near the river bottom. Dissolved oxygen in Blue Creek ranged from 4.95 mg/l in the seep located in Transect 2 to 9.72 mg/l in a flowing channel. At all other stations dissolved oxygen was fairly consistent and ranged from 5.61 – 8.48 mg/l (Figure 45).

The mid summer sampling effort occurred at the confluence of Blue Creek on 23 August 2005. Water temperature was again highest in the flowing reach of the Klamath River measuring 22.4 ºC throughout the water column (Figure 46). Dissolved oxygen at this site was from 8.23 – 8.39 mg/l (Figure 46). Only one channel and the seep at Transect 2 were providing surface flows during this sampling effort. Water temperatures of these inputs were 12.9 ºC in the seep and 15.2 ºC in the Blue Creek channel (Figure 46). Dissolved oxygen values at these same sites were 6.75 mg/l in the seep and 6.84 mg/l in the Blue Creek channel. During this survey, all three transects were stratified with respect to water temperature and dissolved oxygen (Figure 46). Water temperatures were highest in Transect 1 with values ranging from 15.9 – 18.8 ºC at the sites protected from direct river flow (Figure 46). Water temperatures at Transects 2 – 3 were slightly less with values ranging from 12.6 – 18.0 ºC. Dissolved oxygen was fairly stable at all sites with values generally ranging from 5 – 8 mg/l (Figure 46).

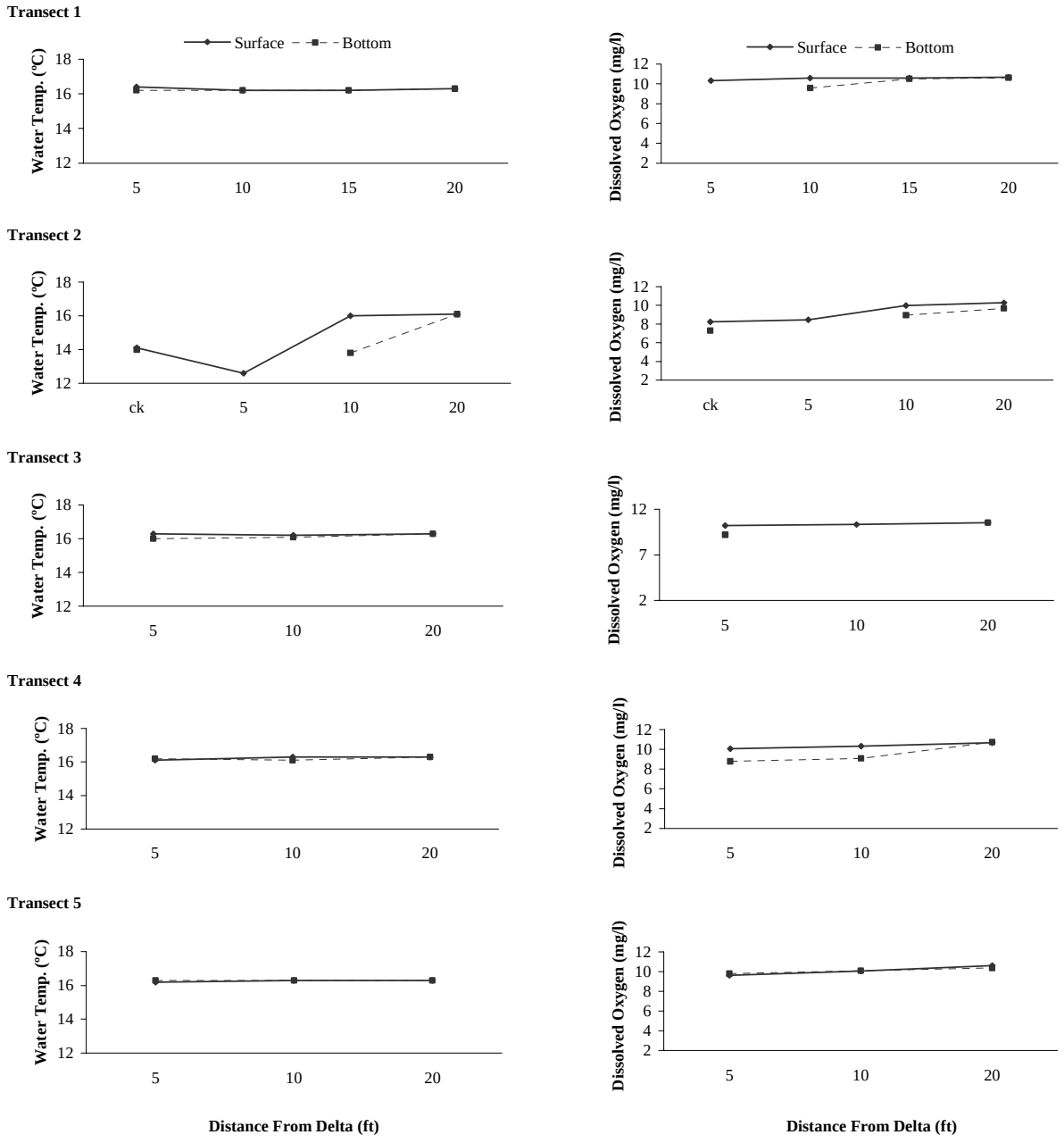


Figure 44. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with McGarvey Creek on 27 September 2005.

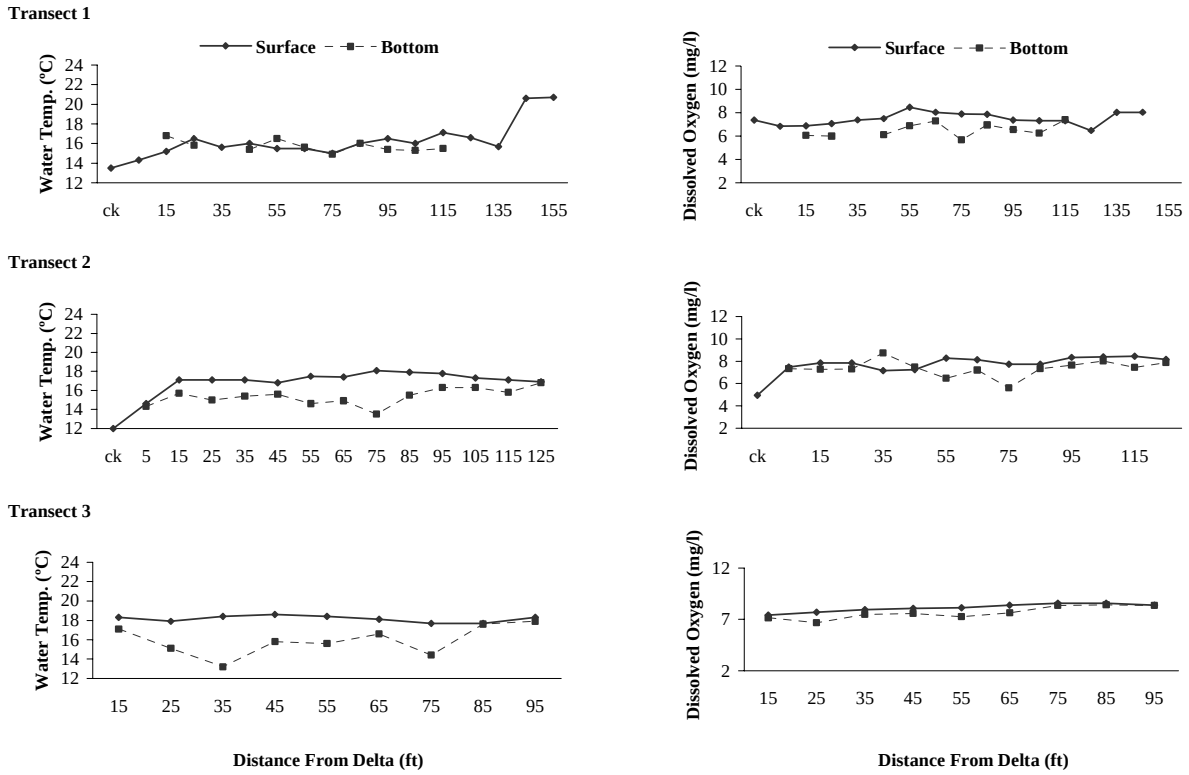


Figure 45. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Blue Creek on 27 July 2005.

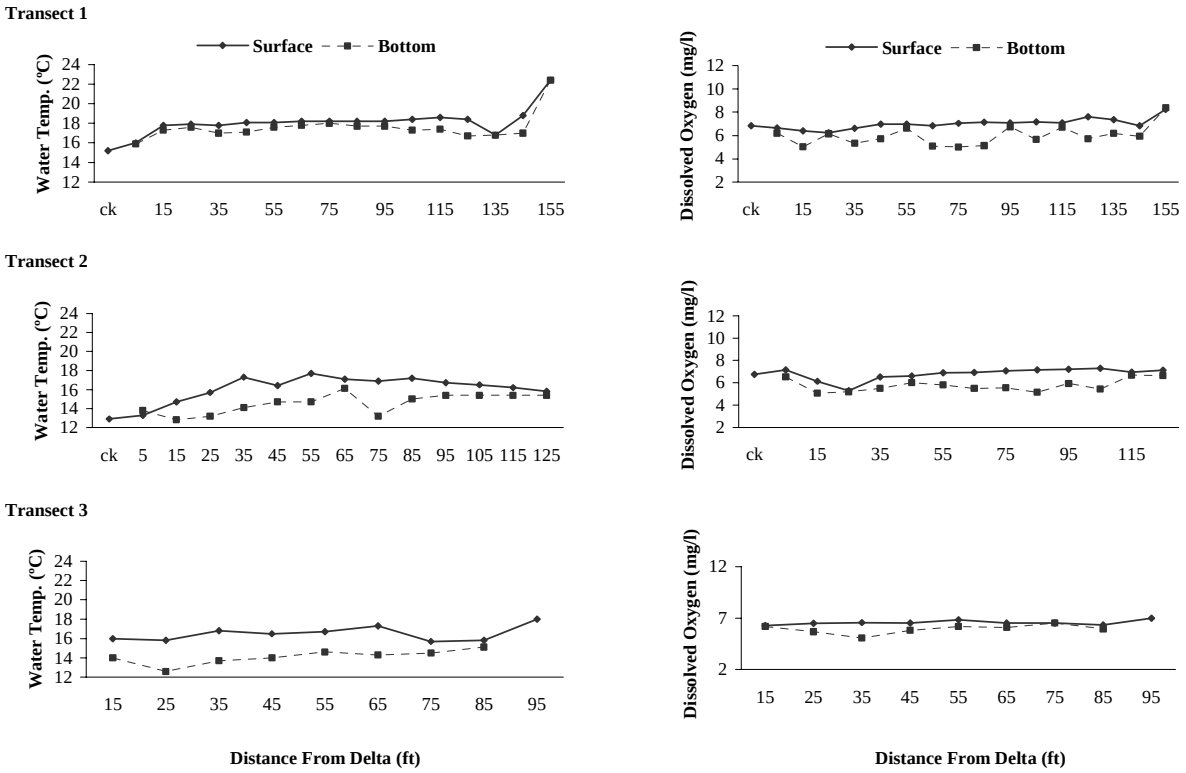


Figure 46. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Blue Creek on 23 August 2005.

The final water quality sampling of the Blue Creek confluence occurred on 28 September 2005. Water temperatures in the Klamath River had dropped since August 2005 with 16.7 ºC measured at the flowing reach site in Transect 1 (Figure 47). Values measured at all other sites in Transect 1 ranged from 15.0 – 16.6 ºC (Figure 47). Only the seep in Transect 2 was providing surface flows to the study area during this survey. Water temperatures along Transect 2 ranged from 13.6 – 16.1 ºC and were from 14.2 – 15.6 ºC along Transect 3 (Figure 47). Dissolved oxygen was highest in the Klamath River site in Transect 1 while values in most other sites ranged from 5.8 – 9.30 mg/l (Figure 47). The low dissolved oxygen value observed at a site in Transect 3 may have resulted from accidentally placing the probe in the anoxic sediments that make up parts of the river bottom.

Tectah Creek

Water quality sampling at the confluence of Tectah Creek began on 18 July 2005 and consisted of three transects (Figure 16). Water temperatures measured in two flowing reaches of Tectah Creek were 12.2 ºC and 17.3 ºC (Figure 48). While cooler temperatures were observed in Tectah Creek and at stations nearest to the shore, dissolved oxygen concentrations were fairly low at these sites due to subsurface flow inputs (Figure 48). The coolest water temperatures were observed along Transect 1 with only the furthest two stations from the delta reaching temperatures above 22 ºC (Figure 48). Water temperatures along Transect 3 suggested that tributary inputs had negligible effect on river temperatures.

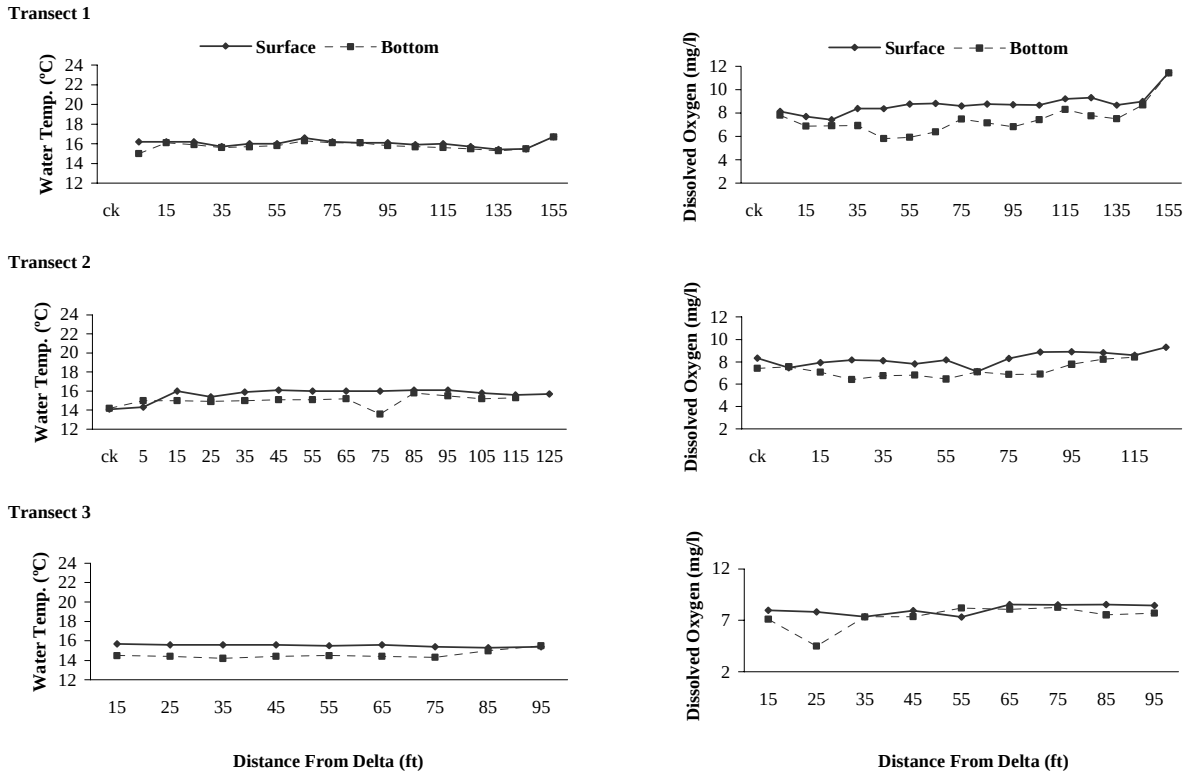


Figure 47. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Blue Creek on 28 September 2005.

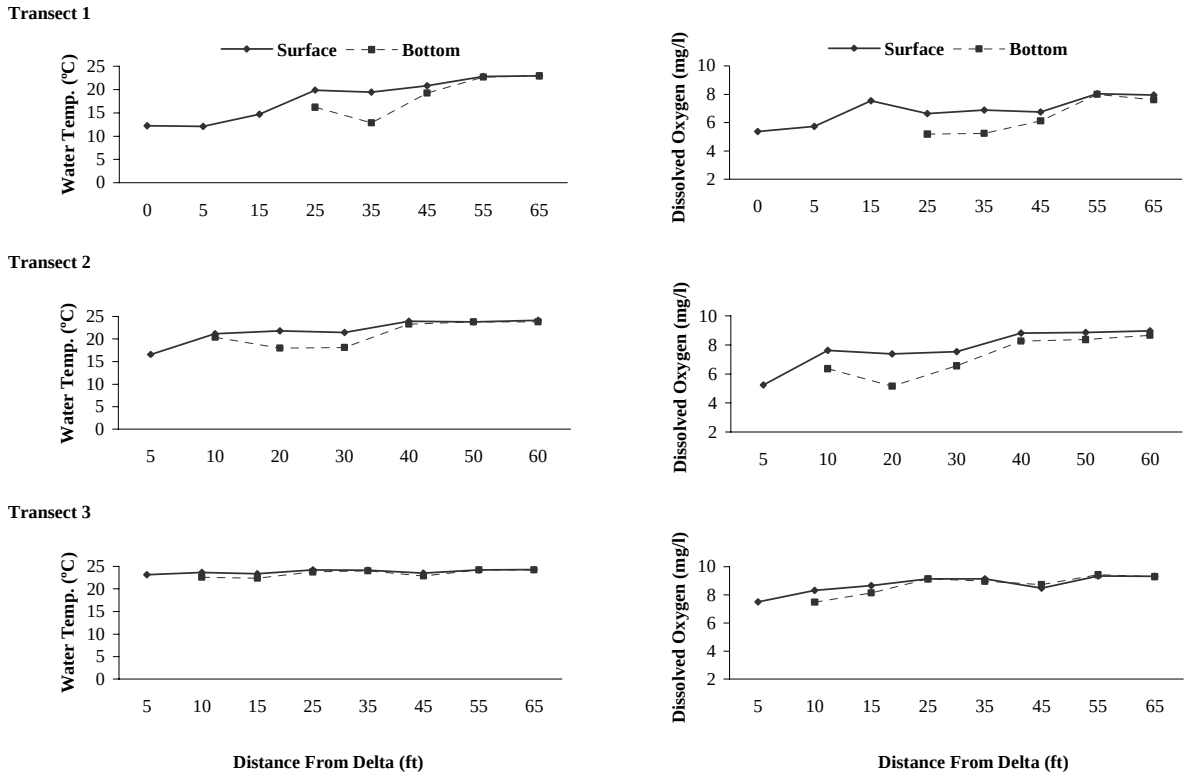


Figure 48. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Tectah Creek on 18 July 2005.

The area sampled on 25 August 2005 was greatly reduced due to low flow conditions. Many of the near shore stations were out of water or very shallow. A site located upstream of the confluence with Tectah Creek was added on this date to document river conditions upstream of tributary inputs (Figure 16). Water temperature at this site was measured at 21.9 ºC at all depths with dissolved oxygen ranging from 7.65 mg/l near the river bottom to 8.38 mg/l at the surface. Water temperatures measured in flowing reaches of Tectah Creek or seeps emanating from the delta ranged from 14.1 – 22.9 ºC on this date. Water temperatures along Transect 1 were heavily influenced by tributary flow inputs with only the furthest site with temperatures above 20 ºC (Figure 49). Tributary inputs affected water temperatures at half of the sites located along Transect 2 while the furthest three sites measured above 20 ºC (Figure 49). Surface measures at sites located along Transect 3 appeared unaffected by tributary inputs with water temperatures ranging from 21.3 – 22.1 ºC (Figure 49). Water temperatures were slightly less near the river bottom along Transect 3, however, temperatures less than 20 ºC only occurred at one site. Dissolved oxygen patterns were similar to those observed in July 2005 with lower values occurring in the vicinity of tributary inputs (Figure 49).

Final sampling at the Tectah Creek confluence occurred on 5 October 2005. At this time, water temperatures in the river had dropped substantially with 15.1 ºC measured at the site located upstream of Tectah Creek (Figure 50). Dissolved oxygen at this site ranged from 10.64 mg/l near the river bottom to 11.44 mg/l at 3.3 ft depth. Water temperatures along

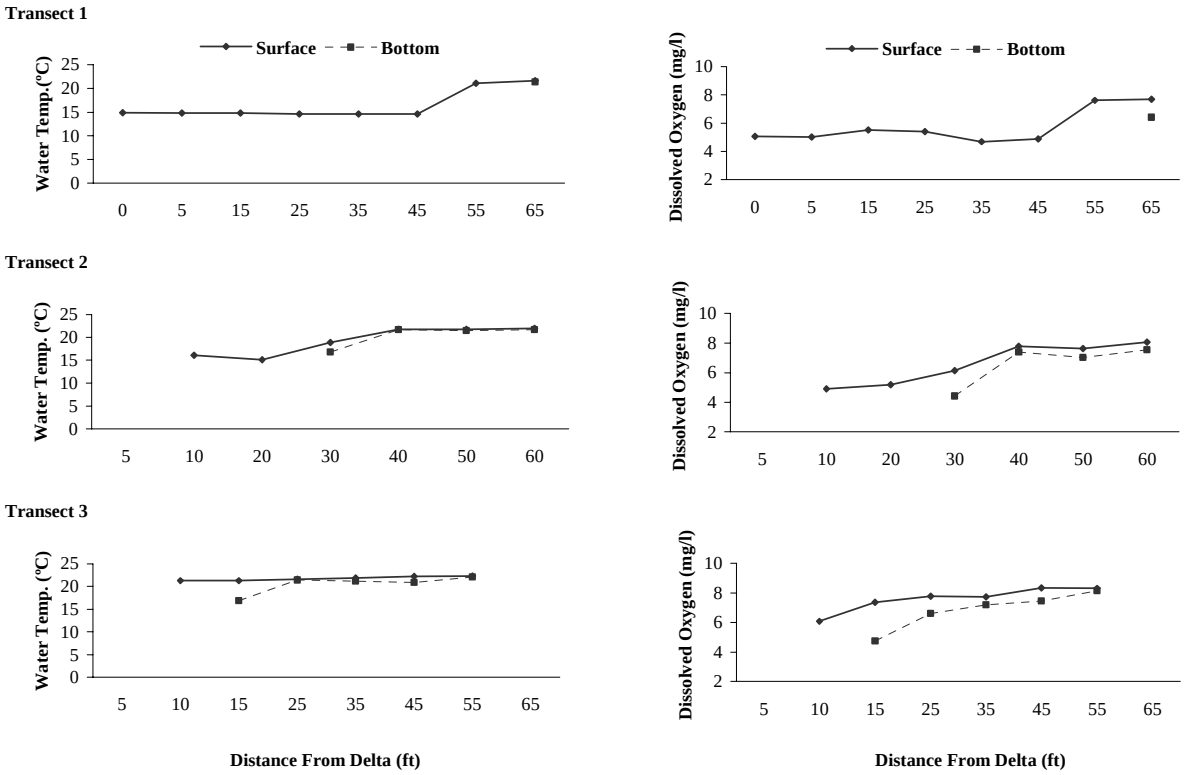


Figure 49. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Tectah Creek on 25 August 2005.

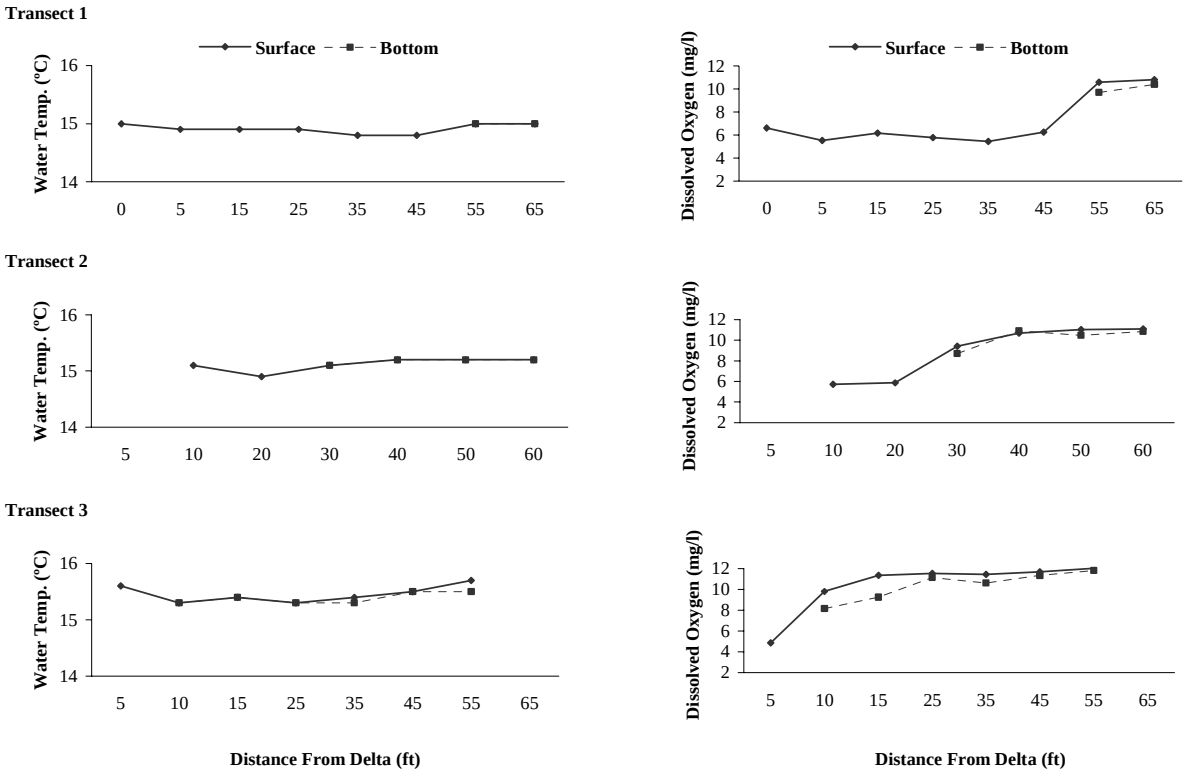


Figure 50. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Tectah Creek on 5 October 2005.

Transects 1 – 3 ranged from 14.8 – 15.7 ºC with dissolved oxygen ranging from 4.86 mg/l nearest the shore in Transect 3 to 12.03 mg/l measured at the furthest site in Transect 3 (Figure 50).

Roaches Creek

Water quality sampling at the confluence of Roaches Creek began on 20 July 2005 and consisted of ten transects (Figure 17). Water temperatures less than 20 ºC were only measured at two locations within Transects 1 – 6 (Figure 51). Water temperatures measured at three sites in Roaches Creek ranged from 18.9 – 19.6 ºC. Tributary inputs appeared to affect water temperatures near the bottom of the Klamath River along Transects 7 – 8, however river surface temperatures in these transects were all above 22 ºC (Figure 51). Water temperatures were most affected by tributary inputs along Transects 9 – 10 (Figure 51). These cooler temperatures likely resulted from the moderate surface and subsurface flows emanating from Roaches Creek and the reduced tendency of the water column at these sites to mix with mainstem flows. Dissolved oxygen values generally ranged from 7 – 9 mg/l at all sites (Figure 51). Lower values observed in Transects 1 – 2 were likely related to subsurface tributary flow inputs. The extremely low dissolved oxygen values observed in Transects 5 – 7 and 9 may have resulted from accidentally placing the probe into anoxic sediments that make up parts of the river bottom (Figure 51).

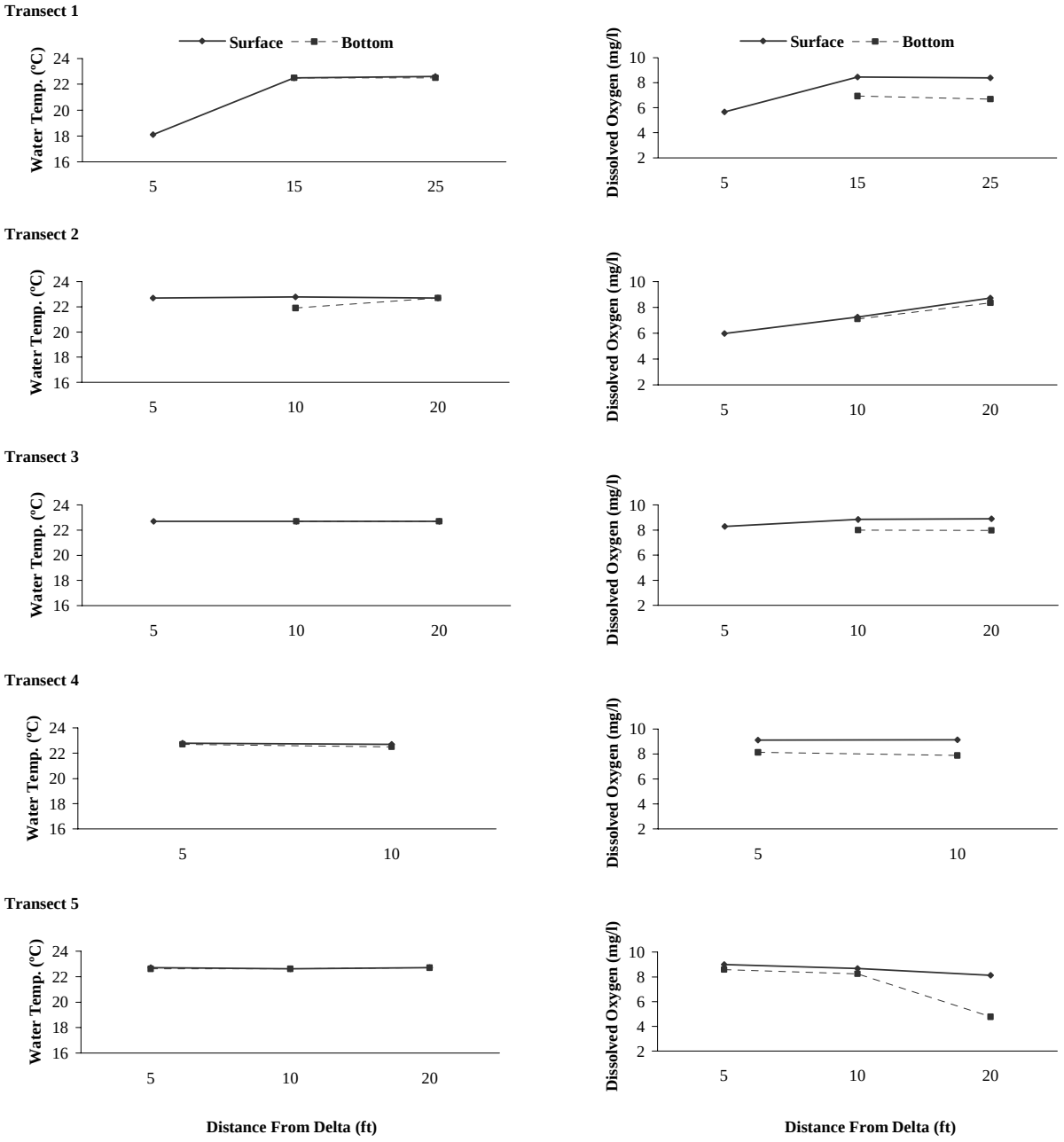


Figure 51. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Roaches Creek on 20 July 2005.

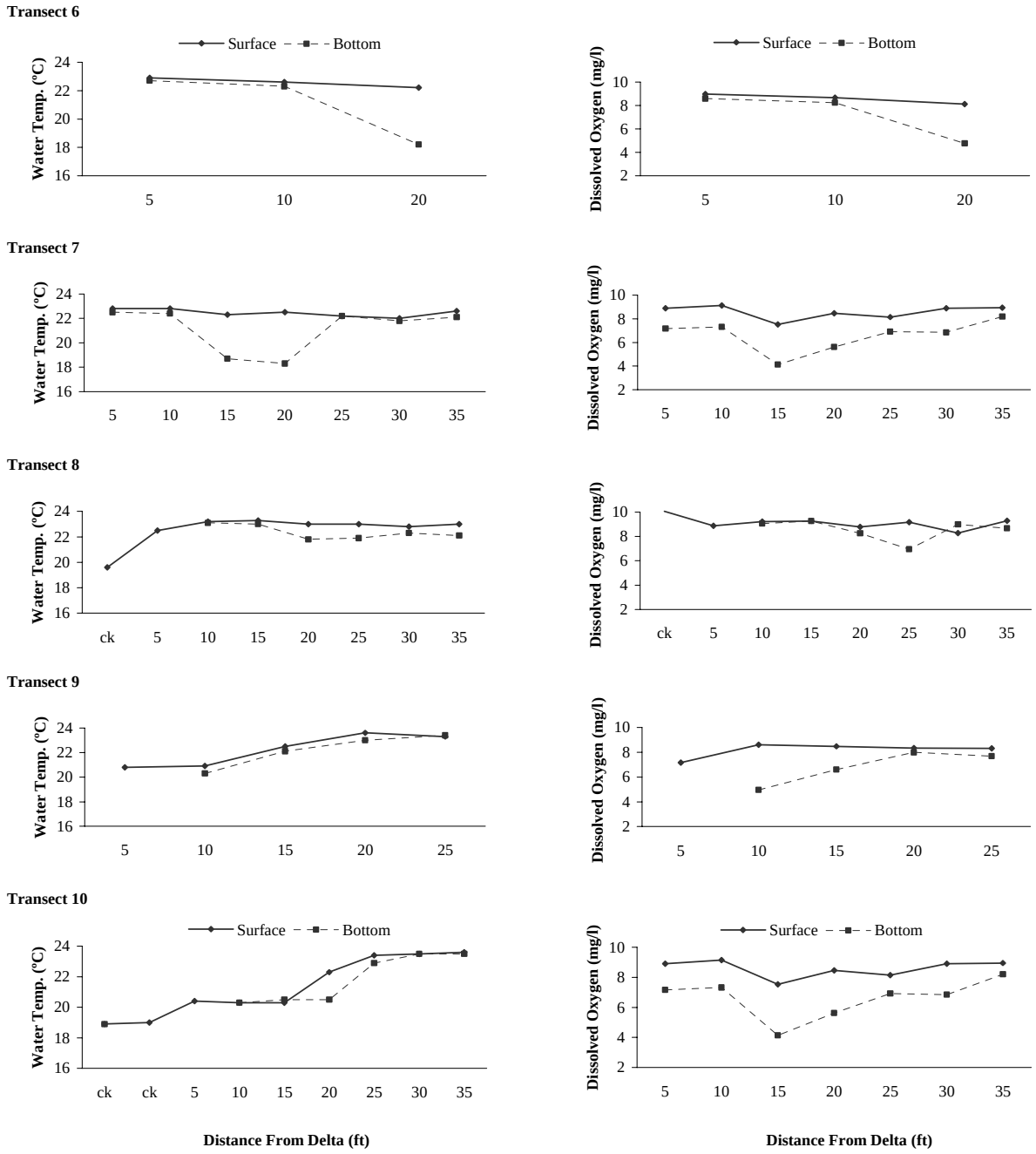


Figure 51. Continued.

On 24 August 2005, water quality was sampled again at Roaches Creek confluence, however Transects 1 – 2 were not sampled on this occasion. The water column at Transects 3 – 5 was fairly mixed with a majority of the water temperatures measured above 22 ºC (Figure 52). Water temperatures were cooler along the river bottom in Transects 6 – 10 and ranged from 18.6 – 22.9 ºC (Figure 52). Surface flows were no longer present in the channel that drained nearest to Transect 8. Surface flows at the site nearest to the delta in Transect 9 appeared affected by tributary inputs with water temperature measured at 19.3 ºC (Figure 52). Cooler surface water temperatures were observed at many of the sites nearest to the delta in Transect 10 (Figure 52). Water temperature of Roaches Creek near the Klamath River interface was 18 ºC on this date. Dissolved oxygen conditions among all sites were fairly similar and values ranged from 6.25 – 10.26 mg/l (Figure 52).

Final water quality sampling at Roaches Creek confluence occurred on 29 September 2005. Transects 2 – 3 were not sampled during this occasion. Water temperatures in the Klamath River had dropped from July – August 2005 as evident by values measured along Transect 1 (Figure 53). The water column was well mixed along Transects 1 and 4 – 6 with water temperature holding steady just above 16 ºC (Figure 53). Water temperatures at many of the sites located along Transects 7 – 10 were cooler due to tributary inputs with the lowest value of 13.4 measured near the river bottom in Transect 10 (Figure 53). Water temperature of Roaches Creek during this survey was measured at 14.0 ºC (Figure 53). Dissolved oxygen conditions were similar among all sites except for an extremely low value observed at the river bottom in Transect 7 (Figure 53). This low value likely resulted from accidentally placing the probe into anoxic sediments that make up parts of the river bottom.

Water Temperature Monitoring

Daily mean water temperatures at the site located downstream of Coon Creek began to rise in early July 2005 with a peak of 24.6 ºC occurring on 8 August 2005 (Figure 54). Daily mean water temperatures at this site began dropping on 23 August 2005 with the lowest values occurring in late September 2005 (Figure 54). The highest water temperature recorded at the Coon Creek site was 25.3 ºC and occurred in the late evening on 7 – 8 August 2005. The lowest water temperature recorded at this site was 14.4 ºC and occurred in the morning on 16 – 17 October 2005.

Daily mean water temperatures at the site located downstream of Roaches Creek began rising in early July 2005 with a peak of 24.7 ºC occurring on 8 August 2005 (Figure 55). Daily mean water temperatures began declining after this peak with the lowest mean temperatures occurring in early October 2005 (Figure 55). A very similar but cooler thermal pattern occurred at the site located nearest to the Roaches Creek confluence (Figure 55). Daily mean temperatures at this site were from 2.5 to 5.9 ºC cooler relative to daily mean values observed at the downstream site (Figure 55). The increase in daily mean water temperature from 10 July to 11 July 2005 resulted from a repositioning of the logger to compensate for declining flow levels (Figure 55).

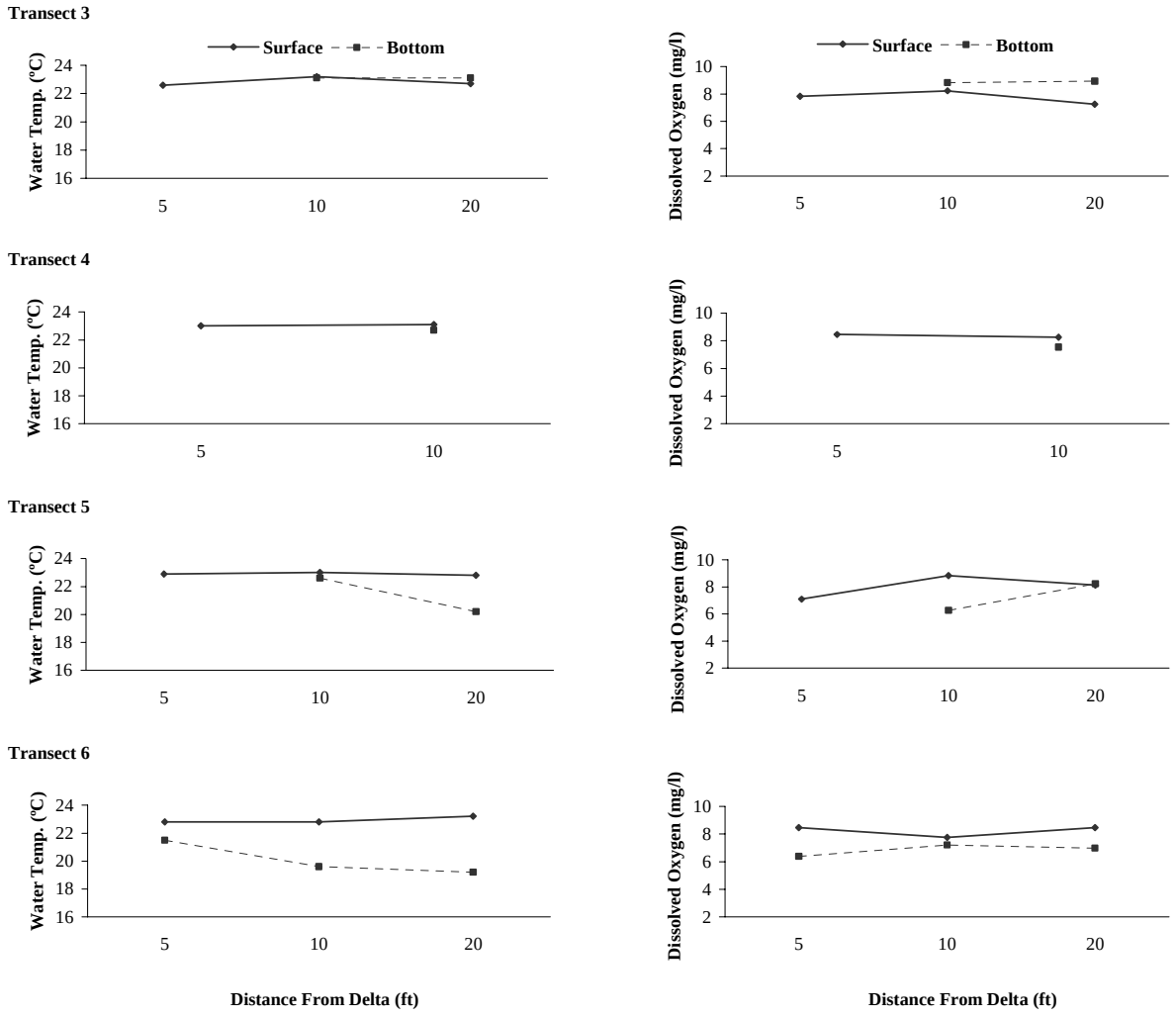


Figure 52. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Roaches Creek on 24 August 2005.

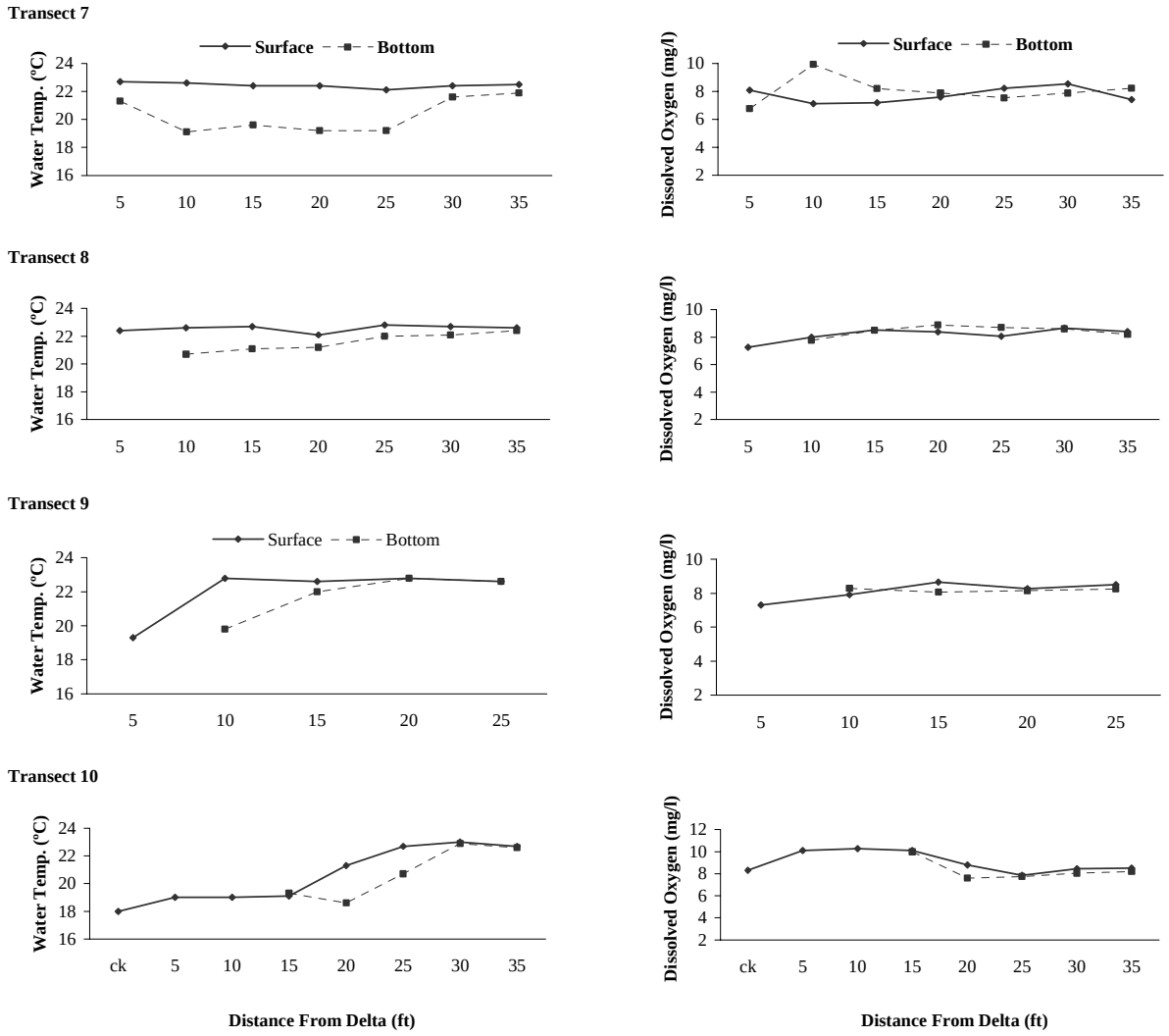


Figure 52. Continued.

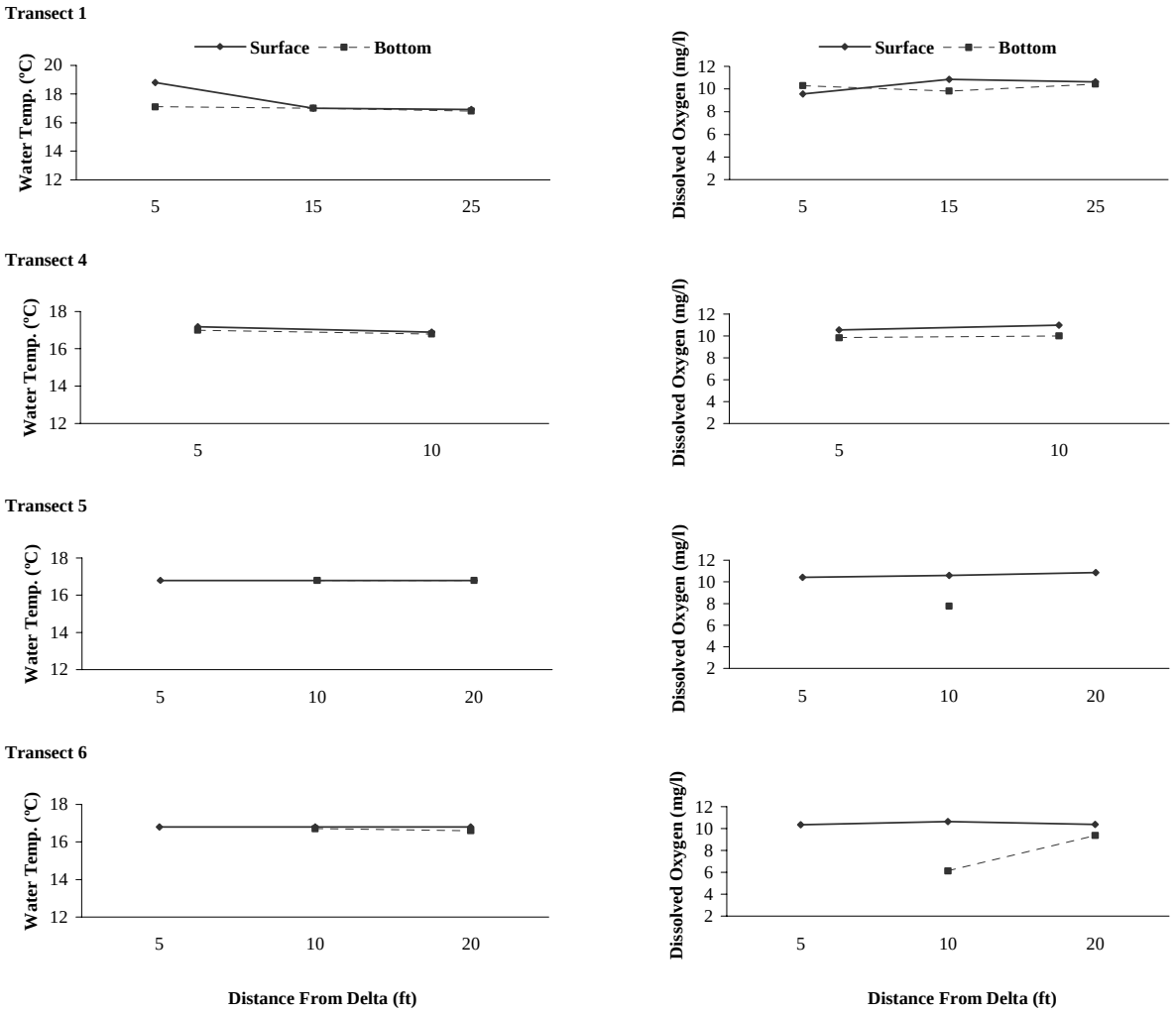


Figure 53. Water temperature and dissolved oxygen data for sites located in the Klamath River in the vicinity of the confluence with Roaches Creek on 29 September 2005.

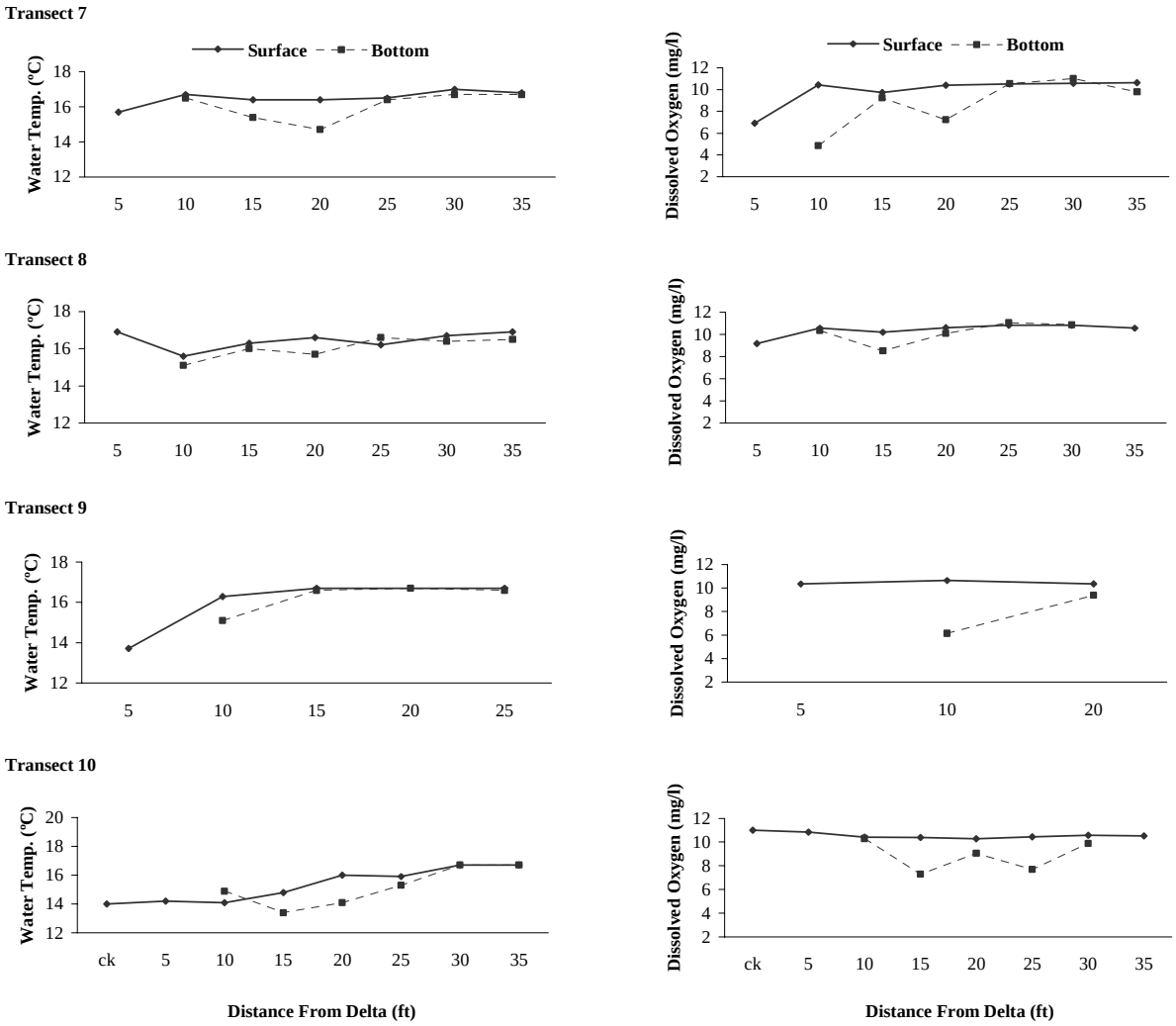


Figure 53. Continued.

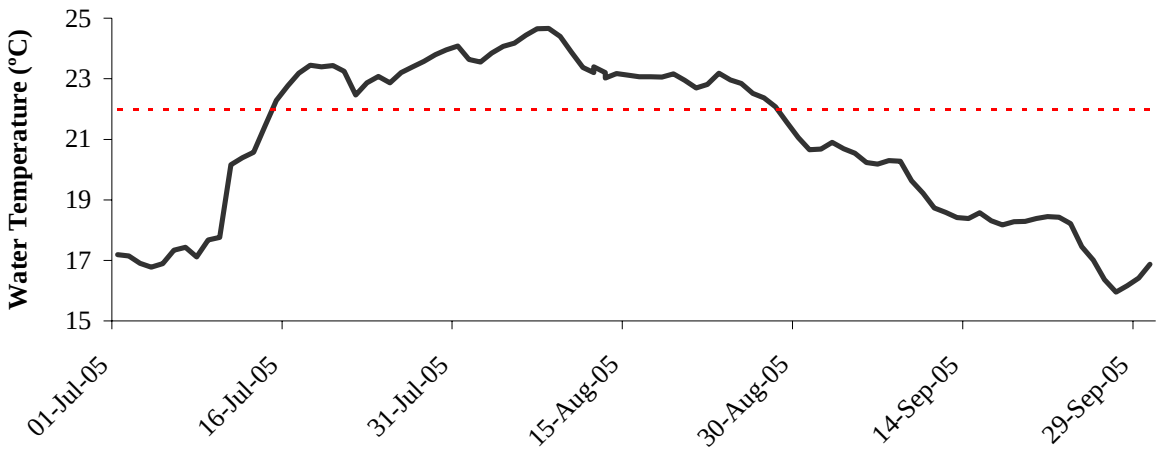


Figure 54. Daily mean water temperatures from a site in the Klamath River located downstream of Coon Creek, Lower Klamath River Sub-basin, California. The dotted red line provides an approximate visual reference for the migration inhibition threshold for adult Klamath River Basin chinook salmon (Strange 2005).

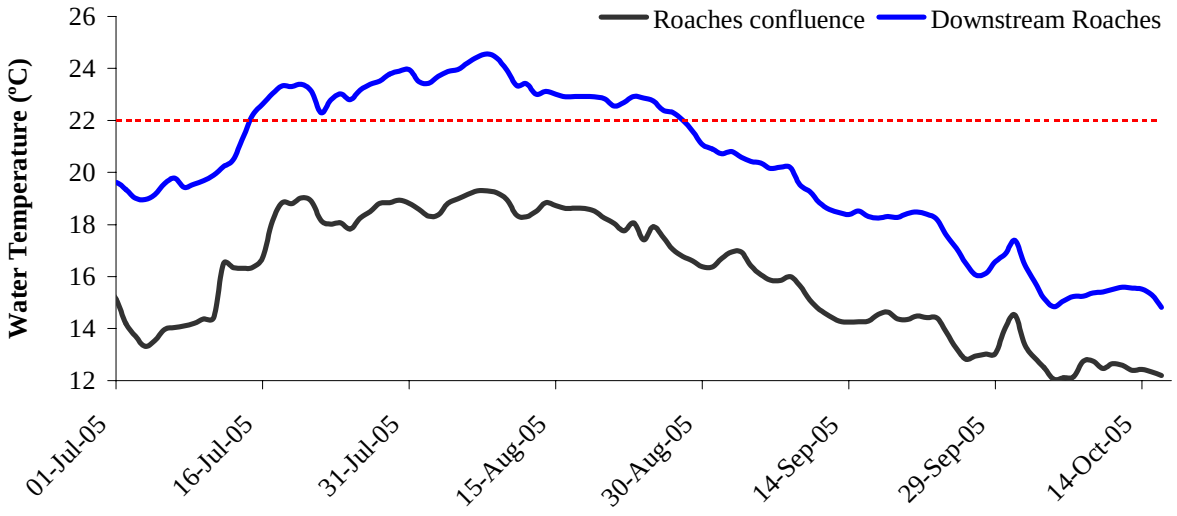


Figure 55. Daily mean water temperatures from two sites in the Klamath River located in the vicinity of Roaches Creek, Lower Klamath River Sub-basin, California. The dotted red line provides an approximate visual reference for the migration inhibition threshold for adult Klamath River Basin chinook salmon (Strange 2005).

Maximum water temperatures recorded in the vicinity of Roaches Creek were 24.6 ºC (7 – 9 August 2005) downstream of the confluence and 21.5 ºC (14 – 15 August 2005) at the confluence. The lowest water temperatures were 14.3 ºC (16 October 2005) downstream of the confluence and 11.1 ºC (5 – 6 October 2005) at the Roaches Creek confluence. Water temperatures at the confluence site were highly variable over 24 hour intervals during most of August 2005. This variability was related to declining tributary and river flow levels as well as having to reposition the logger to adjust for the changing conditions.

Daily mean water temperatures in lower Roaches Creek were much lower relative to those observed at the Klamath River sites located in the vicinity of the confluence (Figure 56). Roaches Creek daily mean temperatures began increasing in late June 2005 with a peak of 19.4 °C occurring on 6 August 2005 (Figure 56). Daily mean water temperatures began decreasing after this peak with a minimum value of 11.6 °C occurring on 5 – 6 October 2005 (Figure 56). Low tributary flow levels caused the logger to be exposed to the atmosphere from 27 August to 7 September, 2005 (Figure 56).

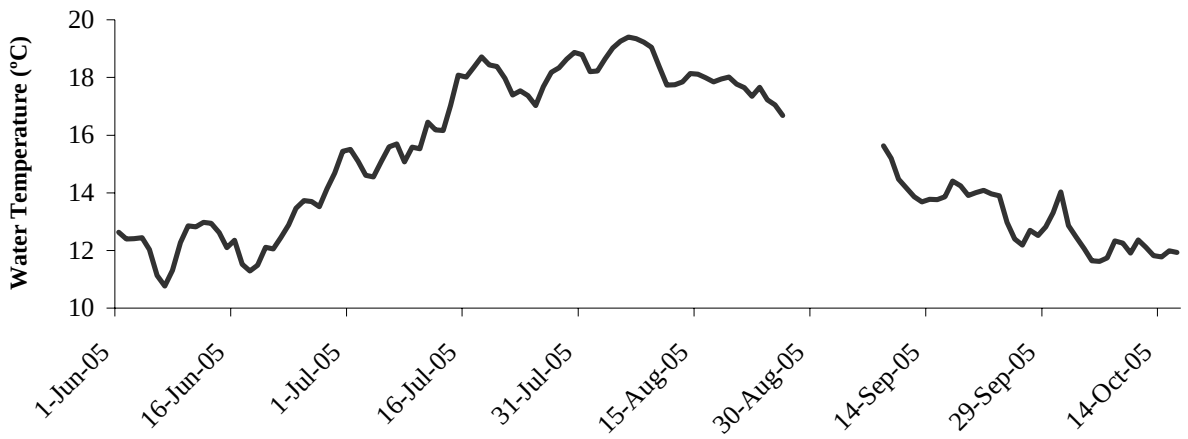


Figure 56. Daily mean water temperatures from a site in lower Roaches Creek, Lower Klamath River Sub-basin, California.

Daily mean water temperature values and patterns were similar at the sites located upstream and downstream of the Tectah Creek confluence (Figure 57). The river began warming at these sites in early July 2005 and daily mean water temperatures above 22 ºC persisted through late August – early September 2005 (Figure 57). Daily mean water temperatures at these sites began decreasing in late August with the lowest mean values observed in October 2005 (Figure 57). Maximum water temperatures recorded at these sites were 25.7 ºC on 8 August 2005 (17:00 hours) at the upstream site and 25.5 ºC on 8 August 2005 (18:30 hours) at the downstream site.

Daily mean water temperatures at the Tectah refuge sites were variable over the study period due to declining river and tributary flow levels and repositioning these loggers to adjust to the changing conditions (Figure 57). In general, daily mean water temperatures at the Tectah

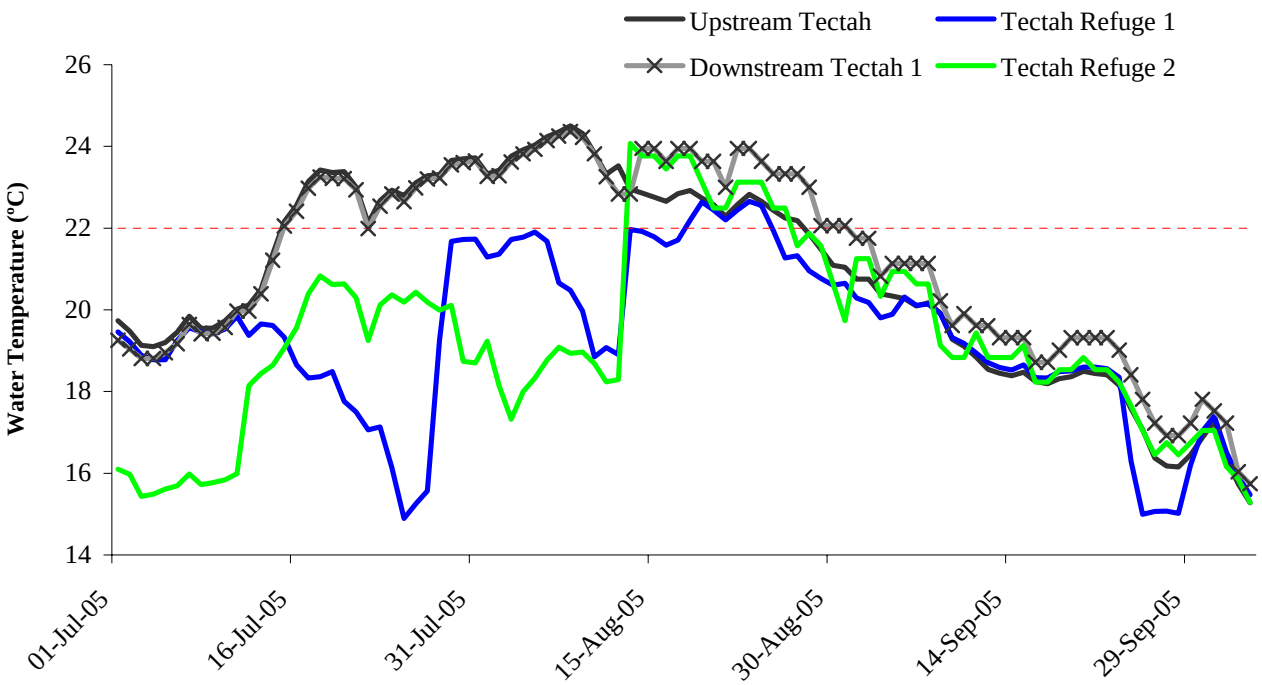


Figure 57. Daily mean water temperatures from four sites in the Klamath River located in the vicinity of Tectah Creek, Lower Klamath River Sub-basin, California. The dotted red line provides an approximate visual reference for the migration inhibition threshold for adult Klamath River Basin chinook salmon (Strange 2005).

refuge sites were cooler than those observed at the sites located further away from the confluence during the first part of the season (Figure 57). Similarities in daily mean water temperatures observed in mid August 2005 at all of the sites was related to low flows and subsequent increased water column mixing at the refuge sites (Figure 57). Daily mean water temperatures in lower Tectah Creek began increasing in late June 2005, peaked at 16.2 °C on 5 August 2005, and then began declining (Figure 58). The maximum water temperature recorded in lower Tectah Creek was 17.4 °C in early August 2005. Water temperatures began declining after the early August peak.

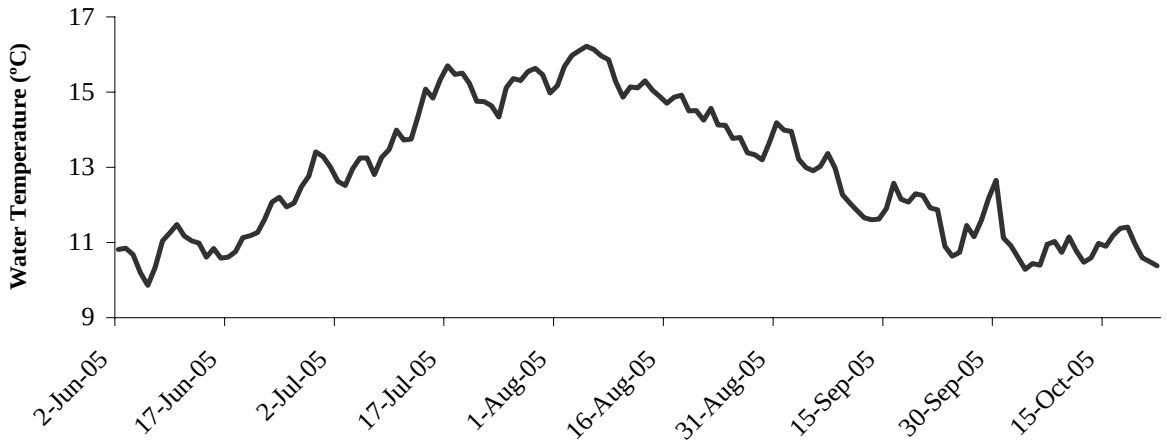


Figure 58. Daily mean water temperatures from a site in lower Tectah Creek, Lower Klamath River Sub-basin, California.

Discussion

Tributary Delta Study

Our historical review of delta formation and extent for Bear Creek, Tectah Creek, and Roaches Creek revealed deltas began forming in the early 1940's (Figures 18, 21, and 24). These findings agreed well with the results presented by Payne and Associates (1989) (Figure 59). They did not observe measurable deltas in the 1936 imagery. As in our study, they reported delta formation began during the early 1940's. In general, they observed deltas increased in extent from 1948 – 1976 and decreased from 1976 – 1989 (Figure 59).

Bear Creek

Payne and Associates (1989) reported Bear Creek delta gradually increased in extent from 1948 – 1954 then underwent a period of stability from 1954 – 1975 (Figure 59). They measured a maximum delta extent of 2.23 acres from the 1976 imagery. They observed decreases in delta extent from the peak in 1976 to 0.85 acres in 1989 (Figure 59). Although we felt this component was too subjective to repeat, obtaining the historic imagery for this particular area was extremely important for our study.

Bed elevations through the Bear Creek delta were slightly higher in 2004 relative to the surveyed profile presented by Payne and Associates (1989) (Figure 60). The 1989 delta profile was also less steep at the distal edge allowing a Klamath River flow of 20,000 cfs to inundate the delta to a slightly greater extent than was predicted by the 2004 inundation model (Figure 60). However, both models indicated that Klamath River flows much greater than 20,000 cfs were required to facilitate fish access to the first pools located in Bear Creek (Figure 60). The increased bed elevations reflected the overall increase in sediment storage occurring in this reach. Examination of the images from 1948 – 2004 revealed that lateral bars have formed upstream of the delta and along the opposite side of the river downstream

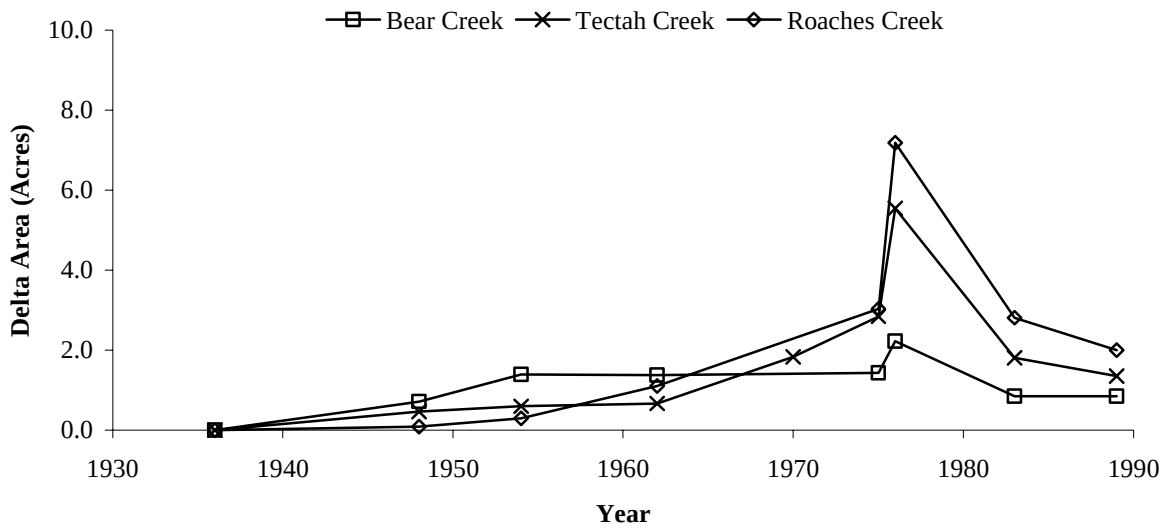


Figure 59. Historical changes in tributary delta extent for Bear Creek, Tectah Creek, and Roaches Creek as presented by Payne and Associates (1989). Lower Klamath River Sub-basin, California.

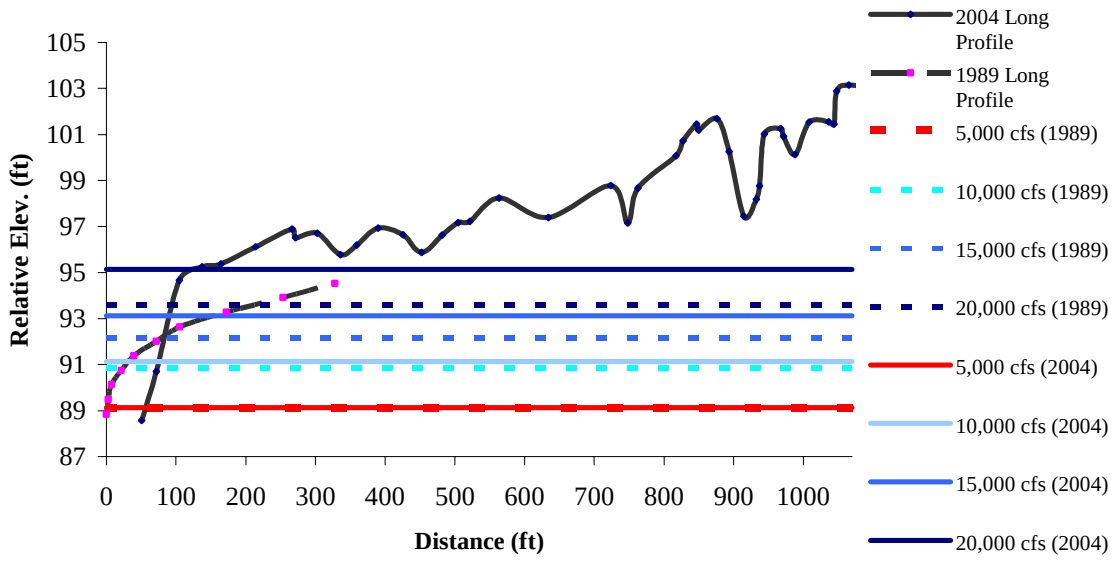


Figure 60. Klamath River inundation elevations on the Bear Creek delta profile as presented by Payne and Associates (1989) and the Yurok Tribal Fisheries Program (2004).

from Bear Creek (Figure 61). Transport of legacy sediments from historic land management activities, currently stored in large bar formations, may only be mobilized during large floods (e.g. 1964, 1974, 1997). Geomorphic investigations addressing sediment storage and transport dynamics on the sub-basin or larger scale should be conducted.

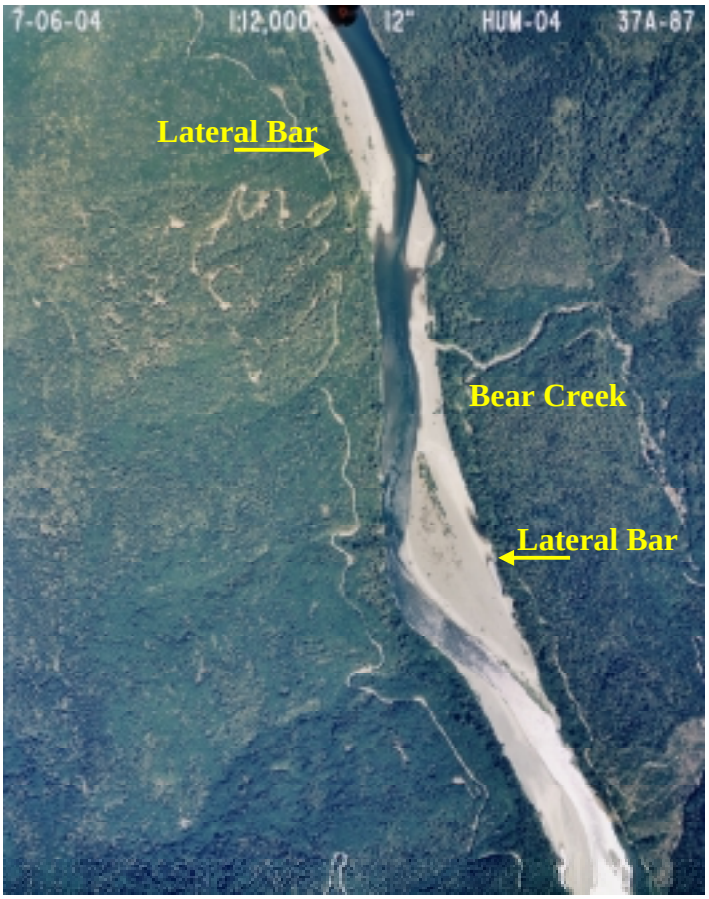


Figure 61. Aerial photograph of the Bear Creek confluence, Lower Klamath River Sub-basin, California (2004).

Tectah Creek

Our estimates of delta extent in Tectah Creek were fairly similar to those reported by Payne and Associates (1989) for the period 1948 – 1965 and in 1988 (Figure 62). However, comparing results of our historical review with those presented by Payne and Associates (1989) was difficult given the differences in imagery used. Payne and Associates (1989) reported a substantial increase in delta extent from 1962 – 1975 and a dramatic increase from 1975 – 1976 (Figure 59). Although we were unable to obtain 1976 aerial photographs, we measured delta extent from 1970, 1974, and 1975 RAPs and did not observe any substantial increases in delta extent as was reported by Payne and Associates (1989) (Figure 62). We hypothesized that some of the discrepancies observed between the two studies were due to differences in methodology. We kept the upstream boundary of the delta consistent in our

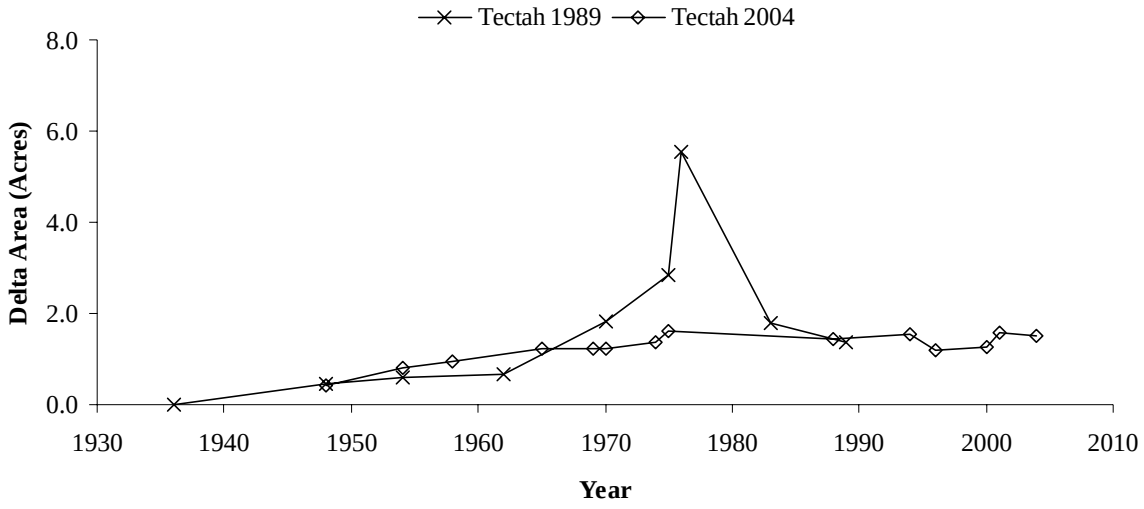


Figure 62. Historical changes in tributary delta extent for Tectah Creek as presented by Payne and Associates (1989) and the Yurok Tribal Fisheries Program (2004). Lower Klamath River Sub-basin, California.

study and also took into account the Klamath River flow level associated with each image. We were unsure whether or not Payne and Associates (1989) included tributary sediment storage (extending the proximal end of the delta further upstream) in their delta measurements or accounted for Klamath River flow level.

Although the 2004 estimate of aerial extent for Tectah Creek delta was similar to that estimated by Payne and Associates in 1989, delta profiles and Klamath River water surface profiles for these same years were quite different (Figure 63). The 1989 delta profile was much steeper at the distal edge and bed elevations were approximately 2 – 3 ft higher than elevations surveyed in 2004. However, both inundation models estimated Klamath River flows of 15,000 cfs or greater would facilitate fish access into Tectah Creek (Figure 63).

Tectah Creek enters the Klamath River on the outside of a meander bend and becomes a backwater feature when Klamath River flows are 20,000 cfs or greater. A fairly large bedrock exposure is present just upstream of the Tectah Creek delta (Figure 21). This exposure protects the tributary outlet from Klamath River flows that may have the capacity to transport the delta sediments but not cause backwater conditions at the delta. Based on our observations, delta sediments will persist in Tectah Creek until upslope and channel stored sediment supplies diminish. Evacuation of the delta would also require tributary flows capable of transporting delta sediments to occur during periods of low mainstem flows. This type of tributary flow asymmetry tends to occur in Lower Klamath River tributaries during fall – early winter depending on the timing and magnitude of early season storm events.

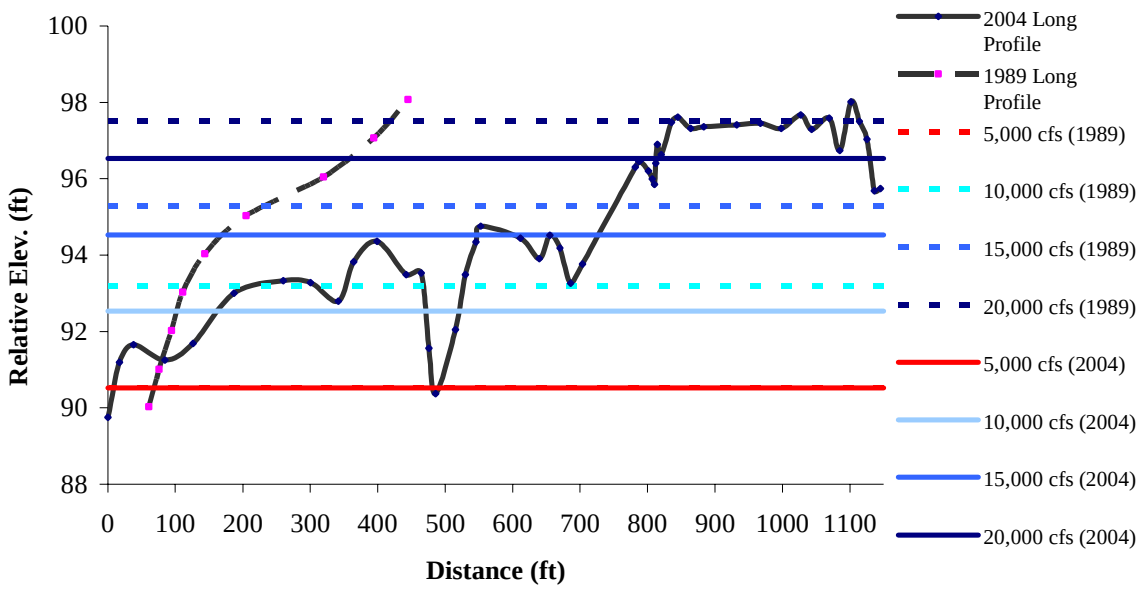


Figure 63. Klamath River inundation elevations on the Tectah Creek delta profile as presented by Payne and Associates (1989) and the Yurok Tribal Fisheries Program (2004).

Roaches Creek

Although most of our estimates of delta extent in Roaches Creek appeared high relative to those reported by Payne and Associates (1989), the pattern of formation was similar (Figure 64). Both studies observed substantial delta extent increases from the late 1940's to the 1970's followed by a period of delta extent reduction (Figure 64). Our peak estimate measured for 1970 was 1.62 acres less than the maximum reported by Payne and Associates (1989) for 1976 (Figure 64). However, our estimate of delta extent for 1988 was nearly 2.0 acres greater in size than the 1989 estimate presented by Payne and Associates (1989) (Figure 64). Again, it was impossible to evaluate if observed discrepancies in delta extent were actual or related to differences in imagery and methodologies used in the two studies.

Stream bed elevations through Roaches Creek delta in 2004 were similar to those surveyed in 1989 for the distal portion of the surveyed reach (Figure 65). However, bed elevations in the upper reach of the 2004 profile were lower relative to bed elevations surveyed in 1989 (Figure 65). This slight deflation of the proximal end of the delta resulted in slightly greater delta inundation at a Klamath River flow of 15,000 cfs relative to the 1989 inundation model (Figure 65). Although the delta appeared to be deflating, we believe delta sediments will persist in Roaches Creek for the same reasons presented for Tectah Creek. The location of the confluence on the outside of a meander bend and the presence of several bedrock flow obstructions at the delta severely limits transport capacity at this site (Figure 22).

Based on the historical review of the deltas and examination of the image library, we hypothesized that legacy Klamath River sediments may have translated from upper sub-basin habitats, including Roaches Creek confluence to habitats located downstream. Tectah Creek

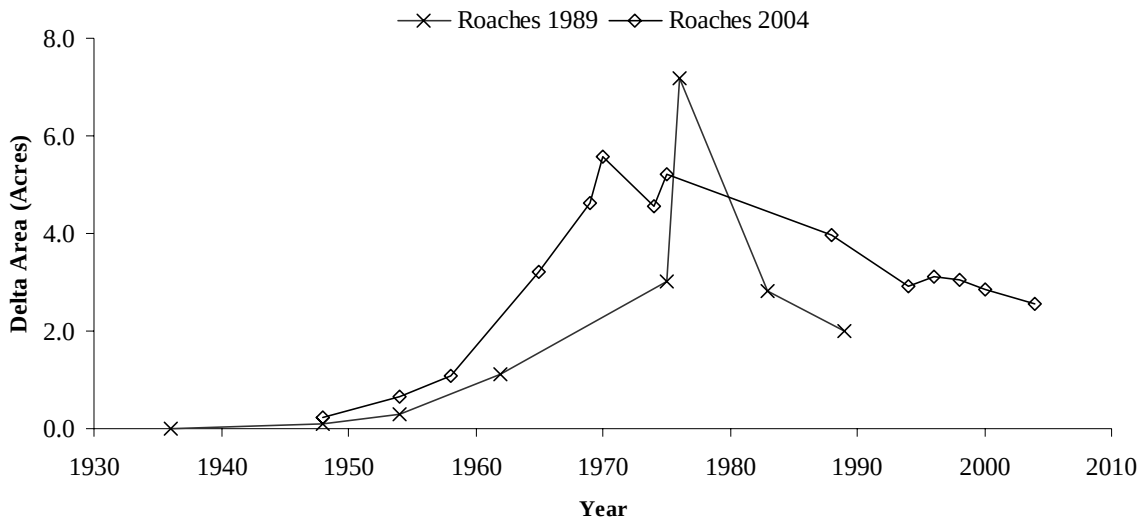


Figure 64. Historical changes in tributary delta extent for Roaches Creek as presented by Payne and Associates (1989) and the Yurok Tribal Fisheries Program (2004). Lower Klamath River Sub-basin, California.

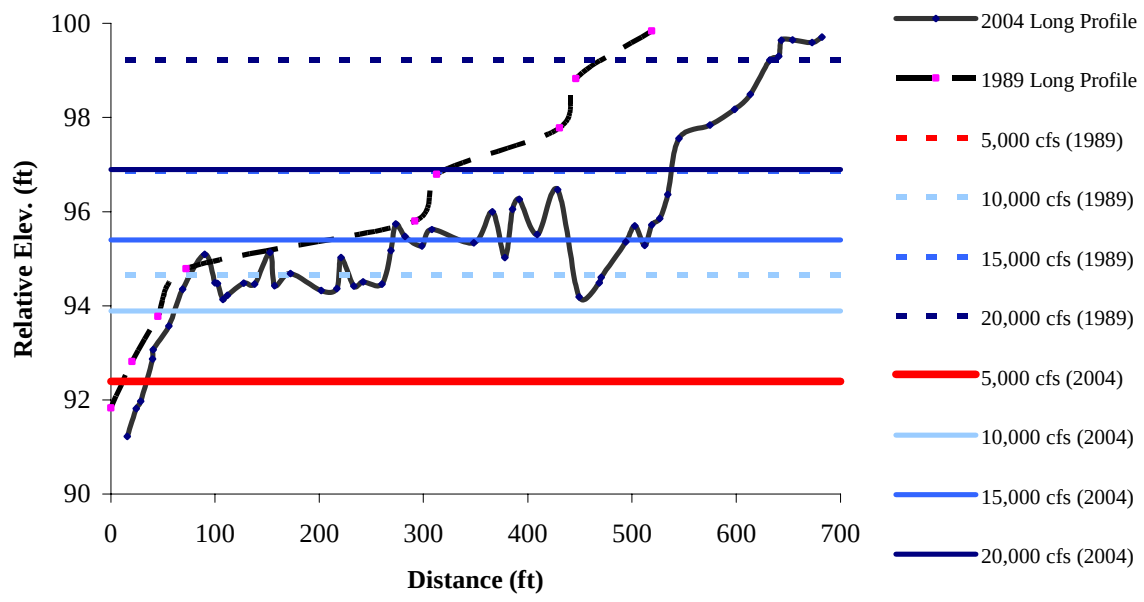


Figure 65. Klamath River inundation elevations on the Roaches Creek delta profile as presented by Payne and Associates (1989) and by the Yurok Tribal Fisheries Program (2004).

confluence remains impacted by legacy mainstem and tributary sediments; while the Bear Creek confluence has experienced increased sedimentation relative to the 1989 data (Figures 60 – 61).

Klamath River Flows and Fish Passage at Tributary Deltas

Discharge data from the USGS gage station Klamath River near Klamath (KNK) was used to assess timing and frequency of daily mean flows equal or greater than 15,000 and 20,000 cfs. These flow levels were selected based on our delta inundation models that suggested flows of 15,000 – 20,000 cfs may provide improved adult and juvenile fish passage conditions at Tectah Creek and Roaches Creek (Figures 63 and 65). The KNK gage record was divided into three time periods: 1) WY 1911 – WY 1926 and WY 1951 – WY 1962; 2) WY 1963 – WY 1989; and WY 1990 – WY 2005. Dividing the gage record in this manner was related in part to the construction of the Trinity River Dam in 1962 – 1963 and subsequent operations. We also wanted to investigate a more recent time period given the timing of the Payne and Associates (1989) study and our 2004 topographic surveys of the tributary deltas (Figures 60, 63, and 65). In addition we assessed the frequency of tributary inundating flows over the entire USGS record (WY 1911 – WY 1926 and WY 1951 – WY 2005).

For the entire period of record, daily mean discharges of 15,000 cfs or greater occurred 38 percent of the time, while daily mean flows of 20,000 cfs or greater occurred 29 percent of the time (Figure 66). Frequencies of daily mean flows of 15,000 cfs or greater in the first two time periods were similar to values calculated over the entire gage record (Figure 66). Daily mean discharges of 15,000 cfs or greater occurred the least during the most recent time period (Figure 66). Decreased frequency of delta inundating flows observed in the recent period was likely related to changing climate patterns; and increased diversion of surface flows and pumping of groundwater within the Klamath Basin.

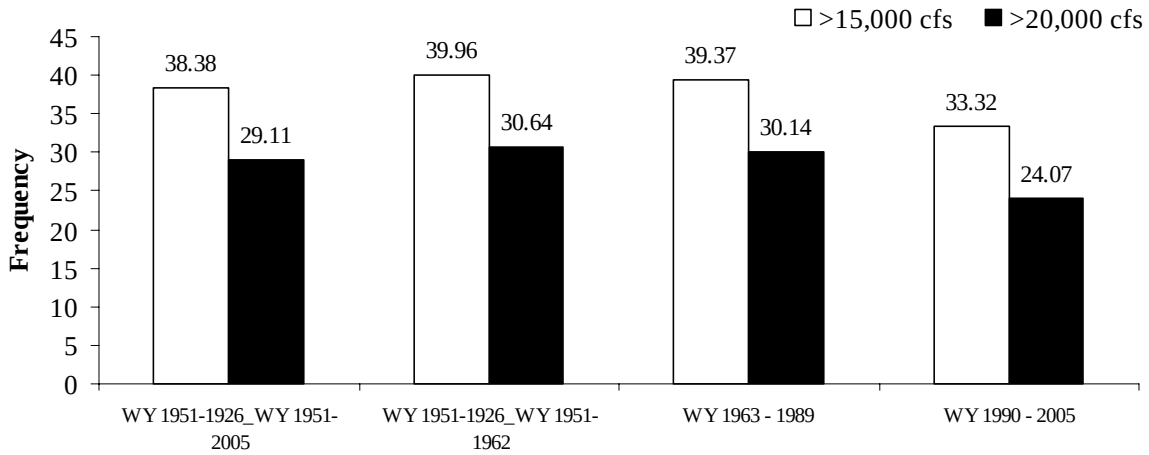


Figure 66. Frequency of Klamath River daily mean discharges of 15,000 cfs or greater over the period for water years (WY) 1911 – 1926 and 1951 – 2005. Discharge data was obtained from the U.S. Geological Survey for the Klamath River near Klamath gage.

Although the frequency of daily mean discharges of 15,000 cfs or greater were relatively similar among the time periods selected; differences existed in the timing of these events (Figure 67). Differences in timing among the three periods were numerous; however we focused on times of the year when salmonid populations rely heavily on tributary access. Strange (2005) identified four distinct groups or runs of Klamath River Basin chinook (spring, summer, Klamath fall, and Trinity fall) based on telemetric data including estuary tagging data and initial upriver migration timing. In addition, the Lower Klamath Sub-Basin supports a unique population of late-fall run chinook that is genetically distinct from other Klamath River chinokk stocks (Banks et al. 2000; Gale 2003). Other salmonid populations present include coho salmon, summer and winter run steelhead, and coastal cutthroat trout. Past fisheries studies conducted in the Lower Klamath River Sub-basin were used to construct a time-table displaying times of the year when various salmonid populations may be present in Lower Klamath River habitats (Figure 68).

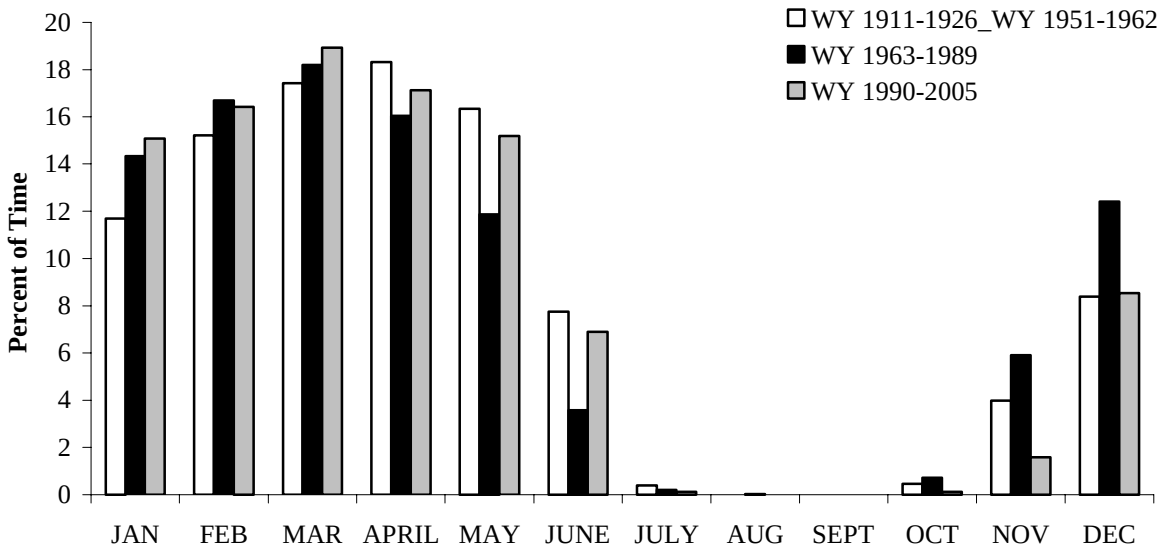


Figure 67. Timing and frequency of Klamath River daily mean discharges of 15,000 cfs or greater over the period: water years (WY) 1911 – 1926 and 1951 – 2005. Discharge data was obtained from the U.S. Geological Survey for the Klamath River near Klamath gage.

For this study we considered March – November as the most critical time of the year for Klamath Basin salmonids based on documented spawning, rearing, and migration requirements. Summer is a critical period for adult and juvenile salmonids given the relatively poor water quality conditions persisting in the Klamath River during this time of year. However, based on the KNK gage data Lower Klamath River discharges of 15,000 cfs or greater were rare in the Lower Klamath River Sub-basin during the summer, especially during August and September (Figure 68). Klamath Basin salmonids likely rely heavily on tributary inundating flows in the fall when adult chinook and coho enter tributaries to spawn; in the late-fall/winter to allow juvenile salmonids access to tributary habitats to escape high

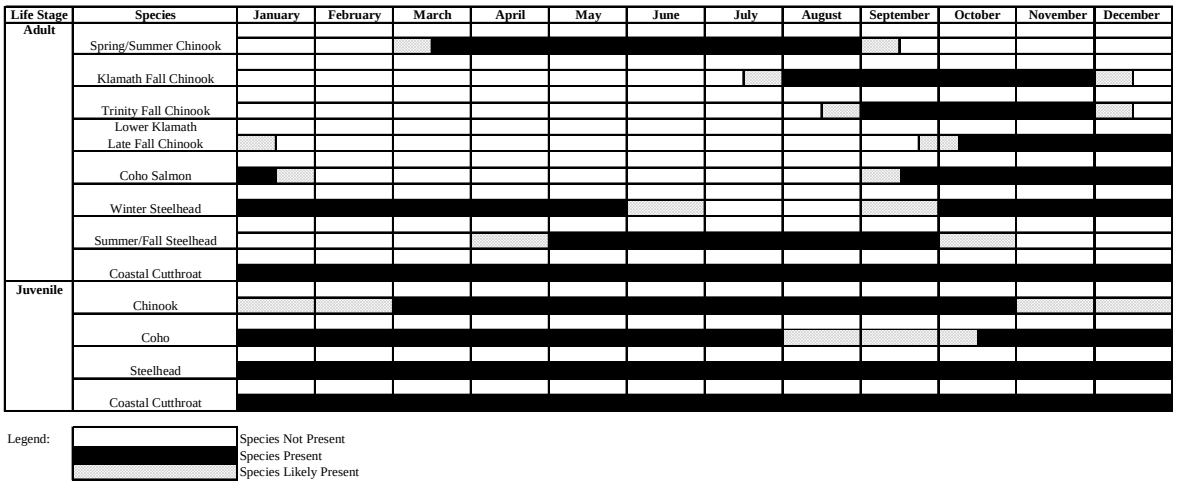


Figure 68. Salmonid migration patterns in the Lower Klamath River Sub-basin based on spawning, rearing, and migration data collected by the Yurok Tribal Fisheries Program.

velocity flows and/or excessive turbidity in the Klamath River; and in spring – early summer when juvenile salmonids migrate from tributary habitats to the river and eventually the ocean.

Tributary inundating flows were fairly rare during October in all three time periods assessed (Figure 67). October tributary inundating flows occurred the least during the most recent time period (Figure 67). More substantial differences in the frequency of tributary inundating flows existed among the three time periods for November (Figure 67). Again, tributary inundating flows occurred in November the least in the most recent time period assessed (Figure 67). The frequency of tributary inundating flows in November was similar among the earliest two time periods with values ranging from 3.8 % for the earliest time period to 5.8 % for the period WY 1963-1989. Differences in flood frequency observed among the three time periods during fall were likely related to climatic differences and possibly water management activities. The lack of mainstem flood events in the fall likely impacts adult chinook and coho by limiting access to preferred tributary spawning habitats; and unquantified impacts to juvenile salmonids seeking quality, low velocity rearing habitats (e.g. flooded tributary deltas and inundated Klamath River floodplains).

The frequency of tributary inundating flows in December were very similar among the earliest time period (8.3 %) and the most recent time period (8.5 %) (Figure 67). December mainstem flood events were most frequent during the period WY 1963-1989 (12.4 %). The frequency of tributary inundating flows occurring during January through March was similar among the three time periods (Figure 67). The frequency of tributary inundating flows for April – June was similar among the earliest time period and the most recent time period (Figure 67). Spring and early summer tributary inundating flows occurred the least during the period WY 1963-1989. Mainstem flows capable of inundating tributary deltas were very rare in July (Figure 67). Flow levels during late spring through early fall, in both the mainstem and tributaries will likely continue to decline due to local effects related to global

climate change (e.g. increased air temperatures, reduced annual snow accumulation, and decreased summer snow melt runoff events).

Tributary Connectivity Monitoring

Many of the Lower Klamath River tributaries displayed similar patterns in connectivity over the years studied (Figures 26 – 28). However, the duration of time that fish access was limited appeared to increase over time for Omagaar Creek, Little Surpur Creek, and Pecwan Creek. Tributaries such as Tarup Creek, Omagaar Creek, Bear Creek, and Little Surpur Creek entered the Klamath River on large bar features and tended to experience prolonged periods of hindered or no access. Tributary connectivity and fish access in these types of streams appeared strongly influenced by sediment storage and flow conditions of the Klamath River. In the case of Pecwan Creek, access conditions appeared to be deteriorating over time due to delta aggradation. These data suggest that fish access to a majority of Lower Klamath River tributaries was severely limited during periods of low flow. The most severe conditions appeared to persist during spring and summer (Figures 26 – 28), coinciding directly with outmigration of millions of juvenile salmonids from the Klamath Basin. Depending on precipitation events, poor tributary connectivity can persist late into fall and thus directly affect migration of adult salmonids as well as migration of non-natal juvenile salmonids using Lower Klamath River tributaries to rear over winter (YTFP 2007).

Intensive Subsurface Flow Monitoring

The spatial pattern of subsurface flow was similar in Hunter Creek (Figure 29), Terwer Creek (Figure 32) and McGarvey Creek (Figure 33) during both study years. In these streams, subsurface flow first occurred in a valley reach upstream of the tributary mouth and spread from that point as the low flow season progressed. Alternately, subsurface flow initiated from the Tectah Creek delta during both years and migrated upstream as the low flow season progressed (Figure 34). The differences observed in subsurface patterns in these tributaries were likely related to differences in stream profile and depth to bedrock. Hunter Creek, Terwer Creek, and McGarvey Creek all had relatively large valley reaches located upstream from their mouths compared to Tectah Creek. The lower reaches of these tributaries appeared more susceptible to backwatering events during moderate – high Klamath River flows and consequently less able to transport channel stored sediments.

The extent of subsurface flow was similar during both study years in Hunter Creek and Terwer Creek (Figures 30 – 31). However, subsurface flows occurred later in 2005 relative to 2004 in both tributaries (Figures 30 – 31). Subsurface conditions first occurred in these tributaries in May 2004 and surface flows resumed in December 2004. In 2005, subsurface conditions were first observed in July 2005 and surface flows resumed in early November 2005. The difference in timing was directly related to the timing and magnitude of storm events occurring in spring through fall (Figure 3). In 2004, rainfall accumulation was negligible from April through September relative to the same period in 2005 (Figure 3). The extent of dry channel was slightly reduced in Tectah Creek and greatly reduced in McGarvey Creek during 2005 relative to 2004 (Figures 30 – 31).

Although the timing and magnitude of precipitation events appeared to strongly influence subsurface conditions in these watersheds, the amount of channel stored sediment appeared to directly affect where subsurface conditions persisted. Over the past few years, YTFP has been monitoring stream profiles through critical reaches in Hunter Creek, Terwer Creek, and McGarvey Creek. These data will allow YTFP to assess long-term trends in channel stored sediments and possibly relate those trends to the spatial occurrences of subsurface flow. Developing a better understanding of the geomorphic processes affecting these critical reaches would also improve site specific and watershed level restoration planning efforts.

Tributary Water Table Monitoring

Tributary water tables appeared to be strongly influenced by the timing and magnitude of rainfall events and connected to fluctuations in surface flow levels. Klamath River flows directly influenced water tables at MG Well 1 in McGarvey Creek (Figure 38) and at both wells in Tectah Creek (Figure 40). Although the weekly data provided trends over the study period, this method failed to provide information for short-term events such as the managed flow release associated with the Hoopa Valley Tribe's Boat Dance in late August 2005. Increases in groundwater elevations related to this managed flow release were recorded a few days after the release from Lewiston Dam. Establishing continuously logging gages at all the wells would have provided a better understanding of how Klamath River flows influence tributary water tables.

Tributary Confluence Water Quality Monitoring

Salmonids migrating through the Klamath River Basin from late spring through fall rely on cool water inputs to minimize exposure to the often sub-lethal and in some cases lethal mainstem water temperatures that persist during this period (Belchik 1997, Strange 2005). Major thermal refuges previously documented in the Lower Klamath River Sub-basin included the confluence areas at Blue Creek, Pecwan Creek, Roaches Creek, Ka'pel Creek, Tully Creek, and Pine Creek (Strange 2005).

Based on the confluence areas we assessed, tributary water inputs appeared to affect water temperatures in the mainstem Klamath River in fairly small areas adjacent to tributary outflows. The degree to which tributary inputs affected mainstem water temperatures was strongly related to input quantity and temperature as well as the amount of calm water present near the tributary confluence. In all cases, areas in the mainstem affected by tributary water inputs decreased in size as afternoon winds (blowing upriver) increased and caused mixing of the water column at the tributary confluence. The degree to which the water column was affected by wind was also influenced by the orientation of the channel and bedrock outcrops at the tributary confluence.

Although Tectah Creek enters the Klamath River on the outside of a meander, no significant bedrock outcrops are located downstream of the confluence to inhibit upriver winds (Figure 13). Our historical review of the Tectah Creek delta indicated that a majority of the potential refuge habitat has been filled with tributary and river sediments (Figure 21). Therefore, the areas with cooler water were often very shallow (~ 2 ft depth) with no available cover for

either juvenile or adult salmonids. Very few smolts were observed at Tectah Creek and were only observed in morning hours prior to the onset of upriver winds.

Alternately, areas of cooler water observed at the confluences of McGarvey Creek and Roaches Creek were fairly deep and had limited cover for juvenile and adult salmonids. Both of these confluence areas were also better protected from upriver winds relative to Tectah Creek. Channel orientation and the presence of bedrock outcrops downstream of the McGarvey Creek confluence seemed to reduce the impacts of upriver winds (Figure 14). Adult steelhead and schools of juvenile salmonids were observed on nearly every sampling occasion at Transects 2 – 5 (Figure 14). Roaches Creek confluence was protected from upriver winds by multiple bedrock outcrops surrounding the delta (Figure 17). Schools of juvenile salmonids were observed in Roaches Creek at Transects 9 – 10 (Figure 17) during the July 2005 sampling event (Figure 51). Adult steelhead and schools of juveniles were observed during the August (Figure 52) and September (Figure 53) 2005 sampling events.

Blue Creek provides the most significant thermal refuge areas for migrating adult and juvenile salmonids in the Lower Klamath River (Strange 2005). For several years, a large Klamath River backwater pool has existed adjacent to the bedrock outcrop located downstream of the mouth of Blue Creek (Figures 15 and 66). This pool is known locally as Blue Hole due to the strong influence Blue Creek surface and subsurface flows have on the water quality of this pool. Strange (2005) studied migration patterns of adult Klamath River Basin (KRB) chinook salmon to document run-timing, travel rates, and behavioral responses to environmental influences such as flow and water temperature. He reported observing large numbers of adult chinook salmon (100s to 1,000s) in Blue Hole during late July – early August in 2001 – 2003. Blue Hole is a transient river feature changing in extent and configuration depending on flow events and sediment transport and storage dynamics. In summer 2005, a gravel bar protected Blue Hole from receiving Klamath River surface flows.

Water quality data collected in Blue Hole during our study indicated the upper water column did experience mixing when upriver winds were high and prolonged. Nevertheless, a majority of the habitat available to adult and juvenile salmonids was considered good quality with respect to water temperature and dissolved oxygen. Although water clarity in Blue Hole was excellent (~10 ft) during the 2005 sampling efforts, our ability to observe fish in Blue Hole was hindered due to surface turbulence related to wind and habitat complexity. We did not observe any adult salmonids in the areas sampled. Strange (2005) reported smaller adult steelhead used Blue Hole in relatively good numbers but only a few adult chinook entered Blue Hole in summers 2004 and 2005. During summer 2004 and 2005, the pool tail of Blue Hole was on average 1 – 3 ft deep and the water column was fairly mixed. Strange (2005) concluded the long and shallow pool tail behaviorally deterred adult chinook from entering Blue Hole. Instead, adult chinook preferred to hold in deeper mainstem habitats downstream of Blue Hole or in the vicinity of the mouth of Blue Creek during these years (Strange 2005).

Our tributary connectivity monitoring revealed that adult and juvenile access to tributary habitats during late spring – fall was extremely limited due to steep deltas existing at many Lower Klamath River tributary confluences and low mainstem and/or tributary surface flows. Therefore, adult and juvenile salmonids migrating through the lower river most likely

depended on mainstem thermal refuges during the low flow season. With the exception of Blue Hole, water quality and habitat data collected during our study suggested that areas of cool water were fairly limited at tributary confluences. The major factor limiting the amount of cool water areas at Lower Klamath River tributary confluences appeared to be excessive sedimentation of the potential thermal refuge habitats.

Water Temperature Monitoring

Klamath River water temperature patterns observed downstream of Coon Creek and Roaches Creek; and at the sites located upstream and downstream of Tectah Creek appeared unaffected by cool water inputs or thermal stratification (Figures 54 and 57). In contrast, water temperatures at the Roaches Creek and Tectah Creek confluence sites were affected by cool tributary inputs (Figures 55 and 57). However, declining river and tributary flow levels occurring over the study period and the static placement of temperature loggers did not allow us to truly assess the quality or quantity of cool water habitat available to adult and juvenile salmonids at these confluences. Although problems existed in the methods, this study component supported our findings that tributary flow inputs affected mainstem water temperatures during summer 2005; and that Lower Klamath River tributary confluence thermal refuge areas were limited by excessive tributary and mainstem sedimentation.

Strange (2005) monitored Klamath River water temperatures at several locations in the Klamath Basin during the same time period as our study. Water temperatures and seasonal patterns reported by Strange (2005) for a site located upstream of McGarvey Creek and another site located downstream of the Trinity River confluence were similar to our sites that were unaffected by tributary flow inputs. Strange (2005) reported that the thermal thresholds for migration inhibition for adult KRB chinook salmon occurred at daily mean water temperatures of 21.0 – 23.5 ºC depending on thermal patterns. During summer 2005, mainstem water temperatures were limiting to adult KRB chinook salmon migration from mid-July through late August (Figures 54 and 57). Strange (2005) reported that although substantial weather-induced cooling events occurred in late July – early August in 2002 – 2004; these types of events did not occur in summer 2005. Strange (2005) reported that weather-induced cooling events in summer often resulted in increased initiation of adult migration from the estuary to their natal spawning grounds. However, the occurrence of summer precipitation events may become less frequent as a result of global climate change.

Recommendations

This study greatly improved our understanding of the geomorphic and hydrologic conditions affecting the quantity and quality of salmonid habitat in the Lower Klamath River Sub-basin. YTFP is currently integrating this study into the Yurok Tribe's Lower Klamath River Sub-basin Restoration Plan (Gale and Randolph 2000). YTFP has been working with other Tribal Departments to update the Sub-basin Plan by including the Klamath River estuary and other tributaries not previously assessed, and to reprioritize habitats based on current assessment and monitoring data. YTFP will also coordinate with our restoration partners to incorporate the findings presented in this report into on-going Klamath River flow studies and the Trinity

River Restoration Program's adaptive management process, as these efforts develop scientifically based flow recommendations to support viable Klamath Basin fish populations.

The following section presents both research and monitoring recommendations as well as potential restoration strategies to improve habitat conditions for Klamath Basin salmonids.

❖ Expand Image Library of Lower Klamath River Sub-basin Habitats

The Yurok Tribe should continue to obtain aerial photographs of the Lower Klamath River Sub-basin, especially for the estuary. Ideally, the images would be scanned at high resolution, rectified in ArcView, and incorporated into the YTFP GIS. YTFP recently partnered with Green Diamond Resource Company (GDRC) to acquire current (2008 – 2009) LiDAR (Light Detection and Ranging) imagery and data for the Yurok Indian Reservation (YIR) (Figure 1). This LiDAR data will provide the baseline data necessary to develop a highly accurate digital elevation model (DEM) of the area. The YIR LiDAR DEM would be a critical addition to on-going Klamath River flow studies, sub-basin and watershed assessments, and large-scale restoration planning efforts (e.g. assessing dam removal). The YIR LiDAR DEM would also provide baseline data necessary to assess changes in river, estuary, and tributary delta habitats resulting from natural events (e.g. floods, sea level changes), and anthropogenic activities (e.g. changes in land/water management activities).

❖ Continue and Expand the Tributary Delta Study

YTFP should establish permanent benchmarks at other high priority tributary deltas (e.g. Terwer Creek, Surpur Creek, Blue Creek, and Mettah Creek) and periodically survey stream profiles and delta features. All Lower Klamath River tributary benchmarks should be tied to the North American Vertical Datum (NAVD) to obtain actual elevation data and improve the accuracy of past and future surveys. Three-dimensional surveys of stream profiles and floodplain features in the confluence areas should be conducted every 5 – 10 years or following geomorphically effective flood events to monitor changes in delta extent and elevation through time. Klamath River tributary inundation models should be developed for surveyed deltas during the same year according to methods outlined in this study. These models are critical for 1) determining which river flow magnitudes are capable of inundating specific deltas; 2) documenting times of the year when flows may either facilitate or inhibit fish access to tributary habitats; and 3) improving our understanding of how flow asymmetry and stream power influence delta sediments and configuration; and 4) developing process-based restoration strategies that are linked with comprehensive effectiveness monitoring.

Documenting historic changes in mainstem bar and tributary delta features over the entire YIR is also a critical resource assessment need for YTFP. Understanding how these features have evolved and responded to varying levels of disturbance would greatly enhance our ability to develop meaningful water management related recommendations and large-scale restoration strategies. We are currently seeking the funding to expand the Lower Klamath River tributary delta study to conduct the field portion of this effort in spring – summer 2009 to best integrate the survey and inundation models into the development of the YIR LiDAR DEM. YTFP continues to work with various entities to acquire the historic aerial

photographs necessary for documenting changes to the Lower Klamath River corridor through time.

❖ Lower Klamath River Tributary Delta Restoration Strategies

Although our study only focused on three tributary deltas, recent geomorphic studies conducted by YTFP and Fiori GeoSciences revealed a majority of the Lower Klamath River tributaries had persistent, aggraded delta reaches. These observations also revealed that most of the deltas appeared to consist of both tributary and mainstem sediments. Therefore, the primary strategy for addressing sedimentation of tributary confluence areas should be reducing the quantity of sediment delivered to stream channels and subsequently the river. To help meet these objectives, the Yurok Tribal Watershed Restoration Department (YTWRD) has been conducting watershed level road assessment and restoration need inventories, and treating or decommissioning priority road segments in the sub-basin since the mid-1990s. Their efforts play a critical role in reducing existing and potential road related impacts to stream and floodplain habitats, and facilitating the long-term success of any stream and riparian enhancement programs. We work closely with YTWRD to ensure a coordinated sub-basin approach. Recent YTWRD decommissioning efforts have provided us with substantial quantities of large wood for stream and riparian enhancement projects.

Bear Creek

The Lower Klamath Restoration Plan identified Bear Creek as a medium priority stream for receiving restoration and was selected for this study only because it was assessed by Payne and Associates (1989). Addressing upslope sediment sources and riparian dysfunction would be the priority restoration measures for this watershed. YTWRD has not yet conducted any road related assessments or decommissioning in this watershed given their focus on high priority sub-basin watersheds (e.g. Terwer Creek, McGarvey Creek). In the interim YTFP could conduct channel and riparian surveys in the anadromous portion of the watershed to assess current valley conditions and develop stream and riparian enhancement strategies to improve conditions in the lower valley and confluence area.

During our study, Bear Creek confluence was accessible by vehicles and heavy equipment, which increased the potential treatment options for this site. Options include assessing the potential benefits of removing channel and floodplain stored sediments from the area to reduce channel instability and bank erosion, and improve riparian conditions. The YIR LiDAR DEM and analysis of historic aerial photographs would likely be required to address removal of sediment from lower Bear Creek and adjacent river bars. A potential strategy would be to use heavy equipment to reduce the elevation of select floodplain, delta, and mainstem bar surfaces and sculpt geomorphically appropriate alcove and backwater habitats to increase winter and spring salmonid rearing and staging capacity in this area of the river.

Enhancing riparian forests in lower Bear Creek should be a priority focus of any treatment option implemented in the future. Feral cattle inhabit the Bear Creek watershed and thus any channel and riparian restoration strategies would require cattle exclusion or eradication measures to ensure plant survival and improved channel function. Floodplain features of

lower Bear Creek and its delta were mainly comprised of relatively coarse grained sediments with limited riparian vegetation (alder dominated with young fir). Planting survival in this reach may strongly depend on local air and soil temperatures, water storing capacity of planting mediums, and the availability of soil nutrients. Burying woody debris and incorporating more fine grained sediments into planting areas may be necessary to improve plant survival in this type of setting. More floodplain assessments including water table investigations should be conducted to develop a comprehensive riparian restoration plan.

Tectah Creek

A priority restoration objective for Tectah Creek includes reducing impacts associated with upslope sediment sources and channel stored sediment. YTWRD conducted a watershed level upslope road assessment and restoration need inventory in Tectah Creek during winter 1998 – 1999. This inventory prioritized road segments for treatment and decommissioning and YTWRD has since conducted limited decommissioning of high priority roads. GDRC has been actively upgrading all road segments not scheduled for decommission. Upslope road assessments and decommissioning activities should be resumed in this watershed to document and address current conditions and address high and medium priority roads. A sediment budget should also be constructed to quantify the dominant hillslope sediment sources in the watershed to improve on-going restoration planning and monitoring efforts.

During our study, the lower reaches of Tectah Creek were not easily accessible by vehicles or heavy equipment. We continue assessing the feasibility of getting heavy equipment into the delta reach and removing excessive delta sediments to improve channel function. However, even if access routes were developed to the confluence, the costs associated with sediment removal from the site would be extremely high. In the interim, YTFP has initiated a project to place large wood throughout the lower five miles of Tectah Creek using a helicopter and ground crews. This project was developed specifically to address limiting factors (e.g. seasonal lack of tributary surface flows, persistent sedimentation of the channel and confluence area) identified through our historical review of Tectah Creek delta, the intensive subsurface flow study, and the tributary water table monitoring efforts.

Adding large wood to Tectah Creek should provide immediate improvements to water quality and excessive sediment yields by increasing channel storage capacity, reducing delivery to downstream habitats, and increasing bed and bank stability. Other high priority objectives of adding large wood to Tectah Creek include improving spawning and rearing potential by facilitating the formation of critical stream habitats (e.g. pools, spawning beds), increasing stream and riparian habitat complexity, providing areas of reduced stream velocities, and altering sediment storage and delivery dynamics. By attenuating sediment run-out rates in the watershed, we hypothesize the probability of mobilizing delta sediments will be increased. YTFP will be conducting long-term project effectiveness monitoring in this watershed to learn from our efforts and to and help guide future sub-basin restoration.

Excessive channel and delta sedimentation in the lower reaches of Tectah Creek also currently limits riparian growth and survival. Recent field surveys of the confluence reach revealed substantial loss of mature cottonwood due to channel instability and bank erosion. Investigations of historic and current floodplain dynamics should be conducted in the

anadromous reaches of Tectah Creek and incorporated with an expanded water table monitoring program to better understand riparian vegetation dynamics. The goal of these efforts would be to develop a process-based strategy to establish healthy, diverse riparian habitats dominated by native conifers. Reestablishing native conifers in riparian habitats of Tectah Creek would greatly improve future large wood recruitment potential to stream and floodplain habitats and help restore the geomorphic processes necessary for maintaining complex and productive stream, floodplain, delta, and riparian habitats.

Roaches Creek

As with Bear Creek and Tectah Creek, reducing impacts associated with upslope sediment sources is a priority restoration objective for Roaches Creek. Therefore, YTWRD should complete the upslope assessments in this watershed and begin addressing high-priority sites. Developing restorative strategies for lower Roaches Creek was difficult due to the remote location of this tributary, the lack of heavy equipment access to the delta, and the presence of a high gradient bedrock/boulder cascade located just upstream of the delta. This cascade currently limits salmon spawning in this watershed. YTFP and other resource agency staff have considered the potential for modifying this natural feature to allow salmon access to quality spawning and rearing habitats located upstream. Although the idea is very appealing, a comprehensive assessment of the reach should be conducted by YTFP, a Licensed Geologist, and other technical experts to ensure any design wouldn't result in massive channel degradation (e.g. down-cutting) upstream of the existing cascade. A substantial down-cutting event would likely result in significant sedimentation of the confluence reach and severe impacts to mainstem thermal refuge habitat. Helicopters may be used to modify existing pool control elements to promote increased fish passage.

Historical review of the Roaches Creek confluence indicated the delta was deflating from its peak extent in 1970 (Figures 23 – 25). Although the current delta configuration limits the river's ability to transport delta sediments, deflation of delta sediments may be facilitated by the numerous bedrock exposures present in the lower channel and at the delta. Of the areas assessed during this study, Roaches Creek appeared to provide fairly high quality thermal refuge during the summer low flow season. One treatment option that may enhance existing delta deflation processes would be to focus on enhancing riparian growth and survival on the delta surfaces located upstream of Roaches Creek mouth (Figures 17 and 24). Planting efforts should focus on cottonwood and willow with Douglas fir along the valley side wall. The primary objective of this effort would be to try and maintain the current channel configuration (e.g. along the left side of the delta, looking downstream) (Figures 17 and 24). This particular channel configuration results in a fairly high quality Lower Klamath River thermal refuge. Promoting vigorous cottonwood and willow forests on the alternate bank would facilitate this configuration by limiting channel migration by increasing soil cohesion through root reinforcement and increasing flow resistance to reduce near-bank shear stress.

❖ Tributary Connectivity Monitoring

Tributary connectivity surveys should be continued every 2 – 5 years and conducted over a wide range of water year types. Ideally, permanent benchmarks would be established at all

of the priority tributary deltas so that crews could monitor relative bed elevations during those years surveyed. Documenting long-term patterns of tributary connectivity will be critical to YTFP's sub-basin restoration planning and implementation programs. This component should be conducted alongside any future tributary delta studies.

❖ Intensive Subsurface Flow Monitoring

The study reaches monitored for subsurface flow only represented a portion of the available salmonid habitat in those Lower Klamath River tributaries. YTFP has encountered other subsurface flow reaches in the anadromous portion of both Hunter Creek and Terwer Creek. However, field surveys conducted in McGarvey Creek and Tectah Creek since the late 1990s indicated that subsurface flows occurred exclusively in the reaches documented in this study. Subsurface flow monitoring should be continued in the anadromous portion of these Lower Klamath River tributaries to assess long-term changes in extent and timing of these conditions over a range of water year types. This study revealed that a majority of the tributaries draining the Lower Klamath River experience periods of subsurface flows. Therefore, YTFP should conduct periodic field surveys and document flow conditions in other priority Lower Klamath River watersheds.

Stream, floodplain, and riparian enhancement efforts may result in measurable increases in the timing and extent of surface flows in some Lower Klamath River tributaries. However, any subsurface flow studies should be incorporated into a long-term, comprehensive hydrologic and channel monitoring program (e.g. precipitation, surface flows, water table elevations, longitudinal profile and cross section surveys). GDRC has long-term channel monitoring data for both Hunter Creek and Tectah Creek. YTFP has also been gathering channel monitoring information in Hunter Creek, Terwer Creek, and McGarvey Creek. This summer YTFP and GDRC will conduct a comprehensive topographic survey of Tectah Creek to gather critical baseline data and to assist with wood placement designs.

Topographic surveys of the channel and floodplain habitats of Hunter Creek, Terwer Creek, McGarvey Creek, and Tectah Creek should be conducted in reaches experiencing subsurface flows on reasonable time-scales to assess how channel changes and/or restorative measures affect subsurface flow and fish access conditions in these watersheds. YTFP is also working to tie all topographic surveys to GDRC benchmarks and the NAVD to obtain actual elevation information, improve our ability to assess channel changes through time, and allow for development and maintenance of a YIR LiDAR DEM and other sub-basin DEMs.

❖ Tributary Water Table Monitoring

Tributary water table monitoring efforts should be continued and expanded in select Lower Klamath River tributaries to further characterize the influences of groundwater on surface flow conditions relative to channel stored gravel and riparian function. The working hypothesis is that without sufficient precipitation, water tables recede fairly rapidly in a majority of the Lower Klamath River tributaries due to the coarse alluvium comprising the lower channel and floodplain habitats. Monitoring the slope of the water table recession from spring through early fall is also a critical tool for determining what riparian species may

survive best and where, and for developing strategies to improve survival rates of newly planted trees (e.g. incorporating wood and other organic material in riparian planting areas). Establishing baseline water table information would also allow YTFP to quantitatively assess the effectiveness of on-going and future restoration efforts in high priority tributaries.

YTFP has continued limited groundwater monitoring in Terwer Creek and is seeking the funding required to expand these efforts and maintain the program over the long-term. Terwer Creek is ideal for conducting comprehensive, long-term hydrologic assessments (e.g. monitoring precipitation, subsurface flow timing and extent, surface flows, and water table elevations) and channel monitoring (e.g. longitudinal profile and cross section surveys). The reasons for this include: 1) YTFP and YTEP have both collected a considerable amount of physical and biological data for the watershed; 2) YTEP operates two stream gages and a rain gage in the watershed; 3) the USGS KNK station is located just upstream of confluence of Terwer Creek and the Klamath River; and 4) YTFP has been implementing riparian enhancement and bank stabilization projects in lower Terwer Creek since 2003. The wells established during this project are still functional; however, YTFP is seeking the funding to purchase gage equipment and support the staff required to monitor the wells.

McGarvey Creek would also be a good study watershed due to reasons similar to those described for Terwer Creek (e.g. existing physical and biological data sets, YTEP operates a stream gage and rain gage in the watershed, proximity to the USGS KNK station, and the amount of restoration that YTWRD and YTFP has conducted in the watershed). New wells would need to be established throughout lower McGarvey Creek to better assess tributary water tables in this watershed. YTFP would like to conduct similar studies in several other priority Lower Klamath River tributaries, including Blue Creek and Tectah Creek. Coordinating such an effort would require long-term commitment and funding but would provide critical information that would allow the Yurok Tribe to better characterize existing conditions and develop land and water management related strategies that take into account large-scale changes such as those associated with basin restoration or global climate change.

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