HISTORICAL ANALYSIS OF GEOMORPHIC CHANNEL CHANGES, LOWER MAD RIVER, HUMBOLDT COUNTY, CALIFORNIA

by

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I. ABSTRACT

The Mad River has undergone cycles of erosion and deposition related to changes in sediment production in the drainage basin. Significant flooding occurred between: 1) the late 1870's to about 1910; and 2) from 1951 to 1974. Periods of drought occurred between: 1) about 1910 to 1951; and 2) 1975 to 1992. The banks along the lower river were destabilized between 1854 and the early 1880's as logs were rafted downstream before railroads were constructed. Logging and road building intensified between about 1880 and 1920 and again after 1950, increasing the amount of sediment available for transport into the river. Gravel extraction and artificial channel confinement also accelerated after 1950. In 1938 Sweasey Dam was constructed. It filled with approximately 2,000 acre-feet (3,200,000 yd^3 or 2,400,000 m^3) of sediment in 24 years, giving a bedload recruitment rate of approximately 130,000 yd^3/yr (100,000 m^3/yr), then was dynamited in 1970, aggrading the channel downstream. It will probably take 35 to 40 years for the channel to fully recover. Below the Mad River Fish Hatchery, the channel has changed in pattern and form due to drought and flooding, mechanical manipulations, and gravel extraction rates greater than natural recruitment rates. Conservative sand and gravel extraction rates have been estimated at 425,000 yd^3/yr (325,000 m^3/yr), giving a mean annual deficit of approximately 295,000 yd^3/yr (225,000 m^3/yr) over the past 30 years. Oral histories, repeated surveys, historic photos, and field observations indicate a net bed lowering along the entire width of the active channel between

the Mad River Fish Hatchery and the Hammond Trail bridge of approximately 5 feet. Lowering rates were greatest along the Blue Lake valley after 1975 and between the Arcata and Mad River Railroad bridge and the Hammond Trail bridge during the mid 1950's to late 1960's.

Channel pattern and form recovered between about 1920 and 1950 following significant land use changes and flooding. After another wave of intensive land use and flooding between about 1950 and 1975, the river appears to be recovering again as sinuosity values approach those of the early 1940's. In order to prevent further bed degradation, gravel extraction should not exceed natural bedload recruitment rates.

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V. INTRODUCTION

Human uses and development continue along the Mad River. Channel changes affect bank stability, erosion control, gravel extraction, and water quality on the river. Streambed changes can cause upstream and downstream changes in flow, velocities, depths, and gradient. Changes in rates of erosion, transportation, and deposition of sediment, as well as streambed stability can result from human induced channel changes.

The Mad River ecosystem is a valuable resource. Its behavior should be understood in order to sustain its value. In order to place the present condition of the Mad River in context, it is useful to attempt to analyze its past behavior. Recent analysis has included evaluation of sediment transport models which are simplifications of complex natural systems that may be poorly understood. These models may use one of many different sediment transport equations to attempt to predict sediment transport rates and can produce widely varying results based on small changes in sensitive variables. To check the validity of results produced from these models, an historical analysis is in order. In understanding the past history of the Mad River, we may gain insights into its future behavior.

This study is an analysis of channel changes on the lower Mad River between the former Sweasey Dam site and the Hammond Bridge, just upstream of the mouth of the river. I discuss the river's response to natural (flooding, etc.) and human-induced (land use, etc.) changes as evidenced by changes in the river's pattern and form. My work will add to current knowledge of the behavior of the Mad River.

VI. OBJECTIVES

My objectives in this study were to:

1. Describe qualitatively and quantitatively how the character of the lower Mad River channel changed between 1855 and 1994.
2. Describe how natural versus human-induced influences caused changes in pattern and form of the lower Mad River channel.

VII. SETTING

A. LOCATION AND EXTENT

The Mad River, located in Humboldt and Trinity Counties, California, drains a 497 mi^2 (1,290 km^2) basin (Brown, 1975). The river flows northwesterly for approximately 100 mi (160 km) through the northern Coast Range, emptying into the Pacific Ocean north of Arcata, California (figure 1). This study encompasses approximately 150 mi^2 (390 km^2) of the basin downstream from the former Sweasey Dam site; it is bordered by the Van Duzen River basin to the southwest and the Redwood Creek basin to the northeast. The watershed is sparsely populated upstream of Blue Lake, the only incorporated town in the basin, with a population 1,306 (1990 census, Karen Nessler, city clerk, pers. comm., 1995). The major land uses in the Mad River area that affect the river channel include logging, agriculture, gravel mining, development, road building, and recreation and tourism.

B. STREAMS

The major tributaries of the Mad River within the study area include the North Fork Mad River, with a drainage area of approximately 50 mi^2 (130 km^2), which enters the Mad River on the flood plain approximately 2 mi (3 km) downstream from the Hatchery; Cañon Creek, with a drainage area of approximately 16 mi^2 (40 km^2), which flows into the Mad River approximately 1.5 miles (2.4 km) downstream of the site of Sweasey Dam; and Lindsay Creek, with a drainage area of approximately 17 mi^2 (44 km^2), which enters the river approximately 200 feet (60 m) below the Arcata and

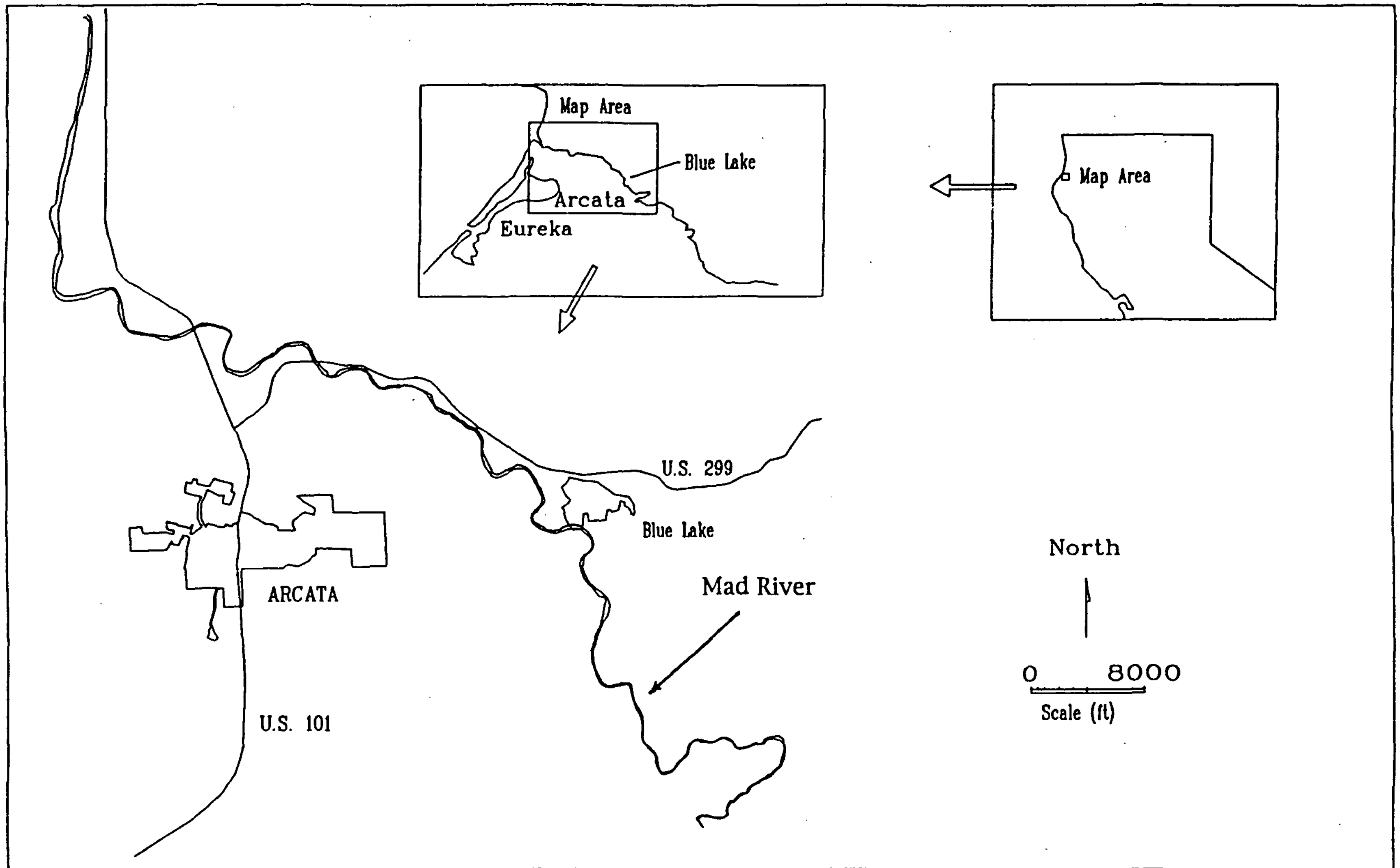


Figure 1 – Location Map, lower Mad River, Humboldt County, California

Mad River Railroad (A&MRR) bridge (figure 1). Other smaller tributaries flow into the Mad River and its tributaries in the study area.

C. PHYSIOGRAPHY

The upper portion of the study area lies in a rugged mountainous region, mostly forested with redwood and Douglas fir trees. The river flows through a V-shaped canyon, aligned along a northwest trend. This trend is structurally controlled by thrust faulting. "The principal streams form a subtrellis drainage pattern following the regional trend and lines of weakness" formed by these faults (U. S. Department of Defense, Army Corps of Engineers, 1968).

The lower portion of the river flows out onto a broad alluvial valley (the Blue Lake valley) at the Mad River Fish Hatchery, 1.5 miles upstream of Blue Lake. Another canyon reach confines the river between the A&MRR bridge and the highway 299 bridge. Below 299, along the Arcata Bottoms, the river flows across a deltaic floodplain to its mouth. The Bottoms are "dissected by flood-stage channels of the river, 15 to 20 feet deep" (Evenson, 1959).

Slopes in the upper study area are steep along the west side of the drainage basin, exceeding 90 percent in places. The east side is characterized by rounded, grass covered hills, along with some steeper slopes.

D. GEOLOGY

The basin is located in the Northern Coast Range geomorphic province which is characterized by northwest trending ridges and river valleys. Rocks underlying the watershed strike northwest and dip northeast; they range in age from the late Jurassic-late Cretaceous Franciscan assemblage to the Pliocene Falor formation. The Franciscan rocks are mostly sandstones and shales with some altered volcanic rocks (greenstones), cherts, conglomerates, and serpentine, overlain in some places by the Falor formation (unconsolidated marine deposits), alluvium, and river terrace deposits.

Landslides (earth and debris flows, slumps, and rockfalls) and earthquakes are common in the region. Mass movements are at a peak during and after periods of heavy rainfall (U. S. Army Engineer District, 1972) and presumably following seismic activity. The area is one of the most seismically active in the United States (U. S. Army Engineer District, 1972) and active tectonism helps contribute to high sedimentation rates observed in the basin both through shearing of bedrock and uplift. The basin is one of several in coastal northern California with suspended sediment discharges of 5 to 50 times those of comparable size in the United States (U. S. Army Engineer District, 1972; Brown, 1975). Earthflows are recognized as one of the significant sediment sources in the region (Kelsey, 1978). A more detailed description of the geology of the basin is given in the Butler Valley Dam and Blue Lake Project Draft Environmental Impact Statement (U. S. Army Engineer District, 1972).

E. CLIMATE

The climate of the Mad River basin is typical of northcoast valleys and is characterized by heavy annual rainfall concentrated in the cool winter months, ranging from 40 in (1,000 mm) along the coast to approximately 65 in (1,600 mm) near Sweasey Dam, and a relatively dry, moderate summer (U. S. Army Engineer District, 1972; Brown, 1975). Snow falls above 2,000 ft and may remain for periods of time above 4,000 ft. "The mean annual precipitation is affected by distance from the coast, altitude, steepness, and the direction in which the mountain slopes face in relation to air mass movements" (U. S. Army Engineer District, 1972).

F. VEGETATION

The upland slopes are covered by a mixed conifer-hardwood forest that has been logged, while lowland areas have been converted to predominantly agricultural and some urban use. The active channel and flood plain are characterized by a variety of annual plants that grow during extended periods of low streamflow (Brown, 1975). A detailed description of vegetation conditions is given in the Butler Valley Dam and Blue Lake Project Draft Environmental Impact Statement (U.S. Army Engineer District, 1972).

VIII. METHODS

A. APPROACH

I analyzed historic descriptions, photographs, interviews, and field data to assess natural versus human-induced changes along the channel. The specific data sources I used are: 1) historic maps; 2) historic oblique photographs; 3) aerial photographs; 4) newspaper accounts; 5) personal interviews; 6) investigative reports, flood/flow records, and climatological data; and 7) field observations and measurements of bed elevation changes.

B. VARIABLES

I analyzed the following variables : 1) channel width; 2) channel length; 3) channel depth; 4) channel area; 5) volume of stored sediment; 6) sinuosity; 7) meander wavelength; 8) meander amplitude; 9) meander radius of curvature; 10) riffle frequency; 11) riparian zone area; 12) net degradation; and 13) net aggradation.

C. NEWSPAPER ACCOUNTS

I documented historic land use and channel changes from archived newspaper records. A list of newspapers used is given in Appendix A. The descriptive nature of these data allows for a qualitative analysis of sediment yield (Kondolf, 1993) and resultant changes in the character and form of the Mad River since 1855. I obtained newspaper accounts from the Humboldt State University Library, the Humboldt County Public Library, and the Humboldt County Historical Society.

These accounts helped me to construct a chronology of land use and flooding and allowed me to qualitatively describe natural and human influences shaping the pattern and form of the channel.

D. HISTORIC MAP ANALYSIS

I obtained historic maps (table 1; also Appendix B) from the Humboldt State University Library (Humboldt Room), the Bureau of Land Management, Trinity Restoration Associates, and the Humboldt State University Geology Department. The intent of many of the surveys was to delineate property boundaries and topographic and cultural features, not to delineate the location of the Mad River. However, most maps depicted the limits of the "high water banks", which I assume correlated with the active channel. Some showed the wetted channel limits. The surveys allowed me to locate and measure channel centerline lengths. I used a computer aided drafting program (AutoCad™ release 11.0) to digitize the following variables: 1) active channel limits, area, and centerline length; and 2) (when present) wetted channel limits, area, and centerline length. I also digitized some of the cultural features shown in order to calibrate and reference each thematic layer to the others for measurement and analysis purposes. The thematic layers were stored in a digital database drawing file.

I located points common to each map and used the USGS topographic quadrangle sheet as a base map in order to align them accurately for overlay analyis purposes. Road or railroad intersections and Public Land Survey System section corners were commonly used as reference points. I digitized as many of these points as possible from each map, then used the

Table 1 – Historic map coverage of the lower Mad River

Year	Map Title	Year(s) Surveyed	Author(s)
1855	Bureau of Land Management, U. S. Department of Interior, Rectangular Survey Index Map	1855, 1858, 1874	Bureau of Land Management
1865	Official Township Map of Humboldt County, California	--	A. J. Doolittle
1886	Official Map of Humboldt County, California	--	Stanley Forbes
1898	Official Map of Humboldt County, California	--	J. N. Lentell
1916	Corps. of Engineers, U.S. Army Tactical Map, Eureka Quadrangle, Grid Zone"G", Controlled Reconnaissance Sheet, 9-N-11-E/2	1909, 1916	Corps of Engineers
1921	Official Map of Humboldt County, California	--	Belcher Abstract and Title Company
1951	United States Dept. of the Interior, Geological Survey, Eureka Quadrangle, 15' Series	1933	U. S. Geological Survey
1951	United States Department of the Army, Corps of Engineers, Blue Lake Quadrangle, 15' Series	1942 aerial photos used	Corps of Engineers
1972, 1979	United States Dept. of the Interior, Geological Survey, Arcata North, Arcata South, Blue Lake, and Korbel Quadrangles, 7.5 minute series	1956, (1959 aerial photos also used)	U. S. Geological Survey

AutoCad™ command [calibrate] which "rubber sheets" or fits the map projection onto an orthogonal surface. Each theme (i.e. active channel, wetted channel, riparian zone, etc.) then became a "layer" or map element in the digital database generated.

E. HISTORIC PHOTOGRAPHS

I obtained historic ground and oblique air photographs from the Blue Lake Historical Society and Museum, the Humboldt County Historical Society, the Humboldt County Public Works Natural Resources Department, the Humboldt Bay Municipal Water District, and the Simpson Timber Company. When the negatives were available I had the photos duplicated. When the negatives were not available I had prints made from the original photographs using a photomechanical transfer process (with a Fuji Pictrostat™ at Village Photo in Eureka, CA.) whereby the original photographic image is scanned and transferred onto recipient photographic paper. The images can be reduced or enlarged from 50 to 200% using this process with little or no discernible loss in image quality. Image density and color balance can be manipulated to produce images of quality comparable to the originals.

I used these photographs to 1) identify, locate, and describe early land use activities; 2) locate the river's position and bed elevation and other morphologic features; 3) describe riparian vegetation along the channel; and 4) document the dates portions of the channel were affected by artificial influences. I also attempted to document changes in channel conditions along the Mad River by rephotographing views of the study area shown as described by Harrison (1974). For some of the old photos I attempted to determine the precise location, date, bed elevation and/or width in order to estimate rates of channel change through time.

F. AERIAL PHOTOGRAPHS

The aerial photographs I used were obtained from the Humboldt State University Geology Department, the Humboldt Room of the Humboldt State University Library, W.A.C. (Eugene, Oregon), the Humboldt County Public Works Natural Resources Department, and Trinity Restoration Associates (Arcata, California). A list of aerial photos used in this study is given in Appendix C.

I used sequential aerial photo sets for the following years: 1941/2, 1948, 1954, 1958, 1962, 1966, 1970, 1974, 1981, 1988, 1992. For each photo set planimetric maps of the active channel, low water channel, and riparian vegetation zone were produced using Computer Aided Drafting (CAD) software (AutoCad™, Version 12.0). I photocopied the original air photos, then drew in the limits of the active and low water channels and the riparian vegetation zone on the photocopies. Each limit was then digitized from the photocopies and input into a digital database of thematic layers. I also digitized some of the cultural features in order to calibrate and reference each thematic layer to the others for measurement and analysis purposes. From these layers I was able to use the software to measure the following variables: 1) active channel areas; 2) active channel lengths; 3) wetted channel lengths; 4) bank erosion rates; 5) longitudinal bar areas; 6) meander wavelengths; 7) meander amplitudes; 8) meander radius of curvature; and 9) riparian vegetation areas. From the data I calculated sinuosity and active channel widths for each reach for each year. I was also able to measure riffle spacing from 3 sets of 1" = 200' scale air photos (1962, 1974, and 1992) provided by Trinity Restoration Associates.

I defined the active channel by delineating the following physical characteristics: 1) topographic breaks; 2) vegetation changes; 3) textural and bedform changes; 4) evidence of changes in transport intensity (wash marks and bedforms), (Reid and Dunne, in preparation, p. 68). Field checks using the 1992 aerial photo set were done to assure consistency with interpretations.

I defined the low water channel by delineating the water's edge on the photos. I assumed the discharge was approximately equal for each aerial photo set since all but part of the 1942 set was taken during the dry season.

I delineated the riparian vegetation zone after defining vegetation differences (i. e. cottonwood, alder, and willow versus conifers) along the riparian corridor, just inland from the active channel. I made field checks using the 1992 aerial photo set to assure consistency with my interpretations.

G. PERSONAL INTERVIEWS

I conducted personal interviews with local residents, fishermen, gravel operators, water district personnel, and others familiar with the history of the channel. I had an outline of questions I posed during the interviews. I took notes, then transcribed these onto the computer. In some cases I used photographs and maps to help the interviewees locate different places and to help them refresh their memories of different events and conditions that had existed. Some of the considerations I made are given in

Reid and Dunne (in preparation, p. 73, Box 14). Notes taken are included in Appendix D.

These accounts helped me to add to, and corroborate, an historic chronology of land uses to document impacts in the watershed. They also assisted me in interpreting changes in the riverine environment as a response to changes in sediment supply and flooding. I was able to obtain dates, causes, and extent of some important natural and human-induced changes by interviewing people familiar with the channel.

H. INVESTIGATIVE REPORTS, FLOOD/FLOW RECORDS, AND CLIMATOLOGICAL DATA

I reviewed investigative reports, flood and flow records, and climatological data to assist in interpretation of flood frequency, recurrence intervals, precipitation patterns and significant events.

I. FIELD DATA

I surveyed a cross-section at the USGS cableway (November and December, 1993) with a total geodetic station and help from Trinity Restoration Associates. I compared bed elevations at the site with photogrammetric measurements from an historic photo to determine bed elevation changes through time. I was also able to locate and measure several features along the river that allowed me to determine bed elevation changes through time, including sites at Camp 4 flat downstream of Sweasey Dam, the A&MRR bridge, the USGS cableway, the abandoned USGS stilling well upstream of 299, and the two old bridge piers upstream of the 101 bridge. I made qualitative observations of downcutting at tributary creek mouths.

IX. RESULTS

For the purposes of this study, I have subdivided the reach between the former Sweasey Dam site and the Hammond Bridge, upstream of the mouth into five subreaches and use the shortened names as follows: 1) Sweasey Dam site (Sweasey) to Mad River Fish Hatchery (Hatchery); 2) Hatchery to Arcata & Mad River Railroad bridge (A&MRR); 3) A&MRR to U.S. Highway 299 bridge (299); 4) 299 to U.S. Highway 101 bridge (101); and 5) 101 to Hammond bridge (Hammond). Each reach is geomorphically distinct, although I do group certain reaches together at times for analysis. Pre-disturbance conditions are described first in order to put natural and mechanical manipulations of the channel during historic time into context. In each section I describe changes in the river's geomorphic features progressing downstream from the Sweasey Dam site to the Hammond Bridge.

A. PRE-DISTURBANCE CONDITIONS

I reconstructed the geomorphic conditions of the channel prior to large-scale land use changes with the help of early surveys, newspaper accounts, and previous research.

Sweasey Dam to Blue Lake

Survey data by Foreman (1874, before logging in that part of the watershed) indicated the channel was narrow and confined between the Sweasey Dam site and the Hatchery. The wetted channel was 33 feet wide where three different section lines cross the river through the reach. Notes on active channel widths and depths were not taken. Foreman's survey notes indicated many redwood trees measured 10 feet and larger in diameter. Logging of timber this size began in the late 1870's to early 1880's around the Sweasey Dam site (sections in Township 5 North, Range 2 East). The channel probably experienced increased sedimentation and aggradation following landscape disturbance due to logging.

Hatchery to 299 Bridge

In the Blue Lake valley, below the outlet at the Hatchery and above the 299 Bridge, there is limited information with which to reconstruct channel conditions. The 1855 Plat map shows a narrow channel between the site of the Hatchery and the Blue Lake bridge that widened downstream toward the A&MRR bridge.

Table 2 shows mean active channel widths before the impacts of human activity. The active channel clearly was narrow as it exited the confined reach above the Hatchery site and flowed toward Riverside and Korbel. It widened significantly below the confluence with the North Fork and entered Blue Lake valley.

Survey notes (Foreman, 1874) indicate that the active channel was 330 feet wide west of the present town of Blue Lake, between sections 19 and 30 (River Mile (RM) 8.0). It measured approximately 3,300 feet from bank to bank along the same section boundary on the 1972 U.S.G.S. topographic quadrangle - a ten-fold width increase. Approximately 500 feet downstream the 1855 channel widens to about 1,750 feet. No in-stream bars were shown on the 1855 Plat map in the Blue Lake valley, which suggests a single thread channel. Active channel widening, avulsions, and aggradation between RM 8.0 and 6.0 following large floods may be related to a constriction at the

Table 2 -- Mean active channel widths (ft), Hatchery to A&MRR, from 1855, 1858, and 1874 surveys

Width	Hatchery to Blue Lake	Blue Lake to A&MRR
Active Channel Width*	278	919

* compiled from 1855, 1858, and 1874 surveys and plat maps; width was calculated by dividing the active channel area by the centerline length

A&MRR bridge which apparently produces a decrease in slope upstream.

This account from 1866 suggests that the bed along the reach between Warren Creek to below the 299 bridge did not consist of rocky outcrops as it does today; it may have appeared similar to the 1941/42 aerial photos which show large point bars separated by shallow riffles:

> "The Mad River being so low in early December he [a local rancher from near Warren Creek] was able to drive a team [of horses] down the river bar, fording the small riffles and coming out on Arcata Bottom there being no wagon road up Mad River at that time" (Susie Baker Fountain Papers, vol. 82, pg. 228).

Wagon roads and railroad lines that were subsequently built (and still exist today) probably defined the upper extent of the floodplain at that time.

Brush ("hazel and salmon brush"), timber ("pine, oak, and fir"), and redwood forests mapped outside the "high water banks" (Murray, 1854) indicates the existence of an extensive riparian community.

Downstream of the 299 Bridge

A report by Robert W. Thompson (1971) suggested "the Mad River at some time during the Recent geologic past must have emptied into an ancestral form of Humboldt Bay". His idea is supported by borings he made along the northern margin of the bay which contained river gravels and large woody debris. Meander scars visible on the 1941/42 air photos indicate that the river occupied a course as far south as the northeast portion of the City of Arcata during pre-European time.

Through a reconstruction of the Wiyot landscape before anglo settlement, Haynes (1986) conjectured:

> " . . . there were long, deep pools in the river through this section [along a former meander bend between 299 and 101 in the present Valley West area] that could accommodate the large

> fish [sturgeon] which can attain weights of 200 to 500 pounds." (Haynes, 1986, p. 32)

During Wiyot time, the channel contained long, deep pools and an undisturbed riparian vegetation corridor. The Wiyot food gathering site along the south bank of this meander was "utilized as a salmon and sturgeon spearing place", which gave rise to Haynes' conclusion. He also reported:

> "The big meander of the lower Mad River was a traditional fishing area for the semi-annual run of fish that crowded the river. "He was afraid to drive a horse across the river, the salmon ran so thick [quote from Loud, "Wiyot Territory", p. 233]," was how one pioneer put it. One can infer from this the channel morphology of the lower river was in a shape much more conducive to support this many fish. It suggests long, deep pools, cobblestone riffles, and a general lack of silt that characterizes the river today." (Haynes, 1986, p. 25-26)

The Mad River below the 299 bridge was apparently confined by riparian vegetation, and contained long, deep pools able to support salmon and sturgeon populations.

An article in the Arcata Union reported on the debate over the impacts of the Mad River Canal, built to float logs from the Mad River to the Mad River Slough and mills along Humboldt Bay. The article contended that before the floating of logs "the banks of that stream except in the vicinity of the mouth, seldom changed." ("Mad River Canal - Shut It Up", *Arcata Union*, August 14, 1886). This adds credence to the idea that the pre-disturbance channel maintained a single thread, stable, and meandering pattern below the water gap at the 299 bridge crossing.

Another early newspaper account from the Arcata Union describes the early character of the Mad River channel and said:

> "...that at some period [flooding] yearly inundated the entire bottom until the depth of the deposit and the growth of trees and other vegetation checked the previously uninterrupted course of the water and gradually caused it to conform its

> course to the present north bank . . . "("Lower Mad River Damaged By The Winter Flood. Protection Needed", *Arcata Union*, April 5, 1890).

It also described the role of riparian vegetation in bank stabilization and assumed that the riparian corridor helped to confine the channel along a "natural waterway".

During the flood of 1861-62 a house on the terrace near the present 299 crossing was inundated with water: "At Prigmore's the water was several inches deep in his house and other families down the river were obliged to leave for higher land." ("Letter From Arcata, Dec. 6th, 1861, Editor Times", *Humboldt Times*, December 7, 1861). The Prigmore ferry crossing was located where the 299 bridge crosses the Mad River today (shown on the 1865 Official Township Map of Humboldt Co. Cal.) and was downstream of the Daby ferry crossing (approximately one mile upstream of the confluence of Warren Creek and the Mad River), which was "abandoned after an Indian attack on it, June 6, 1862" (Mrs. E. F. Fountain, Historian, "Early Days of Humboldt", Blue Lake Advocate, February 7, 1957). Since ferries were needed to cross the Mad River in the 1850's and early 1860's, I assume that the river below 299 was generally too deep to ford for much of the year.

By 1887 the river was "low and fordable, in some places" (Mrs. E. F. Fountain, Historian, "Early Days of Humboldt", Blue Lake Advocate, February 7, 1957) and may represent the cumulative effects of large scale human-induced land use changes, such as logging and agriculture, and natural flooding. In 1889 the Arcata Union reported:

> "That the clearing and cultivation of our valley land, and logging in the gulches and on the hill sides of the adjoining country has been the main cause of shoaling our channels and raising the mud flats in the bay, there cannot be the least doubt" (Arcata Union, May 4, 1889).

Summary of Pre-Disturbance Channel Conditions

The historic accounts suggest that from Sweasey Dam to the Hammond bridge, the Mad River, prior to anglo settlement and the onset of large-scale in-stream and watershed disturbance, was probably a single, meandering channel with deep pools, shallow riffles, point bars, and cut-banks. The width-depth ratio was probably relatively small compared to the post-disturbance period. An extensive riparian zone helped to keep the channel confined and stable, except perhaps between Blue Lake and the A&MRR bridge where avulsions, aggradation, and channel widening may have been common following large magnitude floods.

B. HISTORIC FLOODING

The largest historic floods occurred in 1861-62, 1878, 1879, 1881, 1884, 1890-91, 1903, 1906, 1907, 1915, 1927, 1932, 1937, 1953, 1955, and 1964. Appendix E lists historic floods compiled from Eureka rainfall records, newspaper reports, work by Haynes (1986), and USGS streamgaging records Appendix F lists peak discharge and partial duration values for the period 1951 to 1992. Appendix G lists exceedance probabilities and recurrence intervals for the same period. Five of the ten largest floods gaged by the USGS occurred during the 1950's and nine of the ten occurred between 1951 and 1975.

During the second half of the 19th century a series of major regional storms occurred (Harden and Nolan, 1982). In order to compare these with recent floods of known discharge (figure 2), I measured area of inundation on the Arcata Bottoms as reported by Haynes (1986). Table 3 summarizes the results and shows that earlier flooding generally affected larger areas. This may be due to some combination of the following factors: 1) discharges were simply greater for earlier flooding; 2) construction levees and highway 299 (the Blue Lake road) limited the extent of flooding by restricting floodwaters from traveling through the Janes Creek corridor; and 3) bed lowering along the reach has increased channel capacity below 299. Harden and Nolan (1982) found that earlier storms were comparable with a series of storms that occurred between 1953 and 1972. They also found "the earlier storms had a dramatically smaller erosional impact [which] is logically attributable to the changes in runoff regimes, hillslope

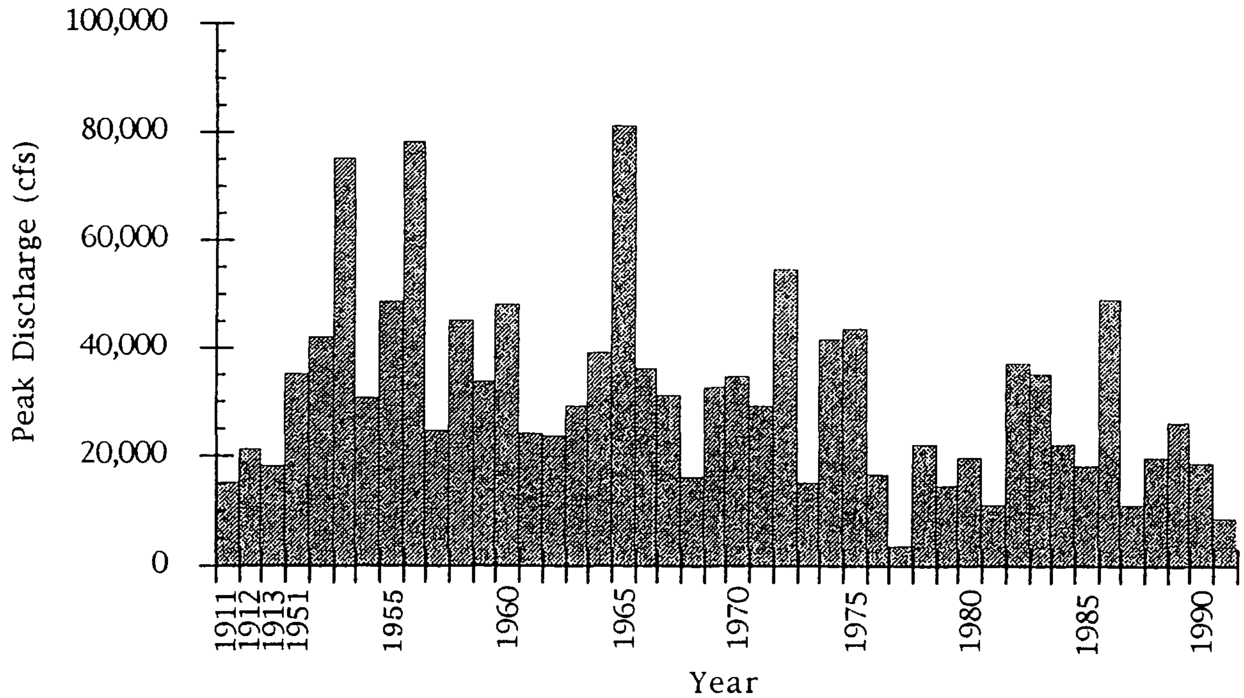


Figure 2 -- Annual peak discharge bar graph, Mad River near Arcata, USGS gage #11481000, 1911-1913 & 1951-1991

Table 3 -- Comparison of area flooded on the Arcata Bottoms during historic floods, 1859 to 1964 (after Haynes, 1986)

Flood Year(s)	Area Flooded (acres)
1859	1,020
1861	8,230
1878	1,950
1879, 1881, 1884	7,650
1890	7,950
1903	5,470
1906, 1907	4,620
1953	4,570
1955	4,860
1964	6,050

stability, and sediment loads that accompanied the intensive human activities in the basin during the second half of this century" (Harden and Nolan, p. 218). The most dramatic channel changes on the lower Mad River occurred during storm events of the 1960's and 1970's following intensive human activities.

The two day maximum volume of runoff for the December 1964 flood exceeded the December 1955 flood by about 25 percent (U. S. Army Corps of Engineers, 1968). Landowner Ben Spini observed that the 1964 flood lasted for "days" while the 1955 flood was much shorter in duration (pers. comm., 1994). The Corps of Engineers also reported that historical flood marks for the nearby Eel and Klamath basins indicated "the 'great flood of 1862' was about equal to the December 1955 flood" adding the two basins are much larger and "are not conclusively indicative of the order of magnitude of floods on the Mad River basin" (U. S. Army Corps of Engineers, 1968).

C. HISTORIC GEOMORPHIC CONDITIONS, LOWER MAD RIVER, 1855 TO 1992

1. Sweasey Dam to Hatchery

a) Reach Description

The reach between the former Sweasey Dam site (Sweasey) and the Mad River Fish Hatchery (Hatchery) is a composite alluvial-bedrock channel approximately 5.5 miles long extending from River Mile (RM) 15.8 to RM 10.3 (figure 3). This reach has undergone cycles of erosion and deposition related to changes in sediment production in the watershed. The bed configuration consists of alternating bars approximately 500 to 5,000 feet (150 to 1,500 m) in length and as much as 500 feet (150 m) in width (Brown, 1975). A channel junction bar exists at the confluence with Cañon Creek (drainage area 16 mi^2 (40 km^2)), approximately 1.5 miles (2.4 km) downstream of Sweasey at RM 14.6. Terrace and landslide deposits along the reach typically erode at higher flows (Brown, 1975).

b) Land Use History Summary

Land use changes following anglo settlement included logging and railroading in the late 1880's (Evans, Blue Lake Museum, pers. comm., 1994, Appendix D). The logging towns of Korbel and Riverside (at the confluence of the North Fork and the Mad River) were settled by the mid 1880's. At that time the Arcata & Mad River Railroad carried a large volume of freight which reflected the increase in agricultural and lumber exports from the area (Weekly *Times Telephone*, January 9, 1886). Logs were cut, secured with cables, dragged along corduroy roads initially by oxen, then as technology changed, by steam donkeys. The timber was then loaded onto

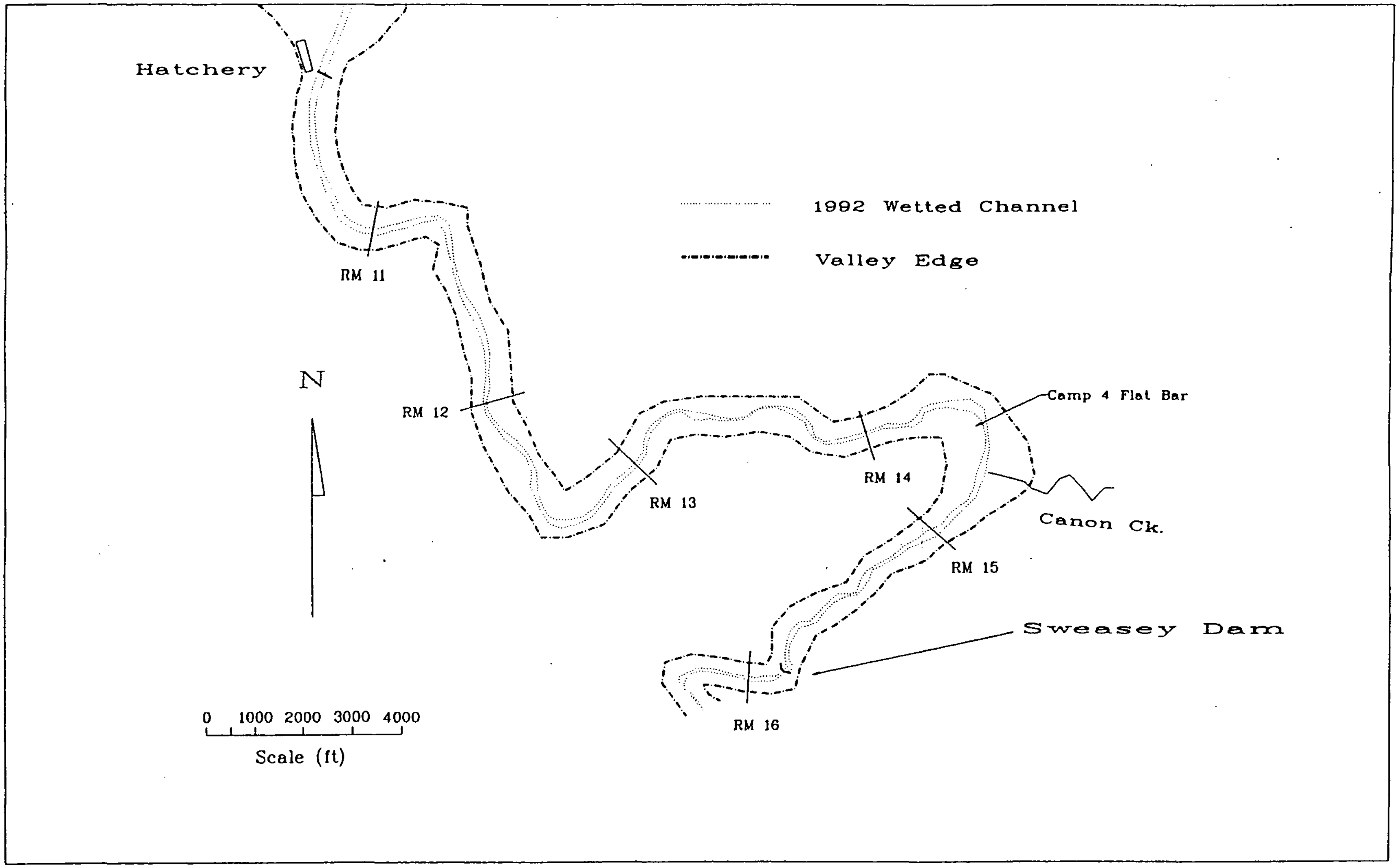


Figure 3 -- Sweasey Dam to the Hatchery reach, lower Mad River

railcars for transport to mills (Elmer Evans, Blue Lake Museum, pers. comm., 1994; Clyde Patenaude, pers. comm., 1994). This change in land use to logging and railroad building upstream of the Hatchery disturbed the landscape significantly and increased the sediment available for transport into the channel of the river.

I located a photograph which documented the land use changes along Cañon Creek in 1906 (figure 4). Clearcutting is visible down to the banks of Cañon Creek and the Mad River. The railroad tracks running along the base of the scarp in the photo have been eroded away since the photo was taken, indicating that bank erosion has occurred at this site since 1906. I was unable to determine whether railroad construction at the base of the slide caused it to occur.

The first wave of logging in the reach dramatically slowed in the 1920's as train tracks were pulled and moved up the North Fork watershed (Elmer Evans, Blue Lake Museum, pers. comm., 1994). Roadbuilding for transport of logs by trucks began in the 1920's ("To Haul Lumber With Trucks", *Blue Lake Advocate,* June 2, 1923). Sweasey Dam, owned and operated by the city of Eureka, was completed in 1938 (*Humboldt Times,* "Water Flows Over the Dam; Ready For Eureka When Chlorination Arranged", November 4, 1938; Roberti, 1971). The dam impounded 3,000 acre-feet (4,840,000 yd^3 or 3,700,000 m^3) of water (Brown, 1975) and supplied Eureka via a redwood stave pipe. Figure 5 shows the dam and fish ladder in 1969. Tractor logging first occurred in the 1940's. Activity in the upper watershed intensified in the post-war period after a lull during the Depression and reached a peak in the 1950's and early 1960's (Haynes, 1986; Hank Harrison, BLM, Arcata, pers. comm., 1994). By 1962 the dam filled with

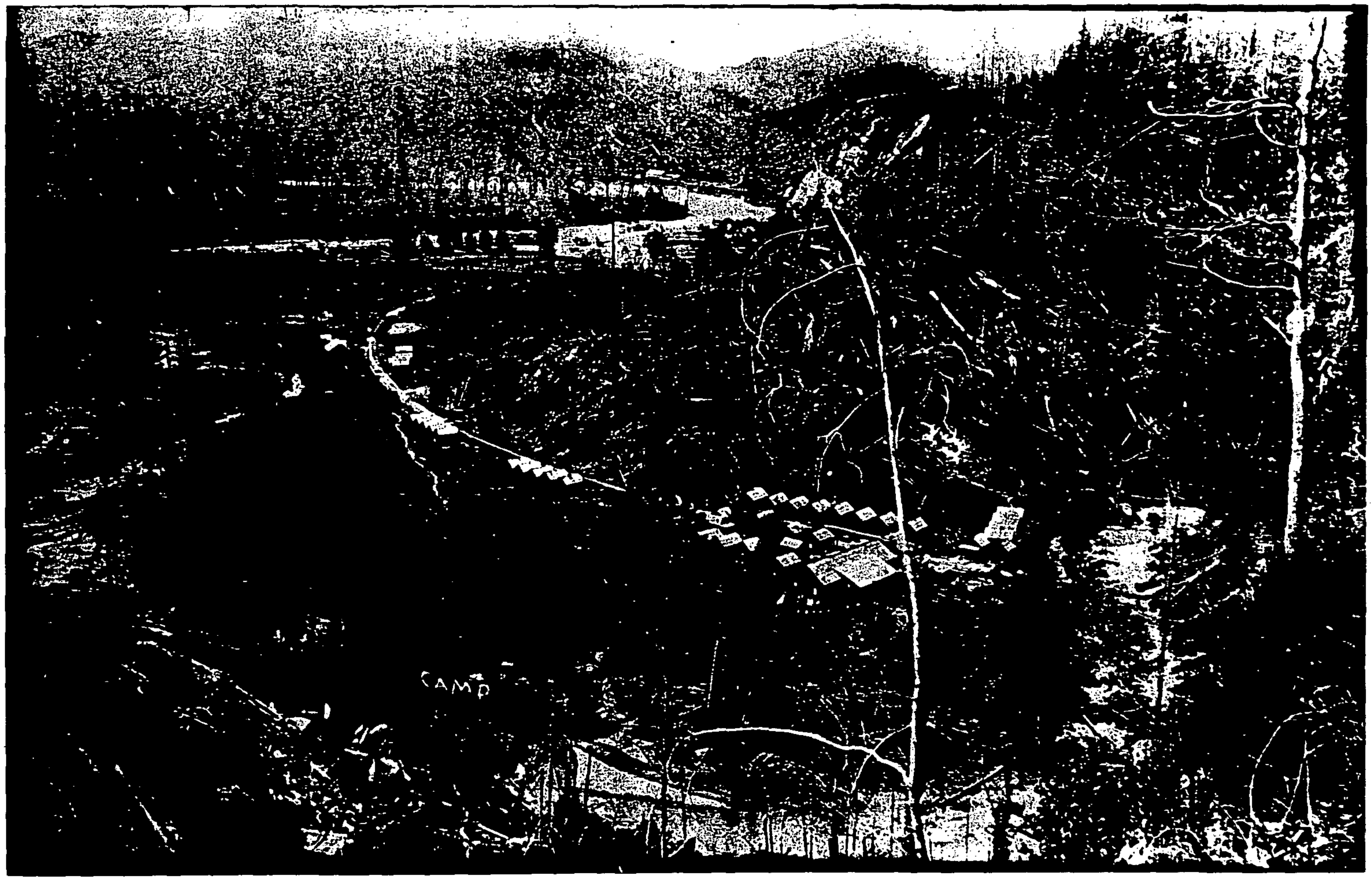


Figure 4 – View northwest of Canon Creek (foreground) and Mad River in the background. Note landslide on outside bend of Mad River. (Photo by Maseman, courtesy of Don Tuttle, Humboldt County Public Works Collection, Natural Resources Dept.; also part of the Peter Palmquist collection).

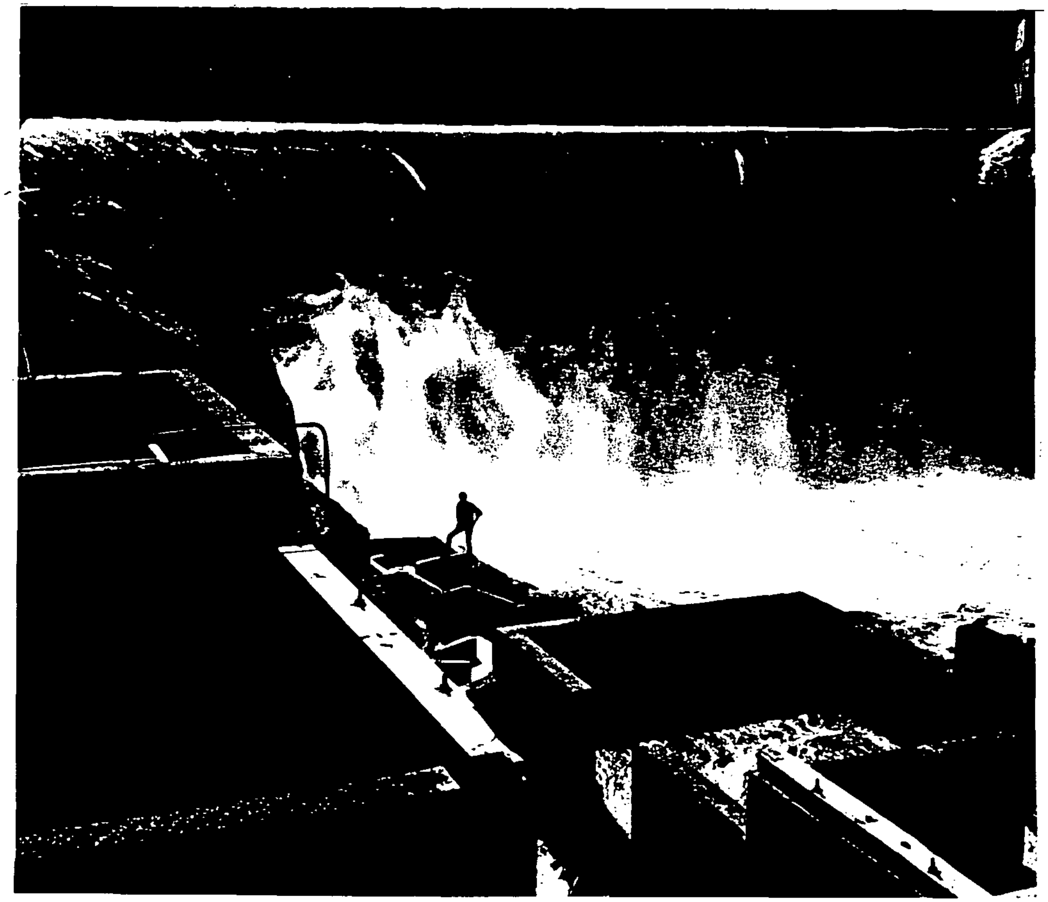


Figure 5 – View of Sweasey Dam in 1969. Note fish ladder in foreground. The ladder was repeatedly vandalized and the dam was dynamited in 1970 to allow fish access to upstream reaches. (Photo by Kip Roberti, courtesy of Jerry Momber, Simpson Timber Company).

sediment (Brown, 1971; Roberti, 1971; Elmer Evans, pers. comm.). Figure 6 is an oblique aerial view of the dam and impounded sediment in 1969. The dam was dynamited in 1970, which released stored sediment into the channel (Brown, 1971; Brown, 1975). Air photo and field observations show that logging of second growth forest upstream of the Hatchery began in the mid 1960's and continues to the present. Other land use activities along the reach include grazing, road construction and maintenance, quarrying, and recreation.

c) Historic Geomorphic Conditions of the Sweasey Dam to Hatchery Reach

Pre-Aerial Survey Period

The first surveys of the area took place in the 1870's (Foreman, 1874) and showed a narrow channel along the reach. The wetted channel was 33 feet (10.1 m) wide where three different surveyed section lines crossed the river upstream of the Hatchery (RM 15.5, RM 15.4, and RM 12.0) (figure 2). Foreman's surveys noted many redwood trees measured 10 feet (3 m) and larger in diameter (Foreman, 1874). A headline from the Blue Lake Advocate reported the size of one of the largest trees in the area, along Simpson Creek, just upstream of Sweasey:

> ". . . One Tree 93 Feet Around Base . . . ", (*Blue Lake Advocate*, September 3, 1921, "May Save Simpson Creek Redwoods").

A tree with a 93 foot (28.3 m) circumference would have a diameter of about 30 feet (9.1 m). Another tree of this size was logged 2 miles (3.2 km) to the north sometime after Foreman's observations were made and indicated these redwood groves were common above Blue Lake before 1874:

Figure 6 – Sweasey Dam (near center of photo) is seen impounding sediment in 1969, one year before the dam was removed to allow fish passage. Arrow denotes flow direction. View is toward the east. (Photo by Kip Roberti, courtesy of Jerry Momber, Simpson Timber Company).

> " . . . At Korbel, two miles above Blue Lake, some years ago, the Korbel Company felled a tree measuring 33 feet in diameter at the butt . . . The tree was over 300 feet in height when it was felled." (*Blue Lake Advocate,* January 5, 1924, "A Mammoth Redwood Tree")

His observations tended to support the claim that the width to depth ratio was also relatively smaller along the lower reaches of the river to the sea, including the reach through the Blue Lake valley.

Landslides in the study area are common. The geomorphic features map of the Korbel quadrangle shows a minimum of 30 mass movements along the channel between Butler Valley, a few miles upstream of the dam, and the Hatchery. These slides input an unknown, but presumably significant, amount of sediment into the river's tributaries and channel. Sediment input into the channel has been a result of both human and natural activity. The contributions of each could not be quantified in this study.

The following headline in 1924 documents the beginning of work toward completion of the Sweasey Dam project: "Eureka Engineer Busy Making A Survey Of Proposed Mad River Water Supply System For Eureka . . . [would] bring the water to Eureka by means of gravity." ("Want Mad River Water", *Blue Lake Advocate,* September 13, 1924). Gravel for construction of the dam came from the channel nearby: "Excellent gravel and sand aggregate is found at the dam site . . ." ("Huge Mad River Project Is Planned", *Blue Lake Advocate,* February 25, 1933). The gravel source may have been the bar at the mouth of Cañon Creek (Leslie Christopherson, pers. comm., 1995; Appendix D). A minimum of 20,000 yards, taken from the river bed, was used to build the dam: "Confronted with continuing slides at the west abutment of the Mad River water project dam site, . . . the city council . . . [asked for] . . . 20,000 cubic yards additional excavation . . . " ("Additional Excavating Necessitated By Slides At The Mad River Dam", *Blue Lake Advocate*, August 31, 1935).

Post-Aerial Survey Period

Air Photo Observations

Detailed notes of air photo observations are given in Appendix H. A summary of important changes between 1941/42 and 1992 shows the following:

1. 1941/42 to 1948: Following impoundment of water and sediment by the dam, the channel narrowed downstream. The mean active channel width decreased from approximately 390 feet to 190 feet. Encroachment of riparian vegetation occurred along the banks at the confluence of Cañon Creek and on the bar opposite Camp 4 Flat (RM 15.0 to RM 14.2). A debris flow at approximately RM 12.0 along the left bank introduced sediment directly into the channel. At RM 10.8 I observed evidence of approximately 150 feet of right bank erosion.

2. 1948 to 1954: The channel migrated toward the left bank at Cañon Creek. The channel changed from multiple to single-strand at the confluence with Cañon Creek. The channel shortened by approximately 500 feet along the reach. I observed evidence of left bank erosion and channel widening just upstream of the Hatchery site.

3. 1954 to 1958: The channel migrated toward the right bank at Cañon Creek and slightly increased its length. The channel continued to widen by eroding its banks in the 1950's. More boulders were exposed along the bed and banks in the 1958 air photos. The reservoir was nearly filled with sediment by 1958.

4. 1958 to 1962: The reservoir was completely filled by 1962. The position of the mouth of Cañon Creek did not change between 1958 and 1962 and the length of the river remained the same.

5. 1962 to 1966: The channel widened to approximately 300 feet. Bank erosion occurred along the reach in several locations. The mouth of Cañon Creek was eroded and the confluence migrated eastward. The channel widened along Camp 4 Flat. Vegetation

between the channel and the roadway along the right bank disappeared downstream of Cañon Creek. Parts of the access road were washed out. Between RM 13.0 and RM 10.3, upslope of the right bank, new roads were constructed and the watershed was extensively logged.

6. 1966 to 1970: Mean active channel width decreased between 1966 and 1970 as the channel recovered from the flooding and vegetation began to grow back on the bars (observed in the 1970 photo set). The channel formed a multiple-strand pattern at the confluence with Cañon Creek.

7. 1970 to 1974: The channel widened from approximately 280 feet to 320 feet. By 1974 bank erosion caused the pipe used to transport water to Eureka (buried in a causeway approximately 0.5 miles (0.8 km) downstream of the dam) to fail as the channel widened. The channel migrated to the left bank along Camp 4 Flat.

8. 1974 to 1981: Air photo coverage for 1981 was unavailable.

9. 1974 to 1988: In 1988 the channel was positioned along the left bank at Camp 4 Flat and formed a single strand.

10. 1988 to 1992: The 1992 mean channel width was similar to the width measured in 1974. In 1992 the channel along the left bank at Camp 4 Flat remained unchanged.

Effects of Impoundment

Following impoundment of water and sediment by the dam, the channel downstream responded by narrowing as it became more entrenched and vegetation encroached onto the bars. Bank erosion may have resulted from "sediment hungry" water regaining its sediment load by eroding its bed and banks.

Between 1948 and 1966 the mean active channel width increased steadily from 190 to 300 feet (table 4). This period was marked by 7 of the 10 largest floods on record (Appendix F). The channel continued to widen by eroding its banks in the 1950's. Heavy equipment was used to maintain the water pipeline which had washed out several times at different locations

Table 4 -- Active channel centerline length, width, and area measurements, Sweasey to Hatchery, (1855 to 1992)†

Year	Length (ft)	Width (ft)	Area (acres)
1855††	N/A	N/I	N/A
1865††	22,900	N/I	N/A
1886††	21,100	580	553
1898††	25,800	570	673
1916††	21,700	280	279
1921††	28,500	290	371
1933*	N/A	N/A	N/A
1941-42	29,600	390	422
1948	30,400	190	277
1954	29,900	230	309
1958	30,100	250	340
1962	N/A	260	N/A
1966	N/A	300	N/A
1970	30,000	280	385
1974	29,500	320	434
1981	N/A	N/A	N/A
1988	N/A	N/A	N/A
1992	29,800	320	430

† see also Appendices I, J, and K for a comprehensive list of all reaches
†† = map accuracy is questionable
* = map only covers the lower portion of the reach
N/A = Not Available
Note: estimates depend on scale and resolution of photos

along the right bank (Vic Guynup, pers. comm., 1994, Appendix D). Air photos show more boulders were exposed by erosion along the bed and banks.

The 1964 flood widened the channel and eroded riparian vegetation along the reach. Logging began to affect the immediate reach again. The channel recovered from the flooding and vegetation began to grow back on the bars until the dam was blasted. Following removal of the dam and the release of stored sediment into the channel in late 1970, the channel aggraded and eroded its banks (Brown, 1971, 1975). Immediately downstream of the dam the bed elevation rose a minimum of 10-12 feet (3.1 to 3.7 m) (Jerry Momber, Simpson Timber Company, pers. comm., 1994, Appendix D). Brown (1975) noted the "channel has aggraded slightly, and, consequently, unstable channel banks have been scoured" downstream from the damsite. Bank erosion caused the pipe used to transport water to Eureka (buried in a causeway approximately 0.5 miles (0.8 km) downstream of the dam) to fail by 1972. A photo of the failure is shown in Brown (1975). A significant quantity of sediment was deposited near the mouth of Cañon Creek and a bar built up along the right bank (Brown, 1975). After high water in 1972, the channel had migrated to the left bank due to deposition of eroded material from the Cañon Creek watershed and aggradation in the main stem of the Mad River (Brown, 1975). Momber's observations indicated that most of the sediment had been eroded from behind the old damsite and deposited downstream following high water in 1972 (Jerry Momber, pers. comm., 1994, Appendix D). According to Chris Haynes, who frequently fished the river in the early 1970's, the bed aggraded approximately 6 to 12 feet near Cañon Creek (Haynes, pers. comm., 1994, Appendix D). He observed that thousands of fish - many 30 to 40 pounders - had suffocated in water that was only inches deep. Only the fish smaller than approximately eight pounds made it through (Haynes, pers. comm., 1994, Appendix D).

After the dam was removed, the amount of material available for transport by the river exceeded the river's capacity to carry it and suggests that the river has been transport limited through the reach. Based on bedload transport rate estimates given below (approximately 67 to 100 acre-feet per year) it should take between 20 and 44 years for the river to remove dam-stored sediment from the dam site to the Hatchery ignoring confounding factors such as increased sediment input from: 1) the Cañon Creek watershed; 2) the river upstream of Sweasey Dam; and 3) increased bank erosion and landsliding along the reach. I concluded it would take closer to 35-40 years for the sediment to be removed based on: 1) observations by some of the locals familiar with the reach that suggest channel conditions are starting to resemble those before the dam was removed, though recovery is not complete (Christie, pers. comm., 1994; Christopherson, pers. comm., 1994; Haynes, pers. comm, 1994; Appendix D); 2) U.S.G.S. flow data that indicate 7 of 10 of the largest peak flows occurred between 1951 and 1966 which suggests that the bedload transport rate calculated by estimating infilling rate of the dam may have been artificially high for the period; and 3) logging and road building and consequent sediment production accelerated following World War II, also suggesting artificially high bedload transport rates for the period. Relatively fewer high flows over the last 20 years means a reduced volume of material transported through time.

Haynes (pers. comm., 1994, Appendix D) reported that the bed elevation was level with the Camp 4 Flat terrace in 1970. My field observations in 1994 indicated that the bed had dropped approximately 10 to 12 feet (3.1 to 3.7 m) along the left bank at Camp 4 Flat where Simpson's summer logging bridge crossed the river opposite the location of the mouth of Cañon Creek. This would give a minimum bed lowering rate at the mouth of Cañon Creek of approximately 0.4 feet/year (0.12 m/yr).

Air photos and oral histories show that the pools between Sweasey and the Hatchery filled with sediment (Evans, Christie, Momber, Haynes, Christopherson, pers. comm., 1994, Appendix D); bank erosion was observed as the bed raised. Many pools 12 to 15 feet (3.7 to 4.5 m) deep disappeared and may only now be reappearing (Evans, Christie, Haynes, Christopherson, pers. comm., 1994, Appendix D). The 1992 mean channel width was similar to that measured in 1974 (table 4) and may reflect logging activity and a changed flow regime in tributary creeks which would tend to contribute to high sedimentation rates.

The flow regime of Cañon Creek may have been significantly altered over the last 10-15 years by clearcut logging in its watershed. The creek now appears "flashier" and has moved some stream restoration weirs and logs put in along the banks (Jerry Momber, pers. comm., 1994).

Medial Bar Measurements

I measured the length and width of a total of 30 medial (in-stream) bars observed on air photos taken between 1941/42 and 1992 in order to determine how the spatial frequency of medial bars changed following flooding, impoundment, and release of sediment into the channel. The frequency increased following impoundment and flooding in 1955 and 1964. No data was available to assess the effects of dam removal. Most medial bars observed were elongated and sausage shaped, but a few were rectangular to round. The length to width ratios averaged 4.6 and ranged from 2.7 to 8.3 (table 5; see also Appendix L for comparison with other bars on the lower Mad River). The number of bars along the reach ranged from 0 in 1988 to 6 in 1958. The two bars in the 1948 photos observed upstream of the Hatchery were the result of widening of the channel and bank erosion described above.

Sediment Budget

The Sweasey Dam reservoir filled with sediment by 1962. I was able to calculate a simple sediment budget for the reach based on the infilling rate and volume of sediment impounded. Although the dam's valve for flushing sediment and debris stuck "around the year 1940-41" (Roberti, 1971), coarse sediment would have been deposited once the impoundment began in 1938. In approximately 24 years the dam was filled with sediment. Brown (1975) stated "that more than 2,000 acre-feet (2.5 hm^3 [3,200,000 yd^3 or 2,400,000 m^3]) of sediment was deposited behind Sweasey Dam". Brown's data (1971) suggests most of the volume of sediment deposited behind the dam was coarse sand and gravel (approximately 80% of the total deposits). This is supported by Brown's observations (1975) of suspended sediment discharge which "showed no significant variation with respect to discharges for previous years". He assumed most of the trapped sediment was coarse sand and gravel. Under these assumptions I obtained a minimum bedload transport rate of approximately 108,000 yd^3/yr (83,000 m^3/yr) over 24 years

Table 5 -- Medial bar measurements (ft), Sweasey to Hatchery, (1941-42 to 1992)

Year	Location	Length	Width	L/W Ratio	Mean L/W Ratio for Each Year†	Number of Bars Observed
1941-42	blw Sweasey dam	350	112	3.1	5.4	3
	US Cañon Ck.	931	192	4.8		
	Cañon Ck.	1644	199	8.3		
1948	blw Sweasey dam	340	108	3.1	5.4	5
	US Cañon Ck.	913	184	5.0		
	Cañon Ck.	1658	209	7.9		
	abv Hatchery	811	163	5.0		
	abv Hatchery	521	89	5.9		
1954	abv Cañon Ck	906	214	4.2	4.0	4
	blw Cañon Ck	449	92	4.9		
	blw Cañon Ck	753	246	3.1		
	abv Hatchery	810	497	1.6		
1958	@ Cañon Ck	675	206	3.3	4.1	6
	blw Cañon Ck	470	133	3.5		
	DS Cañon Ck	533	123	4.3		
	DS Cañon Ck	371	72	5.2		
	DS Cañon Ck	471	97	4.9		
	DS Cañon Ck	595	195	3.1		
1962	blw Sweasey dam	629	204	3.1	2.9	3
	DS Cañon Ck	205	68	3.0		
	DS Cañon Ck	464	171	2.7		
1966	DS Cañon Ck	504	75	6.7	4.8	3
	DS Cañon Ck	552	152	3.6		
	DS Cañon Ck	812	197	4.1		
1970	Cañon Ck	2558	325	7.9	5.2	5
	DS of bend	865	150	5.8		
	just DS of bend	528	146	3.6		
	big bar @ Hatchery	1293	317	4.1		
	sm bar @ Hatchery	592	126	4.7		
1974*	N/A	N/A	N/A	N/A	N/A	N/A
1981*	N/A	N/A	N/A	N/A	N/A	N/A
1988	none observed	--	--	--	--	0
1992	just DS of Hatchery	1437	216	6.7	4.8	1
	Mean =	788	176	4.6	Total =	30

† = reach mean; compare to Appendix for lower Mad River mean
* = incomplete data above Hatchery

and a maximum bedload transport rate of 161,000 yd^3/yr (123,000 m^3/yr) using 3,000 acre-feet over 24 years. This compares favorably with the bedload transport rate estimated by Lehre of 110,000 - 140,000 yd^3/yr (84,000 - 107,000 m^3/yr) (Lehre and others, 1993). Several factors may cause my estimates to be artificially high. These include: 1) the period during which deposition occurred was unusually wet (the 1953 and 1955 floods were the second and third largest of record and five of the ten highest discharges on record occurred between 1951 and 1962 (Appendix F)); 2) the scale and style of tractor logging in the late 1940's and 1950's and 1960's was significantly different than before or after and increased the amount of sediment transported into the system; 3) draglines were used to mine an unknown amount of gravel from behind the dam and dump it into the stream below the dam toward the end of its lifespan (Christopherson, 1994, Appendix D). This transported material downstream of Sweasey Dam for the last few years of the dam's life and would tend to cause an overestimation of the bedload transport rates.

d) <u>Summary of Historic Conditions of the Sweasey Dam to Hatchery Reach</u>

Evaluation of available data shows some important trends. Hydrologic changes along the reach include: 1) dam construction which trapped sediment and reduced sediment supply downstream; 2) dam removal which released stored sediment into the channel downstream; 3) logging and road construction which have increased the amount of sediment delivered to the channel and changed the hydrologic regime by increasing peak discharges and decreasing flood durations through the reach.

Geomorphic changes include: 1) channel degradation and a decrease in width following impoundment of water and sediment behind Sweasey Dam in 1938 due to vegetation encroachment onto bars and probably channel entrenchment; 2) widening and continued degradation between 1948 and 1966 as the river eroded its bed and banks in response to impoundment and flooding; 3) aggradation and some braiding following removal of the dam in 1970; and 4) the return of some deeper pools and a single thread channel in the last 10 years.

Sweasey Dam filled completely with material by 1962, impounding over 2,000 acre-feet (3,200,000 yd^3 or 2,400,000 m^3) of sediment. A sediment budget for the reach gives a bedload transport rate (averaged over 24 years) ranging from approximately 108,000 to 161,000 yd^3/yr (83,000 to 123,000 m^3/yr) and is consistent with estimates by Lehre (1993) for the lower Mad River. Following removal of the dam in 1970, the channel aggraded up to 10-12 feet (3.1 to 3.7 m) downstream of the dam. The channel has since degraded at a rate of approximately 0.4 ft/yr (0.12 m/yr) near the mouth of Cañon Creek. I estimated that the channel would take approximately 35-40 years to recover from the effects of sediment input from behind the dam. A second wave of logging along the reach began in the mid 1960's and continues today, altering the flow regime of the river and its tributaries.

2. Hatchery to Blue Lake Bridge

a) Reach Description

The reach between the Mad River Fish Hatchery (Hatchery) and Blue Lake bridge is an alluvial channel constrained artificially in places (see figures 7 and 8). The reach has undergone cycles of erosion and deposition related to changes in sediment production in the watershed. The reach is approximately 1.6 miles (2.6 km) long, extending from River Mile (RM) 10.3 to RM 8.7 (see figure 9). The channel's bed configuration has at times consisted of alternating bars, point bars, and medial bars. The confluence with the North Fork of the Mad River (drainage area of 50 mi^2 (130 km^2)), is approximately 1.5 miles (2.4 km) downstream of the Hatchery at RM 8.8. Bank materials such as terrace deposits along the reach typically erode at higher flows. Riprap used along both banks confines the channel in places.

b) Land Use History Summary

Clement Chartin originated the name of Blue Lake and founded the town in 1871 ("The Story of Blue Lake", *Blue Lake Advocate,* April 21, 1955, Mrs. Eugene F. Fountain, Historian). The low land near Mad River [in Blue Lake Valley] was "covered with thickets of salmon berry vines and shrubs,in addition to alder and cottonwood trees" ("The Story of Blue Lake", *Blue Lake Advocate,* April 21, 1955, Mrs. Eugene F. Fountain, Historian). Earliest land use changes included farming, ranching, logging, and railroading (Haynes, 1986; Scalici, 1993). Three articles in the Weekly Times Telephone (March 24, 1882, April 14, 1882, and January 6, 1883) discussed

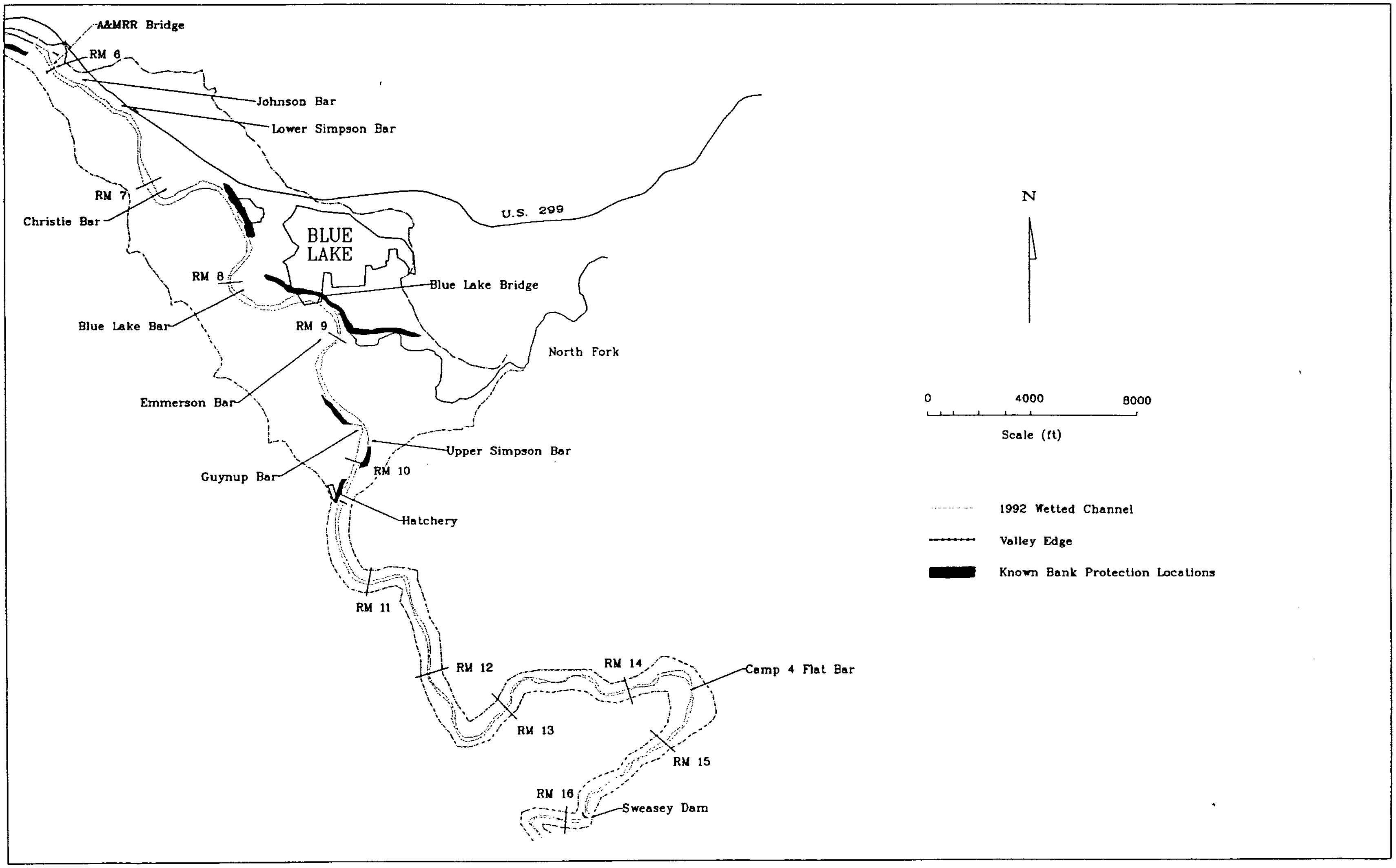


Figure 7 -- Known bank protection structures between Sweasey Dam and the A&MRR bridge

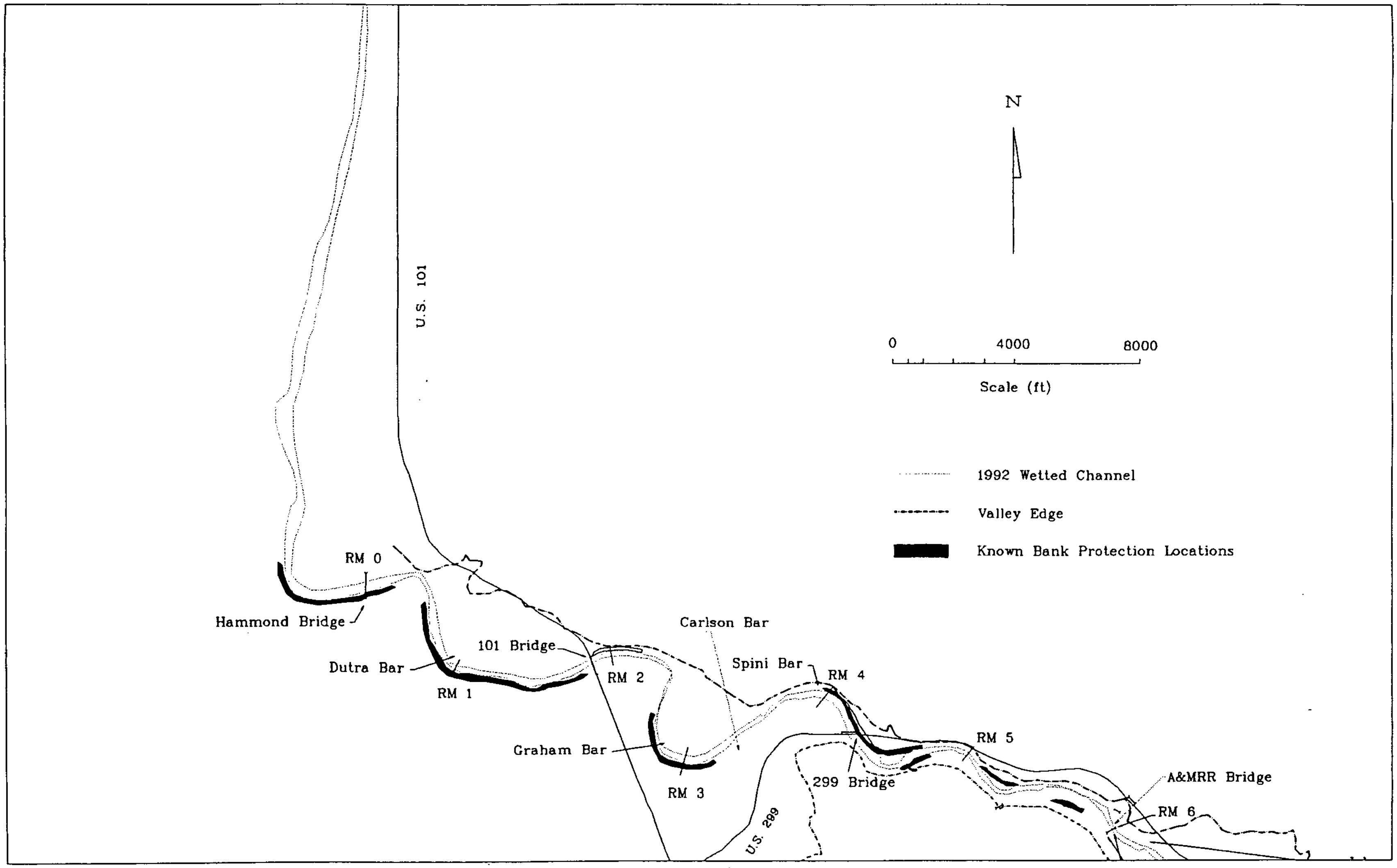


Figure 8 – Known bank protection structures between the A&MRR bridge and the Hammond bridge

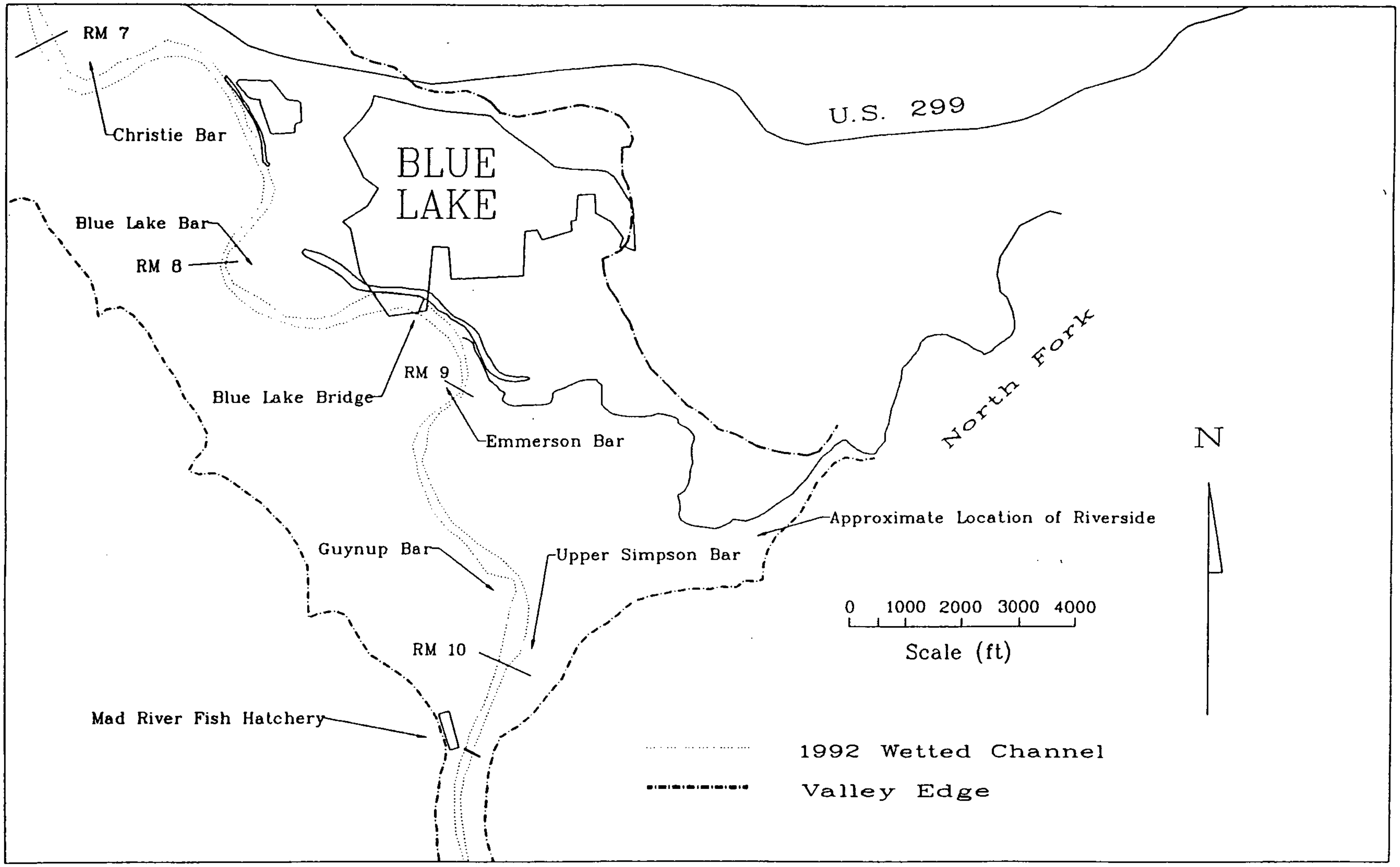


Figure 9 -- Hatchery to Blue Lake reach, lower Mad River

the purchase of the Arcata and Mad River Railroad by the Korbel brothers and their plans to extend the line to the North Fork of the Mad River. They did this and created the logging towns of Korbel and Riverside. Logging activity intensified shortly thereafter in the watershed upstream of Blue Lake on both the North Fork and the main fork of the Mad River. By the mid 1880's the Arcata & Mad River Railroad carried a large volume of freight which reflected the increase in agricultural and lumber exports from the area (Weekly *Times Telephone*, January 9, 1886). This change in land use to logging and railroad building upstream of the Hatchery disturbed the landscape significantly and increased the amount of sediment available for transport into the channel of the river. Logs were cut and skidded down streambeds along corduroy roads to landings along the river, then floated downstream to the Mad River Canal where they were diverted into the Mad River Slough and floated on to mills along the bay. Rafting of logs ended with the introduction of railroads into the watershed in the 1870's as logs were loaded onto railcars and transported to the mills. Logging activity continued into the 1920's: "The Korbel and Riverside Mills and Four Logging Camps Running Full Blast" [Headline from the Blue Lake Advocate] ("Local Mills and Camps are Busy", *Blue Lake Advocate*, July 9, 1921). Trucking replaced railroads in the 1920's and 1930's: " . . . two or three trucks hauling lumber from Fernwood mill to the Essex railroad station . . . " ("To Haul Lumber With Trucks", *Blue Lake Advocate*, June 2, 1923) and roadbuilding in the watershed increased. Northcoast mills were cutting over 1 billion board feet of timber per year in 1921 with new orders coming in (*Blue Lake Advocate*, August 6, 1921, "Boom Coming in Lumber"). In 1923, the Northern Redwood Lumber Company purchased 16,000 acres of timber in the North Fork drainage and expected it: "will probably be all cut and logged within the next six or seven years . . . " (*Blue Lake Advocate*, August 4, 1923, "Surveying For Railroad Extension"). The company paid native Americans $1 per day to cut redwood sprouts to help maintain pasture land for cattle and sheep during this era (Momber, Simpson Timber Company, pers. comm., 1994). Mass movement on grazed melange slopes in the Van Duzen watershed increased as native, deep-rooted grasses gave way to shallow-rooted grasses (Kelsey, 1978). Logging activity decreased during the 1930's and many mills either closed or operated intermittently as the economy suffered from the Great Depression (Borden, 1954): "Korbel Active After Being Closed Since Summer Of 1931", (*Blue Lake Advocate*, September 23, 1933). The Northern Redwood Lumber Company mill shut down for several years during this period:

> "The Northern Redwood Lumber Company holdings exceed two billion feet of merchantable timber and when in operation the company employs from 350 to 600 men. The mill has been closed for nearly four years in all departments except maintenance." ("N.R. Lumber Co. Asks Permit To Reorganize", *Blue Lake Advocate*, April 4, 1936).

Following World War II, logging in Humboldt County boomed and peaked in the late 1950's and early 1960's (Bolsinger, 1980; Centaur Associates, 1980). Tractor logging became popular and significantly disturbed the landscape in both the North Fork and main fork watersheds (Haynes, 1986). Today's logging styles have changed, reducing the amounts of sediment input into the channel system. Gravel extraction along the reach began in 1962 (Vic Guynup, pers. comm., 1994) and continues to date.

c) Historic Geomorphic Conditions of the Hatchery to Blue Lake Bridge Reach

Pre-Aerial Survey Period

The town of Blue Lake derives its name from one of several lakes formed during the great flood of 1861-62. During this storm, the Mad River and the North Fork both overflowed their banks, flooding the lower part of Blue Lake:

> ". . . the lake in this vicinity, called Blue Lake, was formed by the worst flood of all, the great inundation of 1861. Sacramento was under water, one thousand persons leaving for San Francisco on one boat. On February 22, 1862, Dr. Kirpatrick, U.S.A., informed the Humboldt Times that a government rain gauge carefully kept at Fort Gaston [near Hoopa on the Trinity River], showed that from December 22, 1861 to February 8, 1862, rain fell to the amount of 92.55 inches" ("The Story of Blue Lake . . . ", Blue Lake Advocate, May 10, 1956, by Mrs. Eugene F. Fountain, Historian).

When the waters receded, three lakes remained (the largest was named Blue Lake) ranging from 5 to 13 acres in area ("The Story of Blue Lake", *Blue Lake Advocate*, April 21, 1955, Mrs. Eugene F. Fountain, Historian; Isabel Evans, Blue Lake Museum, pers. comm., 1994). One observer reported that "the valley looked like a small ocean" and noted: "where now stands the blacksmith shop of G. P. Dow (near the Blue Lake Hotel,) [just south of the Annie and Mary Railroad Depot] the water must have been fully eight feet deep" ("The Story of Blue Lake", *Blue Lake Advocate*, April 21, 1955, Mrs. Eugene F. Fountain, Historian). The floodplain was inundated by both the Mad River and the North Fork periodically until construction of a revetment in 1953, which continues to protect lower Blue Lake from flooding. All four lakes have since disappeared.

The first surveys in the valley were completed by William J. Lewis, U.S. Deputy Land Surveyor, in 1858 (Lewis, 1858), followed by Solomon Foreman, U.S. Deputy Land Surveyor, in 1874 (Foreman, 1874). Maps from these surveys show that the river flowed toward Korbel and Riverside as it made a northeast turn at the Hatchery (figure 10). The channel's pattern appeared to be stable, showing a narrow, single-thread river. The mean active channel width for the reach in 1855 was approximately 280 feet (85 m) and increased to approximately 480 feet (145 m) by 1898 (table 6). Map accuracy is uncertain, but gives information on general trends and patterns.

An account of flood damage and bank erosion along the North Fork in 1881 was given in the Blue Lake Advocate: "Fred Burg's farm, at the location which was later Korbel, was almost all washed away . . . " ("The Story of Blue Lake . . . ", *Blue Lake Advocate*, April 4, 1957, by Mrs. Eugene F. Fountain, Historian). Agricultural land use changes along the Mad River have contributed to bank erosion. Such changes have been observed along the Russian River due to increased flow velocities (Philip Williams & Associates, 1993).

During the flood of 1889-90 a meander cutoff occurred naturally just below the Hatchery (see also Scalici, 1993). This account from the Blue Lake Advocate gives a description of the cutoff that shortened the channel of the Mad River by approximately 5,800 feet (1,800 m) (Appendix I):

> ". . . The ranches of all three [Mike McMillan, Dan McMillan, and Charles Kirkham] were swept completely out of existence in less than twenty-four hours time; rapid annihilation that was. . . . The cause, apparently, was Old Man Mad River's impatience with having forever to make a full right angle turn in his course, at a point directly southwest from Riverside and about one and one-half miles upstream. The water had

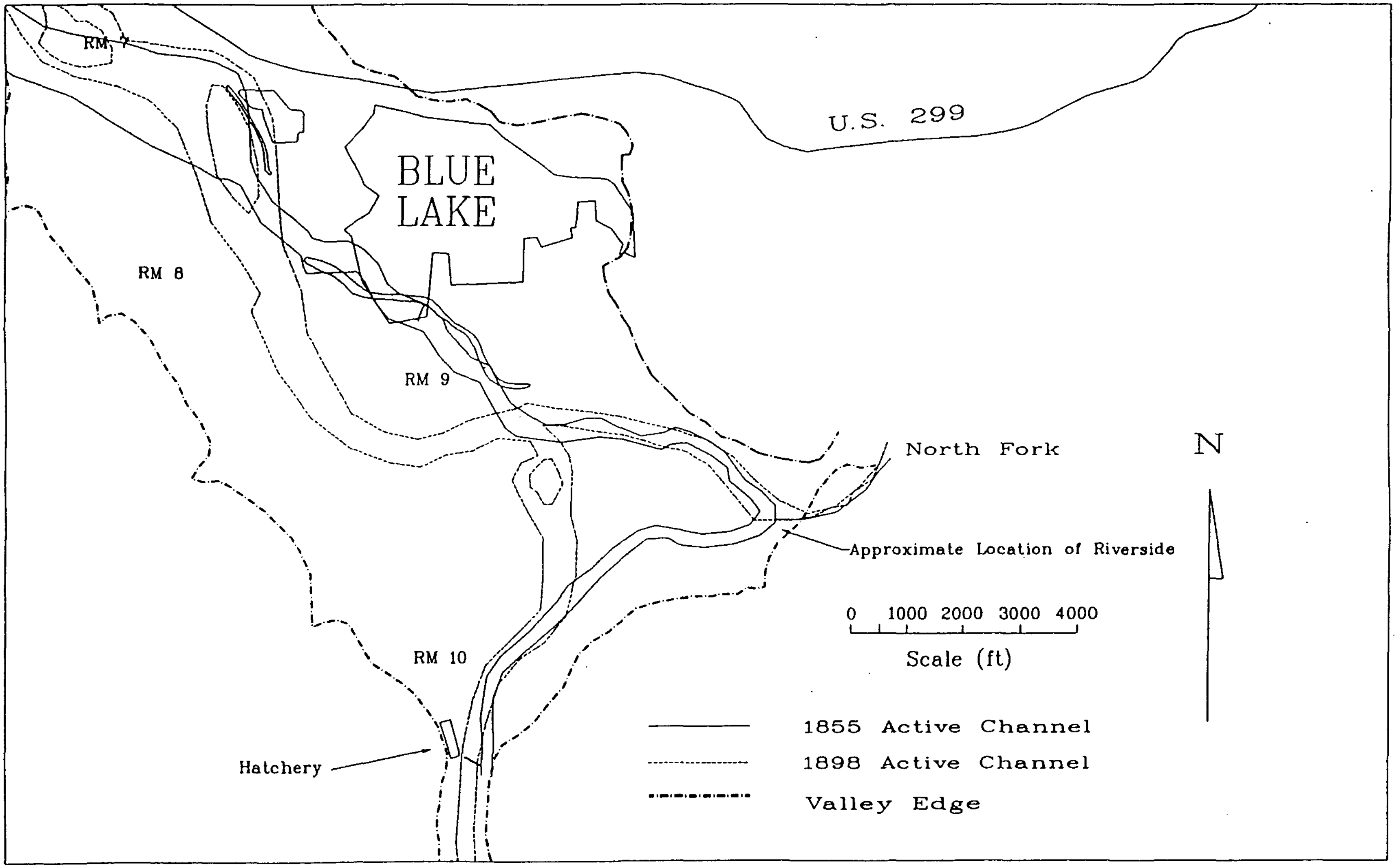


Figure 10 -- Meander cutoff near Blue Lake and Riverside following the 1890 flood

Table 6 -- Active channel centerline length, width, and area measurements, Hatchery to Blue Lake bridge, lower Mad River, (1855 to 1992)†

Year	Centerline length (ft)	Width (ft)	Area (acres)
1855††	15,600	280	100
1865††	7,600	570	99
1886††	14,500	580	193
1898††	9,800	480	108
1916††	9,000	450	93
1921††	7,700	1,370	242
1941-42	6,900	580	92
1948	6,600	460	70
1954	7,200	670	110
1958	7,600	840	147
1962	7,500	1,170	201
1966	8,000	1,990	365
1970	8,900	610	125
1974	8,500	630	123
1981	8,600	470	93
1988	8,800	740	149
1992	8,900	500	102

† see also Appendices I, J, and K for a comprehensive list of all reaches
†† = map accuracy is questionable
Note: estimates depend on scale and resolution of photos

> been coming in heavy volume out of the mountains at the time, although it was not raining. . . . The river had abandoned the right angle turn and struck out on a "beline" for its old channel opposite Blue Lake. It was during thewinter of 1889-90. On that day, Mad River had shortened its over-all length one and one-half miles, while simultaneously, the over-all length of the North Fork was increased by approximately an equal distance. The confluence of the two rivers changed from Riverside to Blue Lake . . ." (*Blue Lake Advocate*, June 21, 1956, by Mrs. Eugene F. Fountain, "The Story of Blue Lake . . . ")

Another account by Charlie Blake (recounted by Mrs. Eugene F. Fountain in the *Blue Lake Advocate*) describes the cause of the flood - a rain on snow event:

> " . . . There has been so much said as to the cause of the flood that I will add only this item. Where there had been four to five feet of snow, after the four or five days of that heavy warm rain, the ground was bare, so you see there was a good cause for the flood."

The story continues with a description of how the avulsion event took place:

> " . . . The first cause of the change in the course of Mad River was the fact that a very large tree came down the river, roots first, and the butt hit the bank across the bend. The top of the tree swung around, forming a boom across the river and in seconds there was a mass of drift lodged against the log. This virtually dammed the river, causing the water to drive across country. . . . When the channel was deepened down the valley, the log went on down the river and the water from the lake was drained back into the river." ("The Winter of 1889 and 1890", *Blue Lake Advocate*, Thursday, June 21, 1956, by Charlie Blake, recounted by Mrs. Eugene F. Fountain)

This event caused significant bed and bank erosion along the reach between the Hatchery and Blue Lake bridge. The channel degraded, straightened, and shortened as the new confluence between the North Fork and main fork moved downstream from Riverside to Blue Lake (figure 10). A single thread, meandering pattern can be seen in a photograph taken between 1883 and 1890 as the river flows past Riverside (figure 11). The confluence with the North Fork is visible and appears to have deposited

Figure 11 -- Riverside on Mad River near Blue Lake. View toward the west from Riverside before 1890 meander cutoff (taken between 1883 and 1890) at the confluence of the Mad River with the North Fork. Mad River flows from left to right. (Photo courtesy of Don Tuttle, Humboldt County Public Works Collection, Natural Resources Dept.).

sediment into the active channel of the main fork. The watershed of the North Fork was being logged at this time, providing the source of this sediment.

Between 1898 and 1921 the channel widened from 480 feet (150 m) to 1,370 feet (420 m). A series of floods (Appendix E) coupled with intensive logging in the watershed in the early 1900's may have contributed to widening of the channel. This period was followed by a relatively dry period through the 1920's and 1930's (Appendix E). The North Fork overflowed its channel as late as 1932 ("Freak Storm Over Weekend Hits County", *Blue Lake Advocate,* January 2, 1932). The following summer a small dam was bulldozed across the North Fork channel, which created a swimming pool 200 yards (183 m) long by up to 60 yards (55 m) wide, 5 to 12 feet (1.5 to 3.7 m) deep (Splendid New Pool Opened At Blue Lake", *Blue Lake Advocate,* July 9, 1932). The channel was manipulated by summer pool construction until at least 1960. During drier conditions between 1921 and 1941/42 (Appendix E) the main channel's width decreased from approximately 1,370 feet (418 m) to approximately 580 feet (175 m). Channel width decreased further to 460 feet (140 m) by 1948 following impoundment in 1938 of mostly coarse sediment behind Sweasey Dam.

A "low-level" bridge constructed between 1941/42 and 1948 between West End Road and the present Hatchery Road bridge (near Potter's Organic Farm) acted as a velocity barrier, which created a zone of deposition on its upstream side:

> "The low level bridge did more than accommodate the public going across. It slowed the flow of the Mad River and banked the gravel up against the bridge which formed a gravel bar up from the bridge about 1,000 feet. Today the Mad River parallels

the West End Road and enters the north fork." (Lindstrum, L., 1971).

After construction of the bridge the channel migrated toward the right bank and was eventually captured by the North Fork. The bar that built up is now the site of the Emmerson bar (figure 10).

Aerial Survey Period

Air Photo Observations

Detailed notes of air photo observations are given in Appendix H. Air photos taken between 1941/42 and 1992 show bank erosion (summarized in table 7 below) and the following significant channel changes:

1. 1941/42 - 1948: Meander growth occurred. The low-water channel lengthened. Mining was visible in 3 pits on Emmerson bar. Three abandoned channels were observed between Mad River and North Fork at approximately RM 8.3 to RM 8.8.

2. 1948-1954: Meander growth and migration occurred, eroding the left bank at approximately RM 9.7 and the right bank at approximately RM 9.0. The revetment was constructed by 1954.

3. 1954-1958: Approximately 2,000 feet (610 m) of riparian vegetation was cleared along the revetment. The channel straightened below the Hatchery until it made a 90 degree left (west) turn toward the county bridge. Right bank erosion was observed as the meander migrated toward the North Fork.

4. 1958-1962: The main stem of the Mad River was captured by the North Fork (see also Lindstrum, 1971). The position of the confluence of the two streams moved approximately 3,000 feet (910 m) to the east. The river appeared to flow into an overflow channel visible in the 1948 air photos. Bar skimming was observed on the upper Simpson bar. A swimming hole was excavated by the National Guard in the abandoned channel near West End road in the 1962 air photos.

5. 1962-1966: Active channel width was approximately 2,000 feet (610 m) in 1966 (the channel occupied part of the floodplain during the 1964 flood). Gravel extraction began in 1962 at Guynup bar (confirmed by Vic Guynup, pers. comm., 1994).

Approximately 500 feet (150 m) of riparian vegetation was cleared along the revetment by 1966. The channel migrated toward Simpson property and the skimmed area described above. The floodplain between Simpson property and the North Fork was scoured of some of its vegetation and appears to show a deposit of finer grained material. The landscape has preserved small overflow channels, evidence of flooding.

5. 1966-1970: Terrace along the right bank at RM 9.7 and the adjacent active channel were being extensively mined. Highway 299 was being widened east of Blue Lake. The channel narrowed as vegetation encroached onto bars not being mined. Riparian vegetation was removed at the site of the Mad River Fish Hatchery during its construction.

6. 1970-1974: The channel was braided between approximately RM 9.5 and RM 8.9 (Guynup to Emmerson). Bar skimming occurred along that section. The left bank at the Hatchery at RM 10.3 was protected with rip rap in 1971 (confirmed by Roy Camozzi, pers. comm., 1994, Appendix D). The channel has migrated eastward at RM 9.9.

7. 1974-1981: Removal of riparian vegetation along the right bank opposite the Hatchery. The 1974 photos show a pit below water surface level along the right bank at approximately RM 9.7 (Guynup bar). By 1981 riparian vegetation had grown into the pit. The channel was braided in 1981. A portion of flow occupied a trench formed by mining operations (confirmed by Vic Guynup, pers. comm., 1994). Downstream, approximately 10-20 acres (41,000 - 81,000 m^2) of riparian vegetation was cleared in the old channel at Potter's organic farm on West End road. By 1981 the channel reformed into a single-thread upstream of the confluence with the North Fork. Riparian vegetation had begun to encroach onto the bar along the right bank upstream of confluence.

8. 1981-1988: The river occupied a single channel through the reach. Meander growth continued as left bank erosion occurred at approximately RM 9.0 (Emmerson bar). I saw evidence of continued mining activity and water diversion toward a pond along the left bank at approximately RM 9.6 (Guynup bar) in the 1988 photos. Small medial bars were observed in the 1988 photos.

9. 1988-1992: Meander growth continued. The water diversion continued toward the pond described above (field observations and discussion with the landowner indicate diversion has since ceased). A beaver pond exists at the site today.

Changes in Channel Length, Width, and Area

Table 6 summarizes active channel centerline length, width, and area measurements. Largest width and area values generally correspond to flooding and mining impacts on the channel. The centerline length correspondingly decreases with increasing width and area as the channel straightened in response to natural and human-induced impacts.

Bank Erosion

Bank erosion measurements for Guynup bar and Emmerson bar show that the highest erosion rates correspond to channel widening following flooding (table 7). Sediment supply into the reach significantly increased, aggrading the channel. The impacts of sediment input into the reach from Sweasey Dam were not as significant as flooding and perhaps mechanical manipulations of the channel by gravel extraction. Active channel width decreased between 1966 and 1981 by a factor of 2.1 (table 6).

"Bank beavers" have removed of an unknown quantity of riparian vegetation and may have contributed to bank erosion by decreasing bank cohesion (Leslie Christopherson, pers. comm., 1994, Appendix D). Root wads have delivered and unknown amount of material into the stream channel. Beavers continue to inhabit the reach today.

Bank erosion continues to date. The January 1995 flood (approximately 35,000 cfs at Arcata) caused approximately 100 to 150 feet (30 to 46 m) of right bank retreat at Guynup bar and 1 acre (4,000 m^2) was eroded along the left bank just downstream (Vic Guynup, pers. comm., 1995).

Table 7 – Bank erosion/bar accretion, Hatchery to Blue Lake bridge, lower Mad River, 1941-42 to 1992

Guynup Bar

Time Period	Length (ft)	Ave. Width (ft)	Area (acres)	E/A†	Rates†† (ft/yr)	Notes
1942 to 48	--	--	--	--	--	no change
1948 to 54	1,830	350	15	A	58	RB erosion
1954-58	2,200	320	16	E	80	LB erosion
1958-62	--	--	--	--	--	no change
1962-66	2,000	350	16	A	88	RB erosion
1966-70	3,100	430	31	E	108	LB erosion
1970-74	2,700	390	24	A	98	RB erosion
1974-81	1,400	170	5	E	24	upstream
	1,400	170	5	A	24	downstream
1981-88	2,700	310	19	A	44	RB erosion
	3,300	500	38	E	71	LB erosion
1988-92	2,100	230	11	A	58	RB erosion

E/A† = Net erosion (E) vs. accretion (A); in some instances, bars may decrease in size due to encroachment of vegetation
Rates†† = mean rate of bank erosion or bar accretion
Note: Table reports mean values along Guynup bar between River Mile 10.0 and 9.2. Estimates depend on the scale and resolution of aerial photographs.

Table 7 (cont.) – Bank erosion/bar accretion, Hatchery to Blue Lake bridge, lower Mad River, 1941-42 to 1992

Emerson Bar

Time Period	Length (ft)	Ave. Width (ft)	Area (acres)	E/A†	Rates†† (ft/yr)	Notes
1942 to 48	2,600	500	16	E	83	LB erosion
1948 to 54	2,300	670	28	A	112	RB erosion
1954-58	1,600	520	14	E	130	upper bar
	3,000	670	29	A	168	lower bar
1958-62	--	--	--	--	--	avulsion
1962-66	--	--	--	--	--	no change
1966-70	1,800	325	12	E	81	LB erosion
1970-74	1,700	260	6	E	65	braided
	1,400	325	7	E	81	braided
1974-81	2,200	660	31	E	94	LB erosion
1981-88		790*	26	A	113*	RB erosion
1988-92		600*	12	A	150*	RB erosion

E/A† = Net erosion (E) vs. accretion (A); in some instances, bars may decrease in size due to encroachment of vegetation
Rates†† = mean rate of bank erosion or bar accretion
* no change in low water channel position
Note: Table reports mean values along Emerson bar between River Mile 9.2 and 8.9. Estimates depend on the scale and resolution of aerial photographs.

Medial Bar Measurements

Table 8 shows medial bar measurements from 1941/42 to 1992. The number of bars reached a maximum in 1970 and 1974 following the 1964 flood and blasting of Sweasey Dam in 1970.

Analysis of Geomorphic Variables

Table 9 reports mean geomorphic variables measured on aerial photographs between 1941/42 and 1992. Meander growth occurred between 1942 and 1958, then flooding and gravel extraction straightened the channel. The channel shows a general stabilizing trend after 1981.

Sinuosity Changes

Figure 12 reports sinuosity between 1855 and 1992 (see also Appendix M). The 1865 map was inaccurate and data for that year should be ignored. Accuracy for the other early maps is questionable, but gives an indication of the general decrease in sinuosity to 1948. The valley length was shorter than the low water channel length between 1921 and 1954, before stream capture by the North Fork. Sinuosity generally continues to increase to date following avulsion, from 1.00 to 1.18 today. This is consistent with meander changes documented above.

Volume of Bed Erosion

Using mean lowering rates at each end of the reach (from Lehre, 1993) and active channel areas digitized from air photos, I estimated a

Table 8 -- Medial bar measurements (feet), Hatchery to Blue Lake bridge, 1941-42 to 1992

Year	Location	Length	Width	L/W Ratio	Mean for Each Year	Number of Bars Observed
1941-42	Hatchery to BL	950	180	5.3	5.3	1
1948	Hatchery to BL	930	190	4.9	4.9	1
1954	--	--	--	--	--	0
1958	--	--	--	--	--	0
1962	--	--	--	--	--	0
1966	abv Blue Lake br.	650	110	5.9	5.9	1
1970	big bar @ Hatchery	1,300	320	4.1	5.8	4
	sm bar @ Hatchery	590	130	4.5		
	lower Guynup bar	500	60	8.3		
	lower Guynup bar	370	60	6.2		
1974	blw Hatchery	700	90	7.8		3
	lower Guynup	790	130	6.1		
	US of Blue Lake br	1,880	250	7.5	7.5	
1981	Guynup bar	1,550	280	5.4	5.4	1
1988	upper Guynup	280	70	4.0	4.0	1
1992	just DS of Hatchery	1,440	220	6.5	5.5	2
	Guynup bar	680	150	4.5		
	mean =	900	160	5.8	Total =	14

Table 9 – Geomorphic variables (feet), Hatchery to Blue Lake bridge, lower Mad River, 1941-42 to 1992

Year	Number of Meanders	Wavelength	Amplitude	Radius of Curvature
1941-42	2	4,340	390	420
1948	2	3,210	350	260
1954	2	3,710	600	400
1958	1	3,140	950	580
1962	0	--	--	--
1966	2	3,140	310	310
1970	2	3,090	330	250
1974	1	3,460	400	380
1981	2	3,150	360	290
1988	1	4,830	700	570
1992	1	4,940	740	620
Mean	1.5	3,700	510	410

Note: Table reports mean values in the Hatchery to Blue Lake bridge reach between River Mile 10.3 and 8.7. Estimates depend on the scale and resolution of aerial photographs.

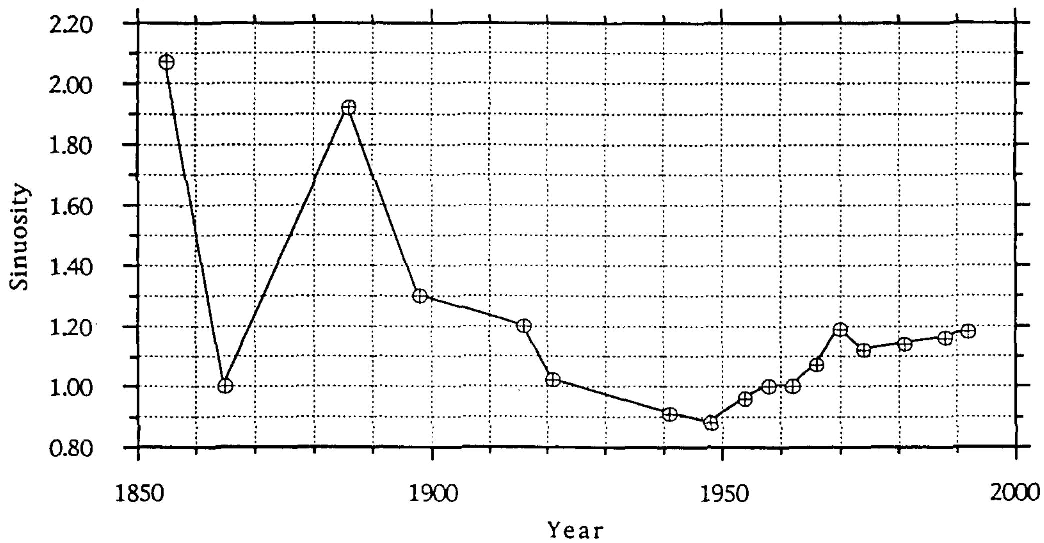


Figure 12 -- Sinuosity, Hatchery to Blue Lake bridge, lower Mad River, 1855 to 1992

minimum of 1,240,000 yd^3 (948,000 m^3) of material was removed from storage between 1962 and 1992. Spread evenly over the active channel, the bed lowered approximately 5.4 feet (1.6 m) between 1962 and 1992. The volume of material removed can be attributed to gravel extraction in excess of natural recruitment (Lehre and others, 1993).

d) Summary of Historic Conditions of the Hatchery to Blue Lake bridge Reach

Evaluation of available data shows some important trends. Hydrologic factors influencing channel morphology include flooding (1861-62, 1890, 1953, 1955, and 1964), relative drought between 1911 and 1940, and impoundment of water and sediment behind Sweasey Dam between 1938 and 1970.

Geomorphic changes include: 1) channel widening following land use changes in the late 1800's; 2) an avulsion during the 1890 flood that shortened the channel by approximately 4,700 feet (1,430 m); 3) an increase in active channel area of approximately 16 acres/year between 1948 and 1966 as the channel widened dramatically after the 1953, 1955, and 1964 floods; 4) an avulsion in 1962 in which the confluence with the North Fork moved approximately 3,000 feet (910 m) upstream; 5) a gradual decrease in active channel area of approximately 10 acres/year between 1966 and 1992 as the river was confined by trenching and vegetation encroachment onto unmined bars; 6) a multiple-thread pattern in 1970 and 1974 following increased sediment input from upstream; 7) greatest bank erosion rates between 1966 and 1970 on Guynup bar (108 ft/yr or 33 m/yr along the right bank) and between 1954 and 1958 on Emmerson bar (130 ft/yr or 40 m/yr along the left bank); 8) meander growth and increase in sinuosity between 1962 and 1970, channel straightening and braiding during the early 1970's, then meander growth and increase in sinuosity again between 1974 and 1992; 9) narrowing of the riparian corridor by approximately 6 acres/year between 1948 and 1992 due to floodplain reclamation; and 10) mean bed degradation of approximately 3 feet (1 m) along the reach between 1960 and 1992.

In addition, the following reconstruction describes the cycles of erosion and deposition as accurately as can be done with the data available: 1) aggradation between 1875 and 1890; 2) degradation following the 1890 flood; 3) aggradation between approximately 1900 and 1938; 4) degradation between 1938 and approximately 1964; 5) aggradation between 1964 and 1975; 6) degradation between approximately 1976 and 1992. Over the last 7 years lowering rates may have been as high as 0.57 to 0.86 ft/yr (0.17 to 0.26 m/yr). Approximately 1,240,000 yd^3 (948,000 m^3) of material was removed from storage between 1962 and 1992.

3. Blue Lake Bridge to A&MRR Bridge

a) Reach Description

The reach between the Blue Lake bridge and the A&MRR bridge is an alluvial channel constrained artificially in places (figures 7 and 8). The reach extends approximately 2.7 miles (4.3 km) from River Mile (RM) 8.7 to RM 6.0 (figure 13). The channel has undergone cycles of erosion and deposition during different periods of its history. Klein (Lehre and others, 1993) stated "the combination of a gentler gradient and broad alluvial valley favors deposition" between the Hatchery and the A&MRR bridge indicating a sediment storage zone. The channel bed configuration has consisted of alternate bars, point bars, and medial bars and has shown both a meandering and braided character. Terrace deposits along the reach typically erode at higher flows. Riprap used along both banks confines the channel in places.

b) Land Use History Summary

According to the Weekly Humboldt Times, the redwoods in the Blue Lake valley area were "dense" and "a sight to behold" (*Weekly Humboldt Times*, December 14, 1878, "Our Railroad Interests") suggesting that some of the largest old growth timber in the region existed here before the 1870's. The Democratic Standard reported that above the 299 bridge:

> "The next sixteen miles up the river on the south side is redwood timber, with the exception of a few small farms. The belt extends to the tops of the ridges, which on an average are about four miles, making about sixty-four square miles of redwood timber yet to be rolled into Mad river from the south . . . " (*Democratic Standard*, January 19, 1878).

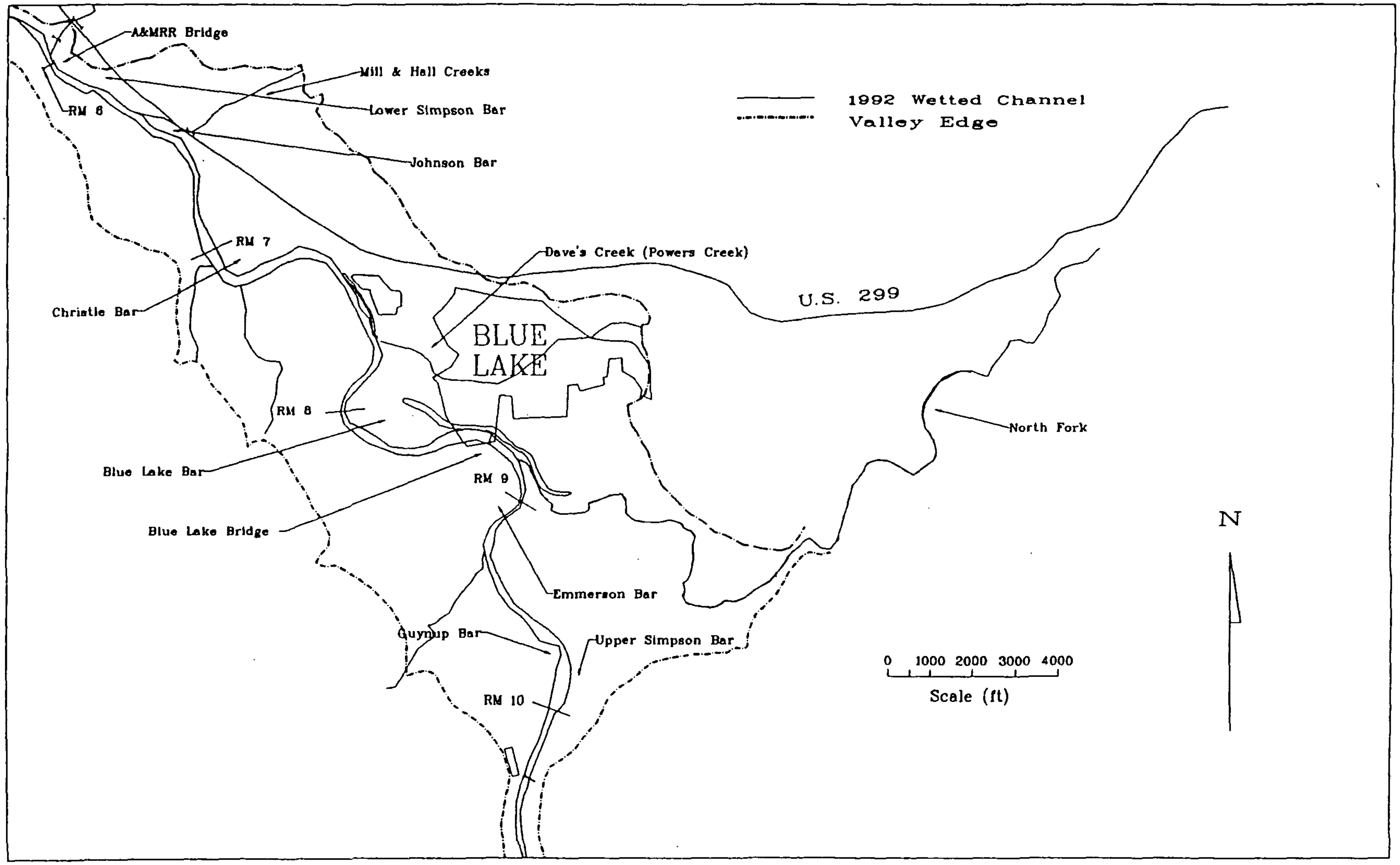


Figure 13 -- Blue Lake Bridge to A&MRR Bridge reach, lower Mad River

The same article described the north side of the river similarly and noted it was already being logged.

In the Blue Lake valley, land use changes accelerated after two technological advances: 1) construction of the boom and canal project in the 1870's (*Arcata Union*, August 14, 1886, "Mad River Canal - Shut It Up"); followed within approximately ten years by 2) railroading and the introduction of steam powered machinery into the forests (Borden, 1954). As logging claims increased in the 1870's, the rate of land use change increased. Timber was piled onto landings along the river, then floated downstream during high water to the Mad River Canal. Portions of the floodplain and riparian zone were converted to pasture and farmland:

> "The McCahan ranch extended on both sides of Mad River in 1870, and there was no road from West End to Blue Lake passing through it. The river itself was much farther south than it is now. The sandy wastes of the present wide river bed were then the fertile farm lands belonging to Daniel and the Mahans [sic] and other early settlers along the river. Several successive freshets around 1890 forced Mr. McCahan to move his home." ("The Story of Blue Lake . . . ", *Blue Lake Advocate*, June 16,1955, by Mrs. Eugene F. Fountain, Historian).

By clearing riparian vegetation from the floodplain roughness elements were removed and the river's mean velocity increased, allowing it to more readily scour its bed and erode its banks.

This account in the Blue Lake Advocate referenced an earlier article published in the Humboldt Times (April 13, 1883) by Albert Etter, a naturalist and founder of the Ettersburg Experiment Station:

> "As to what can be done about the flood problem in Eel River valley, the bars along the river should be purchased and held as state property and planted to willows, alder, etc., to cause the bars to be built up by sand and gravel and thus retard the overflow and increase the volume of water in the channel. The increase in volume would create that additional current necessary to float the debris on down the river and out to sea.

> Any pocket where brush and small trees deaden the current causes the sediment to settle and build up. Much could be done to good advantage by systematic planting to cause the sediment to settle and build up the land, where under present conditions of open road, the current is too great and only sand and gravel are deposited when fine silt could be had.
>
> "Whether our native species of willow are best or some other exotic species, at any rate willows have been a great factor in shaping stream courses." ("The Story of Blue Lake . . . Reports on The Storm [of 1881], A Real Disaster", *Blue Lake Advocate*, Thursday, April 4, 1957, by Mrs. Eugene F. Fountain, Historian)

This strategy was not used along the Mad River. The account implies that regional land use changes described above contributed to increased flood hazard due to a decrease in channel capacity. With an increase in sediment production and a change in flow regime to "flashier" conditions, I assume the width to depth ratio increased and channel aggradation began to occur.

Logging moved upstream in the early 1880's toward Blue Lake, Korbel, and Riverside following purchase of the A&MRR by the Korbel brothers in 1882-83 (*Weekly Times Telephone*, March 24, 1882, April 14, 1882, January 6, 1883). By the mid 1880's the Arcata & Mad River Railroad carried a large volume of freight which reflected the increase in agricultural and lumber exports from the area (*Weekly Times-Telephone*, January 9, 1886). This increase in logging and agriculture disturbed the landscape significantly and increased the sediment available for transport into the channel of the river. An article in the Blue Lake Advocate indicated a minimum rate of landclearing near West End in 1936 : "The plaintiffs asked . . . $125 for failing to keep an agreement to clear at least three acres a year . . . " ("Sues To Recover West End Ranch", *Blue Lake Advocate,* March 14, 1936).

Gravel extraction on a small scale probably occurred prior to the 1940's, but large-scale operations began in the 1950's and 1960's. Extraction rates on the river reached a peak around 1970 (Lehre and others, 1993). Gravel extraction continues along the channel.

c) Historic Geomorphic Conditions of the Blue Lake Bridge to A&MRR Bridge Reach

Pre-Aerial Survey Period

The first surveys in the valley were completed by William J. Lewis, U.S. Deputy Land Surveyor, in 1858 (Lewis, 1858), followed by Solomon Foreman, U.S. Deputy Land Surveyor, in 1874 (Foreman, 1874). Comparison of historic maps shows longitudinal or medial bar changes between 1855 and 1933 from Blue Lake bridge to the A&MRR bridge (table 10). Medial bar formation in the Blue Lake valley followed: 1) the largest magnitude flooding of the period in 1861-62 and 1890; and 2) increased sediment production during the late 1800's to early 1900's (table 10). Assuming medial bar formation is a function of increased sediment input into the reach, it took the river approximately 15 to 25 years to recover from the effects of bed aggradation.

Examination of historic newspaper accounts suggests river channel changes have been caused by a combination of: 1) human induced land use changes, such as logging, agriculture, and gravel extraction; and 2) natural flooding events. The Weekly Humboldt Times reported:

> "there are about 700,000 feet of lumber in the river . . . [with] 800,000 feet cut and peeled and ready to be thrown into the river. After the logs are thrown into the river they will have to be floated about six and a half miles to the mouth of the

Table 10 -- Medial bars observed on historic maps between the Blue Lake bridge and the A&MRR bridge, 1855 to 1933

Year	River Mile Location	Size (acres)
1855	--	--
1865	7.7	4
1886	--	--
1898	7.9	2
	7.7	7
	6.5	9
1916	6.7	2
	6.6	20
	6.3	9
1921	--	--
1933	--	--

canal which leads from the river into the bay." (*Weekly Humboldt Times*, July 4, 1874).

The banks below Blue Lake were destabilized by the removal of riparian vegetation and the floating of large timber along the channel, then eroded during a wet period that began in 1890 and continued through 1910 (15 out of 21 years had above average precipitation, Appendix E) (Haynes, 1986). Landowners having to contend with bank erosion commonly used individual management practices along the reach. Several articles reported channel improvements and bank stabilization projects undertaken by local farmers between Blue Lake and the A&MRR bridge from the 1910's through the 1930's:

> "John Kane of West End is busy hauling timber from Blue Lake to his ranch there, which will be used in building boxes along the river bank to protect his land from the river encroachment in winter time. He expects to build twenty 16-foot boxes this summer, making about 175 boxes in all since he began protecting his land from the river." ("To Protect His Land From River", *Blue Lake Advocate*, July 5, 1919).

> "In order to protect their rich bottom land in West End from the ravages of high water during the winter time, Mssrs. John J. McCahan, John Kane and Mrs. Mel Robert who own land along the west bank of Mad River, are now engaged in building a line of boxes along their respective ranches, about 200 feet in all. Along the banks some brush is being put down first then wooden boxes measuring from 12 to 18 feet long and 4 ft. wide, which are filled with rocks and gravel. The boxes are fastened to the banks by means of a heavy wire cable. This is considered one of the most efficient breakwaters to be used along the river. [cost c. $1500-2000]" ("Building A Breakwater Along River", *Blue Lake Advocate*, September 3, 1927)

The following article was the first I found that mentioned the use of heavy equipment in the channel to combat chronic bank erosion:

> "The work on the breakwater on the West End side of Mad River across from Blue Lake was started Monday with a crew of fifteen men. A scraper and bulldozer are being used. Brush and willows with big rocks, which are being hauled from the hillside near Glendale are being used for the breakwater. . . .

> Every year valuable land is being washed away and it is expected that the breakwater will prevent further damage." ("Building Breakwater Near Blue Lake", *Blue Lake Advocate*, November 25, 1930)

The Army Corps of Engineers was reported to have used "bulldozers and scrapers" in 1938 to remove "drift, willow and other growths and gravel bars with a view to straightening the channels as much as possible . . . from the Mad river bridge up as far as West End" ("River Channel Funds Ready; State and County Asked To Help $22,000 Program Of Federal Improvements", *Blue Lake Advocate*, June 14, 1938). Interviews with long-time residents indicate that the channel was confined to a single thread with pools and riffles in the 1930's and 1940's and generally had a more extensive riparian vegetation zone (Busman, pers. comm., 1994; Christie, pers. comm., 1994; Christopherson, pers. comm., 1994; Evans, pers. comm., 1994; Patenaude, pers. comm., 1994; Reid, pers. comm., 1994; Appendix D).

Aerial Survey Period

By 1947 the river meandered through Blue Lake valley exhibiting a more stable, single-thread pattern (figure 14). Well developed point bars and cut banks are observed in the photo. The bars are vegetated and pool/riffle sequences are undisturbed. Attempts to protect the right bank from erosion are also evident. Old car bodies filled with gravel, sluice boxes filled with dirt/gravel, and railroad ties driven into the bed and banks to form wing dams ultimately proved futile (Christie, pers. comm., 1994).

Figure 14 -- View is northwest over Blue Lake valley, lower Mad River, July 12, 1947. Blue Lake bar is at the bottom center of the photo. Christie bar is along the right bank, just downstream of the wing dams. (Photo by Merle Shuster, courtesy of Don Tuttle, Humboldt County Public Works Collection, Natural Resources Dept.).

Air Photo Observations

Comparison of sequential air photos between 1941/42 and 1992 shows significant channel changes. Detailed notes of air photo observations are given in Appendix H. Some of the more important changes are listed here:

1. 1941/42 - 1948: Gravel extraction dates back to at least 1941/42 on Johnson bar. The river shows two strands at Blue Lake bar. Meander growth observed downstream of Christie bar.

2. 1948-1954: A meander cutoff opposite Christie bar occurred between 1942 and 1954 as an artificial channel was apparently trenched by farmers to save agricultural land by preventing bank erosion. The channel was shortened by approximately 1000 feet (300 m), steepening the hydraulic gradient. Construction of the revetment along the right bank by the Corps of Engineers (COE) is seen by 1954 and confines the channel along the right bank for approximately 4,000 feet (1,200 m) below the Blue Lake bridge.

3. 1954-1958: Significant bank erosion and channel widening occurred along most of the reach between 1954 and 1958.

4. 1958-1962: The confluence with the North Fork moved upstream approximately 3,000 feet (900 m) between 1958 and 1962. Extensive mechanical manipulation of the channel is observed in the 1962 photos due to gravel extraction. In-stream sediment berms and pits are evident.

5. 1962-1966: Highway 299 was completed by 1966 and partially confined the channel near Christie bar during the 1964 flood. Extensive mining on Blue Lake and Christie bars in 1966. Blue Lake bar was reworked by the 1966 flood. Significant bank erosion and channel widening along most of the reach occurred between 1962 and 1966. Channel pattern is braided. Riparian vegetation area has decreased.

6. 1966-1970: Left bank erosion and meander growth occurred downstream of the Hatchery Road bridge. Right bank erosion occurred toward Blue Lake bar and the sewage treatment ponds. Some channel widening occurred near the sewage treatment ponds (to southwest); loss of riparian vegetation and right bank erosion is seen toward the ponds. The channel is braided downstream of the ponds. Bank erosion occurred along Leavey's; riparian vegetation and farmland were eroded. The active channel is still mostly devoid of riparian vegetation due to the 1964 flood. Extensive mining and mechanical manipulations are observed on Christie bar; equipment is visible. Some pits are visible near the channel. Mining appears

less extensive on Christie bar by 1970. Gravel was stockpiled on the bar. The channel shows left bank erosion above the A&MRR bridge.

7. 1970-1974: Extensive mining on Blue Lake, Christie, and Johnson/Lower Simpson bars in 1970 and 1974. Channel pattern remains braided. Blue Lake bar growth continues in 1974. COE constructed a revetment in 1974 confining the channel along the right bank for approximately 1,700 feet (520 m) to protect the Blue Lake sewage treatment ponds. Three trenches are seen diverting the flow away from the construction site.

8. 1974-1981: By 1981 the channel shows a meandering pattern along most of the reach. Riparian vegetation is beginning to fill in on unmined portions of bars along the reach. Extensive mining on Johnson bar is observed in 1974 and 1981.

9. 1981-1988: Meander growth is occurring by 1988; bank erosion observed; some braiding along the outer edge of mined point bars.

10. 1988-1992: Gravel extraction (trenching, skimming) continues to be observed in 1992; some braiding along noses of mined bars; meander growth continues upstream of Christie bar; channel has straightened slightly downstream of Christie bar.

Changes in Channel Length, Width, and Area

Table 11 shows several trends in channel planform measurements between 1855 and 1992. Changes in width, area, and length between 1855 and 1941/42 are consistent with flood timing and erosion cycles described above. After 1941/42 width and area show gradual increases until 1974 as the river adjusted to:

1) an increase in sediment input following tractor logging during the 1940's, 1950's and 1960's;

2) flooding in 1953, 1955, and 1964;

3) release of sediment by the blasting of Sweasey Dam; and

4) gravel extraction rates exceeding natural recruitment rates.

Table 11 -- Active channel centerline length, width, and area measurements, Blue Lake bridge to A&MRR bridge, 1941-42 to 1992†

Year	Centerline length (ft)	Width (ft)	Area (acres)
1855††	14,700	920	310
1865††	14,400	550	182
1886††	14,500	660	220
1898††	15,500	940	335
1916††	16,900	490	190
1921††	15,200	1,530	534
1933*	N/A	N/A	N/A
1941-42	16,900	560	217
1948	17,000	750	293
1954	15,900	1,010	369
1958	15,800	1,450	526
1962	14,500	1,400	466
1966	15,300	1,510	530
1970	14,400	1,530	506
1974	14,500	1,660	553
1981	14,800	1,260	428
1988	15,600	1,060	380
1992	16,500	680	258

† see also Appendices I, J, and K for a comprehensive list of all reaches

†† = map accuracy is questionable

* = map only covers the lower portion of the reach

N/A = Not Available

Note: estimates depend on scale and resolution of photos

A gradual decrease in width and area is observed to 1992. Centerline lengths gradually decreased until 1970 and have increased gradually since then, reflective of the river's return to a meandering pattern.

Medial Bar Measurements

Table 12 shows medial bar measurements between the Blue Lake bridge and the A&MRR bridge. The number of bars ranged from zero to eight, with the eight appearing in 1970, consistent with observations of braiding following flooding in 1964 and extensive mechanical manipulations of the channel corresponding with a peak in gravel extraction rates in 1970 (figure 15).

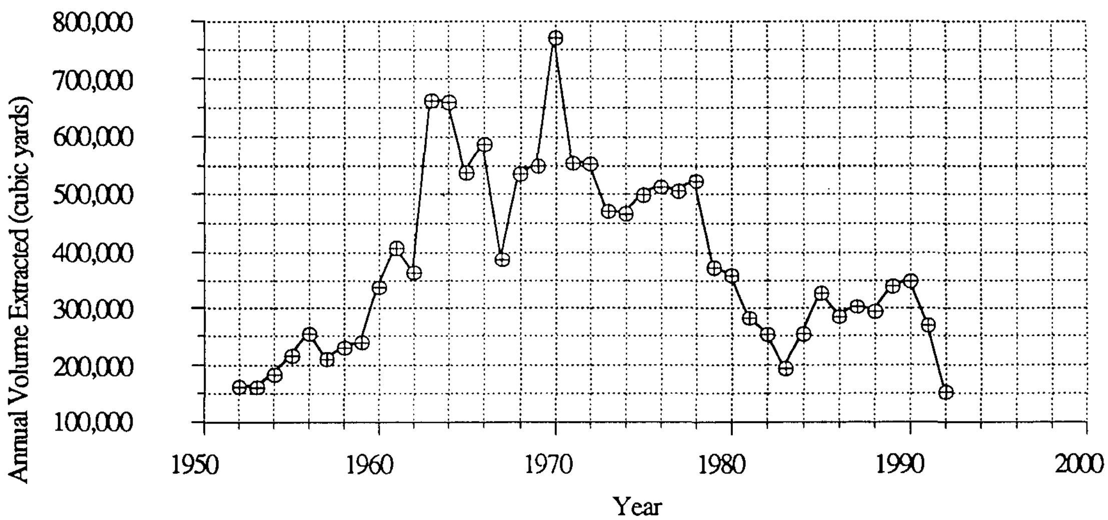
Analysis of Geomorphic Variables

Table 13 compares mean geomorphic variables for the Blue Lake bridge to A&MRR bridge reach between 1941/42 and 1992 (see also Appendix N). The number of meanders decreased along the reach through 1974, then increased through the 1980's. The channel straightened above the A&MRR bridge between 1988 and 1992, eliminating the last meander along the reach. Two smaller meanders in the 1988 channel formed into one larger one by 1992 as the wavelength, amplitude, and low-water channel lengthened. Table 14 compares mean geomorphic variables for the Hatchery to Blue Lake and Blue Lake to A&MRR bridge reaches. Meanders between the Blue Lake and A&MRR bridges are generally longer and have a larger amplitude and radius of curvature than meanders between the Hatchery and the Blue Lake bridge. Meander growth over the past 20 years generally reflects the lack of flooding and mining impacts which reached a

Table 12 -- Medial bar measurements (feet) between Blue Lake and A&MRR, 1941-42 to 1992

Year	Location	Length	Width	L/W Ratio	Mean L/W Ratio for Each Year†	Number of Bars Observed
1941-42	bet BL & A&MRR	1,510	503	3.0	3.4	3
	bet BL & A&MRR	897	202	4.4		
	bet BL & A&MRR	552	193	2.9		
1948	bet BL & A&MRR	818	332	2.5	3.6	3
	bet BL & A&MRR	724	130	5.6		
	bet BL & A&MRR	1,650	615	2.7		
1954	abv A&MRR	1,122	537	2.1	2.1	1
1958	blw N. Fork	595	92	6.5	6.5	1
1962	--	--	--	--	--	0
1966	DS of Blue Lake revet.	680	84	8.1	8.1	1
1970	DS of BL br	764	127	6.0	4.7	8
	DS of BL br	280	127	2.2		
	DS of BL br	663	91	7.3		
	DS of BL br	500	61	8.2		
	bet BL & A&MRR	5,939	1,327	4.5		
	bet BL & A&MRR	3,662	878	4.2		
	bet BL & A&MRR	245	95	2.6		
	bet BL & A&MRR	697	287	2.4		
1974*	DS of BL br	1,464	412	3.6	3.6	1
1981*	US of A&MRR br	937	354	2.6	2.6	1
1988	DS of BL br	1,713	439	3.9	4.6	2
	US of A&MRR br	2,166	417	5.2		
1992	--	--	--	--	--	0
	Mean =	1,091	268	4.6	Total =	74

* = incomplete data above Hatchery
† = reach mean; compare to Appendix P for lower Mad River mean



Note: Bedload transport rate estimates range from approximately 108,000 to 161,000 yd^3/yr (83,000 to 123,000 m^3/yr)

Figure 15 -- Estimates of annual gravel extraction volumes (yd^3) from the lower Mad River, 1952-1992 (from Lehre and others, 1993)

Table 13 -- Mean geomorphic variables (ft), Blue Lake bridge to A&MRR bridge, 1941-42 to 1992

Year	Number of Meanders	Wavelength	Amplitude	Radius of Curvature
1941-42	5	2,500	380	380†
1948	4	3,200	720	460
1954	5	2,700	410	300
1958	3	3,900	710	560
1962	2	3,500	670	630†
1966	2	3,800	470	540
1970	2	4,200	800	660
1974	2	5,500	940	630
1981	4	3,600	690	460†
1988	4*	3,700	690	580
1992	3	5,200	800	820†
Mean	3.3	3,800	660	550

† = estimated based on data available
* = some braiding
Note: Table reports mean values in the Blue Lake valley reach between River Mile 8.7 and 6.0. Estimates depend on the scale and resolution of aerial photographs.

Table 14 -- Comparison of mean geomorphic variables for the Hatchery to Blue Lake bridge and Blue Lake bridge to A&MRR bridge reaches

Reach	Number of Meanders	Wavelength (ft)	Amplitude (ft)	Radius of Curvature (ft)
Hatchery to Blue Lake bridge	1.5	3,700	510	410
Blue Lake bridge to A&MRR bridge	3.3	3,800	660	550
Hatchery to A&MRR bridge	4.6	3,730	570	470

† = estimated with available data

maximum between the late 1950's and early 1970's and presumably signifies a return to a more stable configuration.

Bank Erosion

Bank erosion and bar accretion rates are shown in table 15 for bars between Blue Lake bridge and the A&MRR bridge. The largest rates correspond to periods following large magnitude flooding (1953, 1955, and 1964). I show mean values for each period, though the majority of bank erosion likely occurred discretely during floods. Two landowners along the river noted that bank erosion predominantly occurred on the recession of flood peaks as the wetted banks collapsed. Jim Leavey thought the vegetation protecting the banks was scoured by the peak flows; the banks typically retreated after the peaks had passed (pers. comm., 1994; Appendix D). Leslie Christopherson noticed that in most cases when big "chunks of dirt" would fall into the river there was a wet gravel layer overlain by finer silty material. He thought longer duration floods did the most damage to banks (pers. comm., 1994; Appendix D). This style of erosion is consistent with observations by Ricks along Redwood Creek and can be related to high pore pressures in the banks as the stage drops (1985). Figure 16 shows lateral changes between 1948, 1958, and 1992 for the wetted channel between the Hatchery and the A&MRR bridge.

Sinuosity Changes

Figure 17 reports sinuosity between 1855 and 1992 (see also Appendix M). Accuracy of early maps is questionable, but gives an indication of the general decrease in sinuosity to 1948. The valley length was shorter than

Table 15 -- Bank erosion/bar accretion, Blue Lake bridge to A&MRR bridge, lower Mad River, 1941-42 to 1992

Blue Lake Bar

Time Period	Length (ft)	Ave. Width (ft)	Area (acres)	E/A†	Rates†† (ft/yr)	Notes
1942 to 48	2600	500	23	A	83	
1948 to 54	--	--	--	--	--	no change
1954-58	2,900	1,100	43	E	276	RB erosion
1958-62	3,800	580	50	A	144	LB erosion
1962-66	2,200	760	29	E	189	RB erosion
1966-70	2,700	200	12	A	50	LB erosion
1970-74	2,900	310	14	A	78	LB erosion
1974-81	2,400	100	6	A	14	LB erosion
1981-88	--	--	--	--	--	no change
1988-92	--	--	--	--	--	braided

E/A† = erosion (E) vs. accretion (A)
Rates†† = mean rate of bank erosion or bar accretion
* no change in low water channel position
Note: Table reports mean values along Blue Lake bar between River Mile 8.6 and 7.8. Estimates depend on the scale and resolution of aerial photographs.

Christie Bar

Time Period	Length (ft)	Ave. Width (ft)	Area (acres)	E/A†	Rates†† (ft/yr)	Notes
1942 to 48	3,500	250	14	A	42	LB erosion
1948 to 54	1,700	800	49	A	134	LB erosion
1954-58	3,400	1,160	58	E	290	upper bar
	2,800	620	36	A	154	lower bar
1958-62	6,600	620	63	A	155	LB erosion
1962-66	--	--	--	--	--	braided
1966-70	--	--	--	--	--	braided
1970-74	4,500	1,360	100	E	340	RB erosion
1974-81	1,600	140	5	A	20	upstream
	1,900	200	9	E	29	downstream
1981-88		829*	32	A	118*	trenched
1988-92	--	--	--	--	--	trenched

E/A† = erosion (E) vs. accretion (A)
Rates†† = mean rate of bank erosion or bar accretion
* no change in low water channel position
Note: Table reports mean values along Christie bar between River Mile 7.4 and 6.8. Estimates depend on the scale and resolution of aerial photographs.

Table 15 (cont.) -- Bank erosion/bar accretion, Blue Lake bridge to A&MRR bridge, lower Mad River, 1941-42 to 1992

Johnson Bar

Time Period	Length (ft)	Ave. Width (ft)	Area (acres)	E/A†	Rates†† (ft/yr)	Notes
1942 to 48	2,700	550	18	A	92	LB erosion
1948 to 54	1,200	425	7	A	70	LB erosion
1954-58	1,900	610	16	E	154	RB erosion
1958-62	--	--	--	--	--	braided
1962-66	--	--	--	--	--	braided
1966-70	--	--	--	--	--	braided
1970-74	--	--	--	--	--	braided
1974-81	2,100	690	33	A	99	LB erosion
1981-88						
1988-92	--	--	--	--	--	no bar

E/A† = erosion (E) vs. accretion (A)
Rates†† = mean rate of bank erosion or bar accretion
* no change in low water channel position
Note: Table reports mean values along Johnson bar between River Mile 6.7 and 6.5. Estimates depend on the scale and resolution of aerial photographs.

Lower Simpson Bar

Time Period	Length (ft)	Ave. Width (ft)	Area (acres)	E/A†	Rates†† (ft/yr)	Notes
1942 to 48	3,600	650	40	A	108	LB erosion
1948 to 54	2,600	1,275	32	E	213	RB erosion
1954-58	3,600	640	34	A	160	LB erosion
1958-62	4,200	910	61	E	226	RB erosion
1962-66	--	--	--	--	--	braided
1966-70	--	--	--	--	--	braided
1970-74	--	--	--	--	--	braided
1974-81	--	--	--	--	--	no change
1981-88		941*	31	A	134*	* = max
1988-92		905*	27	E	226*	* = max

E/A† = erosion (E) vs. accretion (A)
Rates†† = mean rate of bank erosion or bar accretion
* no change in low water channel position
Note: Table reports mean values along Lower Simpson bar between River Mile 6.3 and 6.1. Estimates depend on the scale and resolution of aerial photographs.

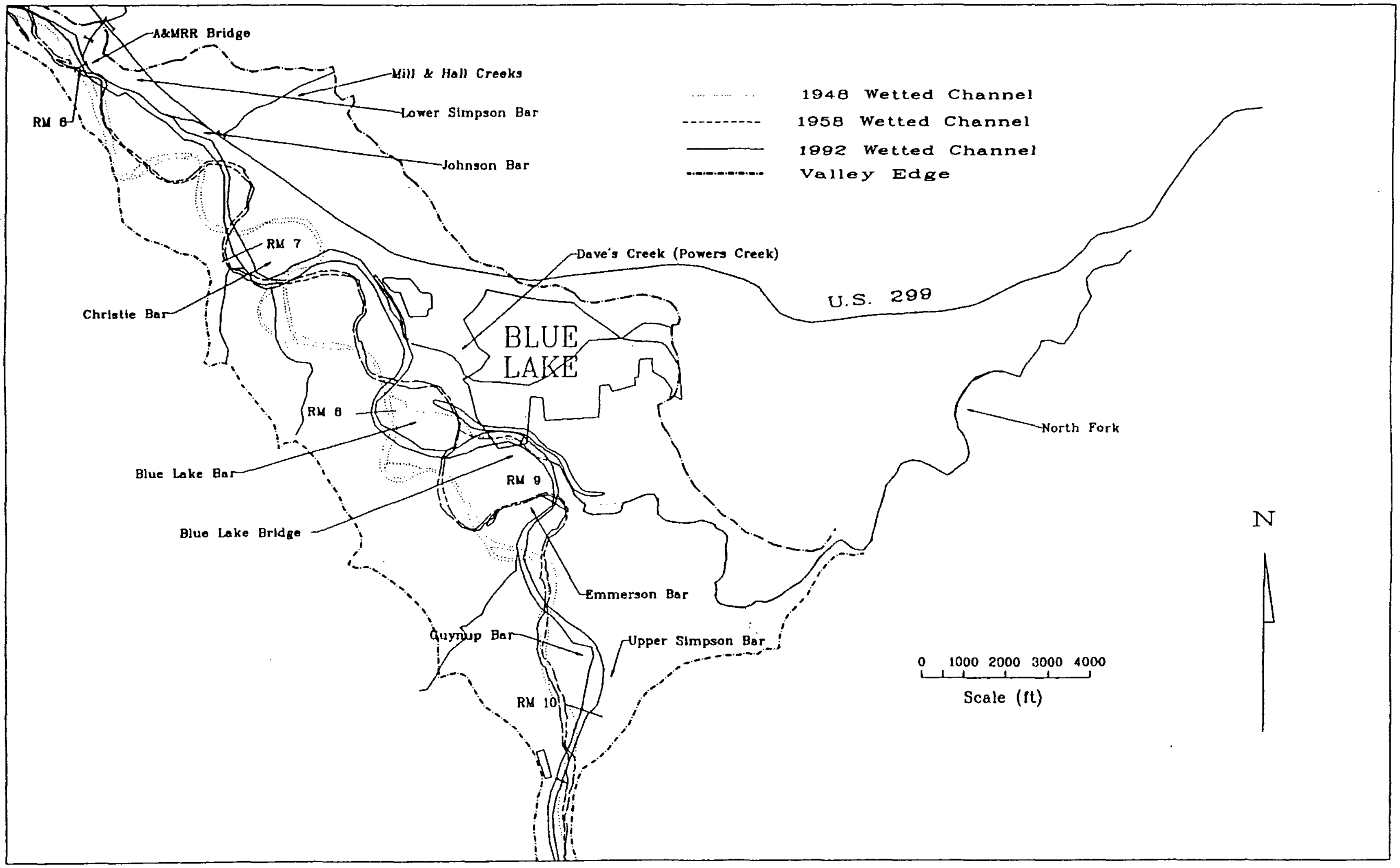


Figure 16 -- Lateral channel changes between 1948, 1958, and 1992, Hatchery to A&MRR Bridge

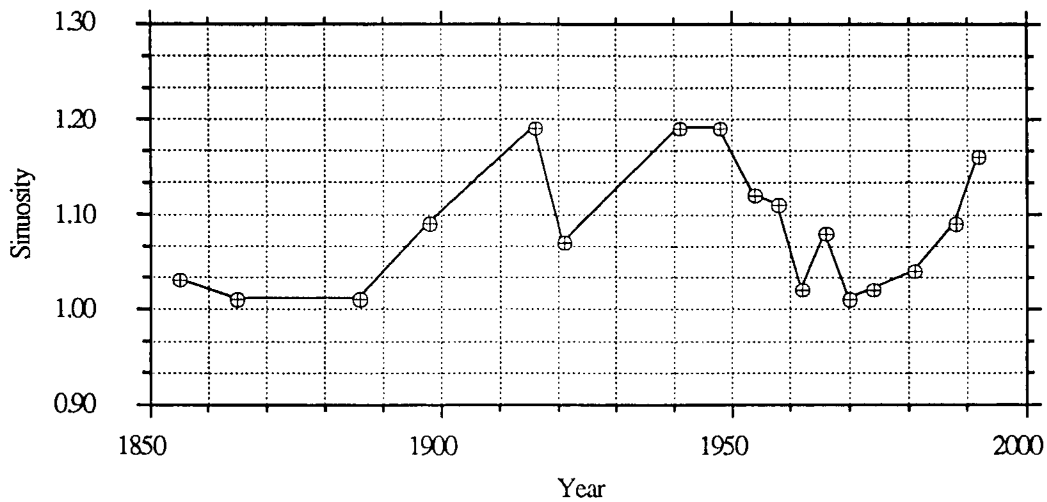


Figure 17 -- Sinuosity, Blue Lake bridge to A&MRR bridge, lower Mad River, 1855 to 1992

the low water channel length between 1921 and 1954, before stream capture by the North Fork occurred. Following avulsion, sinuosity generally continues to increase to date, from 1.00 in 1970 to 1.16 today. This is consistent with meander changes documented above.

Volume of Bed Erosion

A minimum of 2,980,000 yd^3 (2,278,000 m^3) of material was removed from storage between 1962 and 1992. Spread evenly over the active channel, the bed lowered approximately 4.5 feet (1.4 m) between 1962 and 1992.

d) Summary of Historic Conditions of the Blue Lake Bridge to A&MRR Bridge Reach

Evaluation of available data shows some important trends. Hydrologically the periods between approximately 1879-1910 and 1940-1975 were marked by above average rainfall and large peak discharges. Below average rainfall occurred between 1911-1939 and 1976-1992. Impoundment of sediment behind Sweasey Dam between 1938 and 1970 decreased sediment supply to the reach.

Geomorphic changes included: 1) medial bar formation/braiding following large magnitude flooding in 1861-62 and 1890; 2) increases in width, area, and bank erosion and decreases in length following the 1955 and 1964 floods; 3) channel confinement by construction of individual bank protection projects, revetment construction, and gravel extraction; 4) a decrease in sinuosity between 1941/42 and 1970, then a gradual increase until 1990; 5) bed aggradation during the 1960's to approximately 1974, then bed degradation through 1992. A mean bed lowering rate of 0.15 ft/yr (0.05 m/yr) was estimated between 1962 and 1992. The volume of sediment removed from the reach during that period was approximately equal to 2,980,000 yd^3 (2,278,000 m^3), approximately 230,000 yd^3/yr (176,000 m^3/yr). About 4.5 feet (1.4 m) of bed lowering can be attributed to gravel extraction volumes in excess of natural recruitment.

4. A&MRR Bridge to 299 Bridge

a) Reach Description

The reach between the A&MRR bridge and the 299 bridge (the Essex Gorge) is an alluvial and bedrock channel constrained artificially in places by rip rap (figures 7 and 8). Length of the reach is approximately 1.7 miles (2.7 km) from River Mile (RM) 6.0 to RM 4.3 (figure 18). The channel has undergone cycles of erosion and deposition during different periods of its history. Bed configuration consists of alternating bars and point bars and has shown both a meandering and braided character. Bed and bank material such as terrace deposits along the reach typically erode at higher flows. Riprap used along both banks confines the channel in places.

b) Land Use History Summary

By 1866 the Skeedaddle Murphy Ranch, located just above Warren Creek, was producing potatoes - the start of agricultural land use along the reach (Scalici, 1993; SBF vol. 82, pg. 228). John Parker Warren, one of the first settlers in the Mad River valley in 1868, settled on what is now Warren Creek and began clearing the land ("The Story of Blue Lake", Blue Lake Advocate, Feb. 7, 1957, Mrs. Eugene F. Fountain, Historian). In 1869 a petition for the first wagon road along the river was submitted to the Board of Supervisors (*Humboldt Times*, February 6, 1869). Examination of the earliest air photos lends support to the claim that the location of the first wagon roads and rail lines was just above the highest historical high water marks. Across the river John Vance started logging in the Fieldbrook

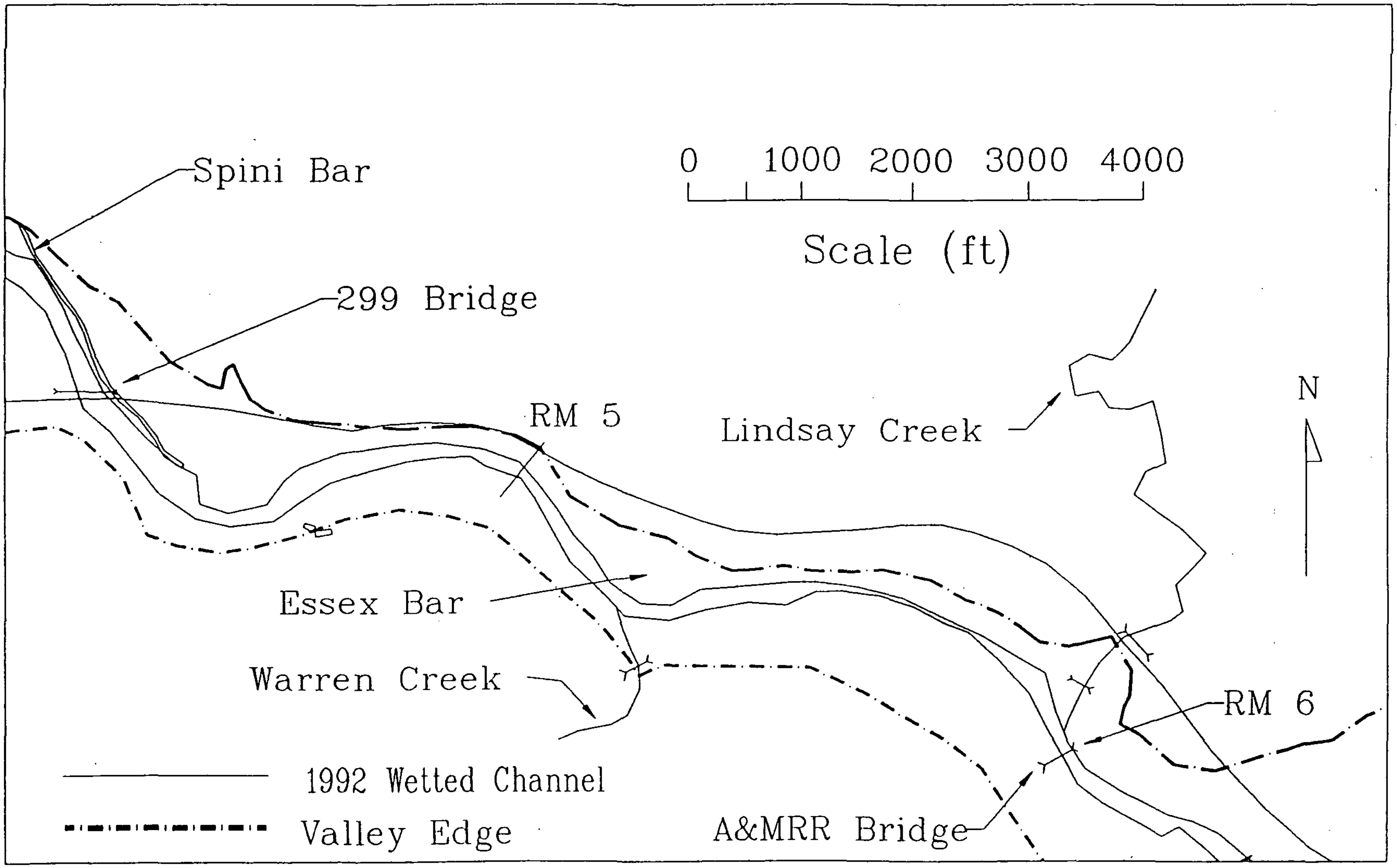


Figure 18 -- A&MRR Bridge to 299 Bridge reach, lower Mad River

and lower Blue Lake valley areas in the early 1870's. A description of Vance's operations was given in the Democratic Standard:

> " . . . further up the stream will embrace first the Lindsey (sic) creek tributary, the mouth of which one of Humboldt county's enterprising citizens dammed thereby forming a large basin of water for logging purposes. At this place he has his shingle and sawmills and machinery for hauling up logs for loading his cars which are taken by a genuine locomotive over his own iron road some four miles down the river on the north side, then it crosses the stream on a substantial bridge and runs one mile further to the tidewater of Humboldt Bay.
>
> "This Lindsay creek is about eight miles long and runs in a southeasterly direction. Its watershed is almost entirely covered with redwood timber and embraces thirty-two square miles." (*Democratic Standard*, January 19, 1878).

The Weekly Humboldt Times also reported on the construction of the dam which was "two miles long by half a mile wide [640 acres]", (*Weekly Humboldt Times*, December 14, 1878, "Our Railroad Interests"). The pond trapped sediment from the Lindsay Creek drainage and altered the amount of sediment transported into the Mad River just below the A&MRR bridge (figure 19, photo of Vance's pond, pre-1900). It is difficult to say how this sediment starvation affected the channel of the Mad River.

Agricultural conversion (figure 20) probably increased sedimentation rates during this period and confounded the effects of starvation from the heavily logged Lindsay Creek drainage. This account from the Blue Lake Advocate in 1896 explained the dam's fate:

> "The Lindsay Creek Dam, that impounded the water held in Vance's 160 acre pond, had washed out in late spring. . . . We rebuilt it. . . . After a few months of operation, the dam was blown up and the pond turned into a farm." (*Blue Lake Advocate*, Sept. 19, 1896, "Korbel Bridge Disaster")

Apparently the pond had decreased in size by 480 acres between 1876 and 1896, possibly due to deposition of sediment derived from upstream. I

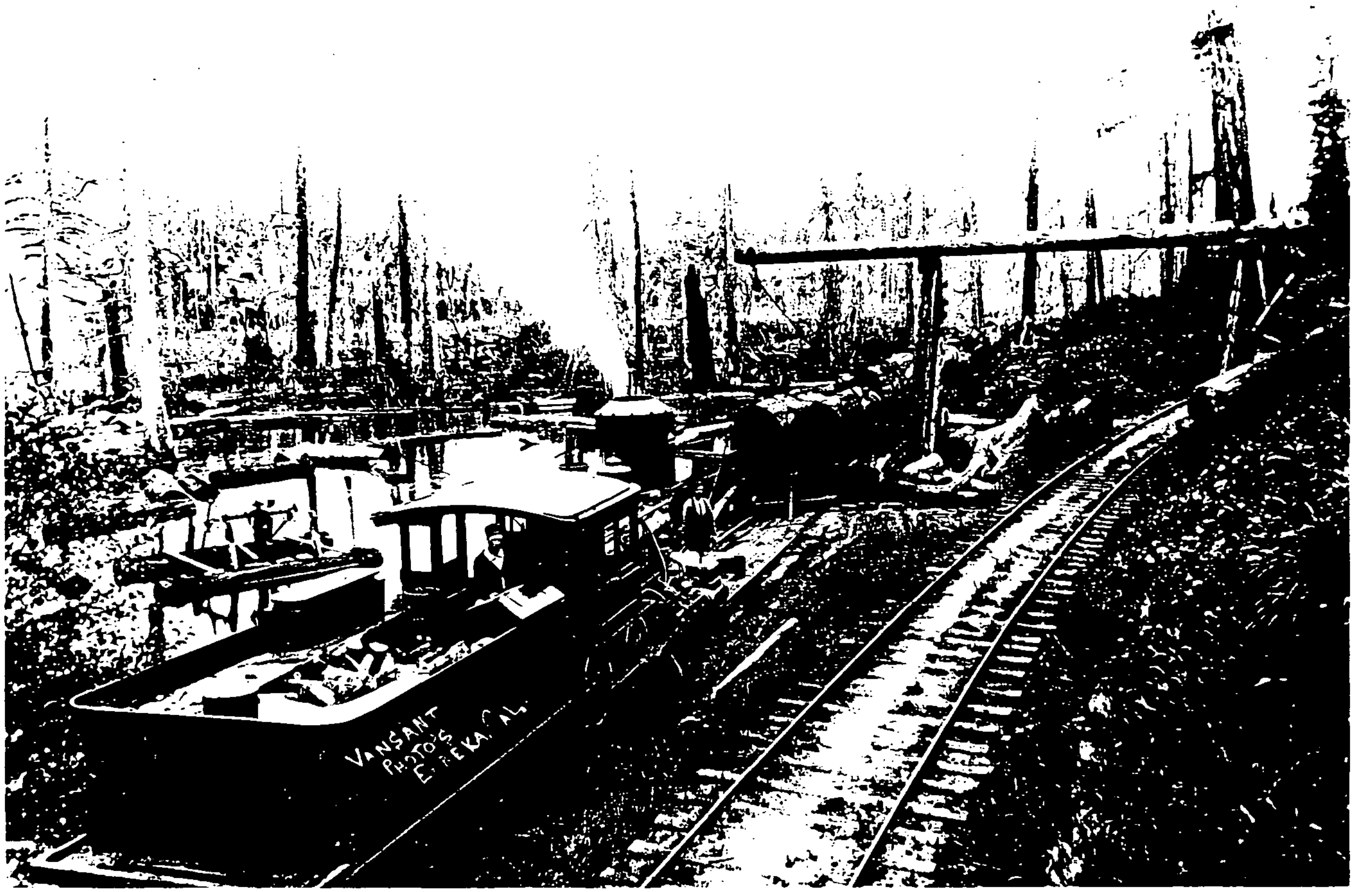


Figure 19 -- Vance's pond, ca. 1875. The pond was two miles long by half a mile wide on Lindsay Creek. (Photo #570 from the Humboldt County Historical Society Collection).

Figure 20 – Fieldbrook pre-1900. The land has been logged and converted to agricultural use. (From the Humboldt County Historical Society Collection).

assume that sediment was released into the channel of the Mad River when the dam washed out and again when it was blasted. The channel of the Mad River may have aggraded at the confluence, though no estimates of amounts can be made.

The style of logging (figure 21) shows the level of soil disruption experienced on hillslopes in the watershed. Sediment input from this type of disturbance may have contributed to channel aggradation, widening, and bank erosion. Logging moved upstream in the 1880's toward Blue Lake, Korbel, and Riverside.

The next important land use change can be traced back to at least 1872 when bids were advertised by the Board of Supervisors: "for graveling the upper Mad River road on W. Lindsey's land, and also twenty rods near John Warren's house where the road is planked; Three loads of gravel to the rod . . . " (*Blue Lake Advocate*, February 14, 1957, "Early Days of Humboldt"). Roadbuilding intensified during the 1910's and 1920's (Arlene Hartin, CalTrans, pers. comm., 1994) and gravel operations on the Mad River grew increasingly important. The Mercer-Fraser Company of Eureka operated a pit at the Essex site as early as the 1920's (Fred Bott, pers. comm., 1994) and was awarded a paving contract for "35 blocks of streets in Arcata in 1922 ("Arcata Paving Contract Let", *Blue Lake Advocate*, December 30, 1922). The company began to work around the clock to supply gravel for highway construction, street paving, and railroad work ("Three Shifts Work at Gravel Pit", *Blue Lake Advocate*, February 10, 1923). Trucks replaced railroad cars as the primary means of hauling timber ("To Haul Lumber With Trucks", *Blue Lake Advocate*, June 2, 1923), increasing the demand for

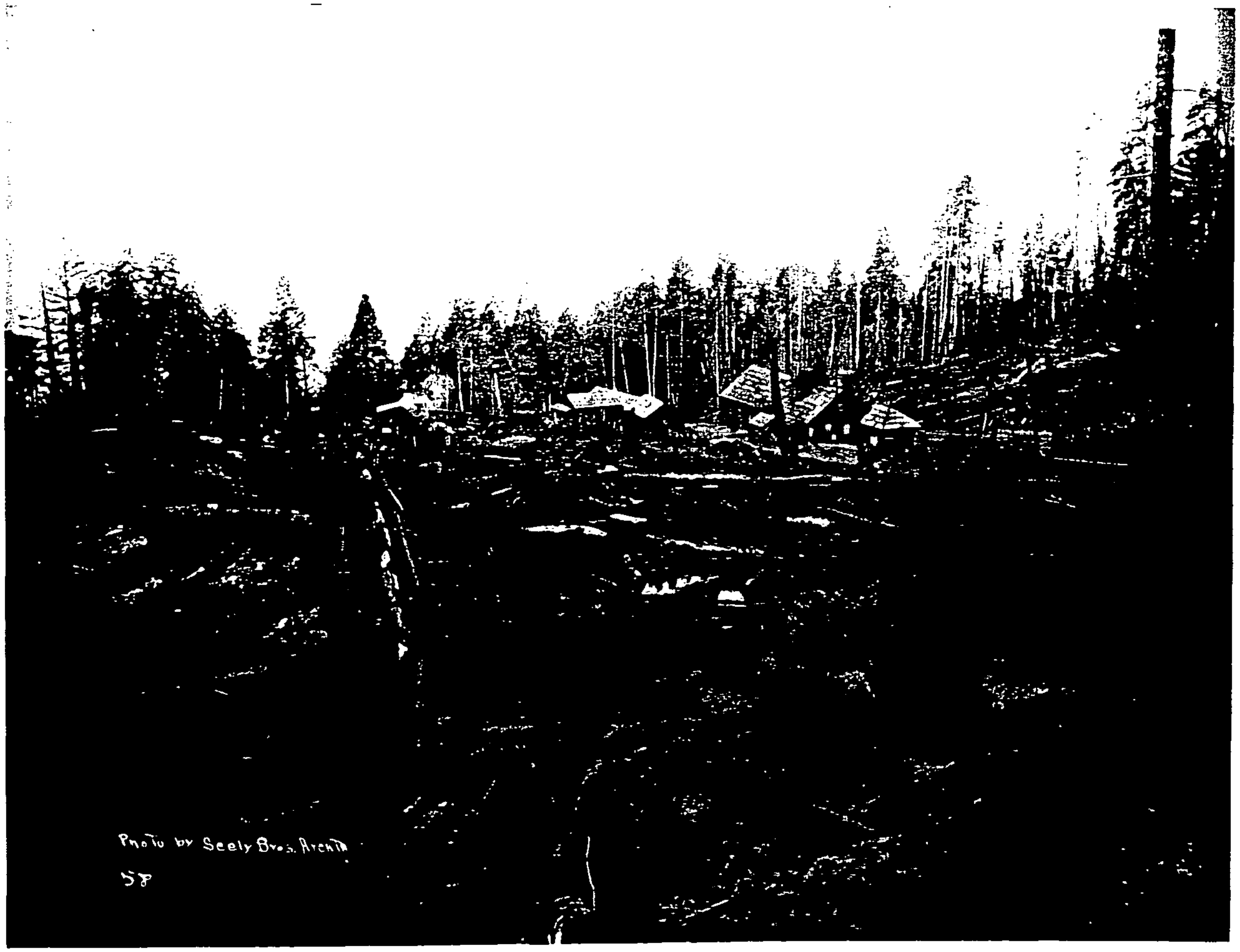


Figure 21 – Glendale-Oceanview logging camp (near Glendale/Essex) ca. 1885 showing level of soil disruption caused by logging on hillslopes drainging into the Mad River. (Photo by Seely after 1907, courtesy of Don Tuttle, Humboldt County Public Works Collection, Natural Resources Dept.).

road aggregate. Roadbuilding into the forests soon followed, which disturbed the landscape and probably increased the amount of sediment available to be transported into the Mad River. Gravel extraction from the Mad River continued into the 1930's:

> "The Mercer-Fraser Company was also doing large highway jobs and was responsible for paving most of the streets throughout Eureka during the 1930's. Mercer-Fraser had their own blacktop plant located at Essex." ("Mercer-Fraser Company", The Humboldt Historian, by Glen Nash, March-April, 1991, pgs. 10-14).

According to Fred Bott, Mercer-Fraser was the only company on the river during most of the 1930's and 1940's (pers. comm., 1994). He also said gravel was hauled as far as Orick for different projects. Mercer-Fraser ended most gravel extraction at the Essex site in 1975.

The Humboldt Bay Municipal Water District was formed in 1956 and between 1960 and 1967 constructed 5 Ranney collectors and a direct diversion facility in the Essex gorge, and Matthews Dam at Ruth Lake. The system was designed to provide up to 75 million gallons (116 cfs or 3.3 m^3/s) of water per day to the Humboldt Bay region. A more detailed description of the history and operation of the system is given by Henley in the "Proceedings of the Mad River Symposium" (1971). Water diversion continues along the reach.

c) <u>Historic Geomorphic Conditions of the A&MRR Bridge to 299 Bridge Reach</u>

<u>Pre-Aerial Survey Period</u>

An account given by Scalici (1993) from the Suzie Baker Fountain Papers (vol. 82, pg 228) indicates that the river bed elevation was much higher in 1866 than at present and the channel configuration consisted of point bars, riffles, and pools between Essex and Arcata. In December of 1866 a farmer from the Skeedaddle Murphy Ranch (located above the confluence with Warren Creek) was able to:

> " . . . drive a team [of horses] down the river bar, fording the small riffles and coming out on Arcata Bottom there being no wagon road up Mad River at that time".

I was not able to determine the effects of the 1861-62 flood on bed elevations. I was able to find little data of specific conditions along the reach until just after the turn of the century. Figure 22 shows the river bed below the A&MRR bridge in the early 1930's. I was unable to rephotograph the view due to thick vegetation growth, but since that time degradation has clearly occurred, exposing the bridge piers (discussed below). Figure 23 shows the river bed elevation just upstream of 299 around 1910. The bed has dropped significantly since then, exposing boulders in the channel and steepening the banks (discussed below). Vegetation along the bank has obscured the view disallowing a similar photo perspective today.

Post-Aerial Survey Period

Today the banks are very steep, point bars have become terraces - isolated geomorphically from the river, and the riffles are not fordable along the same reach. Large boulder and rock outcrops presently characterize the channel between Warren Creek and 299. Bed lowering is discussed in further detail below.

Air Photo Observations

Detailed notes of air photo observations are given in Appendix H. A summary of air photo observations taken between 1941/42 and 1992 is given

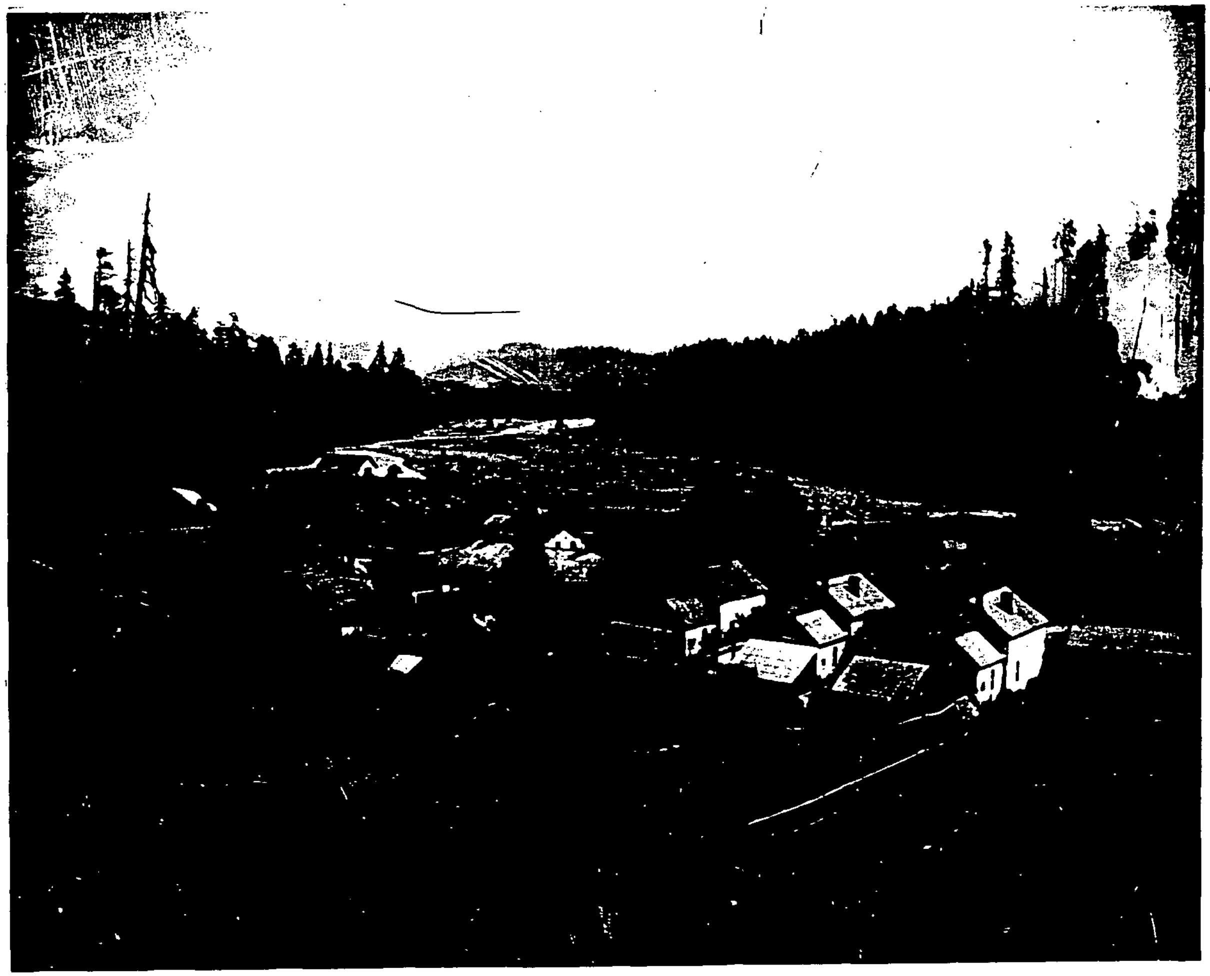


Figure 22 -- View from Essex looking upstream toward the A&MRR bridge ca. 1930-1935. Note the river bed position at pier bases. (Photo courtesy of Don Tuttle, Hum. Co. Public Works Collection, Nat. Resources Dept.).

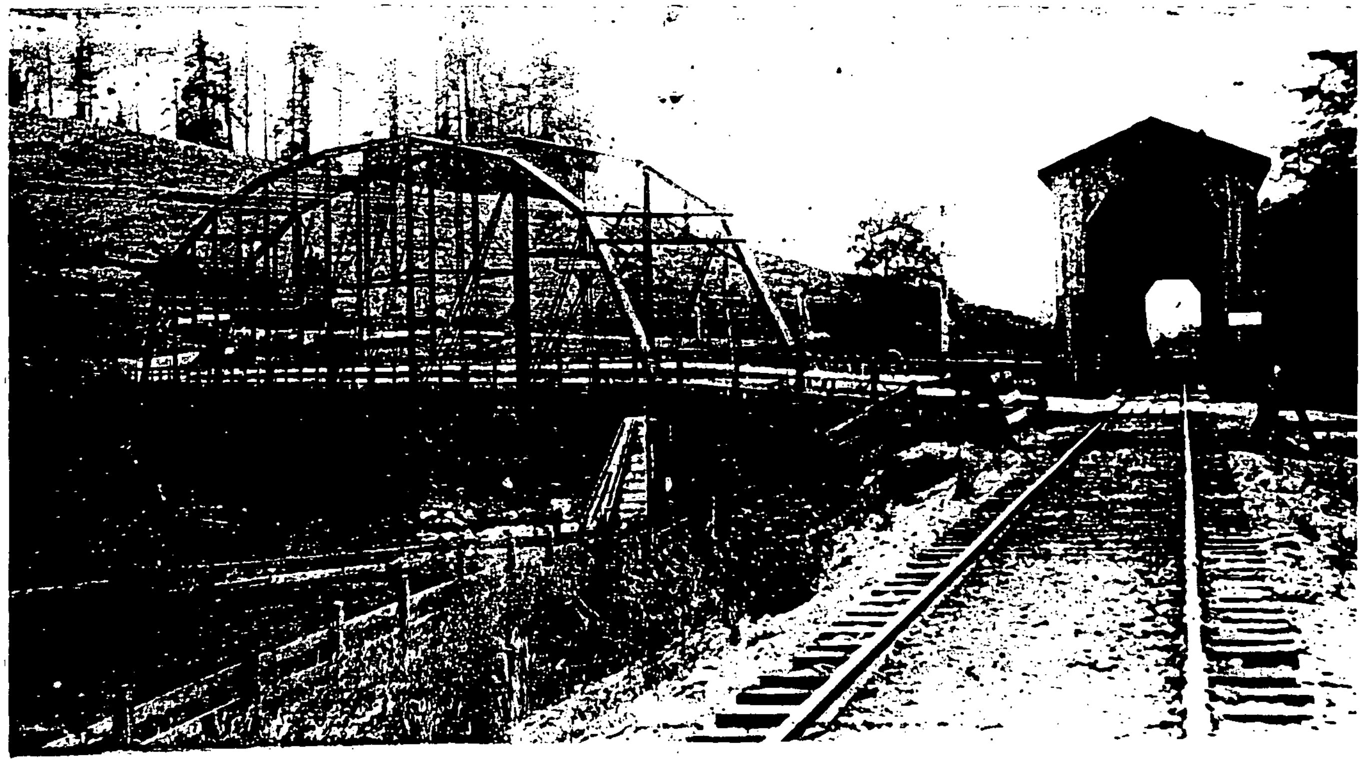


Figure 23 -- Mad River Bridge. Crossing at the present USGS cableway site ca. 1910. Photogrammetric measurements indicate 20-25 feet of bedlowering at this site (see Appendix R). Note horse and buggy on bridge. (Photo #1006 from the Humboldt County Historical Society).

here and shows the following significant channel changes:

1. 1941/42 - 1948: By 1948 active mining removed riparian vegetation and widened the channel at Essex bar. The channel migrated by approximately 500 to 600 feet (150 to 180 m) toward the right bank at Essex bar (possibly captured by trenching). The channel shortened slightly at Essex bar. Approximately 4 acres of riparian vegetation were removed from the bar and terrace along the right bank above 299 by both mining and agricultural activity. Banks appear to slope gently when viewed in stereo.

2. 1948-1954: The low-water channel at Essex shows migration back toward the center of the active channel. Trenching is visible at Essex bar, confining the channel. A large rock outcrop, approximately 1,250 feet upstream of 299 along the left side of the channel, is visible in the 1954 photo.

3. 1954-1958: Active mining in the channel is visible at Essex bar. No mining is visible on the bar just upstream of 299 along the right bank; a road is visible that drops down onto the bar. The channel appears to have widened slightly - less vegetation on bars. The outcrop approximately 1,250 feet upstream of 299 is barely visible in 1958.

4. 1958-1962: Left bank erosion just upstream of Pump Station 4 occurred. The bar along the right bank above Essex shows active mining. Extensive channelization is evident at Essex, due to mining. A large berm in the river diverts water away from the bar and also into pools/pits dug into the bar. A rock outcropping is first visible at the mouth of Warren Creek in 1962. The outcrop approximately 1,250 feet upstream of 299 is barely visible in 1958 and is very prominent by 62; rock diverts flow partly toward RB as exposure increases. The channel divides into multiple threads at the bar just upstream of 299 along the right bank. Extensive mining of the terrace and bar surface, some below the water surface, is observed on this bar in 1962.

5. 1962-1966: The river migrated toward the right bank downstream of Lindsay Creek (thalweg may have been captured by trenching observed in 1962 photos) exposing a rock outcrop. Rocks are observed DS of the Lindsay Ck. confluence - not visible in 62 photos (the river was on the other side of the channel). Six wing dams constrict flow along the left bank at Pump Station 4. The river has migrated away from these structures in the 1966 photos. Extensive mechanical manipulations of the channel are visible around the Pump Stations. Construction/widening of 299 constricts flow downstream of Essex. Rocks are visible at the mouth of Warren Creek. The rock outcrop approximately 1,250 feet upstream of 299 is more exposed in 1966 than in 1962. Approximately 900 feet (100 m) of riparian vegetation along the

right bank above the USGS gaging station was removed by 1966. Extensive mining on the bar upstream of 299 was visible in 1966.

5. 1966-1970: Extensive mechanical manipulations of the channel around the Pump Stations is observed. Continued mining on Essex bar is seen. The right bank terrace and bar surface above 299 shows evidence of mining. The rock outcrop approximately 1,250 feet upstream of 299 is more exposed than in 1966.

6. 1970-1974: Water diversions toward the Ranney collectors are visible. The river is braided between the A&MRR bridge and Essex. The rock outcropping upstream of 299 is visible. The bar opposite the outcrop lacks vegetation.

7. 1974-1981: A single thread channel was observed - no water diversions to Ranney collectors. No mining on Essex bar was observed in 1981. The rock outcrop 1,250 feet upstream of 299 is visible. rock US of 299 on LB quite visible in 81; 74 shows gravel around rock, doesn't protrude as much; flow diverted by rock (around it)

8. 1981-1988: The meander wavelength of the low-water channel decreased between the A&MRR bridge and Essex. The rock outcrop 1,250 feet upstream of 299 diverts the flow toward the RB above 299 and appears to protrude more than in previous photos.

9. 1988-1992: No changes in channel pattern were observed. More vegetation on bars is visible by 1992. The rock outcrop 1,250 feet upstream of 299 is visible.

Changes in Channel Length, Width, and Area

Earliest surveys of the reach indicate that the channel width generally decreased until 1933, then changed very little until 1966, when it widened following the effects of flooding and intensive gravel extraction (Table 16). Channel width decreased gradually to 1974, then stabilized. Area measurements show a similar pattern. Centerline length has shown relatively little change through time.

Mechanical Manipulations of the Channel

Excavators were used for digging gravel from below the water surface until around 1973, when the California Department of Fish and Game prohibited mining below the water surface (Fred Bott, Bob King, pers. comm., 1994). Holes were dug in the river during high flow and gravel was removed and stockpiled for later use. As the flow continued, the holes filled in with gravel recruited from upstream. Approximately 70,000 to 100,000 tons (98,000 to 140,000 yd^3 or 75,000 to 107,000 m^3 using 1.4 tons/yd^3 (after Lehre (1993)) of aggregate would be stockpiled during a season at the Essex site (Fred Bott, pers. comm., 1994). Extraction rates were highest at the site during the 1960's when freeway construction reached a peak (figure 15). John Murray (pers. comm., 1994) observed that operations in the river below water level were common during the 1950's and 1960's until regulations changed. He said trenches channelized the river and estimated some of the trenches were 14 to 16 feet (4.3 to 4.9 m) deep and 50 feet (15.2 m) wide (Appendix D). Some of these trenches are up to 500 feet (152 m) long on air photos, thus measuring up to 15,000 yd^3 (11,000 m^3) in volume.

Additionally the channel has been mechanically manipulated by the Humboldt Bay Municipal Water District near its Ranney Collectors (figures 24 and 25). Berms and water diversions were constructed to channel the flow toward the collectors during the 1960's and early 1970's (Henley, 1971). A more detailed description of construction and operation of the water supply system and the effects of the 1964 flood is given in the Mad River Symposium (1971).

Table 16 -- Active channel length, width, and area measurements, A&MRR bridge to 299 bridge, 1941-42 to 1992†

Year	Centerline length (ft)	Width (ft)	Area (acres)
1855††	9,400	750	162
1865††	10,200	420	98
1886††	9,700	670	149
1898††	9,500	750	164
1916††	9,800	630	142
1921††	9,600	640	141
1933	9,800	370	83
1941-42	10,500	400	96
1948	10,200	370	87
1954	10,200	420	98
1958	10,300	430	102
1962	10,000	350	80
1966	9,700	520	116
1970	9,900	460	105
1974	9,900	380	86
1981	10,100	420	97
1988	9,900	390	89
1992	10,200	380	89

† see also Appendices I, J, and K for a comprehensive list of all reaches
†† = map accuracy is questionable
Note: estimates depend on scale and resolution of photos

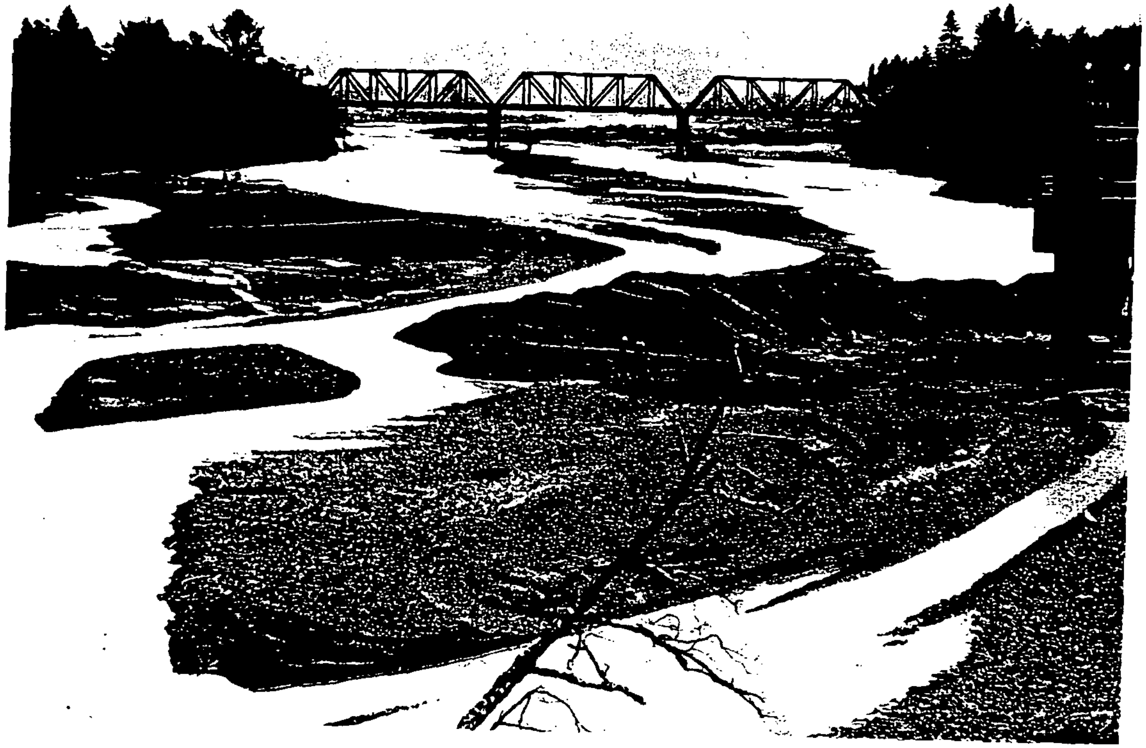


Figure 24 -- A&MRR bridge, 1968, looking upstream. Note berms and water diversions around Ranney Collector #5 (right). Note also position of river bed at base of bridge piers. (Photo courtesy of Dale Stoveland, Humboldt Bay Municipal Water District).

Figure 25 – Essex Gulch, 1968. Oblique aerial view downstream (northwest) just below the A&MRR bridge to 299 bridge (upper left of photo). Ranney Collector #5 is in the right foreground. (Photo courtesy of Dale Stoveland, Humboldt Bay Municipal Water District).

Volume of Bed Erosion

Based on my own photogrammetric measurements and gravel extraction estimates from Lehre et al (1993), a minimum of 870,000 yd^3 (665,000 m^3) of material was removed from storage between 1962 and 1992. Spread evenly over the active channel, the bed lowered approximately 5.7 feet (1.7 m) between 1962 and 1992.

d) Summary of Historic Conditions of the A&MRR Bridge to 299 Bridge Reach

The channel was initially disturbed by the rafting of logs downstream in the 1870's. The river inundated point bars along the reach during high flows until large scale gravel extraction began in the 1950's, initiating bed lowering. The banks steepened as gravel was removed and the river was confined by artificial means. Bed lowering rates were greatest during the 1960's when road construction and gravel extraction rates were correspondingly highest and have averaged approximately 0.15 to 0.20 ft/yr (0.05 to 0.06 m/yr). Lehre, et al (1993) estimated approximately 850,000 yd^3 (650,000 m^3) of material were removed along the reach by bed lowering between 1962-92, or about 28,000 yd^3/yr (21,000 m^3/yr) primarily due to gravel extraction.

5. 299 Bridge to Hammond Bridge

a) Reach Description

The reach between 299 and Hammond is an alluvial channel artificially constrained in places (figures 7 and 8). The reach extends approximately 4.3 miles (6.9 km) from River Mile (RM) 4.3 to RM 0.0 (figure 26). The channel has undergone cycles of erosion and deposition. Bed configuration has consisted of alternating bars and point bars and has shown both a meandering and braided character. Terrace deposits along the reach typically erode at higher flows. Riprap used along both banks confines the channel in places.

b) Land Use History Summary

A detailed history of land use changes on the Arcata Bottoms is given by Haynes (1986) and Scalici (1993). I will summarize their findings below in order to put geomorphic changes into context with land use changes.

Shortly after the first European settlers arrived in the early 1850's, land was cleared along the Arcata Bottoms in order to grow crops which would support mining efforts along the Trinity and Klamath Rivers. Logging on the Mad River soon followed. The Mad River Canal was constructed in 1854 (Haynes, 1986; Shimps, 1986) to allow timber to be floated from the Mad River into the Mad River Slough where mills were constructed. Milled timber was then loaded onto ships for transport to distant markets. The riparian forest along the reach was logged and the floodplain was reclaimed and converted into farmland in the 1850's and

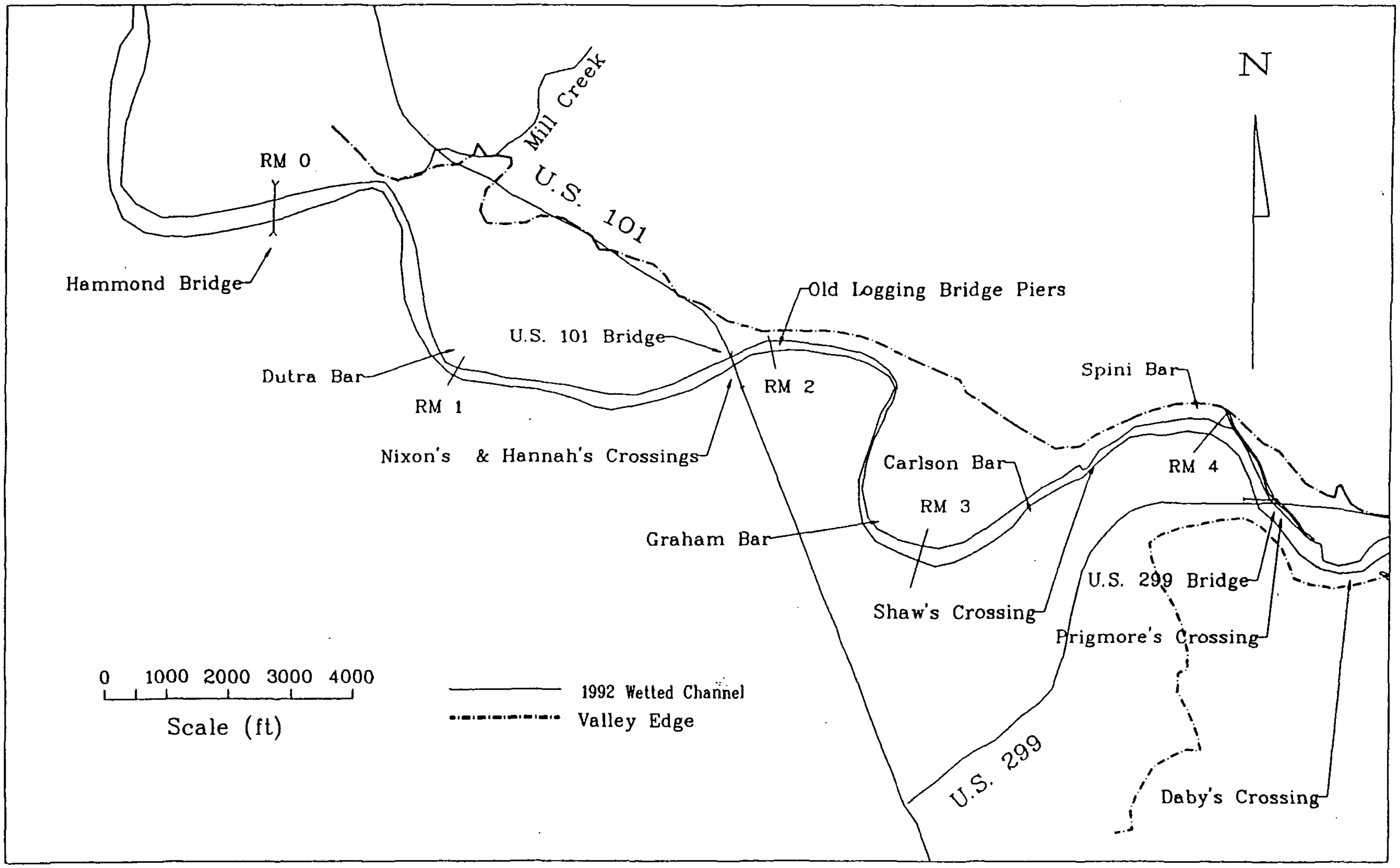


Figure 26 -- 299 Bridge to Hammond Bridge reach, lower Mad River

1860's. Toward the last quarter of the century dairying became popular and cattle were grazed along the Bottoms. Land use has changed very little since that time, excluding gravel mining.

Gravel mining probably occurred on a small scale prior to the first accounts I was able to find in 1921. Crews working "a day and night shift" in a pit at Hannah's crossing (just upstream of 101) extracted gravel to pave "the Trinidad section" and "the Arcata-Eureka highway" (*Blue Lake Advocate,* September 24, 1921, "Graveling Road towards Trinidad"). Gravel extraction rates were highest along the reach during two road building phases which occurred: 1) between the mid 1910's and the mid 1920's when the Redwood highway was constructed; 2) during the late 1950's to late 1960's when 101 and 299 were widened into 4 lanes (Arlene Hartin, California Department of Transportation, pers. comm., 1994).

c) Historic Geomorphic Conditions of the 299 Bridge to the Hammond Bridge Reach

Pre-Aerial Survey Period

Comparison of historical maps and aerial photographs shows several significant changes along the reach:

1) a meander cutoff in 1862 near RM 3.0 (the present Valley West area);

2) meander migration and growth between RM 1.5 and 0.3 (upstream of the Hammond bridge);

3) channel confinement by bank protection projects;

4) the relative abundance, then disappearance of medial bars near RM 0.0 (Hammond bridge) before and after 1966;

5) meander migration and growth/retraction near Graham bar;

6) extensive gravel extraction between RM 4.3 (299) and 1.0 (Dutra bar) beginning in the 1950's;

An account of the meander cutoff in 1862 can be found in Arcata Union:

> "The summer following the flood . . . a canal or ditch was cut, commencing near the crossing at the Shaw (RM 3.5) place that diverted the water of the river from the old channel and made a new one, connecting with the old bed some miles below. Since that time more than 25 years ago [c. 1862], the old bed of the river has been dry during the summer seasons, some of it having been converted into fields for pasture and agricultural purposes." ("Then and Now", *Arcata Union*, February 4, 1888).

Comparison of the 1855 and 1898 maps shows the active channel shortened by approximately 8,400 feet (2,600 m). The 1865 Official Township Map of Humboldt County by A. J. Doolittle shows the meander had not yet been cut off leading me to believe it was drafted using the surveys from 1855. Active channel centerline measurements are given in tables 17 and 18.

Scalici (1993) describes the meander migration between RM 1.5 and 0.3, which he calls the "Sheppard cut". The river migrated approximately 2,600 feet (800 m) between 1855 and 1916 giving a mean migration rate of 43 ft/yr (13 m/yr). Local farmers initiated bank protection measures which stabilized the channel following the 1890 flood. By the early 1900's the channel between 101 and the Hammond bridge was fairly well confined (Scalici, 1993).

Post-Aerial Survey Period

Air Photo Observations

Detailed notes of air photo observations are given in Appendix H. A summary of air photo observations taken between 1941/42 and 1992 is given here and shows the following:

1. 1941/42 to 1948: A medial bar is observed at Shaw's Crossing (RM 3.5) in 1942. Bank protection is evident at approximately RM 2.8.

2. 1948 to 1954: A rock outcrop at Shaw's crossing is visible in the channel by 1954 (where a medial bar was observed in the 1941/42 photos). Approximately 1000 feet (300 m) of riparian vegetation was cleared by 1954 upstream of Hammond bridge.

3. 1954 to 1958: Rocks at Shaw's Crossing are exposed. A trench in the channel approximately 3,900 feet (1,200 m) in length is visible. Five wing dams are visible along the right bank just upstream of 101; riparian vegetation disappeared by 1958; bridge repair is still under way following the 1955 flood. Three wing dams are visible 2,000 feet (610 m) downstream of 101 protecting the left bank from erosion.

4. 1958 to 1962: Two trenches are visible in the channel at Graham bar, one along the outside bend and one along the inside bend. They measure approximately 4,000 feet (1,200 m) and 2,500 feet (760 m) in length. The rocks at Shaw's Crossing are larger in area and protrude more than in the 1958 photos.

5. 1962 to 1966: Significant right and left bank erosion at Spini's bar (RM 4.0) has occurred; the channel has widened. The channel has widened and shortened at Graham bar. Evidence of active mining within the channel is visible. Approximately 4,200 feet (1,300 m) and 2,700 feet (820 m) of revetment/dikes were added following the 1964 flood along the left bank downstream of 101. Riparian vegetation along dikes is absent. Significant mining is observed at Dutra bar (RM 1.0). The channel is braided just upstream and may indicate knick-point migration taking place toward 101 -- braiding indicating a distinct slope break. Four wing dams are visible just upstream of Hammond bridge along the right bank.

6. 1966 to 1970: Clearing of riparian forest (replaced by a trench) along the right bank at Graham bar has occurred. Riparian forest

has filled in just downstream. Dutra bar shows evidence of mining below the water surface in 1970.

7. 1970 to 1974: Right bank erosion along Spini property is observed. Trenching along Graham bar does not extend as far downstream by 1974. The riparian forest south of Azalea Road (RM 2.3) has increased in area. The channel is braided, but has narrowed.

8. 1974 to 1981: The rock at Shaw's Crossing is still visible. Riparian forest continues to recover near Graham bar.

9. 1981 to 1988: The channel shows two strands at Spini bar, one strand at Graham bar.

10. 1988 to 1992: The riparian vegetation has filled in further along the reach, narrowing the channel slightly.

Changes in Active Channel Length, Width, and Area

Tables 17 and 18 report active channel length, width, and area measurements for the 299 to 101 and 101 to Hammond bridge reaches. The effects of meander cutoff, channel migration, flooding, and gravel extraction can be seen. I was unable to separate the impacts of flooding from those of gravel extraction in the 1960's and 1970's. Figure 27 shows effects of the 1955 flood near the 101 bridge. Extensive gravel mining on Graham bar, just upstream, occurred before this flood. Erosion along the right bank is clearly evident. Figure 28 shows the 1955 floodwaters over the Redwood Highway (101 between Giuntoli Lane and McKinleyville) and deposition of logs and debris onto the floodplain.

Medial Bar Measurements

Medial bar changes (table 19) show that the reach has undergone periods of deposition near the Hammond bridge before 1966. No bars were

Table 17 -- Active channel length, width, and area measurements, 101 bridge to Hammond bridge, 1941-42 to 1992

Year	Centerline length (ft)	Width (ft)	Area (acres)
1855	9,900	520	118
1865	9,600	610	134
1886	9,200	490	103
1898	8,800	890	180
1916	9,400	520	112
1921	9,200	870	184
1933	9,600	360	79
1941-42	9,600	320	71
1948	9,500	270	59
1954	9,500	300	65
1958	9,400	290	63
1962	9,800	280	63
1966	9,500	450	98
1970	9,800	360	81
1974	9,500	300	65
1981	9,900	340	77
1988	9,700	350	78
1992	9,700	300	67

Note: Estimates depend on the scale and accuracy of historic maps and scale and resolution of air photos.

Table 18 -- Active channel length, width, and area measurements, 101 bridge to Hammond bridge, 1941-42 to 1992

Year	Centerline length (ft)	Width (ft)	Area (acres)
1855	9,900	520	118
1865	9,600	610	134
1886	9,200	490	103
1898	8,800	890	180
1916	9,400	520	112
1921	9,200	870	184
1933	9,600	360	79
1941-42	9,600	320	71
1948	9,500	270	59
1954	9,500	300	65
1958	9,400	290	63
1962	9,800	280	63
1966	9,500	450	98
1970	9,800	360	81
1974	9,500	300	65
1981	9,900	340	77
1988	9,700	350	78
1992	9,700	300	67

Note: Estimates depend on the scale and accuracy of historic maps and scale and resolution of air photos.

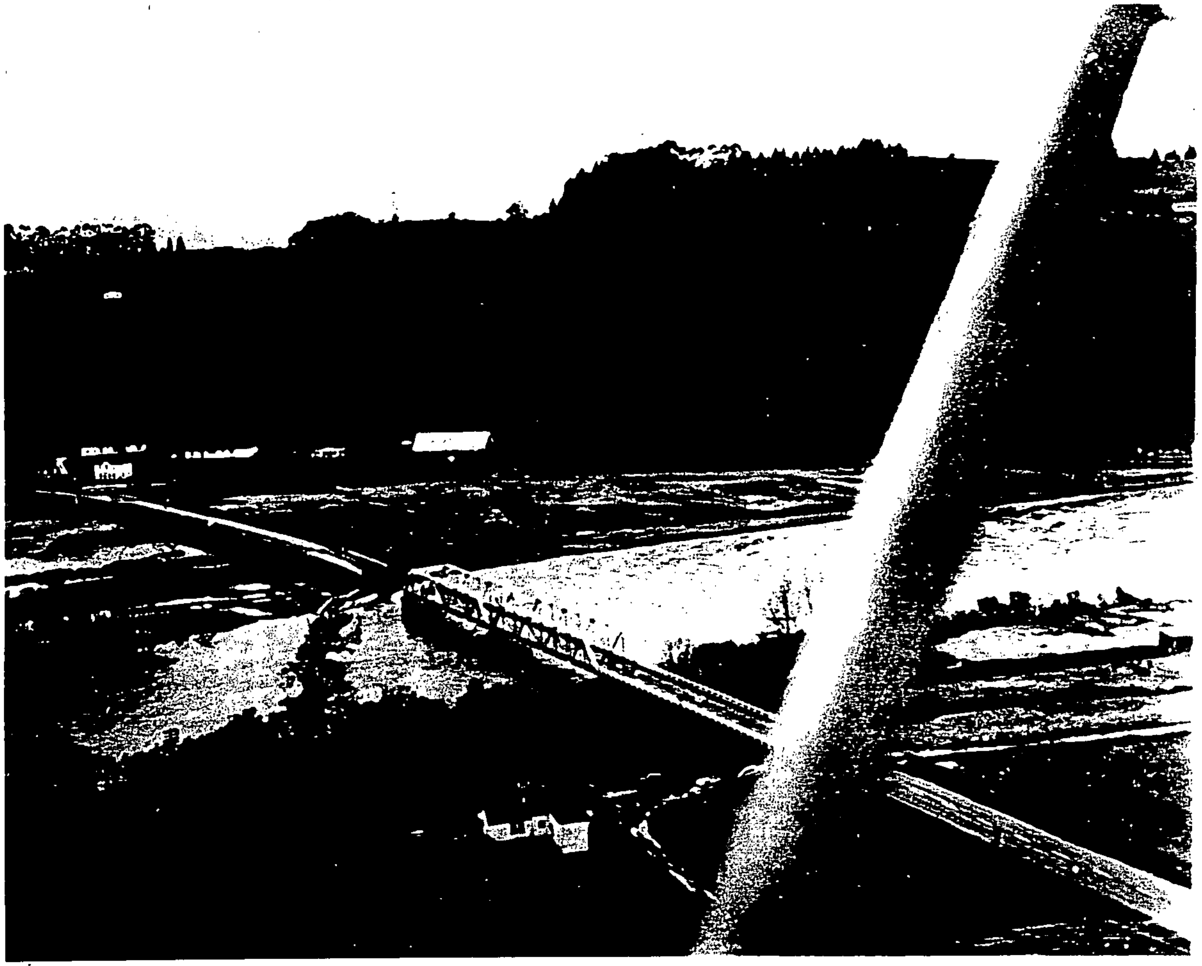


Figure 27 -- Mad River, at U.S. 101. Oblique aerial view (N-NE) following the flood of December 22, 1955 (77,800 cfs). Note right bank erosion and collapse of part of the bridge structure. (Photo courtesy of Don Tuttle, Humboldt County Public Works Collection, Natural Resources Dept.).

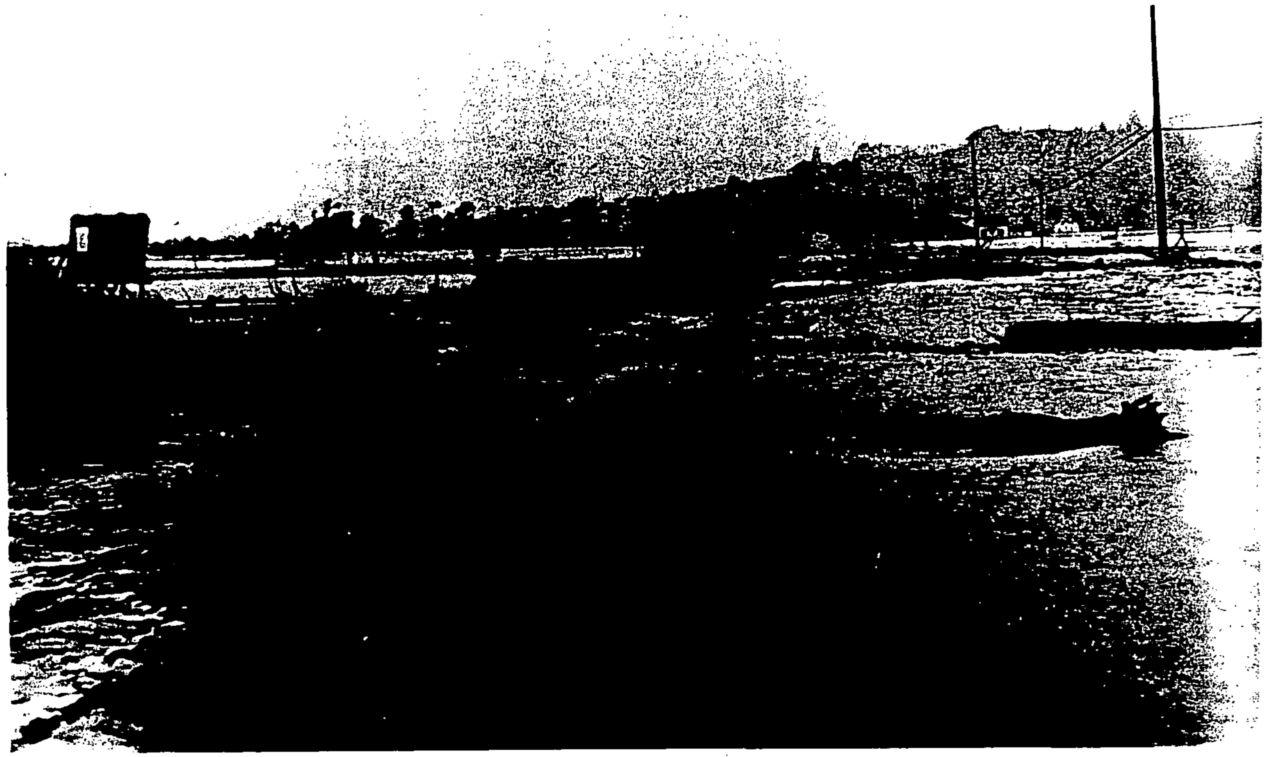


Figure 28 -- Mad River, U.S. 101 north of Arcata. View north along Redwood Highway (101) from near Giuntoli Lane toward McKinleyville. Photo taken following the December 22, 1955 flood (77,800 cfs). (Photo courtesy of Don Tuttle, Humboldt County Public Works Collection, Natural Resources Dept.).

Table 19 -- Medial bar measurements near Hammond bridge, 1855 to 1992

Year	Bar area (acres)	Location
1855	18	RM 0.0
1865	--	--
1886	--	--
1898	--	--
1916	2	approx. 0.6 mi DS of RM 0.0
	3	approx. 0.7 mi DS of RM 0.0
	6	approx. 0.9 mi DS of RM 0.0
1921	--	--
1933	--	--
1941-42	3	RM 0.0 (Hammond bridge)
	10	approx. 0.3 mi DS of RM 0.0
1948	7	approx. 0.7 mi DS of RM 0.0
1954	--	--
1958	9	RM 0.0
1962	--	--
1966	3	approx. 0.3 miles DS of RM 0.0
1970	--	--
1974	--	--
1981	--	--
1988	--	--
1992	--	--

Note: Estimates depend on the scale and accuracy of historic maps and scale and resolution of air photos.

observed since 1966, partly due to: 1) gravel extraction just upstream which greatly reduced sediment supply during the time of its operation; 2) gravel extraction further upstream which reduced the volume of sediment supplied to the lower reaches initiating bed degradation (Lehre and others, 1993); and 3) confinement of the channel by bank stabilization projects which also decreased sediment supply to the reach by not allowing bank erosion and prevented channel widening and braiding.

Analysis of Geomorphic Variables

Wavelength, amplitude, and radius of curvature were greatest at Graham bar (RM 3.3 to 2.2) in 1948 before significant mining and flooding occurred (table 20). Values for 1992 approach those of 1948, indicating a return to the form observed 50 years ago, before flooding and extensive gravel extraction.

Bank Erosion

Rates of bank erosion and bar accretion near Graham bar ranged from 40 to 108 ft/yr (12 to 33 m/yr) and were generally greatest during the period of extensive mining and severe flooding between 1953 and 1970 (table 21). Figure 29 shows the wetted channel in 1948, 1958, and 1992 and lateral migration near Graham bar.

Sinuosity

Changes in sinuosity are consistent with other geomorphic variables (figure 30, Appendix M). Meanders grew until impacts of gravel extraction during the 1950's, 60's, and 70's and flooding in 1955, 1964 and 1972.

Table 20 -- Geomorphic variables (feet), Graham bar meander, lower Mad River, 1941-42 to 1992

Year	River Mile	Wavelength	Amplitude	Radius of Curvature	Notes
1941-42	2.5	3,100	940	670	medial bar
1948	2.6	4,400	1,380	860	meander growth; mining starts
1954	2.5	2,900	1,070	680	increased mining/confinement
1958	2.5	2,800	890	500	1955 flood; extensive mining
1962	2.5	3,100	1,120	660	extensive mining/trenching
1966	2.4	3,500	990	690	1964 flood; extensive mining
1970	2.4	3,600	990	680	multiple threads due to mining
1974	2.4	3,200	890	530	multiple threads due to mining
1981	2.4	3,900	970	710	single thread, riparian recovery
1988	2.4	4,100	920	660	1986 flood; single thread
1992	2.4	4,200	1,100	760	single thread, riparian recovery

Note: Table reports mean values along Graham bar between River Mile 3.3 and 2.2. Estimates depend on the scale and resolution of aerial photographs.

Table 21 -- Bank erosion/bar accretion, Graham bar, lower Mad River, 1941-42 to 1992

Time Period	Length (ft)	Mean Width (ft)	Area (acres)	E/A †	Rates†† (ft/yr)	River Mile	Notes
1942 to 48	2,000	240	11.0	E	40	2.2-2.5	braiding by 1948
	1,350	240	7.4	E	40	2.5-2.7	meander growth
	2,000	330	15.2	E	55	2.7-3.0	"
1948 to 54	2,300	310	16.4	E	52	2.3-2.6	meander growth
	2,100	400	19.3	E	67	2.6-2.8	"
	2,500	440	25.3	E	73	2.8-3.2	"
1954-58	1,000	125	2.9	A	31	2.5-2.7	rip veg growth
	2,000	310	14.2	E	78	2.7-3.1	flooding, mining
1958-62*	--	--	--	--	--	--	"
1962-66	4,700	270	29.6	A	68	2.3-2.9	rip veg growth
	3,900	300	26.8	E	75	2.3-2.9	flooding, mining
	840	420	8.1	E	105	2.3-2.5	channel widening
1966-70	2,600	430	25.7	E	108	2.6-3.1	extensive mining
	890	230	4.7	A	58	2.3	rip veg growth
1970-74*	--	--	--	--	--	--	extensive mining
1974-81	2,900	550	36.6	A	79	2.5-3.0	no trenching
1981-88*	--	--	--	--	--	--	rip veg growth
1988-92*	--	--	--	--	--	--	"

E/A† = erosion (E) vs. accretion (A)
Rates†† = mean rate of bank erosion or bar accretion
* no change in low water channel position
Note: Table reports mean values along Graham bar between River Mile 3.3 and 2.2. Estimates depend on the scale and resolution of aerial photographs.

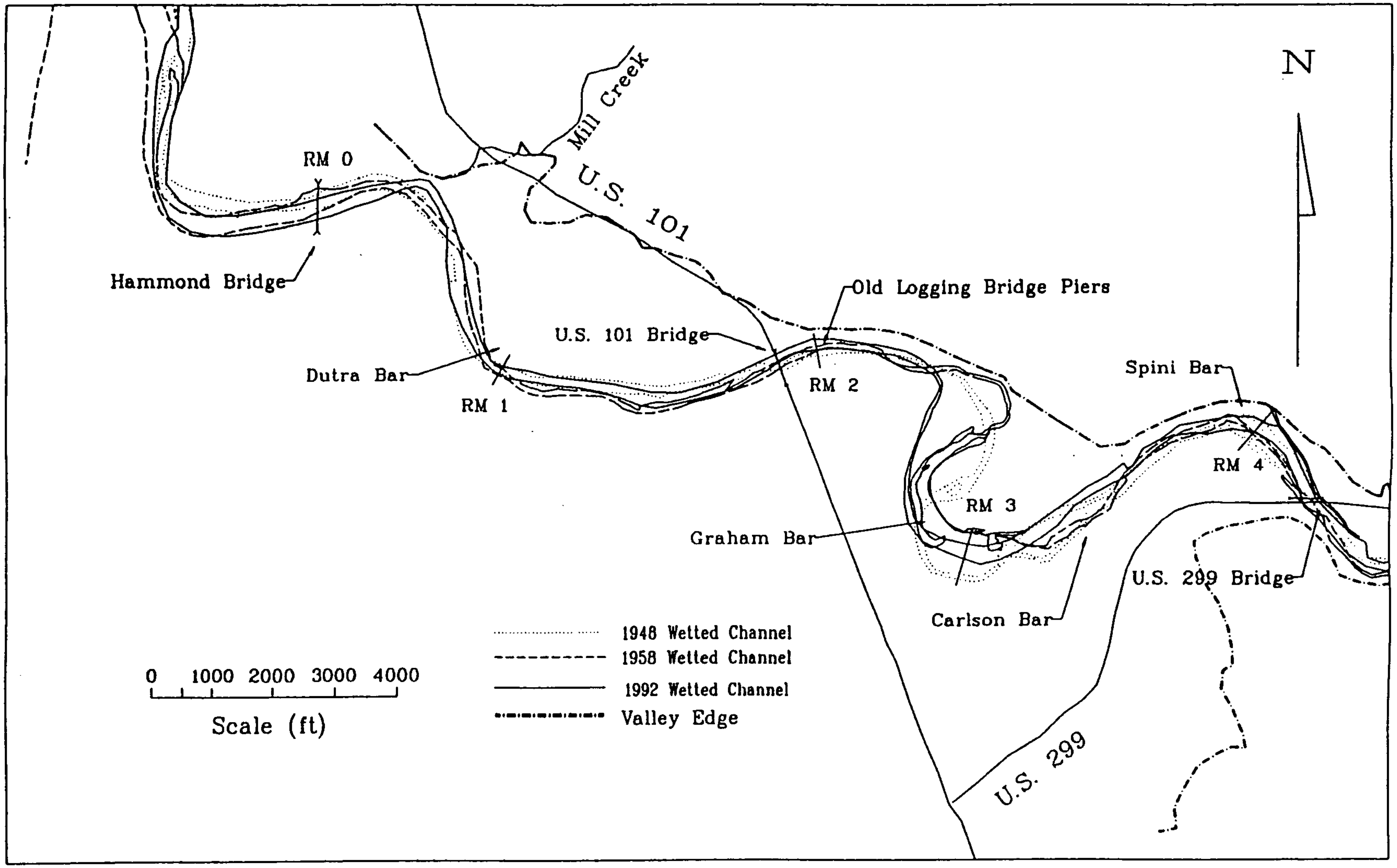
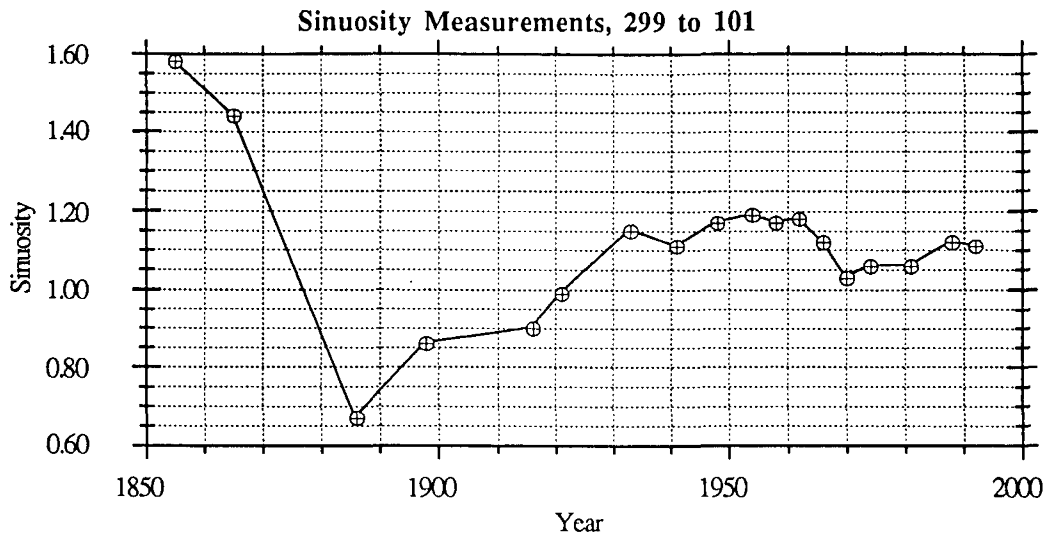


Figure 29 -- Wetted channel in 1948, 1958, and 1992, near Graham Bar, lower Mad River



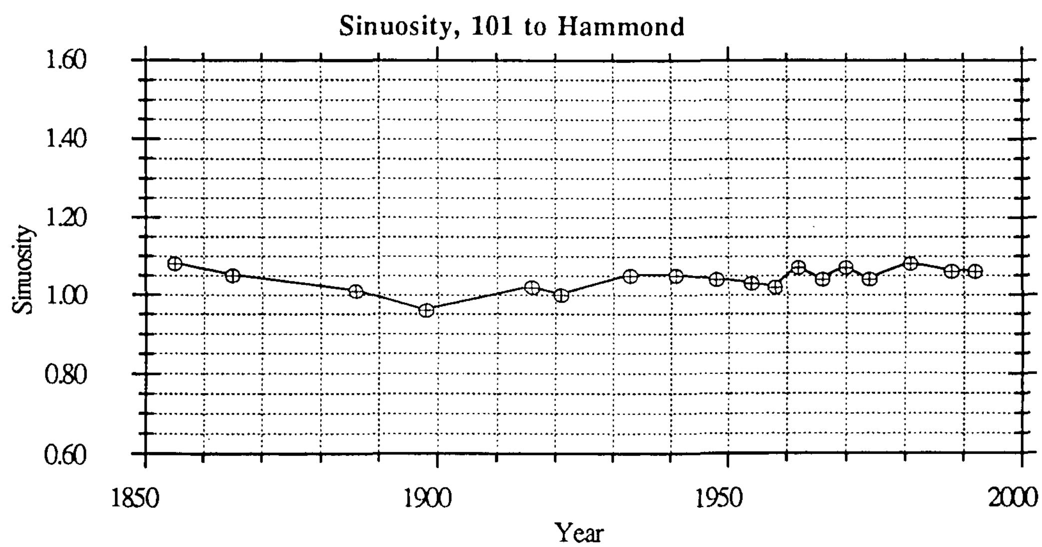


Figure 30 -- Sinuosity, 299 to Hammond bridge, lower Mad River, 1855 to 1992

Volume of Bed Erosion

I estimated a minimum of 1,260,000 yd^3 (963,000 m^3) of material was removed from storage between 299 and 101 and 550,000 yd^3 (420,000 m^3) between 101 and the Hammond bridge between 1962 and 1992. Spread evenly over the active channel, the bed lowered approximately 6.3 feet (1.7 m) between 299 and 101 and 4.8 feet (1.5 m) between 101 and Hammond bridge from 1962 to 1992 giving lowering rates of 0.21 to 0.16 ft/yr (0.06 to 0.05 m/yr).

d) Summary of Historic Conditions of the 299 Bridge to the Hammond Bridge Reach

Construction of a canal in 1854 for rafting logs from the Mad River into the Mad River Slough was the first human induced change affecting the channel. The channel was subsequently disturbed by the rafting of logs downstream in the 1870's. The river overflowed its banks during floods in the late 1800's. The river was confined by artificial means during the early 1900's. Following a relatively dry period large scale gravel extraction began in the 1950's, initiating bed lowering. The banks steepened as gravel was removed and sediment hungry flood waters scoured the bed and banks. Bed lowering rates were greatest during the 1960's when road construction and gravel extraction rates were correspondingly highest and have averaged approximately 0.21 to 0.16 ft/yr (0.06 to 0.05 m/yr). Approximately 1,655,000 yd^3 (1,265,000 m^3) of material was removed from storage between 299 and Hammond by bed lowering between 1962-92, or about 55,000 yd^3/yr (42,000 m^3/yr) primarily due to gravel extraction. Spread evenly over the active channel between 299 and the Hammond bridge, the bed lowered approximately 5.2 feet (1.6 m) from 1962 to 1992 giving a lowering rate of 0.17 ft/yr (0.05 m/yr).

D. BED ELEVATION AND VOLUMETRIC CHANGES

1. Bed Elevation Changes

a) <u>Hatchery to Blue Lake</u>

Hatchery Weir

Communication with Roy Camozzi, long-time Hatchery employee (pers. comm., 1994; Appendix D) indicated possible bed lowering at the Mad River Fish Hatchery weir of 4-6 feet over the past 7 years. He noted that the boulders positioned on the downstream side of the weir to prevent scour had dropped significantly. Larry Preston, from the California Department of Fish and Game (pers. comm., 1995) also observed bed scour on the downstream side of the weir. Both wondered if knick-point migration from gravel extraction downstream was occurring. Observations indicate a maximum lowering rate of 0.57 ft/yr (0.17 m/yr) to 0.86 ft/yr (0.26 m/yr) over the past 7 years (Roy Camozzi, pers. comm., 1994). Some of this lowering may be from local scouring due to weir hydraulics; some may be a result of gravel extraction downstream. The relative amounts of each one are not known.

Blue Lake Bridge

Klein (Lehre and others, 1993) reported bed degradation at the Blue Lake (Hatchery Road) bridge that ultimately led to failure of the structure in 1981. He estimated a mean bed lowering between 1962 and 1992 of 3 feet (0.9 m) along the reach and suggested that the constriction at the bridge resulted in bed scour exceeding the mean for the reach. Lehre estimated maximum local bed lowering between 1982 and 1991 of 4.5 feet (1.4 m) and a mean bed lowering of 1.6 feet (0.5 m) at this site (Lehre and others, 1993).

b) Blue Lake to A&MRR

Oral histories indicate that aggradation occurred following the 1964 flood and blasting of Sweasey Dam (Christie, pers. comm., 1994; Evans, pers. comm, 1994; Leavey, pers. comm., 1994; Appendix D). After the removal of Sweasey Dam and high water in 1972, Jim Leavey observed that the river bed elevation had raised to the level of his lower field (pers. comm., 1994; Appendix D). Today the top of this bank is approximately 6-8 feet (1.8-2.4 m) above the water surface. Both Elmer and Isabel Evans thought fine silt was blown around Blue Lake in the few years following dam removal (pers. comm., 1994; Appendix D). Sherry Christie noticed that the river has recently uncovered some of the old bank protection works constructed in the 1940's on her property (pers. comm., 1994; Appendix D). Leslie Christopherson (pers. comm., 1994; Appendix D) noted that the river was filled with riffles in the Blue Lake valley after the blasting of the dam. He thought the river was shallower and warmer as a result. The river seemed to him to be recovering today; more holes were observed. The bed, he said, seems to be dropping. One indicator of this he described had to do with tributary creeks. He noted that steelhead and salmon used to migrate and spawn up these creeks (Kelly Creek, Mahoney or Palmer Creek, and Quarry Creek). Today the mouths of these creeks are inaccessible to the fish, probably due, he thought, to dropping of the river bed, migration of the channel, and choking with vegetation at the mouths. He noted the bank at Leavey's is steeper and higher relative to the river bed now than it used to be in the 1970's. Field observations show degradation at the mouth of Mill Creek, consistent with oral histories and observations by Klein, who reported local channel bed scour near the Blue Lake bridge and Mill Creek (Lehre and others, 1993). Klein estimated a mean bed lowering of approximately 3 feet (0.9 m) for the reach over the past 30 years. Elmer Evans, long-time resident of Blue Lake, indicated one would probably have had to "dig down 3 feet (0.9 m) or more to get to cobble-sized material" after deposition of fine sediment released from behind Sweasey Dam in 1970 (pers. comm., 1994; Appendix D). Fred Bott thought the channel near Christie bar had raised since the 1964 flood (pers. comm., 1994; Appendix D). He observed the channel used to have cutbanks and point bars, but now there are no banks left - the stream channel is flat and wide. He thought the landowner on the southwest side of the river probably lost 1,000 feet (300 m) of property after the 1964 flood.

Discussion with Sherry Christie (pers. comm., 1994; Appendix D) indicates the channel has only recently migrated back toward where the banks on her property were once protected by wing dams and rip rap in the late 1940's. Some of these old structures are being uncovered today.

John Nichols, Bob King, and Bob Carmesin, all gravel operators on the Emerson and Blue Lake bars, indicated old rip rap boulders were found on the Blue Lake bar at a depth of 10 to 12 feet (3.1 to 3.7 m), suggesting the river's bed had aggraded at that point (pers. comm., 1994; Appendix D). However, these probably reflect point bar growth and meander migration. The river has migrated toward the opposite side of the valley since the rip rap was put in and may be incising into its present bed.

Mean bed lowering between the Hatchery and the A&MRR bridge was estimated by Lehre and others (1993) to be approximately 3 feet (0.9 m) between 1962 and 1981. This gives a mean bed lowering rate over 19 years of 0.16 ft/yr (0.05 m/yr), almost identical to the rate of bed lowering I estimated at the A&MRR bridge (see below) of 0.17 ft/yr (0.05 m/yr) over the last 40 years based on exposure of an alder tree on the right bridge pier (Appendix O). It appears likely that most of the bed lowering along the upper reach has occurred since approximately 1975, following:

1) flooding between 1964 and 1975 (annual peak discharges averaged 37,600 cfs during this period - aggradation;

2) blasting of Sweasey Dam in 1970 - aggradation;

3) drought (annual peak discharges averaged 20,700 cfs during this period) and subsequent low recruitment rates - degradation;

4) continued gravel extraction in excess of recruitment - degradation (Lehre and others, 1993).

Most lowering near the A&MRR bridge may have occurred prior to 1975. I present evidence supporting this claim in the next section.

c) A&MRR to 299

A&MRR Bridge

The A&MRR bridge was originally built in 1887; it collapsed in 1896 and was rebuilt in the same year ("Early Days of Humboldt", Blue Lake Advocate, April 11, 1957, Mrs. Eugene F. Fountain, Historian; Isabel Evans, Blue Lake Historical Society & Museum, pers. comm., 1995). Figure 22 shows the bridge before approximately 1935 (the school in Essex closed in the mid 1930's and the town was abandoned around the same time, Isabel Evans, Blue Lake Historical Society & Museum, pers. comm., 1994; Syd Ayers, pers. comm., 1995; Appendix D). Figure 24 shows the bridge in 1968. Photogrammetric measurements from the bridge truss to the bed surface in each photo indicate that the distance was approximately 34 feet (10.4 m) in 1935; 39 feet (11.9 m) in 1968; and based on field observations, 42 feet (12.8 m) in 1993 (figure 31).

Lowering rates ranged from 0.15 ft/yr (0.05 m/y) between 1935 and 1968 to 0.12 ft/yr (0.04 m/y) between 1968 and 1993. I cored and age dated a tree growing on the right pier and determined it was 40 years old in 1993 (Appendix O). I assumed the tree began growing on the bridge pier when the bed was at the elevation of the top of its root system. The bed has lowered approximately 6.9 feet (2.1 m) in 40 years, a rate of 0.17 ft/yr (0.05 m/yr), consistent with historic photograph estimates and those by Lehre and others (1993). John Nichols (pers. comm., 1994; Appendix D) remembered a bar near the mouth of Lindsay Creek (between the Essex bar and the Johnson bar) was approximately 12 feet (3.7 m) high before it was mined during the 1970's. Much of the bed lowering near the bridge may have occurred at the time the bar was mined.

Humboldt Bay Municipal Water District Ranney Collectors

Figure 32 shows evidence of bed lowering at the Humboldt Bay Municipal Water District's Ranney Collector Pump Station Number 1. Photogrammetric measurements show the bed has lowered a minimum of 9 feet (2.7 m) between 1962 and 1992, a lowering rate of 0.30 ft/yr (0.09 m/yr). Nearby mining at Mercer-Fraser's Essex bar peaked in the 1960's (70,000 to 100,000 tons (98,000 to 140,000 yd^3) would be stockpiled during a season) and came to a halt by about 1973 (Fred Bott, pers. comm., 1994; Appendix D). Most bed lowering may have occurred before about 1973 based on dates of

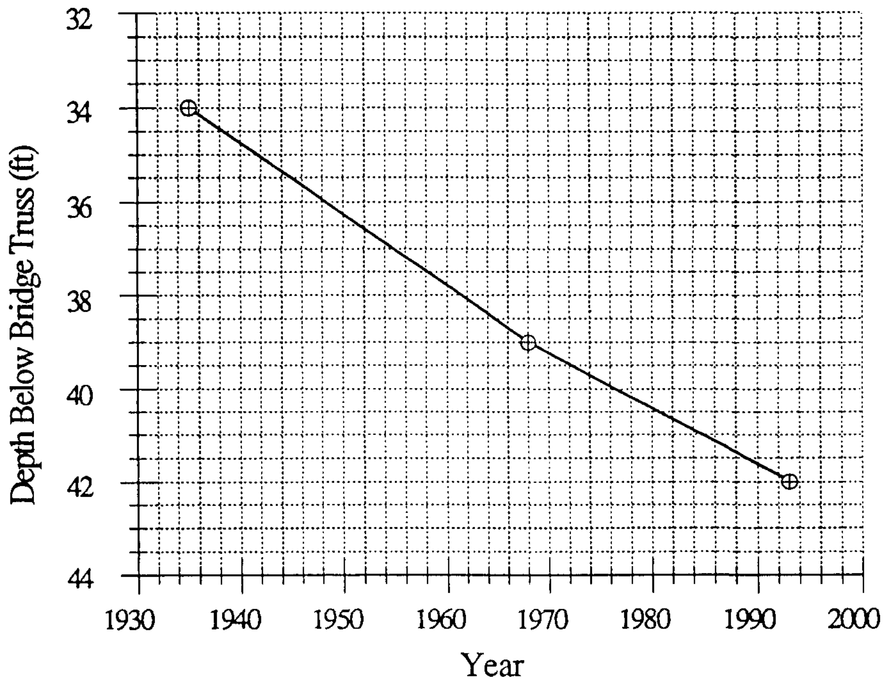


Figure 31: Bed lowering at the A&MRR bridge between 1935 and 1993 based on photogrammetric measurements (1935 & 1968) and field observations of distance below base of bridge in 1993

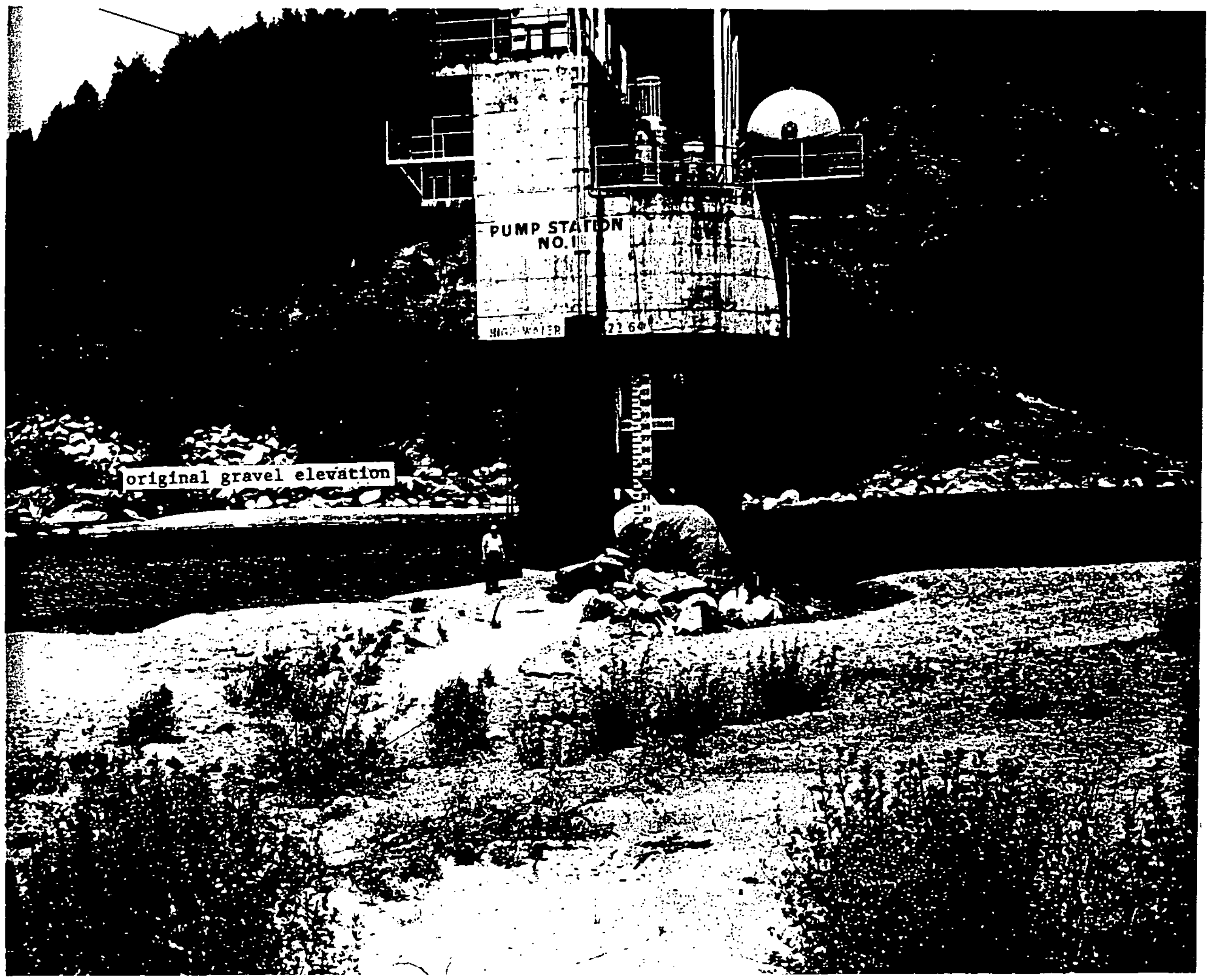


Figure 32 -- Humboldt Bay Municipal Water District's Ranney Collector Pump Station Number 1

removal of gravel, oral histories, air photo observations of mechanical manipulations of the channel, and cross-section data.

USGS Cableway and Gaging Station

Photogrammetric measurements from an historic photo of a bridge at the present USGS cableway (figure 23), indicate approximately 20-25 feet (6.1-7.6 m) of bed lowering over the past 61 to 87 years (Appendix P). Bed lowering rate estimates at the USGS cableway range from 0.23 to 0.41 ft/yr (0.07 to 0.12 m/yr).

In 1965 the USGS replaced its stilling well with a manometer gage (Jerry LaRue, USGS, retired, pers. comm., 1995; Greg Susich, USGS, pers. comm., 1995; Appendix D). The stilling well and static tubes were never removed, however, and I was able to obtain another bed lowering estimate by comparing the elevation of the static tube (installed at the river's thalweg prior to 1965) with the current elevation of the manometer orifice (at the present thalweg). I obtained an elevation difference of 16.4 feet (5 m) giving a bed lowering rate of 0.55 ft/yr (0.17 m/yr) over the last 30 years. USGS staff also noted that a rock outcropping along the left bank immediately above the 299 eastbound span was not visible during the late 1960's and has subsequently become more exposed since that time as has a telltale rock (used to judge whether the river was wadeable for discharge measurement purposes) just upstream of the gage (Greg Susich, pers. comm., 1995; Appendix D).

Hickey (1969) measured 4.7 feet (1.4 m) of scour at the USGS gaging station (Mad River near Arcata, Calif., #11-4810) between 1956 and 1965. This gives a rate of 0.52 ft/yr (0.16 m/yr) over 9 years indicating a net lowering of 21.1 feet (6.4 m) at a rate of 0.54 ft/yr (0.16 m/yr) at the gaging station site between 1956 and 1995. Sediment removal from the channel was noted in the report.

299 Bridge

Repeated cross sections analyzed by Lehre and others (1993) indicate a maximum amount of bed lowering of 22.1 feet (6.7 m) between 1941 and 1991 and a mean lowering of 16.6 feet (5.1 m) (0.33 ft/yr (0.1 m/yr)) between 1947 and 1991 for the eastbound span (built in 1947, figure 33). The westbound span (built ca. 1960) shows maximum bed lowering of 13.7 feet (4.2 m) between 1960 and 1991 and a mean lowering of 7.8 feet (2.4 m) (0.25 ft/yr (0.07 m/yr)). Discussion with Bob King and Bill O'Neill (pers. comm., 1994; Appendix D), gravel operators downstream of the bridge, suggests very little change over the past 25 years or so. Both of them inferred the shape of the cross section run in 1941 appeared "unnatural" and suggested that the line drawn to represent the bed surface actually represented the water surface elevation. They pointed out that the true bed surface at that time would have been lower and scour at the bridge was overestimated by Lehre and others (1993). O'Neill estimated about 3 feet (0.9 m) of lowering at the 299 bridge and 3.5 feet (1.1 m) of scour along the river near his operations (Spini bar) since the westbound span of 299 was built (between 1962 and 1966). This is consistent with estimates by Lehre and others (1993) that show approximately 3.5 feet (1.1 m) of mean lowering since 1972. Based on field data at the USGS stilling gage, air photo and oblique photo observations, cross section data, and oral histories I believe most bed

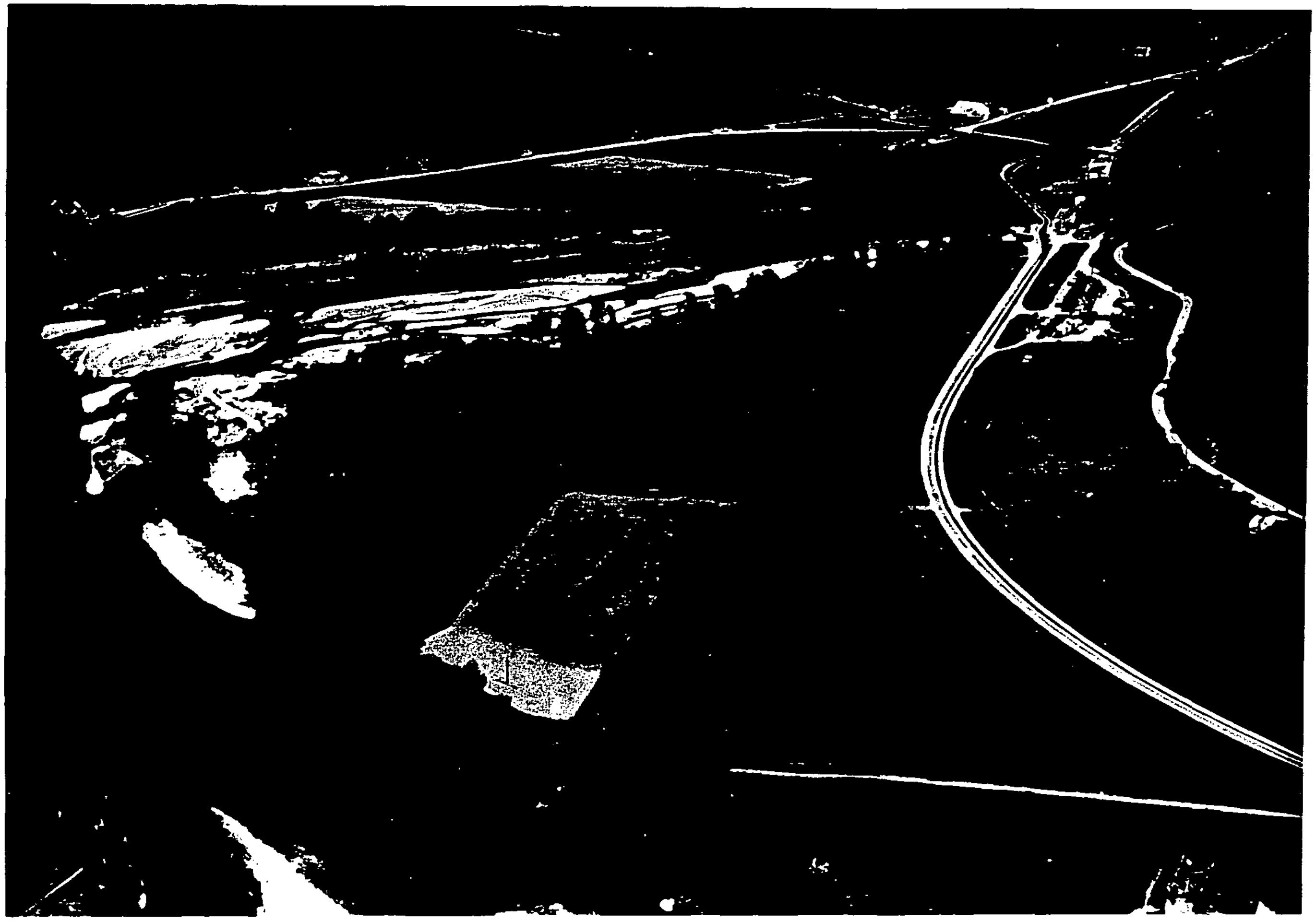


Figure 33 -- Mad River at 299 (April 25, 1947). View northeast, looking upstream. Note bridge construction. (Photo by Merle Shuster, courtesy of Don Tuttle, Hum. Co. Public Works Collection, Natural Resources Dept.).

lowering occurred before 1972 at the latest, during the period of most intensive in-stream mining up- and downstream of the bridge.

Mean yearly lowering rates along the reach for the period 1960 - 1992 obtained by Lehre (Lehre and others, 1993) ranged from 0.11 to 0.27 ft/yr (0.03 to 0.08 m) and averaged about 0.15 ft/yr (0.02 m). My measurements ranged from 0.12 ft/yr (0.04 m/y) to 0.55 ft/yr (0.17 m/yr) and are consistent with estimates by Lehre, et al (1993). Table 22 summarizes bed degradation measurements used along the reach.

The USGS received a Streambed Alteration Agreement from the California Department of Fish and Game in 1962 to construct a boulder weir at their gaging station above 299 which functions as a datum control by maintaining a minimum water level at the gage intake (Laird, 1994). The weir increases the river's slope above 299 which could promote scouring downstream near the bridge. Collins and Dunne (1989, 1990) and Kondolf (1993) describe geomorphic and environmental effects of instream gravel mining including channel incision which can undermine bridge piers. Several structures along the river including the Blue Lake bridge, the A&MRR bridge, the eastbound span of the Highway 299 bridge, two abandoned bridge piers upstream of 101, and the 101 bridge show evidence of scour at their bases (Lehre and others, 1993). Kondolf (1993) reports that scour caused by hydraulic adjustment to bridge piers usually stabilizes "within a few years of construction". This suggests the undermining of most of the structures may be attributed to overall removal of sediment from the system. The 299 bridge may also suffer some scour from the hydraulic effects of weir just upstream.

Table 22 -- Summary of bed degradation measurements used between the A&MRR bridge and the 299 bridge

Site	Period	Time Range (yr)	Maximum Lowering (ft)	Mean Lowering Rate (ft/yr)	Source
A&MRR Bridge	1935-68	33	5.0	0.15	Historic Photos; (figures 22, 24)
	1953-93	40	6.9	0.17	Tolhurst; (tree ring study, Appendix O)
	1968-93	25	3.0	0.12	Historic Photo; (figure 24)
	1935-93	58	8.0	0.14	Historic Photo; (figure 22)
Ranney Collector 1	1962-92	30	9.0	0.30	Historic Photo; (figure 32)
USGS well gage	1965-95	30	16.4	0.55	Tolhurst; (field observations)
Former Bridge at USGS cableway	1906-93	87	25.0†	0.29	Historic Photo; (figure 23)
	1906-93	87	20.0††	0.23	Historic Photo; (figure 23)

† maximum lowering estimate for this photo
†† minimum lowering estimate for this photo

d) <u>299 to Hammond</u>

Gravel extraction has affected the reach significantly. Instream mining was thought to have had an effect on the fish runs as far back as 1921 as noted in the Blue Lake Advocate:

> " . . . The mouth of the river is in shape to allow fish to come in but for some reason they are scarce as compared with runs in previous years. The water is not clear which is attributed by many to the gravel operations of Englehart Construction Company at the lower county bridge." ("Few Salmon in Mad Rivrei [sic]", *Blue Lake Advocate,* October/November, 1921).

A local rancher lost a team of horses in the same gravel pit which was "12 feet deep" at Carlson bar, near Shaw's crossing ("Horses Drowned Near Here", *Blue Lake Advocate,* July 4, 1925). The effects of this pit on the channel are unknown, but generally pits create the opportunity for bed degradation both up and downstream (Kondolf, 1992). Air photo observations show extensive mechanical manipulations of the channel near Graham bar in the 1960's and 1970's. Field observations and some of the oral histories indicate bed degradation along the reach. The banks fronting Ben Spini's property (just downstream of 299 along the right bank) are much steeper and higher now than what they were when he was a child in the 1930's (Spini, pers. comm., 1995, Appendix D). Spini (pers. comm., 1995, Appendix D) indicated that Shaw's crossing (RM 3.5) used to be forded by "horse and buggy" in the 1930's. A rock outcropping at Shaw's crossing is not visible in air photos taken in the 1940's, but does become increasingly exposed in sequential air photos (Appendix H). Some controversy exists around bed degradation along the reach and Bob King of Redwood Empire Aggregates (on Graham bar) has indicated that two culverts put in between 1958 and 1962 show no evidence of scour or bed lowering since they were built (pers. comm., 1994, Appendix D). Based on observations at two bridge piers upstream of the 101 bridge (figure 34; see also Appendix R) the bed has lowered approximately 7.2 feet (2.2 m) in 103 years (maximum length of time) giving a minimum lowering rate of 0.07 ft/yr (0.02 m/yr). Findings by Lehre and others (1993) indicate that most bed lowering occurred before 1972. Air photo observations of extensive mining along Graham bar between 1954 and 1962 and a decrease in subsequent years (Appendix H) suggest most bed lowering may have occurred before 1962.

101 Bridge

The northbound span of the 101 bridge (figure 35) was constructed in 1929 (Arlene Hartin, CalTrans, pers. comm. 1994); the southbound span was built ca. 1960. Repeated cross sections analyzed by Lehre and others (1993) indicate a maximum amount of bed lowering of 17.0 feet (5.2 m) between 1929 and 1989 and a mean lowering of 15.1 feet (4.6 m) (0.30 ft/yr (0.09 m/yr)) over the same period for the east span (Appendix S). The west span shows bed lowering of 8.2 feet (2.5 m) between 1957 and 1989 and a mean lowering of 4.8 feet (1.5 m) (0.15 ft/yr (0.05 m/yr)). Based on air photo observations, cross section data, and oral histories I believe most bed lowering occurred before the culverts at Graham bar were put in (before the 1964 flood according to Bob King, pers. comm., 1994; Appendix D) during the period of most intensive in-stream mining.

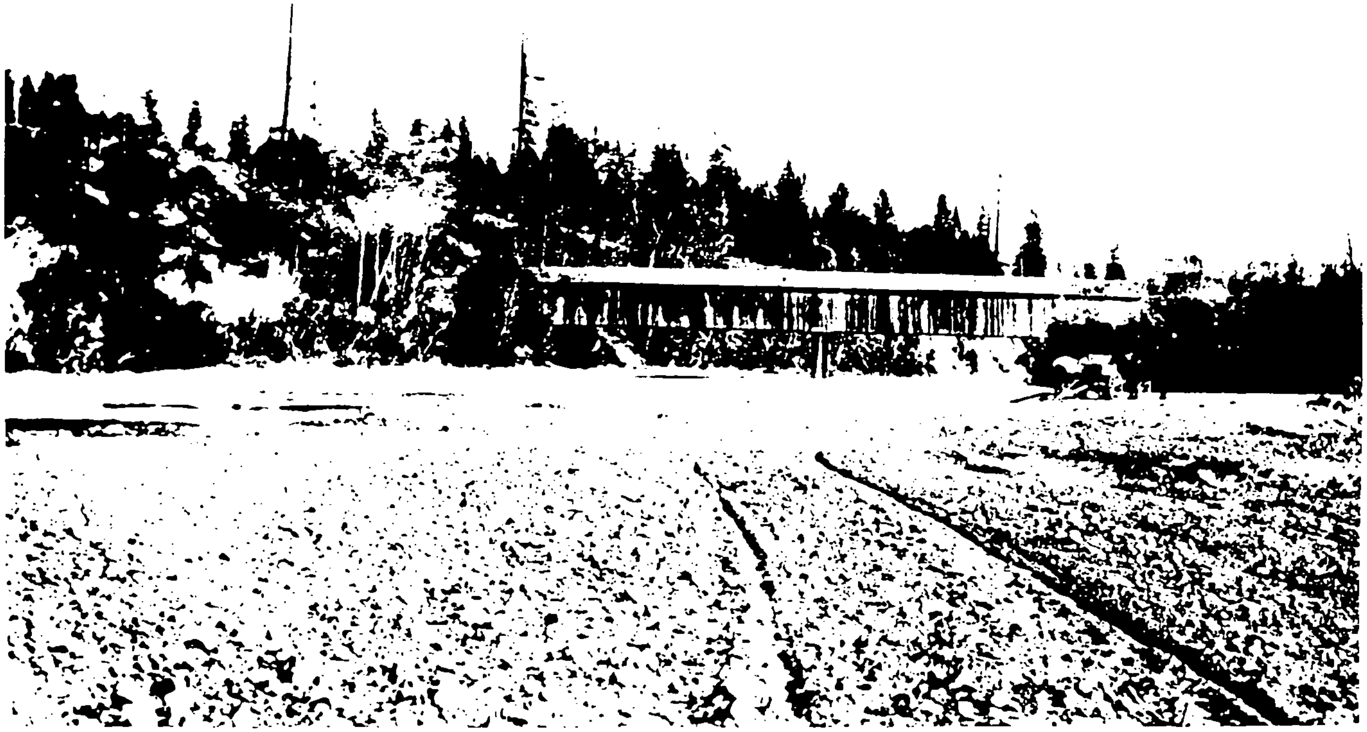


Figure 34 -- Mad River -- "the old timber bridge looking east on (from) 101". The bridge was built in about 1891 and was removed in 1931 (see Appendix R). The two piers are still seen in the river today. Note the grain size of bed material is much larger than that observed today. Also note horse and buggy on gravel bar. Photo was probably taken around the turn of the century. (Photo from Bob Krieger collection (originals in CalTrans' Sacramento office), courtesy of Don Tuttle, Hum. Co. Public Works Collection, Nat. Resources Dept.).

Figure 35 -- Mad River bridge at highway 101 in 1929. View west (downstream) from the old timber bridge (see figure 29). Note bed elevation at the base of the right bank. (Photo from Bob Krieger collection (originals in CalTrans' Sacramento office), courtesy of Don Tuttle, Humboldt County Public Works Collection, Natural Resources Dept.).

Table 23 lists mean bed lowering over the active channel area for the lower Mad River between 1962 to 1992. Spread evenly over the entire active channel between the Hatchery and the Hammond bridge, the bed of the Mad River lowered approximately 5.1 feet between 1962 and 1992.

The following data supports overall bed lowering along the lower Mad River: 1) incision at the bridge sites; 2) incision reported in oral histories; 3) incision observed at the mouths of tributary creeks; 4) incision observed at the Ranney collectors; 5) incision observed at the USGS cableway and gaging station; 6) incision observed at the abandoned bridge piers above 101; and 7) bank steepening reported in oral histories and observed on air photos. The data is consistent and suggests that the lowering rates and cross-sections are representative of net degradation.

2. Volume of Bed Erosion

According to Lehre and others (1993) gravel extraction rates that have exceeded the river's bedload transport rate estimates for the past 40 years (figure 15) have helped contribute to a net decrease in sediment storage through the reach. Sediment recruitment has been relatively low over the last 19 years, which have been drier than normal (Appendix E). Lehre (1993) reported, "mean annual decreases in the volume of stored sediment in the lower Mad River" are "in close agreement with the amount by which extraction exceeded bedload recruitment". He concluded that excessive channel bed lowering along the lower Mad River resulted from "extraction of channel bed sediments at rates exceeding bedload recruitment" and reported a long term bedload recruitment rate of approximately 150,000 cubic yd^3/yr (115,000 m^3/yr), a minimum estimate of

Table 23 -- Mean bed lowering over the active channel area, lower Mad River, 1962-1992

Reach	Average Lowering (ft)
Hatchery to Blue Lake	5.4
Blue Lake to A&MRR	4.5
A&MRR to 299	5.7
299 to 101	6.3
101 to Hammond	4.8
Total	5.1

425,000 yd^3 (325,000 m^3) of sand and gravel extraction per year, and a mean deficit rate of 225,000 - 275,000 yd^3/yr (172,000 - 210,000 m^3/yr) since 1960.

I used the following method to estimate bed erosion volumes for the lower Mad River, reported in table 24. Mean active channel area was calculated from 12 air photo sets (1941/42, 1948, 1954, 1958, 1962, 1966, 1970, 1974, 1981, 1988, 1992) and lowering rates were obtained from Lehre (1993). The 12 data sets used here are more comprehensive than the three years of data used by Lehre and give a better representation of mean active channel areas. Reduction rates of the volume of stored sediment were estimated to be 230,000 yd^3/yr (176,000 m^3/yr). This deficit rate suggests gravel extraction in excess of natural recruitment may be responsible for all of the bed lowering observed over the past 30 years. Lehre (1993) computed a bed sediment budget for the Mad River channel between the Hatchery and 101 using three different methods: 1) comparison of recruitment and extraction volumes; 2) comparison of bedload transport rates at Arcata and Blue Lake; and 3) comparison of cumulative extraction and bed lowering. The methods are consistent with one another and suggest that "bed lowering is strongly connected to gravel extraction" (Lehre and others, 1993).

Historical data indicate gravel extraction is connected to bed degradation. Hickey (1969) reported bed lowering at the USGS gage at 299 following the flood of 1964 even when almost all other rivers in the area showed excessive aggradation. He noted sediment was being removed from the Mad River at that time. Oral histories also show intensive mining has contributed to bed lowering (Appendix D). Following World War II, the

Table 24 -- Bed erosion volumes and lowering rates, lower Mad River, 1962-1992

Reach	Mean Active Channel Area†	Lowering Rate Upper End	Lowering Rate Lower End	Mean Lowering Rate	Volume Removed (1962-1992)	Volume Removed (1962-1992)
	ft²	ft/yr	ft/yr	ft/yr	ft³	yd³
Hatchery to Blue Lake	6,200,000	--	0.18	0.18	33,480,000	1,240,000
Blue Lake to A&MRR	17,900,000	0.18	0.12	0.15	80,550,000	2,980,000
A&MRR to 299	4,100,000	0.12	0.26	0.19	23,370,000	870,000
299 to 101	5,400,000	0.26	0.16	0.21	34,020,000	1,260,000
101 to Hammond	3,100,000	0.16	--	0.16	14,880,000	550,000
Total (1962-1992)	36,700,000	--	--	--	186,300,000	6,900,000
Yearly average (1962-1992)	--	--	--	--	6,210,000	230,000

† -- 1941-42 to 1992

Note: Estimates were made by multiplying the area of each reach by the average of the mean lowering rates at each end (after Lehre and others, 1993).

watershed was significantly altered by logging and roadbuilding. Seven of ten of the most significant floods of record occurred during the 1950's and early 1960's (Appendix F), yet the channel still showed evidence of net degradation (Appendix D). The dynamiting of Sweasey Dam in 1970 released 3,200,000 yd^3 (2,400,000 m^3) into the channel and net degradation has continued (Appendix D). Additionally each rate of bed lowering measurement obtained consistently ranged between 0.12 and 0.26 ft/yr (0.04 and 0.08 m/yr). These observations along with those of Lehre et al (1993) indicate gravel extraction and bed lowering are connected.

E. OTHER OBSERVATIONS BETWEEN SWEASEY AND HAMMOND

1. Riffle Spacing

The number of riffles per mile decreased between 1962 and 1992 (table 25). Disturbance of the channel by mining practices has caused loss of riffle habitat by removal of surface armoring (Randy Klein, pers. comm., 1994) and by a loss of bars since riffles are created by flow over bars (Tom Lisle, pers. comm., 1995).

2. Riparian Zone Observations

Table 26 shows riparian vegetation area for the lower Mad River (see also Appendix T). The riparian corridor has fluctuated in size due, in part, to the effects of land clearing in the 1940's and early 1950's, then large magnitude flooding and gravel extraction from the mid 1950's to mid 1970's. The riparian zone has generally grown in size since the 1970's due to the absence of large magnitude flooding.

3. Woody Debris Observations

Haynes (1986, p. 30) reported a Wiyot village "overlooked a large logjam at the lower end of the meander [at the present Valley West site]" indicating woody debris was an integral part of the riparian system prior to anglo settlement. A report on a storm in 1859 shows the natural propensity of the river to transport and store woody debris before widescale landuse changes:

> "With the falling of the River on Friday morning the roads in the vicinity were choked with drift wood and blocked by immense

Table 25 -- Riffle spacing, lower Mad River, 1962-1992

Year	Distance Between Hatchery & 101 (miles)	# Riffles	Riffles / Mile
1962	9.87	37	3.7
1974	9.60	34	3.5
1991	9.43	27	2.9
1992	9.80	25	2.6

Note: Data gathered from large scale air photo observations (1" = 200').

Table 26 -- Riparian zone areas (acres), lower Mad River, 1941-42 to 1992

Year	Sweasey to Hatchery	Hatchery to Blue Lake bridge	Blue Lake to A&MRR	A&MRR to 299	299 to 101	101 to Hammond
1941-42	115	436	706	109	147	71
1948	152	387	504	87	137	81
1954	164	326	379	81	124	38
1958	122	369	332	85	134	56
1962	N/A	213	476	92	149	62
1966	N/A	15	273	78	97	66
1970	134	195	278	70	127	74
1974	150	134	173	98	124	60
1981	N/A	135	319	91	92	74
1988	N/A	148	398	75	158	54
1992	157	154	553	72	164	63

Note: Areas calculated by subtracting active channel area from riparian area. 1964 flood scars were observed along the floodplain between the Hatchery and Blue Lake.

> logs and trees . . . " ("The Freshet", *Northern Californian*, November 16, 1859).

Woody debris has been systematically cleared from the channel since that time partly to protect booms and bridges across the channel:

> "A large pile of driftwood, stumps, trees, etc. during high water had been deposited against the boom near the bulkhead, causing a jam . . . " ("Mad River, *Weekly Humboldt Times*, February 26, 1881).
>
> "The summer bridge across Mad River between Blue Lake and West End was damaged and the approaches were undermined by debris which piled up against it . . ." ("3 Weeks' Rain Wreaks Havoc In This Sector", *Blue Lake Advocate*, January 18, 1936).

Oral histories indicate the river used to have lots of "drift piles and debris" that created shaded pools where fish could find shelter and cool water (Christopherson, pers. comm., 1994). During the 1950's and 1960's the channel was "cleaned out" near Blue Lake (O'Neill, pers. comm., 1994) probably by Fish and Game as a policy to improve fish habitat was implemented (Christopherson, pers. comm., 1994). Jack McKellar, U. S. Army Corps of Engineers, retired, said the policy in the 1960's was to remove debris that threatened to accumulate on bridges by clearing the channel (pers. comm., 1994). Contracts were let to salvage merchantable material or pile the refuse up for burning. In the last 20 years or so, less woody debris has accumulated in the channel partly due to drought and the absence of high flows and partly due to removal from the channel by humans (Fred Bott, Roy Camozzi, Bob King, Jim Leavey, John Murray, John Nichols, Bill O'Neill, pers. comm., 1994) and a decreased supply from upstream after logging (Tom Lisle, pers. comm., 1995).

X. CONCLUSIONS

The Mad River has undergone cycles of erosion and deposition related to changes in sediment production and extraction in the drainage basin. Flooding, human activity in the watershed, and mechanical manipulations of the channel have significantly changed the pattern and form of the river. Significant flooding occurred: 1) in 1861-62; 2) during the late 1870's to about 1910; and 3) from 1951 to 1974. Logging and roadbuilding coincided with these periods. Gravel extraction increased during the second period and peaked around 1970. Sediment production and channel changes were greatest during these two time periods.

Riparian vegetation was removed from the banks of the river by: 1) the rafting of logs in the 1860's and 1870's; 2) clearing of the Arcata Bottoms by farmers between 1850 and the 1890's; 3) bank stabilization projects of the early 1900's; 4) mechanical manipulations of the channel by mining and channelization between the 1950's and the 1970's; and 5) flooding (1861-62, 1890, 1953, 1955, and 1964). Log rafting, land clearing, and flooding destabilized the banks while rip rapping and mechanical manipulations helped confine the channel in places.

The river is confined between Sweasey Dam and the Hatchery and has maintained a relatively stable pattern. The reach degraded following the construction of Sweasey Dam in 1938, then aggraded after the dam's removal in 1970. In approximately 24 years the dam filled with more than 2,000 acre-feet (3,200,000 yd^3 or 2,400,000 m^3) of sediment. A bedload transport rate was estimated at approximately 108,000 to 161,000 yd^3/yr (83,000 to 123,000 m^3/yr). It will probably take 35 to 40 years for the channel to recover from the effects of impoundment.

In the 1950's, 1960's, and early 1970's the channel between the Hatchery and the A&MRR bridge (Blue Lake valley) increased in width, aggraded, and decreased in sinuosity following flooding and mechanical manipulations of the channel. Since approximately 1975 the channel has narrowed, degraded, and sinuosity has increased as the channel has continued its return to a more stable pattern. Overall the bed has lowered an average of about 5.0 feet (1.5 m) along the reach.

Between the A&MRR bridge and the 299 bridge few lateral changes were observed. Old air photos showed large point bars before extensive gravel extraction began in the 1950's. Since that time the bed has incised up to 20 to 25 feet near the 299 bridge. A mean of 5.7 feet (1.7 m) of bed lowering was measured, spread over the active channel.

The lower reach, between the 299 and Hammond bridges, was confined by the early 1900's and has changed very little in pattern since. Some widening near Graham bar occurred following flooding in the 1950's and 1960's. The channel incised an average of 5.6 feet after intensive in-stream mining mostly between the early 1950's and the early 1960's.

Gravel extraction has been controversial in terms of contributing to channel incision. Over the past 30 years the rate of bedload recruitment has been estimated to be approximately 150,000 yd^3/yr (115,000 m^3/yr). This rate may be artificially high. Conservative extraction rates for sand and gravel have been estimated at 425,000 yd^3/yr (325,000 m^3/yr) for the same period. A mean annual deficit for the period amounts to 275,000 yd^3/yr (210,000 m^3/yr). The volume of stored sediment decreased by approximately 185,000 yd^3/yr (141,000 m^3/yr), primarily the result of channel bed lowering.

Incision threatens the following bridges across the river: 1) the A&MRR bridge; 2) the 299 bridge; and 3) the 101 bridge. The majority of bed degradation along the lower Mad River over the past 30 to 40 years can be attributed to gravel extraction far in excess of natural recruitment. In order to prevent further bed degradation, gravel extraction should not exceed natural bedload recruitment rates.

The channel's pattern and form recovered by about 1950 following intensive land use changes coupled with flooding in the late 1800's and early 1900's. After another significant wave of road building, logging, gravel extraction, and mechanical manipulations of the channel coupled with flooding between 1950 and 1975, the channel appears to be recovering as evidenced by sinuosity values comparable to those before 1950.

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Appendix A:

Historic Newspapers Used:

Newspapers Cited	Location	Other Information
Alta California	Humboldt State University Library	MF 225, 1849 to 1891
Arcata Union	Humboldt State University Library	MF713, January 1886 to present; print kept until MF rec'd
Blue Lake Advocate	Humboldt County Historical Society Humboldt State University Library	May 1, 1888 to April 25, 1936 (in print) MF2191, 1913; 1914; 1947; 1959 to April 3, 1969; scattered issues 1908-1958 (in print)
Daily Humboldt Times	Humboldt State University Library	January 1874 to May 1967 (see also Times-Standard)
Democratic Standard	Humboldt County Public Library	1877 to May 1881; June 1882 to November 1883
Ferndale Enterprise	Humboldt State University Library	MF719, May 1878 to present; print kept until MF rec'd
Humboldt Standard (Daily edition)	Humboldt State University Library	MF9, 1884 to September, 1967
Humboldt Standard (Weekly edition)	Humboldt County Public Library Humboldt State University Library	January 1888 to August 1905 MF8, 1876 to 1883 (incomplete)
Northern Californian	Humboldt County Public Library Humboldt State University Library	December 1858 to July 1860 MF284, v.1 (1856), v.2 (1860)
Pacific Sentinel	Humboldt State University Library	MF 2091, June 14, 1856 to June 6, 1862
Times-Standard	Humboldt County Public Library Humboldt State University Library	June 1967 to present MF10, 1854 to 1908 (weekly edition); 1874-present (daily edition); kept until MF rec'd
Union Democrat	Humboldt State University Library	MF247, July 8, 1854 to June 4, 1870
Weekly Humboldt Times	Humboldt County Public Library	September 1854 to December 1908

Appendix B:

Historic Map Coverage of the lower Mad River:

1855-74 Rectangular Survey Index Map (surveys in 1855, 1858, 1874), U. S. Department of Interior, Bureau of Land Management (available on microfiche in the Arcata office)

1865 Official Township Map of Humboldt County, California, by A. J. Doolittle (available from the Humboldt Room, Humboldt State University Library)

1886 Official Map of Humboldt County, California, by Stanley Forbes (available from the Humboldt Room, Humboldt State University Library)

1898 Official Map of Humboldt County, California, by J. N. Lentell (available from the Humboldt Room, Humboldt State University Library)

1916 Corps. of Engineers, U.S. Army Map (surveys in 1909 & 1916) (courtesy of Aldaron Laird, Trinity Restoration Associates)

1921 Belcher Abstract and Title Company Map, Eureka, California (available from the Humboldt Room, Humboldt State University Library)

1951 Blue Lake Quadrangle, 15 Minute Series, United States Dept. of the Interior, Geological Survey (Topography by plane table survey in 1933 and from aerial photographs by photogrammetric methods 1942) (available from the Humboldt State University Geology Department Collection)

1951 Eureka Quadrangle, 15 Minute Series, United States Dept. of the Interior, Geological Survey (Topography by plane table survey in 1933 and from aerial photographs by photogrammetric methods 1942) (available from the Humboldt State University Geology Department)

1959 Arcata North Quadrangle, 7.5 Minute Series (photorevised in 1972), United States Dept. of the Interior, Geological Survey, (Topography from aerial photographs by photogrammetric methods and by planetable surveys 1959. Aerial photographs taken 1956) (available from the Humboldt State University Geology Department Collection)

1959 Arcata South Quadrangle, 7.5 Minute Series (photorevised in 1972), United States Dept. of the Interior, Geological Survey (Topography from aerial photographs by photogrammetric methods and by planetable surveys 1959. Aerial photographs taken 1956) (available from the Humboldt State University Geology Department Collection)

1979 Blue Lake Quadrangle, 7.5 Minute Series, United States Dept. of the Interior, Geological Survey (Topography by photogrammetric methods from aerial photos taken 1972. Field checked 1973) (available from the Humboldt State University Geology Department Collection)

1979 United States Dept. of the Interior, Geological Survey, Korbel Quadrangle, 7.5 Minute Series (Topography by photogrammetric methods from aerial photos taken 1972. Field checked 1973) (available from the Humboldt State University Geology Department Collection)

1985 Geology and Geomorphic Features Related to Landsliding, Korbel 7.5' Quadrangle, Humboldt County, California; completed by Richard Kilbourne, Geologist, California Department of Conservation, Division of Mines and Geology (available from the Humboldt Room, Humboldt State University Library)

Appendix C:

Aerial Photo Coverage of the Lower Mad River:

Note: All photo sets available from the Humboldt County Public Works, Natural Resources Department, 1106 2nd St., Eureka, CA 95501

1941 / 1942 Set
(flight dates: November 6, 23, 25, 1941, February 16, March 3, 1942)
CVL-3B-31
CVL-3B-32
CVL-3B-33
CVL-3B-34
CVL-6B-12
CVL-6B-13
CVL-6B-83
CVL-6B-84
CVL-6B-85
CVL-9B-80
CVL-9B-81
CVL-9B-82
CVL-9B-83
CVL-9B-147
CVL-9B-148
CVL-10B-135
CVL-10B-136

1948 Set
(flight dates unknown)
CDF2-19-63
CDF2-19-64
CDF2-19-65
CDF2-19-154
CDF2-15-31
CDF2-15-32
CDF2-16-64
CDF2-16-126
CDF2-16-178

1954 Set
(flight dates: July 25, August 3, September 11)
CVL-02N-006
CVL-02N-007
CVL-02N-121
CVL-02N-122
CVL-13N-090
CVL-13N-091
CVL-13N-141
CVL-13N-142
CVL-14N-020

CVL-14N-021
CVL-14N-022
CVL-14N-023
CVL-14N-024
CVL-14N-115
CVL-14N-116

<u>1958 Set</u>
(flight dates: August, September)
HU-9-35
HU-10-34A
HU-11-36
HU-12-33
HU-13-34
HU-14-33
HU-15-30
HU-16-26
HU-16-27
HU-16-29
HU-17-25
HU-17-26
HU-18-25

<u>1962 Set</u>
(flight dates unknown)
HCN-2-12-38
HCN-2-12-39
HCN-2-13B-12
HCN-2-14-38
HCN-2-15A-36
HCN-2-17-33
HCN-2-18A-33
HCN-2-19A-29
HCN-2-19A-31
HCN-2-20-28
HCN-2-20-29
HCN-2-20-30
HCN-2-21-31
HCN-2-21-32
HCN-2-21-33
HCN-2-22-28
HCN-2-22-29

<u>1966 Set</u>
(flight dates unknown)
HC-66-15B-48
HC-66-15B-49
HC-66-16B-49
HC-66-17B-50
HC-66-18-41

HC-66-19-106
HC-66-20-100
HC-66-21B-82
HC-66-21B-83
HC-66-22-96
HC-66-22-98
HC-66-22-99
HC-66-23B-43
HC-66-23B-44
HC-66-24A-92
HC-66-24A-93
HC-66-25-43

1970 Set
(flight dates: July, September)
CH71-R25-18
CH71-R24-33
CH71-R24-34
CH70-23B-43
CH70-23B-44
CH70-R22A-38
CH70-21B-81
CH70-21B-82
CH70-21B-85
CH70-20-94
CH70-R20-95
CH70-19-87
CH70-18B-5
CH70-17B-55
CH70-16B-52
CH70-15B-52
CH70-15B-53

1974 Set
(flight dates unknown)
HC74-4-16B-47
HC74-4-16B-48
HC74-4-17A-49
HC74-5-18A-50
HC74-5-19-92
HC74-6-20-86
HC74-6-21B-2
HC74-7-22A-3
HC74-7-22A-4
HC74-7-22A-5
HC74-7-23A-44
HC74-7-23A-45

<u>1981 Set</u>
(flight dates: June, July)
CDF-ALL-EU-14-20
CDF-ALL-EU-14-21
CDF-ALL-EU-14-22
CDF-ALL-EU-12-20
CDF-ALL-EU-10-20
CDF-ALL-EU-10-21
CDF-ALL-EU-10-22

<u>1988 Set</u>
(flight dates: March, April, July)
WAC-88CA-2-29
WAC-88CA-2-45
WAC-88CA-6-172
WAC-88CA-20-152
WAC-88CA-20-153
WAC-88CA-20-154
WAC-88CA-20-155
WAC-88CA-24-48

<u>1992 Set</u>
(flight date: April 1, 1992)
WAC-92CA-5-74
WAC-92CA-4-100
WAC-92CA-6-43
WAC-92CA-15-7

Appendix D:

Oral Histories of the Geomorphic Conditions of the Lower Mad River

Notes from interview with Syd Ayers, long time Blue Lake and Korbel resident:
June 6, 1995

I spoke with Syd over the phone today. He was born in 1911 (84 years old) in Korbel. He said the river used to be on the West End side in the 1930's and 1940's and shifted sometime after that to about where it is today. Before the turn of the century his father reported the river used to flow past Riverside. After a very large flood the channel headed straight toward Blue Lake and eroded about 1,500 acres of land; ranches were washed away.

There were lots and lots of fishing holes from Sweasey Dam all the way down to the A&MRR bridge that he remembered. Holes near Camp 6 and Camp 16 (between Sweasey and the Hatchery) were 20 to 24 feet (6.1 to 7.3 m) deep before Sweasey was blasted. There used to be spawning grounds in the Mad River near Blue Lake and in all of the tributary creeks according to Syd. He used to spear salmon, when it was legal, in pools below Blue Lake. The river there was narrower and deeper then (he could easily toss a rock across the channel and the pools were "easily over my head"). He used to catch King Salmon that reached up to 55 pounds on the river. He also said a cottonwood forest near the confluence of the North Fork and the Mad River (west-southwest side) was much more extensive before the 1950's.

Since gravel extraction, the holes below the hatchery have disappeared along with the spawning grounds ("there are no holes at all now"). He said gravel operations "changes spawning grounds altogether". He also suggested that logging has impacted the channel, but not as much as gravel operations. Earlier logging style was not as disruptive as post World War II logging with cats, roadbuilding, etc. He thought "moving dirt off of the mountains really does damage". He used to be involved in that kind of work he said, so he really saw the impact. He noted that the earlier railroad stream crossings were done by driving piles into the ground and running a trestle across. Later crossings involved pushing sediment into the creek over buried culverts.

Logging up the North Fork may have introduced quite a bit of sediment into the system. He remembered the watershed when it was just stumps. He and some of the Indians made $1 per day cutting sprouts off of redwood stumps so that they wouldn't grow back. Some of the land was being used to graze cattle. Boxes 4 ft X 4 ft X 12 ft (1.2 m X 1.2 m X 3.7 m) deep were filled with rocks and nailed shut, then placed along the banks of the North Fork (from Camp Bauer to below Riverside) to prevent bank erosion. He told me that he was there when Riverside was shut down in 1929 due to the Depression. He also noted a big "pothole" near Riverside, along the North Fork, was the source of gravel used to construct the railroad grade up the North Fork in the early 1920's.

Lindsay Creek was dammed so that logs could be floated along the Fieldbrook valley flat. Bulls used to pull the logs weren't able to drag them across the valley floor, thus the pond was constructed so that they could be floated instead. The dam was removed during his time though he couldn't remember exactly when (1930's). He remembered Mercer-Fraser was on the Essex bar back then. He thought the town of Essex disappeared during the 1930's.

Notes from interview with Fred Bott, retired manager of Mercer-Fraser gravel plant at Essex:
July 18, 1994

I spoke with Fred by phone today. He said he's been on the Mad river since 1943 and retired in 1992 (49 years). He turned over operations to his son, Bill, upon retiring.

The Mercer-Fraser (MF) Essex Lane property is 13 acres in size and dates back to about 1928. For a long time (including when Fred arrived) MF was the only operator on the river. MF ran the only asphalt plant in the region during Fred's early years. Gravel was hauled from the Mad river as far as Orick for different projects. (Further north, gravel was extracted from the Klamath river for construction jobs). Excavators were used for digging gravel from below the water surface until around 1973. A hole would be dug in the river during high flow and gravel would be removed and stockpiled for later use. As the flow continued, the hole would fill in with gravel recruited from upstream. 70,000 to 100,000 tons (98,000 to 140,000 yd^3 (75,000 to 107,000 m^3) would be stockpiled during a season. MF hauled gravel exclusively from the Mad river to build the Trinidad freeway (4 lane 101 highway bypassing McKinleyville, continuing through Westhaven and Trinidad, on to Big Lagoon) during the 1960's. Fred said they pulled a lot of gravel for that project.

Fred also mentioned that gravel was mined from a bar between the 101 bridge and the Hammond Trail bridge during the 1960's. The bar was owned by Frank Dutra and was used to build part of 101 north of the river. Topsoil was scraped off, stockpiled and later sold as a deep pit was dug at the site. The operation was adversely affected by the tidal prism and the site was apparently abandoned after the job was completed. Gravel extraction downstream of 101 generally has not been done due to the influence of the tidal prism and confinement of the river, limiting bar development.

We discussed the Timmon's bar area, where the Ranney collectors are located. The Humboldt Bay Municipal Water District's wells have had a poor performance history, according to Fred. MF did some of the contracting work to build coffer dams and fish barriers to keep fish from being sucked into some of the wells (which had to be perforated to increase performance).

MF stopped most gravel extraction at the Essex site in 1975. They were being outcompeted economically by S&A Development, a non-union employer upstream and they had lost the ability to extract gravel from below water level in 1973, after the Department of Fish and Game regulations became effective, among other factors.

Fred thought the bed elevation had remained about the same during his years on the river at Essex. His opinion is based on observations of a weir he built into the river. The weir was constructed on the right bank near the Essex plant approximately 30 years ago and it still exists. He said it extends about 150 feet out into the river and was constructed by driving wood pilings into the river bed, then rip rapping the pilings with boulders to protect them from high flows and debris. None of the pilings have scoured out and the river bed elevation hasn't changed over that time according to Fred.

I asked about the effects on the channel of the construction and operation of Ruth dam. He replied the river seemed to remain the same before and after impoundment. He didn't notice any changes to the channel.

We talked about the bed lowering near the 299 bridge. He pointed out that the upstream span was built by MF in the late 1940's (construction is shown on an oblique air photo dated 1947). About 100 feet above the bridge he noted there was bedrock. The river bed can't lower any more at that point. In order to compensate, he thought the bed scoured downstream, under the bridge. He said when the bridge was built, pilings were driven into the bed as far as they could go, without hitting bedrock. Forms were used to pour concrete around the pilings to construct the piers. His opinion about piers built on river beds was the idea wasn't a good one. He thought the extra cost in spanning a river should be endured in the short term in order to prevent the scouring effect observed around piers, such as the center pier under 299.

Fred talked with me about the effects of the blasting of Sweasey Dam. He noted the Guynup and Emmerson bars built up just afterward. He said the river gravel was "dirtier" after the dam was blown. He noticed more fines/silts in the gravel then. Now, some 24 years later, the gravel is, what he called, "thin", meaning there aren't as many fines - the size distribution is not as wide, or great, as it once was.

The 1964 flood altered the channel, according to Fred. He said the channel near Christie bar has raised on account of braiding; the river has run rampant through that reach. He said it loses energy and sediment drops out. The landowner on the southwest side of the river probably lost 1000 ft. of property after the flood. He said the gradient is flatter now through that reach, producing a braided stream. There used to be cutbanks and point bars, but now there are no banks left; the stream channel is flat and wide.

Fred thought the biggest change on the river was the encroachment onto the riverbed of vegetation. The drought and subsequent lack of high water over the last 7 or so years has produced a situation where high flows aren't available to wash away vegetation, keeping the bars devoid of plants. It used to be that you could look up and down the river for greater distances when there was less vegetation.

There also used to be more woody debris in the river. Fred said there were "tremendous amounts of trees" coming down the river during high flows. He thought there was bank erosion occurring upstream of the Hatchery, which would cause trees to fall into the river and float downstream. He also said loggers would leave "broken trees, tree tops", etc. after their operations and these would be carried downstream by large flows. He noted that logging conditions had improved and this was no longer the case, saying the stream is "cleaner" now. He also said the dry period is probably causing an increase in erosion potential since the drought is presumably affecting vegetation - there's less vegetation now since plants are stressed and more soil is exposed to erosion potential.

I asked if the quality of gravel on the Mad has changed through time. He said the gravel is primarily sandstone (as it is on the Eel river) and is of "good" quality. The specific gravity gets up to about 2.4, whereas on the Trinity river it gets up to 2.9, the gravel there is better, being derived from igneous and metamorphic sources.

Notes from interview with Marjorie Bussman, long-time Blue Lake resident: Feb. 25, 1994

I spoke with Marjorie today at the Humboldt County Historical Society library. She is a long-time resident of the Blue Lake/Korbel area.

One of the main ideas she conveyed was that the river underwent constant change through time. After each flood the swimming holes would change to a different location. Also the channel migrated from near West End road to its present position near Blue Lake a few decades ago [1950's].

I asked if she could remember what the river was like back in the 1920's and 1930's when she was a young woman. She said the channel below West End road was more confined - it didn't spread out like it does today. She thought it was one channel rather than braided. She also thought there may have been more vegetation along the reach from Blue Lake to the A&MRR bridge than in recent years.

She also said the main swimming hole near Blue Lake would change from just downstream of the present location of the Hatchery to just downstream of the old county bridge across the main channel near West End road. There was also a swimming hole in the North Fork, upstream of the present confluence with the main fork. She couldn't tell me if the depths of the swimming holes had changed or not after the blasting of Sweasey Dam.

She also said that since the revetment was built, the North Fork hadn't overflowed its banks to fill the old lake (Blue Lake) and that the creek that flows into old Blue Lake (downstream from her ranch) had decreased in volume over the years (maybe due in part to logging? wells drilled? drought? - she wasn't sure).

Interview with Bob Carmesin, REA employee & heavy equipment operator on the Blue Lake bar (has been on the river for past 16 years): October 28, 1994

I talked with Bob over the phone this morning. He said he dug up a car body while excavating the upstream pit on the Nichols/Blue Lake bar this past season. The car body was at the water level, which he thought was down approximately 10 feet below the bar surface [field checks show its closer to 7-8 feet]. Another 8 feet down he hit some boulders that he thought might have been used as rip rap during construction of the Blue Lake levee. These boulders were located approximately 10-20 feet out from the north end of the pond/pit and extended 30 or so feet downstream (northwest).

Bob thought the river bed had raised "quite a bit" in the past. He also dug into a silty material mixed with logs and sticks on the Emmerson bar pit. The material was struck at about 10 feet below the pond's water level (which was probably 6 feet below the bar's bed elevation). The pocket was approximately 20 feet around, located toward the middle of the pond on the east side, in from the east edge about 30 feet. Bob thought the deposit signified a backwater pond that had trapped the debris and fine sediment and it may have represented the bed elevation at one time.

Bob has noticed the river's migration to the south, south-west, as it has eroded the rancher's property on the other side of the river (Leavey's property). He confirmed John Nichols' observations that a row of trees had once lined the left bank and was now gone, having been removed by erosion.

Interview with Roy Camozzi, Dept. of Fish and Game, Mad River Fish Hatchery: October 31, 1994

I visited with Roy Camozzi, who has worked at the Mad River Fish Hatchery since 1975 (longest of any of the employees there). He said the river has not changed very much near the Hatchery since he's been there. The left bank was protected with rip rap during construction of the Hatchery, which opened in 1971. The river has always flowed along the left bank at the site since 1975. He said there was very little, if any, vegetation at the Hatchery when he first arrived and since it was built (he's examined photos of the site and was able to make this statement based on the photographic evidence). Now the vegetation has grown up extensively at the site -- lots of willows, alder, and some cottonwoods along with brush. There were some logs strewn about on the lower levels (below the treatment tanks) that had been deposited by the 1986 flood (49,000 cfs at Arcata gage). He said the water elevation had reached 99 feet at their staff gage. The 1972 (54,400 cfs at Arcata gage) flood had crested at 100 feet -- he remembered from talking with the original crew that worked at the Hatchery in 1971.

He took me to the weir to explain its construction and history. He said initially they had a cable system that allowed them to lower electric probes into the water. These would act as a barrier to fish, diverting them into the fish ladder along the left bank. During high water, however, fish could migrate around the system along the right bank, thus bypassing the ladder. The electric system ultimately proved ineffective, as well as controversial, and was abandoned at least 7 years ago when the newer weir was constructed. The cableway is still seen across the river. The new weir extends approximately 2/3 to 3/4 of the way across the channel and is made of concrete. A number of pilings extend approximately 40 feet down into the river bed, anchoring the structure. Roy said he thought the gravel was at least 100 feet deep at this spot -- these borings along with water wells drilled didn't hit any bedrock. The weir was poured level with the river bed and boulders were put in on the downstream side, acting as an apron to protect against scour as water flowed over it. A steel fencing, angled downward toward the upstream side to allow debris and logs to flow over during high water, acts as a fish barrier. A gate along the left bank allows fish passage into the ladder. The boulders have dropped approximately 4-6 feet along the left bank over the past 7 years. This was the only evidence he knew of showing bed lowering. He thought the drought and resulting lack of recruitment, coupled with gravel extraction downstream may have had something to do with the bed lowering over the past 7 years. He said Larry Preston (Dept. of Fish and Game) has made water elevation measurements at the weir since it was put in and he has noticed the bed has been dropping at a rate of about 1 foot per year. Roy was aware of bed lowering near the Ranney collectors, mentioning the problems they've had with siltation.

He also said they have 18 ground water wells that supply the Hatchery with its water. 80% of the water is recycled and they end up pumping at a rate of about 4 cfs/day, which is also what they discharge back into the river. Roy said they haven't had any problems with siltation, even though he's observed the Mad River gets pretty muddy in the winter. They maintain their wells by flushing them annually. The pumps are generally set at around 45-50 feet down. Four of them are directly on the river's banks.

Roy mentioned that about 15 years ago a fierce storm with 100 mph winds swept through the area and just above the Hatchery, and to the southwest, 400 acres of trees were blown down on Simpson property. They were concerned about the potential for siltation problems following removal of the trees by Simpson, but were assured that sediment traps and reseeding would be done. It was and Roy said he noticed no problems even though rains were heavy that winter. He thought Simpson did an excellent job controlling the sediment on the slopes. He said the stand was second growth; old growth was logged behind the Hatchery about 85 years ago, according to a local old timer with whom he had spoken.

I asked Roy about other changes along the reach. He said he hadn't paid attention to grain size differences or bed elevation changes. He did say that in the past when there were larger flows, large logs 150 feet or so in length, would come floating downstream. There was more woody debris in the river due to these flows. Now since we're in a "drought" condition, we haven't had the flows to bring the material downstream. He acknowledged that woody debris was important to the smaller fish in the river in terms of providing needed habitat. He said he'd also spoken with local fishermen upstream about the summer run. They seemed to think that the runs had diminished somewhat due to past logging practices, but that the run wasn't in danger of becoming extinct now that logging style had changed. These fishermen were quite observant and knowledgeable and were able to distinguish summer run fish from others after questioning by Roy, so he trusted their judgment. Another observation he made centered around the right bank downstream and erosion its undergone. The bank is on Simpson property and has retreated as the channel migrates northeastward. Simpson has dumped boulders into the channel in attempts to divert the flow away from the bank. These boulders are visible from the Hatchery as is the area of bank erosion.

<u>Notes from interview with Sherry Christie, owner of Christie Bar property: July 13, 1994</u>

I spoke with Sherry Christie, longtime Blue Lake resident and owner of the Christie bar property. She has resided on the ranch adjacent to the bar for a long time and remembers the channel changes described below.

In the 1940's bank stabilization activities occurred along the right bank. Old car bodies filled with gravel, sluice boxes filled with dirt/gravel, and railroad ties were commonly used on the property in attempts to stabilize the banks of the river. [1947 oblique air photo shows some of this work along the right bank, outer bend]. Sherry said these efforts ultimately produced little success. Before the flood of 1964, the Christie's owned approximately 70 acres of river bed. Afterwards they owned approximately 300 acres of river bed. [This means about 230 or so acres of agricultural land was eroded by the flood]. Sherry observed that the river was confined to a narrow, meandering channel before the flood. Following the flood, the river's channel was widened significantly and became braided. She seemed to think the flood had washed away a significant portion of land, but since then the bars have been building up until recently. She didn't know if the aggradation was due to Sweasey's blasting or other reasons, but her impression was that overall the bed was rising during the late 1960's and through the 1970's. Only recently has the bed begun the cut back down through its deposits to expose some of the bank stabilization work they had done earlier (some of the railroad ties and sluice box tops are just now beginning to show as the river migrates laterally). She inferred the dry years we've been experiencing are partly responsible as recruitment has been below average and the bed is eroding into the deposits of the 1960's and 1970's.

Sherry used to ride her horses up to 25 miles upstream (not quite as far as Butler Valley). She noticed the reach between Sweasey and Blue Lake change drastically after the blasting of the dam. Fishing and swimming holes filled in with sediment; they were once > 15 feet deep. She said when fishing in the river they might hook a salmon that would stay submerged in deep water for quite some time before it would ever surface. Today this wouldn't commonly happen since the deep fishing holes have filled with sediment. The Simpson Timber Company used to have a floating dock or platform upstream of the Hatchery in a popular hole. Swimmers used to be able to dive off into very deep water (> 15 ft.). This is no longer the case. She thought the channel was still feeling the effects of the release of stored sediment from behind the dam.

Notes on interview with Leslie Christopherson, property owner near the intersection of West End and Hatchery roads:
January 9, 1995

I spoke with Leslie by telephone today. He was born in Blue Lake and has lived on the river for all of his life (66 years, he was born in 1928). He lives approximately 0.5 miles up West End from Hatchery road, on the south side of the road (the white house on the left). As a youth he remembered spending time at school picnics along the river, which has changed in many ways since then. The channel has migrated from bank to bank through time. He noted there used to be many holes along the river -- deep pools where he would fish for trout, etc. He said there used to be lots and lots of drift piles and debris in the Mad River and in the North Fork where fish would find shelter and cool water. He used to frequent these pools in order to fish, knowing they were good sites. He said that a fad came along later, which was to clean out the drift piles and debris in the river (he thought the idea was promoted by the Department of Fish and Game to improve fish habitat). Leslie observed that the drift piles also provided shade for the fish.

He described the river as having "raw banks", which he said meant that the banks were devoid of vegetation (eg. in places where bank erosion was occurring). I asked if he had observed how most bank erosion occurred along the river near Blue Lake. Leslie thought most bank erosion occurred as the water was receding, following flooding -- when the water goes down. The two main processes he thought were involved included 1) bank collapses; and 2) water flowing directly over the "raw banks", eroding material directly into the stream. He and his father had noticed that in most cases when big "chunks of dirt" would fall into the river there was gravel overlain by finer silty material. He thought longer (in duration) floods do the most damage to banks. He noted that vegetation played an important role in preventing bank erosion -- to a degree. He has also observed the collapse of large trees into the river, which introduces sediment attached to the root wads into the channel. Smaller vegetation (willows, etc.) acts to hold the banks together, but also has shallower root systems and can be undercut. He wasn't sure which type of vegetation was best for preventing bank erosion. I asked about the role of beavers along the river. He said he thought there were probably more beavers along the river today than in the past, but that he wasn't sure since it may have been that he didn't pay as close attention to the beaver population when he was younger. He had a problem with the "bank beavers" chewing into cottonwood trees along the banks because he grazes cattle on the flood plain and his fear is that some trees might fall onto, and kill, his cattle since some of the trees invariably fall away from the banks.

Leslie thought the river was generally deeper downstream of the Hatchery before the blasting of Sweasey Dam. He said there were several nice, deep swimming holes that swimmers could dive into with no worries of hitting bottom. These holes existed before the 1960's and 1970's. After the blasting of the dam he observed lots of fine silt and sand-sized sediment in the river. He also told me that he observed draglines were used at the dam to transport material downstream as it filled with sediment and sandbags were used to help increase the capacity of the reservoir. Only now does the channel downstream, near Blue Lake, seem to be recovering as holes are returning. He also observed that sediment was deposited downstream of the dam all the way to Blue Lake, filling in fishing and swimming holes and pools that had previously existed along that reach. He noted the river was filled with riffles in the Blue Lake valley after the blasting of the dam. He thought the river was shallower and warmer as a result.

The river seemed to him to be recovering today; more holes observed. The bed, he said, seems to be dropping. One indicator of this he described had to do with tributary creeks. He noted that steelhead and salmon used to migrate and spawn up these creeks (Kelly, Mahoney or Palmer, and Quarry Creeks). Today the mouths of these creeks are inaccessible to the fish (he said they are farther from the river than they once were), probably due, he observed, to dropping of the river bed, migration of the channel, and choking with vegetation at the mouths. He said the bank at Leavey's is steeper and higher relative to the river bed now than it used to be.

He noted that attempts at bank protection were ultimately futile. Willows would be cut and hauled by horse and wagon to sites of erosion along the banks. The banks were armored with willows and boxes filled with rocks and sediment. Pilings were driven into the banks at points and the boxes were cabled together to prevent erosion. These attempts were transitory in nature, however, as high flows would obliterate the projects.

Before construction of the Blue Lake revetment the river used to overflow its banks on that side, replenishing the body of water known as Blue Lake. It was an old oxbow lake, long and narrow. He said that lower Blue Lake was flooded all the time before the revetment was built. The dikes prevented flooding after 1953 when they were first constructed. Leslie noted that there were "potholes" at Nichols (Blue Lake) bar along the right bank which afforded good trout fishing. This was back when the channel was deeper and more narrow. He said there also used to be a deep hole across from the present site of the revetment which was another good fishing site.

Finally Leslie told a story of his uncle heading over to Blue Lake from West End to go to a dance in town. He needed to take a row boat across the river (no bridge was in place at that time). Leslie was a boy at that time. His uncle took off his clothes to swim to the other bank in order to retrieve the boat and noticed a huge number of fish migrating upstream. He swam back and retrieved a spear pole (legal then) nearby and began spearing fish. He missed the dance because he speared fish late into the night. The next day Leslie's dad helped collect the fish, which they smoked. This story helps to shed light on the nature of fish runs at that time (probably 1930's).

I asked about Riverside and Leslie said the town disappeared during the Depression as logging temporarily declined. He also said that Camp 4 Flat is also known as Swede Flat (opposite Canon Creek). He told me that he thought Mayor Sweasey owned the land around the dam and also the gravel bar from which the gravel used for construction of the dam came ("you know politics").

Notes from interview with Elmer and Isabel Evans:
Feb. 22, 1994

I spoke with Elmer and Isabel Evans today at the Blue Lake museum. They are both around 80 years old and have been life-long Blue Lake area residents.

Air photos taken by Elmer (1953) and Jerry Momber (Simpson Timber Co., 1993), show channel changes at Blue Lake. In 1953 the main channel was much closer to West End Rd. Between 1958 and 1962 an avulsion event occurred, the channel migrated and now occupies a position shown in the 1993 photo. Elmer says another migration occurred around 1902 or 1903, according to his father [Further research shows an avulsion event took place in 1890, cutting off the Riverside meander].

Elmer fished the river until 1977. After Sweasey Dam was blown, many of the pools in the river downstream of the dam filled with sediment. He said there used to be pools 12 to 15 feet deep - for example, just downstream of where the Hatchery Rd. bridge crosses the river. He was mayor of Blue Lake at the time and wrote a letter to the Board of Supervisors expressing opposition to the plan to blast the dam in 1970 because of anticipated sedimentation problems. He talked with both the Army Corps of Engineers and the city of Eureka (Hank Trowbitz (sp?)) and got two estimates for the volume of sediment and debris stored behind Sweasey Dam: 1.3 to 1.4 million cubic yards (Corps) and 1.5 to 1.6 million cubic yards (city). [Note: 2,000 acre-feet = 3.2 million cubic yards.] He was told by Colonel Friedenberg from the Corps that there were enough holes between

Blue Lake and the dam that the sediment would be "absorbed by the channel" and the residents of Blue Lake shouldn't be concerned.

After the dam was blasted, the reach downstream of Blue Lake became more barren of vegetation and silt was commonly blown around and into Blue Lake (much more so than previously, according the Evans'). The Evans think much of the stored Sweasey Dam sediment was deposited on the flood plain around and downstream of Blue Lake. The canyon above the Hatchery acted like a "sluice box" and the material was transported downstream, then out onto the alluvial plain. A blanket of fine sediment covered the reach between Blue Lake and the A&MRR bridge. The area was open, permitting views up and downstream for some distance. One would probably have had to dig down 3 feet or more to get to cobble-sized material after deposition, according to the Evans'. They didn't think this was the case before 1970 (when the dam was blasted). This indicates the bed raised 3 feet or so near Blue Lake after the dam was blasted and the sediment was deposited. They thought that since then most, if not all, of that sediment has been removed by gravel operators.

The Blue Lake revetment was constructed in 3 phases: 1) first phase in 1953; 2) second phase in 1956, after the 1955 flood; and 3) third phase after the 1964 flood. Before the first phase the North Fork of the Mad would overflow its banks from time to time, according to Isabel, and the lake for which Blue Lake was named would fill with water. After levee construction it was filled in with material by the landowner who was in the construction business. He would excavate foundations for homes and businesses in the area and use the excess material from construction sites to fill in "Blue Lake". At one time the lake was probably 14 or 15 feet deep. A trip to the property today shows a swampy area with standing water. Since the revetment and its improvements, the Mad river and North Fork have not overflowed into the old lake. The revetment has confined the channel since 1953 although parts were rebuilt after the 1953, 1955, and 1964 floods.

Elmer's fishing bests include a 57 pound salmon on the Mad and a 68.5 pounder on the North Fork near Camp Bauer (Korbel). Elmer worked on bridge construction projects and estimates that the old county bridge near West End Rd. is buried under about 6 to 8 feet of sediment. This burial has occurred since the channel migration/avulsion event between 1958 and 1962.

Elmer and Isabel were familiar with logging activity in the Mad river watershed between Blue Lake and upstream of Sweasey Dam; the first wave occurred between the 1880's and ended in 1925 or 1926. At that time the railroad track was pulled and logging began further up the North Fork. In the 1920's road building began and logs were trucked out of the watershed. The second wave occurred after World War II, with the greatest intensity during the 1950's and 1960's. Tractor logging became popular during that period.

<u>More Notes</u>: (Wednesday, March 30, 1994) Blue Lake was flooded after a storm in 1943 (?). The Army Corps of Engineers allocated $50,000 in 1953 for construction of a revetment to protect the town from flooding. The revetment was constructed and 5 feet was added to the height after the 1955 flood when it was overtopped and partially washed out.

One of the best fishing holes on the river was near the old Camp 6 site (just downstream of the Camp 4 flat). There was a hole approximately 0.25 miles long, deep enough in places to dive from rocks along the opposite bank without touching bottom. After the blasting of Sweasey, this hole or pool filled with sediment.

<u>Notes on interview with Victor Guynup, owner of the Guynup bar, Blue Lake:</u>
<u>August 28, 1994</u>

I visited Vic at his Eureka home today. He pulled photos and documents pertinent to the study of channel changes along the Mad River near his bar. He had recent photos, but none older than about two years. Bob Brown of Rising Sun Enterprises has been working with Vic to evaluate channel changes annually. Guynup first operated on the bar in 1962 and again in 1963, before buying the property in 1964 during the flood (the previous owner was getting nervous and thought his ranch might wash away!). The flood eroded about 10 acres of land from the property. Vic said it took the topsoil off and left the gravel bar underneath. He said about half of the bar on both sides of the channel on the southern part of the property was washed away.

Mostly coarse sediment is deposited on his property. Finer material is carried further downstream, although if he excavates holes or pockets (pits), these will fill in with fine sediment rather than gravel. Therefore he has either skimmed his bars flat or trenched along the inside bend of the bar along the right bank to prevent this from happening. He said the south side of his property tends to build up while the north side is eroded away indicating the channel has migrated to the northeast over the time he's been operating. The trench mentioned above also helps to keep the northwest side of his property from eroding. He's had to rip rap it in the past.

After Sweasey Dam was blasted, "quite a bit more rock came down" aggrading the river on his property. He said the river tends to deposit sediment on his property after each "normal" winter. When this happens bank erosion occurs on his land as the "bed builds up and pushes the flow to the edge" of the channel. The oblique photos of 1993-4 he had showed bank erosion on the north bank of the river. The south bank showed little change since the 1964 flood -- Vic pointed out a tree that had been growing on the northeast bank since at least 1958. He also pointed out the bar on that side had built up and forced the river to the other side of the channel since the '64 flood.

Vic was involved in repair work on Sweasey Dam during the 1950's. He said the dam had formed a crack during (he thought) the 1955 flood. He drove two Cats in to perform the repair work on the southwest abutment. Subsequently he was hired to help keep the pipeline from Sweasey Dam to Eureka from being destroyed by excessive bank erosion between 1956 and 1959. The high flows during the 1950's had caused significant erosion along the banks, downstream of the dam to the Hatchery, and parts of the pipeline and road along the right bank were being undermined. Vic would "take the points out of the river" or "take out the bars" by bulldozing a straighter channel through curved reaches. When the Humboldt bay Municipal Water District's Ranney collectors were installed, the pipeline improvements were abandoned.

Vic had a report on the sedimentation of the watershed which indicated the Mad and Eel Rivers were among the top two percent in terms of sediment discharge in U.S. rivers (by Brown and Ritter). He said the landsliding in the watershed was responsible for the large amount of sediment. He also thought the trees and their root systems had a significant impact on landsliding. The weight of trees and the forces of root systems on the soil as trees were being blown back and forth increased the chances of landsliding, according to Vic. Removing trees may actually reduce sediment input into streams, he said.

The soil under the Simpson nursery (east of his property) is very gravelly in nature, indicating an old river bed. [This is where the old channel flowed through to Riverside.]

Vic's overall impression was that his bar aggrades each "normal" year. He thought that each mine should be allowed to operate, extracting about 75,000 yards a year (three main operators). He thought the river should be channeled, skimmed in the right places at 1% grade, and deepened to provide for a more suitable fish habitat.

<u>Notes From Phone Call on 9-5-94</u>

Vic called to tell me he had spoken with Jim Timmons, a rancher along Lindsay Creek. Jim said he used to swim in a hole on the creek as a kid. The hole was now filled in with sediment. The bridge at Lindsay Creek has appeared to have been undermined by bed lowering. [Perhaps the bridge is being affected by bed lowering of the Mad. The knick-point hasn't migrated up to the swimming hole yet.] Vic also mentioned that Squaw Creek, a tributary of Lindsay Creek, has gotten runs of salmon in the past during wet winters. Presently a gravel obstruction of some kind has formed which prohibits fish migration. Jim offered to trench through the gravel to allow for fish passage, but the Department of Fish and Game vetoed the idea.

Vic said digging on Blue Lake bar by Bob King showed an old rock structure down around 12-15 feet. He thought the structure was put in by

Fred Bott. He thought the rock came from the Liscom Hill quarry and the structure was built in about 1958. He thought it was a good indicator of bed aggradation along the reach.

Notes on interview with Arlene Hartin, Personnel Manager for CalTrans: October 24, 1994

I spoke with Arlene over the phone, inquiring about the bridge piers over the Mad River, approximately 700 feet upstream of the 101 crossing. She found some old drawings that showed the old bridge (county?) over the river in February of 1929. The drawings were plans for the Redwood Highway extension north of Arcata. The highway was built soon thereafter and is shown on the 1933 USGS topo map. The old bridge is not shown on the 1933 map.

She also gave me some information on the history of CalTrans operations and roadbuilding in the area. There were generally two phases of construction: 1) the first phase occurred between the mid 1910's and the mid 1920's when the Redwood highway was constructed; 2) the second phase occurred during the 1950's and 1960's when 101 and 299 were widened into 4 lanes.

Interview with Chris Haynes, who has done historic research on the Mad River:
November 3, 1994

I spoke with Chris today at the College of the Redwoods where he teaches Physical Geography. He told me he had gone fishing up the Mad River in October or November of 1970. Sweasey Dam was dynamited in August 1970, releasing approximately 3,000 acre-feet of impounded sediment into the channel. Chris had hiked down Cañon Creek to fish when he noticed some of the sediment choked the mouth of Canyon Creek. He saw that the confluence of Cañon Creek and the Mad River had aggraded significantly. He observed the water level in the river bed was very shallow from bank to bank -- approximately 2 inches on average and perhaps ankle deep at the most -- and the salmon run coming upstream was stranded. The largest salmon were suffocated, lying dead in the river. Salmon approximately eight pounds and smaller were able to make it further upstream, according to Chris. He walked up the channel to see where the sediment was coming from. He discovered the Sweasey Dam site and saw that there was a tremendous amount of stored sediment being eroded and transported into the channel. Some of the smaller fish were able to migrate upstream, but he thought there were thousands of the largest fish (many 30 and 40 pound salmon) lying dead downstream. The bed was like syrup, very fine grained and the water extremely shallow, which made it difficult for the fish to swim. He observed the bed was almost the same elevation as that of Camp 4 Flat, the point bar/terrace along the left bank of the river, opposite the confluence of mouth of Cañon Creek. [Field observations today show the bed has cut down approximately 12-14 feet below the elevation of the point bar/terrace at Camp 4 Flat.] Chris did not know what the elevation of the bed was before deposition, but assumed it had aggraded somewhere between 6 and 12 or more feet (based on his general knowledge of the region and river behavior). Chris said he used to frequent the Mad River above the Hatchery and below Ruth dam 5 or 6 times a year to fish. He was very familiar with the upper Mad River.

We talked about the river above the dam. He said that upon examining the 1941 photo set, he was able to determine that significant sedimentation resulted from tractor logging practices in the 1950's and 1960's. The channel was choked with sediment on later air photos and appeared to have widened significantly. He thought a tremendous amount of sediment was continuing to affect the channel from this sediment source upstream of the Sweasey Dam site. Other sources we discussed were landslides along the channel. He didn't know if the frequency of landsliding had increased after logging in the 1950's and 1960's.

Chris thought the swimming hole upstream of the Hatchery at the old USGS gaging station site (approximately 1.5 miles upstream) was recovering from the wave of impounded sediment that was migrating downstream from the dam site. He left the area during the early 1970's and returned in 1978, making these observations post 1978. He didn't think the channel had fully recovered yet and it would be some time before it did completely.

Generally his sense was that the river had probably aggraded since the first wave of logging through the area in the late 1800's to early 1900's. He also thought the rafting of logs along the river to the canal had done significant damage to the channel, destabilizing it, and causing significant bank erosion. I asked him about the flooding of the Bottoms and why the 1953, 1955, and 1964 floods hadn't occupied as much of the Bottoms as earlier floods -- was he aware of any geomorphic changes, either human or natural, that would have prohibited flood waters from inundating the Janes Creek corridor, for example? I asked what he thought of highway 299 acting as a levee. He said in 1959 it was only a two lane road and probably did not have much affect -- although it could have played a small role. He said he thought the earlier floods were of larger magnitude. Some levees along the lower Mad may have helped a bit to prevent some flooding, but he thought, after reconstructing newspaper accounts and using property maps -- and then the Humboldt County 2 foot contour map -- to locate and map flood damages, the evidence showed the earlier floods were simply of larger magnitude. Some of the assumptions he made were that the properties he found mentioned in old newspaper articles were accurately located on his flood maps and that buildings and flood elevations mentioned in the articles were also reasonably plotted on the flood maps. Another assumption was that the estimations of flood elevations and descriptions were accurate in the old newspaper accounts.

We discussed channel capacity. He wondered what affect the logging had on diminishing/changing channel capacity. He thought it would have decreased over time due to aggradation from logging, etc., but was unable to resolve the issue of the smaller flooded areas of 1953, 1955, and 1964 except by assuming they were smaller events than the 1861-62, 1890, etc. floods.

Notes on interview with Bob King, Redwood Empire Aggregates (REA): July 14, 1994

I spoke with Bob by phone. He's been on the river since November 1961 (33 years) all of it with REA on Graham bar and in the Blue Lake valley. He observed two cement culverts when he first arrived on the south side of the channel at Graham bar. He thought they were put in as early as 1958, but wasn't sure. He was sure the culverts were put in before the 1964 flood. These culverts are still in position today, indicating to Bob that the river hasn't degraded through that reach.

He thought most of the degradation in the river bed has occurred near the 299 bridge. His opinion was the rip rap along the channel just upstream had confined the flow and increased the velocity substantially, which would tend to degrade the bed through the reach. He used the term "scour" to describe what he thought might be happening at the center bridge pier. The gravel around the pier was removed just as material around a large boulder would be eroded, creating a scour pool around the boulder. He was skeptical of the earliest cross section at 299 in the EIR put out by the county, saying the cross section line drawn didn't look appropriate for a real river bed. He thought it appeared artificially drawn.

He thought the bar just downstream of the 299 bridge (Johnson/Spini/Hunt bar) had decreased in volume due to gravel extraction over the years. He didn't think the bed had changed that much along Graham bar, although there has been some degradation there. He thought much of the degradation seen recently along the channel was due to the 7 years of drought we've been having. In the 1960's and 1970's there were usually 6 or 7 good flows per winter that would bring gravel downstream, replenishing the bars. That hasn't been the case in recent years.

Bob didn't notice any changes after the blasting of Sweasey Dam. He doesn't remember seeing any changes in grain size of the gravel harvested over the next few years. He thought at the time some of it must have been coming from Sweasey, but doesn't remember any distinct characteristics that would have caused him to say, "Yes, it was Sweasey gravel".

He said the engineers computed about 250,000 yd^3 (191,000 m^3) of gravel were recruited after the 1992 wet season [about 30,000 cfs peak discharge]. He thought a total of 45,000 yd^3 (34,000 m^3) would be permitted to all operators this year if the initial proposal holds up. His company would probably have to purchase gravel from other sites and truck it to their plant, then sell it in order to stay solvent. He likened it to a mill buying logs from individual timber sources. The price of gravel varies, but is generally around $5/yard on the Mad and maybe half that on the Eel river right now.

Woody material along the bed was plentiful during wetter times. He and coworkers would remove trees and logs from the channel after high flows and sell the wood or use it for their own firewood. It was common practice during the 1960's, 1970's and 1980's to harvest logs from the channel. Wood was removed from the channel after the high flows in 1992. He said not much has come downstream since the drought began 7 years ago.

October 24, 1994

I spoke with Bob again, today, about the rip rap found at the Blue Lake bar recently by Bob Carmesin one of the heavy equipment operators. Bob said some boulders were found 12 to 14 feet down, possibly indicating the bed had aggraded by approximately that amount.

Bob thought most of the gravel behind Sweasey Dam came (and may still be coming) down "a little at a time". At first it probably filled in the holes downstream and has been working its way downstream ever since. During the 1960's there used to be much more of a problem with fine silt and mud in the river. Now it is much "cleaner" according to him. He thought this was due to forest practices that have improved through time, but was unsure what impact Sweasey might have had on the change. The gravel on the bars is coarser today than in the past.

Woody debris used to be more plentiful on the river, mainly due to the large flows of the past bringing big trees downstream. He said floods used to create winter projects for the unemployed. They would salvage wood and sell it or use it for themselves. Some trees were actually sold to mills for profit. Most of it was consumed. After the 1964 flood trees were pushed by cats and scrapers into piles and burned; what was left over was pushed to the side of the channel and buried. This was done as a flood control measure and to prevent further damage to bridges as the debris had a tendency to accumulate on bridge piers causing the potential for failure. Various contracts were let to clear the channel.

Interview with Jerry LaRue, retired Eureka Field Office Chief, USGS: February 6, 1995

I talked with Jerry over the phone tonight. I called him because I had found a reference in a report that mentioned he might have estimated bed lowering rates on the Mad River. When questioned about 17 feet of bed lowering in the 20 years prior to 1971 (mentioned in the Proceedings of the Mad River Symposium, sponsored by Office of Dean of Public Services and Department of Geology and Earth Science of Humboldt State College, April 16-17, 1971), Jerry didn't remember whether that was exactly what he had come up with. He recommended going through the annual water supply papers to find datum changes which would correlate to bed lowering.

He came to Eureka in 1965 - he missed the 1964 flood. He remembers having to change the gage datum in 1965 by adding 5 feet after the channel scoured (to keep from going to a negative gage height -- the computer program couldn't handle negative values at that time). He noted the rip rap and concrete slurry that had been poured along the right bank had been undercut, indicating degradation. He pointed out there were 11 gravel operators in the river between Blue Lake and Hammond bridge during the 1960's. He inferred gravel extraction was partly responsible for the bed lowering observed.

Jerry and I discussed the history of the Arcata gage as I referred to some of my notes. Between 1910 and 1913 there was a nonrecording gage at a different datum 0.1 miles upstream. In 1950 a water-stage recorder was installed upstream 0.6 miles at a datum 6 feet higher. In 1956 the gage was moved to the present site at a datum 5 feet higher until 1965 when a datum correction was applied due to scour. The gage was changed from a stilling well to a manometer gage and datum was lowered from 17.79 feet above mean sea level (MSL) to 12.79 feet above MSL.

Notes on interview with Jim Leavey, property owner on West End Rd. near Hatchery Rd., south side of the river:
July 18 & 19, 1994

I spoke with Jim first by phone (on the 18th), then in a personal visit (on the 19th).

July 18th

Jim said his grandfather, then father, owned the property at 13405 West End Road, which he now occupies. His knowledge of the river goes back to his childhood days, the 1930's and 1940's.

At that time the river's confluence with the North Fork was below the industrial park, by where Bob King's operation (leased to him by Jim) is currently located. The main fork flowed through where the organic garden on Hatchery road is presently located (which received some overflow from the 1992 and 1995 high water events). There were two bridges on Hatchery road at that time. One was located a few hundred yards from West End road, toward Blue Lake. It is currently buried under sediment that was deposited after the river migrated to the northeast to its approximate present location. The second bridge was located where the current Hatchery road bridge is. Jim said that bridge washed out and was replaced after debris had piled up on the center pier around 1982.

I asked Jim what changes occurred after the blasting of Sweasey Dam. He noted the buildup of the bar on his property to the level of his pasture. Before the blasting, the bar and riverbed were lower in elevation. He also noted that Emmerson and Guynup bars had built up after the blasting of Sweasey. Guynup's bar is replenished after each larger flow and he's able to pull gravel from his property frequently, whereas, Jim said, other operators need to wait for gravel to travel down to them after passing

Guynup's. One major change he noted was the amount of vegetation on bars and along the channel. When he was a kid, there was an abundance of vegetation along the channel. After the floods in the 1950's and 1960's the vegetation was washed away leaving the channel more open and clear. He said the channel is now returning to its previous condition - more vegetation is encroaching onto the bars. Lots of cottonwood and willow trees have grown up on some of the banks and bars.

July 19th

Jim had heard that the river was near its present location around the turn of the century. Its moved back and forth since then. In the 1940's his land began to erode and rip rap was put in to stabilize the banks. The rip rap consisted of willows covered with hog wire and rocks placed on top. He said this method worked much better than building wing dams, which were anchored to the banks and projected perpendicularly into the stream. The flow would tend to erode into the banks, behind where the wing dams were secured and the whole structure would tend to fail. He remembers his parents and uncle building the bank protection structure and he thought it was before the 1953 and 1955 floods, probably during the 1940's. Jim thought that most of the bank erosion occurred on the recession of floods, after the flood peak had passed. He thought the vegetation protecting the banks would be scoured by the peak flows, then the banks would retreat after the peaks had passed as the exposed banks were undercut and bank failure occurred.

We discussed the effects of the blasting of Sweasey Dam. He said his bar built up to the level of his pasture land (~4-8 feet). He said bank erosion would have been minimized if dredging of the channel had occurred to remove some of the deposits left by the blasting of the dam. His land was eroded during the 1970's as the Mad river migrated to the southwest. Riparian vegetation was washed away and the banks retreated on his property. He thought this was due to the raising of the channel allowing the river to more easily reach his property. Since the late 1970's his bar has been eroding. He thought this was due, in part, to the drought we've been experiencing. Not as much recruitment has occurred recently.

Guynup began his gravel operation around the time Sweasey Dam was blasted. Jim said he had "a gold mine" in gravel. The Guynup and Emmerson bars (as well as Jim's property) built up after the blasting of Sweasey, according to Jim. He mentioned yesterday how Guynup's bar would get the first gravel coming downstream, being replenished before other bars.

The river has meandered near the Leavey ranch through time. Jim said that meander cutoffs have occurred, shortening the channel (see figure D-1).

I asked Jim if he knew where the old swimming hole on the North Fork was. I had found newspaper articles referring to the excavation of the hole in

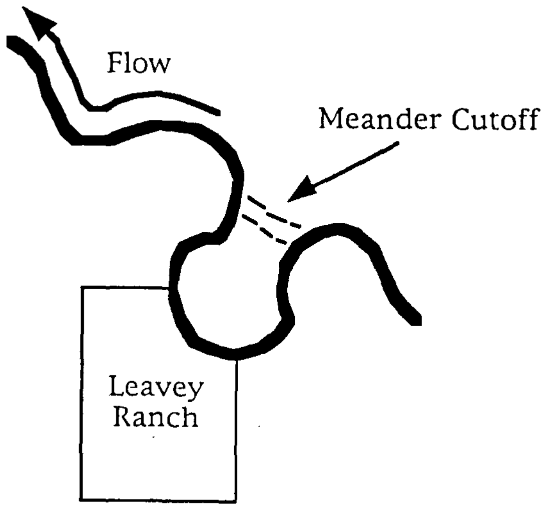

Figure D-1: Mad river meander cutoff near Leavey ranch (not to scale).

the 1920's and the mention of it being part of a park. He said before the McIntosh Mill was put in, a baseball park existed on the flat land along the north/west bank of the North Fork. The swimming hole was below the current location of the bridge on Hatchery road. The Emmerson ranch property is just east, across Hatchery road on the north side of the bridge and was periodically inundated by the North Fork before the revetment was constructed. The revetment was extended downstream to protect the sewage treatment ponds in the 1960's. Jim thought there was a "hook" on the end ofthe revetment (before the jog it makes toward the sewage treatment ponds) that diverted the flow of the Mad river toward his ranch. He asked the Army Corps of Engineers about the "hook" and said they had no response since once construction was completed, the responsibility lay in the hands of the local governing bodies (county or city) (See figure D-2).

I asked him about the abundance of woody debris in the stream. Jim mentioned there was less woody debris now than in years past. He surmised this was probably due to the drought. He said large trees would float down during high water, but since we haven't had any high water in a while, no large woody debris has come downstream.

I showed him some old photos of the Mad river I had. He mentioned the critical factors that would tend to produce a flood on the Bottoms were: 1) rain on snow in the mountains; and 2) high tide. He said when the creek on his property floods, its because the river is too high for the creek to empty into effectively and the creek backs up into the pasture, flooding it. He said something similar happens on the Mad down around Arcata when the creeks back up as high tide affects the drainage of the river. He said there are old culverts that are supposed to drain the sloughs around Giuntoli Lane that often fill with water. This area is prone to flooding as happened in the 1950's and 1960's. He thought it would happen again (and that I should show the photos of the 1955 flood to the county planning department).

Notes from interview with Larry McLaughlin, Eureka Sand and Gravel: July 12, 1994

I spoke with Larry today about gravel operations on the Mad river at the Carlson (near Graham bar), lower Simpson, and Christie bars. Larry said he has worked on the river since 1971. He worked summers for the first couple of years (1971, 1972) at Carlson bar, then operations were split between Carlson and Christie bars.

Gravel operators previous to 1973 (when the Department of Fish and Game began regulating gravel operations) were used to digging below the water level to extract the resource. They would use loaders and trucks to mine gravel from the bars down to water level, then use a drag line to remove gravel from below the water surface. At Carlson bar the river was diverted from the south bank toward the north bank as mining of the bed along the south bank continued. Culverts were put in for access purposes. Approximately 10,000 to 12,000 - and up to 20,000 - yards would be mined in

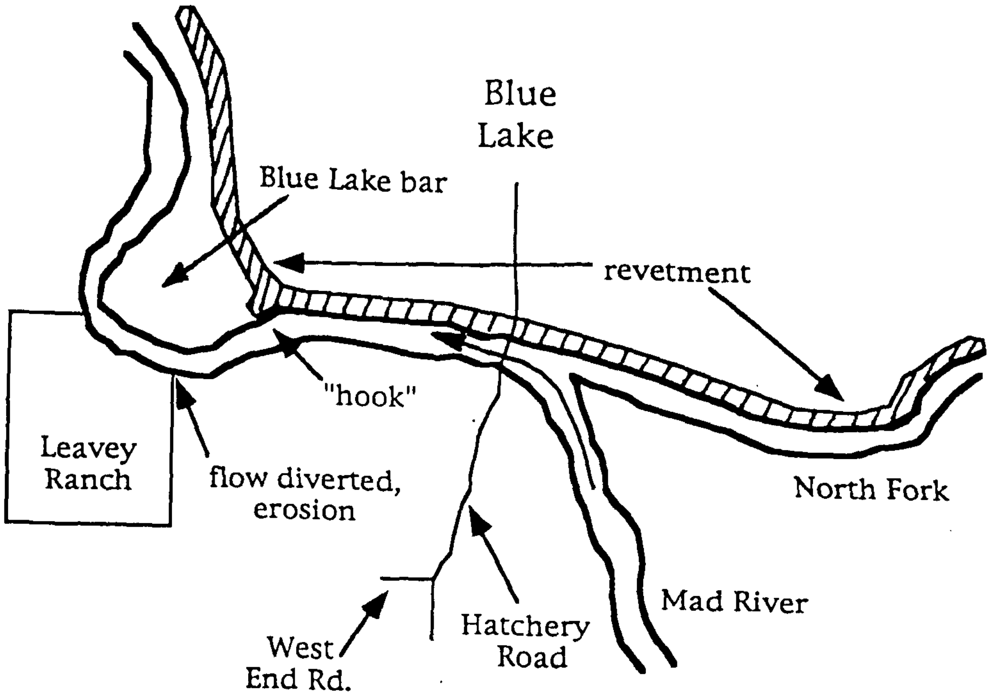

Figure D-2: Blue Lake Revetment and "hook" described by Jim Leavey (see also figure D-3 from John Nichols interview, below) any given year at this site. This method changed in 1973 as Fish and Game halted below water gravel extraction. Only loaders and trucks were used after this. The company purchased scrapers and moved some of their operations to Christie bar near Blue Lake. Both sites were worked during the mid 1970's to mid 1980's when the plant was moved to the Christie bar site and the Carlson bar site was abandoned. Carlson bar was not producing the same amount of gravel and the previous operator at the Christie bar site was having financial difficulties, so Eureka Sand and Gravel Co. moved to Christie bar.

Larry mentioned a stump buried in the Carlson bar that he used as a sort of telltale to judge the amount of gravel deposited after each wet season. He first noticed the stump during his first season on the river. He was running some equipment, scraping gravel off of the bar when he hit the stump. He nearly went through the windshield and was able to remember the location of the stump after that experience. He said he used the stump as an indicator of bar changes through time. He thought, on the average, the bar remained at about the same height during the time he worked it - no net degradation or aggradation.

He also observed the river had migrated south, toward Giuntoli Lane, during the years he operated at Carlson bar. He said it had worked its way southward no more than the distance a person could throw a rock - probably not more than 100-150 feet.

Upon moving to the Christie site, he said gravel was also extracted from the lower Simpson bar, just upstream of the A&MRR bridge. REA takes gravel off of the Johnson bar (between Christie and Simpson). During the last 20 years, he does not ever remember the river's position along the southwest bank or between the left bank and the left bridge pier. He thought the bed had scoured at the base of the right bridge pier just as a scour pool would form around a large boulder. He was skeptical of the amounts of bed degradation estimates reported in the EIR. He has observed the river flowing along the right bank between the right bridge pier and the right bank of the river. He has noticed the river flowing along the left bank, upstream of the bridge, but it has always cut back toward the right-center of the channel before flowing under the bridge.

Within the last 5 years, Fish and Game has been complicit in stream channelization through this reach. According to Larry, the stream through this reach has been braided for the past 20 years or so (since he can remember). In the last few years a channel has been dug to improve fish habitat and to facilitate mining activity. Larry said the reach, after larger magnitude flows, would seem to typically widen as sediment from upstream would be deposited on mined surfaces. I understood him to say he thought this would tend to cause the stream to braid more easily since the cross-sectional shape would be flatter.

I asked about the abundance and size distribution of organic debris and woody material he's observed. He said his father (John, longtime gravel operator on the river) mentioned quite a lot of small ("cigar-sized") sticks, pine cones, and woody debris had appeared along the river after the blasting of Sweasey Dam. He also said his father had mentioned the material mined after the dam was blasted was finer grained than before removal, then became coarser as time progressed.

His overall recollections indicate the river's bed elevation hasn't changed much over time. He didn't have any photos or data to document this other than the telltale stump described above, in Carlson bar. He thought, generally, gravel recruitment occurred each year after high water with natural fluctuations in the amounts carried downstream. Some years the bars would build up more than others, but overall the bar elevations seemed to remain about the same. He thought the string of dry years we've been having have caused a lot of the problems recently perceived (in terms of bed degradation) since recruitment would naturally decrease.

Larry thought permitting for removal of 60,000 yards of material would allow gravel operators to remain solvent, whereas 20,000 yards wasn't enough to be economically viable. He said most of the operators would probably be put out of business on the Mad if they weren't able to take more than is being currently suggested for permitting.

Notes from interview with Rob McLaughlin, Eureka Sand and Gravel: July 12, 1994

I spoke with Rob today about gravel operations on the Mad river at the Carlson and Christie bars. Rob is about 38 years old (he was 9 when the 1964 flood occurred) and his family has been extracting gravel from the Mad river since the 1940's - after World War II. His family started gravel mining on the Elk river in 1928.

Rob has spent a lot of his time in the office and didn't have a lot of detailed knowledge of river channel changes through time. He did say the channel has changed very little since the 1970's when he started with the family-owned business. He noticed the channel seems to move back and forth a bit every year. He said the channel did not *seem* to aggrade or degrade over the last 20 years or so, although he wishes he had photos to document his perceptions. He knew of no photos, surveys, or other data his company would have to provide quantitative information on channel changes.

The amount of woody debris seems to have increased on some of the bars over the last ten years or so, after the highwater subsides. He said he thought there might be more debris than usual due to a lack of removal by high water. When high water does bring material downstream, more than usual seems to be left on the bars after the water recedes.

He thought the amount of riparian vegetation seemed to have increased on bars upstream of Christie bar. He thought this might be due to the lack of flooding in recent years, or in other words, the unusually dry years have allowed vegetation to encroach onto these bars. Part of his observations were the result of examining air photos of the area along with discussions with engineers, scientists, and environmentalists.

Notes on interview with Jack McKellar (Corps. of Engineers rep. for the North Coast) who's been in the area for 50 years (72 years old): October 24, 1994

I spoke with Jack over the phone about COE projects on the Mad River near Blue Lake. He gave information about the style and timing of construction of revetment projects near the mills and sewage treatment ponds. The very first project occurred just after the war and was done to protect the mills operating near the present power plant. Then further construction to extend the project upstream was completed after the 1953 flood. The 1955 flood damaged the revetment somewhat and it was strengthened. The revetment extends vertically approximately 10 feet below ground level, or about 30 feet diagonally. The works were extended further up toward Simpson during this phase. Additional reinforcement was completed after the 1964 flood. Near the sewage treatment ponds erosion during March 1976 threatened development along the west side of Blue Lake (RV park, sewage treatment ponds) and 3 phases of construction began to protect the banks. Initially wing dams were put in for bank protection. The first phase was then built to protect the ponds; the second phase extended the works down further; the third phase protected the reach along the RV park. The revetment was dug down approximately 3 feet into the bed.

The 1964 flood produced tremendous amounts of woody debris -- logs, trees, etc. These choked the channel and would tend to accumulate on bridges, threatening failure. The COE policy was to remove the debris by clearing the channel. Contracts were let to salvage merchantable material or pile the refuse up for burning. Logs were "branded" and salvaged by timber companies. Jack has seen trees 200 to 300 feet long come downstream, clogging the channel, backing up water, creating channel changes. He said ultimately the river is going to do what it wants to do and man has little to say about it. He also questioned whether we were in a drought. Since the late 1940's we've had quite a few wet winters by his estimation. The 1953, 1955, and 1964 floods along with the high water in the 1970's show pretty wet conditions on the Mad River. He didn't think people understood the time scale involved with flood frequencies.

Notes from interview with Jerry Momber, Forester, Simpson Timber Company: March 3, 1994

Jerry and I met over the phone, then he invited me to come to his office to go through his file on Sweasey Dam. He was in college during the mid 1960's and is about 45-50 years old. He had a report by Kip Roberti, affiliated with a fly fisherman's conservation group interested in protecting the fisheries on the Mad during the late 1960' and early 1970's. The report had some photos along with the negatives.

He said he knew the channel below Sweasey Dam pretty well, having worked in that area. He said there used to be many deep, clear pools downstream from the dam before it was blasted. He also said the river used to flow along the west bank around Camp 4 Flat prior to the blasting of the dam. Once removal occurred, he estimated a minimum of 10-12 feet of sediment filled the channel just below the dam. (He took some earth moving equipment - a dozer - across the channel just downstream of the former dam right after it was destroyed). This estimate was based on the observation that several boulders, 6-8 feet over his head in the channel before the dam was blasted, were completely covered with sediment afterward. Thus he estimated a minimum of 10-12 feet of fill in the reach. A large amount of sediment was deposited near the mouth of Cañon creek and a bar built up on the Camp 4 Flat side of the channel (left bank). By about 1972, the channel had migrated to the right bank where it is presently located. He said there was high water in 1972 and by then most, if not all, of the sediment had been flushed/eroded from behind the old damsite and deposited downstream.

The pools downstream to the fish Hatchery also filled with sediment, changing it significantly as the bed raised and widened.

Jerry met with the Evans' and went through their photo collection looking for Mad river photos. He was able to find one of the Blue Lake area showing the town with the Mad River in the background, taken from the air in 1953. He took a helicopter and relocated the position from the air, reshooting the photo in 1993. I have a photocopy of these two photos, but Jerry couldn't find the originals. The photo shows the channel before and after the avulsion that occurred between 1958 and 1962.

Jerry also said that the Northern Redwood Lumber Company paid local Indians $1 per day to cut redwood sprouts to prevent them from regrowing after certain areas had been logged. This was to keep some of the logged land under cultivation as pasture land for production of sheep and cattle.

Notes on interview with John Murray, Humboldt County Public Works Department:
September 16, 1994

I spoke with John on the phone today. He was referred by Don Tuttle, also with Humboldt County Public Works. John was born in 1943 (51 years old) and has spent a lot of time along the Mad River between the Hatchery and Warren Creek. He said the county used to maintain a swimming hole on the Mad River near where Potter's garden is presently located (on Hatchery road, between the Blue Lake bridge and West End road). The river used to flow through what is now a riparian forest of cottonwoods and willows. Each year the National Guard would build a log structure across the river which would create a large swimming hole. This was before the Arcata Pool opened and youngsters would learn to swim at this spot. John remembers spending time during the summers there between 1955 and about 1961.

John said the road between West End and Blue Lake is considered by the county, a "summer road" - meaning it may be washed out during high winter flows, then rebuilt after flows subside. The county used to maintain two bridges across the river: one at the present Blue Lake bridge site; and another across where the channel cut through the present Potter's garden site. This second, now abandoned, bridge is still present, buried under sediment. John said some of the pilings may still be visible. This bridge was no longer needed after the channel migrated to the north, joining the North Fork near the present confluence.

I asked John about changes further downstream. His family had a summer home near the Mad on Warren Creek. He spent time swimming in holes between the railroad bridge and Park 4 -- Pump Station 4. He said Mercer-Fraser (MF) had extensive operations "all up and down the river" including the site of Essex. MF would operate below water level, using drag-lines to remove gravel from the river during the summer. The water would become "muddied" during operations, but people didn't care much back then. Operations in the "live stream" were common during the early 1950's and 1960's until regulations changed. Trenches formed where this digging went on, channelizing the river. Much of the gravel was used for construction of the Eureka-Arcata highway. John estimated some of the trenches were 14 to 16 feet deep and 50 feet wide.

The 1964 flood brought down a lot of woody debris, which clogged the channel in places. John said the Army Corps of Engineers came in after the flood with bulldozers and pushed the wood and debris up out of the channel, clearing it. He didn't know whether it was to prevent it from going out to sea, to protect bridges downstream, or for other reasons. The wood was then burned. He also said the A&MRR bridge piers tended to collect debris after high water events, but other than that, there wasn't much woody material in the channel that he could remember. The swimming holes he was familiar with were formed by rock outcrops, rather than large, downed trees, etc. When I showed John a linear feature across the channel above Blue Lake visible on the 1962 air photo, he said it could be logs or debris landowners would sometimes stack across the channel to prevent people from driving upstream in the river bed.

He was able to give information on bed elevation changes only near the abandoned West End bridge, saying sediment had filled in around the old structure. He had no information about conditions further downstream, when asked about the impact of gravel extraction on swimming hole depth changes.

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Notes on interview with John Nichols, gravel operator on Blue Lake bar: October 24, 1994

I spoke with John today at his office in Blue Lake on the Blue Lake bar. I was interested in finding out about bed/channel changes along the reach near his bar on Blue Lake. He said last year he excavated some boulders, pinkish in color, on his bar. These boulders were found approximately 2 to 3 feet down under the bed. They were found toward the Leavey property on the right bank, in the same general area, but somewhat strewn about - they were not all found together in the same hole. He kept some of the boulders which I examined and found to be generally 0.5 meter diameter, sandstone boulders. (The pit excavations this year uncovered none of these boulders.) He also uncovered some pilings and some metal bands around what he thought was wood pipe. He didn't know if it was from some old pipeline that crossed under the river or whether it was, in fact, debris from the old Sweasey pipeline, which washed out from time to time during the 1950's. These findings occurred about six years ago (~1988) just downstream of the bend in the revetment, below the Blue Lake bridge.

We talked about other changes in the channel and he told me that downstream on the water district bar (between the Essex bar and the Johnson bar near Lindsay Ck.) he remembered the bar was approximately 12 feet high before it was mined during the 1970's. Most of it is gone now. He said further upstream the Leavey property has suffered quite a bit of bank erosion since he's been on the bar (since 1977). There used to be a line of trees that would prevent a view of the Leavey ranch from the Blue Lake bar. Those trees are gone. The river continues to move toward Leavey's. He thought the boulders found (mentioned above) might, at one time, have been part of older bank protection put in by the Leavey's, which have since been eroded into. He said that normally high water would bring down gravel, depositing it along the reach being mined, replenishing what was taken the previous season. He used to be able to mine during the winter, pulling gravel as the river rose. He would have to move back from the water's edge as the water level came up. The gravel was stockpiled for use during the summer. (Today all mining occurs during about 4.5 months in the summer). Overall the river bed seems to have remained at about the same elevation, he thought.

One thing he has noticed has been the encroachment of vegetation on the bars along with established willows growing up taller. He thought this was due to the lack of scouring flows in recent years which would normally remove the vegetation being established. Woody debris was also commonly brought downstream by large flows and used to be more plentiful (since there were more high flows in the past than in the last few years).

They are now mining two pits on the Blue Lake bar -- 12,000 yd^3 (9,200 m^3) and 14,000 yd^3 (10,700 m^3) from each. Much of their gravel is coming from stockpiles which are rapidly being depleted. He said they need some years with high winter flows to replenish their supply.

Observations along the bar show boulders strewn downstream of the bend in the revetment below the Blue Lake bridge (see figure D-3). These boulders are from the revetment on the right bank (same composition and size) and appear to have been moved from the revetment into the channel and have diverted some of the flow toward the left bank and the Leavey property (consistent with discussions with both Jim Leavey and Jack McKellar). Behind and downstream of the boulders are large stumps and woody debris that have been deposited in an overflow channel. This indicates the current slows here as it hits the boulders, decreasing the energy available to transport the woody debris.

Notes on Interview with Bill O'Neill, President of Arcata Readimix: November 21, 1994

I spoke with Bill O'Neill over the phone today about changes in the channel of the Mad River near his gravel operations. He said he has hired Mitch Swanson, a hydrologist from Sacramento (now in Santa Cruz), to evaluate channel degradation near the 299 bridge in attempts to resolve this issue. CalTrans cross-sections show a flat profile which Bill doesn't think makes sense with how river channels actually behave (the thalweg is not represented). He seemed to think the line may have represented the water surface elevation (also flat) and that the amount of degradation has thus been overestimated. He thought there was approximately 3 feet of degradation under the bridge since it was constructed [between 1962 and 1966]. He estimated approximately 3.5 feet of bed lowering downstream near his office during the same time frame. He observed some logs underneath the bridge footing during low water this past fall. The logs were lying length-wise underneath the footings, wrapped, and backfilled with concrete. He has never seen this sort of construction before. He doesn't think the footings were built on bedrock. He thought they were built on river bed alluvium.

Since 1972-73 the channel between 299 and REA hasn't migrated laterally according to Bill. Before that it would wander back and forth every few years. There is a large rock in the channel downstream of the bend below Ben Spini's property (right bank downstream of 299 bridge) which used to be on the left bank of the river. Today it is on the right bank. At one time (early 1950's) swimmers used to dive off of the rock into the channel (between the rock and the right bank). This pool was approximately 10 feet deep. There were other holes nearer to his office and a hole up the river by the Water District that was also approximately 10 feet deep. This hole was apparently directly across from the intake presently located on the left bank, downstream from Pump Station 1. [A hole still exists in that location just downstream of a rock structure which extends into the channel, diverting water toward the District's intake.] Bill said Dutra moved the river back to the left bank after the 1964 flood, which washed some of the car bodies Spini had armored the right bank with. Approximately 5 acres of land washed away along that bank during that flood (Ben Spini, pers.

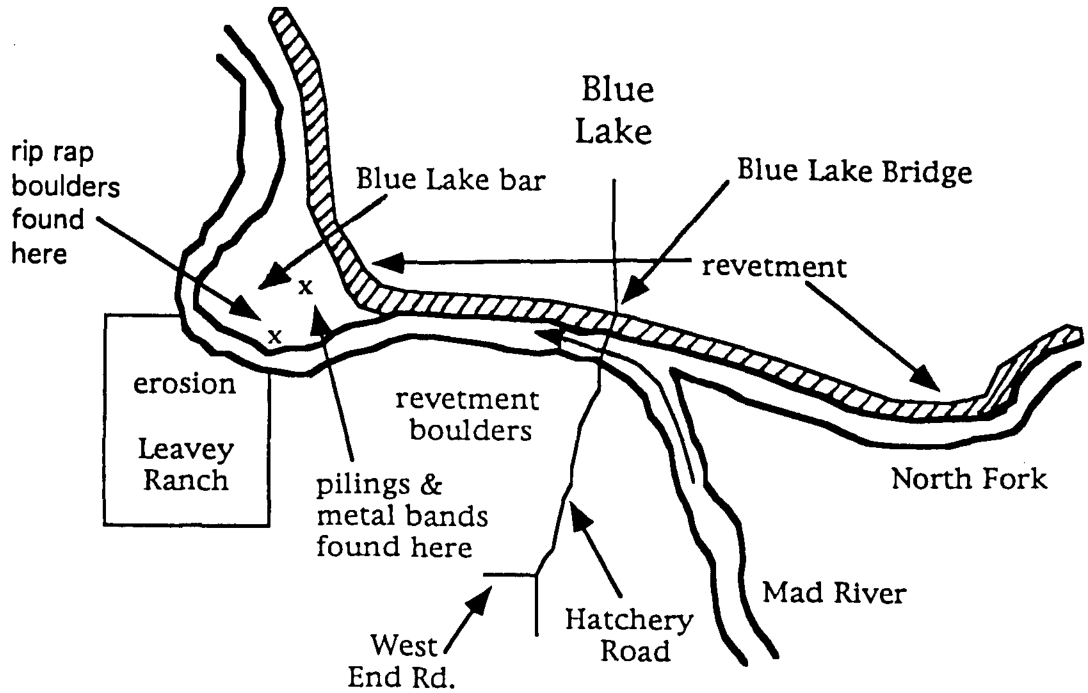


Figure D-3: Blue Lake bar showing boulders at bend in revetment downstream of the Blue Lake bridge and erosion on the Leavey property.

comm.). Bill said the bridge design appears to have diverted the flow toward the right bank, promoting erosion.

After the blasting of Sweasey Dam Bill didn't notice any channel changes of significance. Grain size of sediment was the same. The bed elevation seemed to be the same. Lots of cigar-sized sticks floated downstream and lodged on bars. The only time any grain size changes were observed was when mining in deep holes occurred. Larger cobbles were found down deep, finer gravel on top.

Over the past three years Bill said there are varieties of plants are growing on the bars that he hasn't ever seen before. He didn't know why this was happening. He doesn't ever remember pampas grass growing on the bars, either. Willows have been growing out on the middle of bars (unusual he said) probably because no scouring flows have occurred over the past few years.

The 1964 flood didn't change the channel very much along the reach between 299 and below REA according to Bill's observations. The river overflowed its banks, flooding his office area to a depth of around 6 inches or so. He lost some equipment during the flood, but most of it had been moved out of the channel and was up on the banks. At most, the bed of the river was 1 foot higher after the flood. He said after floods in the 50's and 60's a company called Conners Construction would clean out the channel with D8's and D6's up by Blue Lake by bulldozing debris out of the river bed. He also said quite a lot of channel work was done by the Water District during the 1960's between the A&MRR bridge and 299 -- Bill Sheppard from Blue Lake did much of the work.

Bill didn't know where the boulders upstream of the 299 bridge came from. He's interested in finding out the history behind these rocks and their impact on the channel downstream.

Notes from interview with Clyde Patenaude, long-time Korbel and Blue Lake resident.
April 11, 1994

I spoke with Clyde this afternoon; he's in his 80's. He said he remembered there was one main channel that was narrow with deep pools and that the river used to meander through the Blue Lake valley. Today its wider and flatter through the same reach. There was a popular swimming hole downstream of Shaw's Crossing when he was young (in the 1920's and 30's) that was at least 10 to 12 feet deep. It was a popular place for people from Arcata and Blue Lake to gather. The channel had many more deep holes than in recent years - most of the popular holes have disappeared or filled in. The best fishing holes disappeared. There was a deep pool at Camp 16 (upstream of the Hatchery & downstream of Camp 4 Flat) that afforded excellent fishing and swimming. The pool was probably at least 10 to 12 feet deep there.

During the last two decades there has been much less rain than during the previous several decades. There were many more fish in the river during the 30's, 40's, and 50's.

After World War II, logging accelerated as did road building. Tractor logging increased during the same time. Before tractor logging and cable logging, corduroy roads were built and logs were skidded down streambeds onto landings where they were then loaded onto railcars and transported to the mills. Korbel was logged around 1897, according to Clyde.

There was much less pollution in the river in the early years (ex. sewage, pesticides, herbicides, etc.).

Notes on Interview with Percy Reid, longtime Blue Lake resident (since 1942).
April 11, 1994

Percy said there were fewer holes today than in the past. He also said the river appeared shallower and was "table-like" now, meaning that the channel was spread out and braided more now than in the past. He thought gravel mining was primarily the cause for this change. He noticed the operations would typically skim gravel from the channel, forming large, flat areas and the water would occupy these areas once mining was completed for the season. The channel used to "reform itself" -- or change from a flat, braided reach to a narrower, meandering reach -- after the large floods of the 50's and 60's. Percy said that it used to rain much more in the past than today and flooding or high flows were much more common. Overall the channel was narrower and more confined in the past near Blue Lake than today. He didn't perceive any significant changes after the blasting of Sweasey Dam. He remembers people talking about potential changes, but he didn't notice any himself. He also thought there was generally about the same amount of riparian vegetation along the banks today as there was in the past.

Percy also said that during World War II the mills were booming with at least 50 operating. Logging steadily tapered off after the war.

Notes on interview with Ben Spini, owner of the property along the right bank, downstream of the 299 bridge:
January 9, 1995

I spoke with Ben over the telephone about river changes along his property, which fronts the Mad River downstream of the 299 bridge on the right bank. Ben was born in 1924 (70 years old) and has lived on the site since 1935 (60 years). He observed damage from the 1964 flood and concluded it had been the most damaging, eroding away fences and approximately 10 acres of land owned by he and his neighbors (Johnson's and Kane's) immediately upstream (between his property and the 299 bridge). Riparian vegetation along the right bank was washed away and the bank began to retreat. The water was within 10 feet of his house at the flood's peak. During the 1955 flood, the water covered the lower field, but did not reach as high as the 1964 flood. He described it as being "considerably" lower and estimated the '55 flood covered the lower field (terrace just below his house, which is along North Bank road, the westernmost group of buildings approximately 0.25-0.5 miles downstream of the bridge) to a depth of 3-4 feet. The 1964 flood covered the same field to a depth, he estimated, of approximately 10 feet. One reason for the bank erosion, he noted, was the river appears to be directed at the right bank as it flows out from under the 299 bridge. The 1953 flood wasn't notable. He didn't have any recollection of it having been comparable to the 1955 or 1964 floods. Another difference between the 1955 and 1964 floods was the duration of flow. He remembered the flood of '55 lasted perhaps 3 days at the most, while the 1964 flood lasted "days and days and days" due to the continuing rain. He also mentioned that the 1964 storm had rained onto previously deposited snow in the mountains. Ben said high tides also played a role by backing up the water running off into the ocean. He thought the tides may have been unusually high at that time.

I asked about changes in the river's bed elevation. Ben's opinion was the bed had dropped through time. His claim was based on noting that the river's banks are much steeper and higher now than when he was a kid. The bank on his side drops off sharply compared to the past when the bank slope was gradual. He also noted the rock at Shaw's crossing (downstream, between O'Neill's and his property) protrudes more now than it did in the past. As a youngster, he could dive off of the rock into a deep pool. The river has migrated toward the opposite (south) bank today, so it has changed both vertically and laterally. Ben also told me that Shaw's crossing used to be shallow enough to take a horse and buggy across in the 1930's. He didn't think it could have been crossed in the 1950's and 1960's, partly due to bed lowering, partly because there was so much high water. He thought the drought period during the last 10 years or so might have allowed the river to be forded in the some places.

Upstream of the 299 bridge along the right bank the vegetation has been removed by flooding according to Ben. He said the vegetation was not taken out by gravel operators that worked on the bar. He noted that cottonwoods and alders have shallow, delicate roots systems and they "go fast" when bank erosion occurs.

Notes on Interview with Greg Susich, U.S. Geological Survey, Eureka: February 3, 1995

Greg thought the bed has dropped approximately 5 feet since he started working at the 299 gage (summer of 1969). He's had to lower the staff plate recently (2 feet extension added between 10/27/93 and 12/4/93) to account for bed lowering. He used to use a telltale rock near the gage to judge whether the river was wadeable for a measurement. The rock is now exposed approximately 5-6 feet more than in 1969 -- the USGS (Ukiah office) has a photo of the rock taken in 1969 which shows just the tip protruding from the water at low flow compared with 5-6 feet exposed today. Greg also noted the left bank rock outcrop wasn't there when he started, another indication of bed lowering. The channel used to be much finer grained, mostly alluvium, whereas now it consists of large boulders at the weir/control and bedrock along the banks. Greg's supervisor, who started in 1962, noted approximately 10 feet of scour after the 1964 flood. He said the gage was left "high and dry" afterward and a manometer gage had to be installed. His supervisor also said the gage was moved around 1956-58 and the two gages were not connected by datum. He said to be careful about trying to reconstruct bed elevations. The older, original gage was upstream of the current gage. Greg said he saw at least one of the static tubes from the stilling well when he went out to the gage after high water on January 9th, this year. He thought a measurement could be made from the static tube down to the current bed level to obtain an estimate for bed lowering.

Appendix E:

Flood and rainfall data, Eureka, California (1852-53 to 1993)

Year	Rainfall (in)	Mean Difference† (in)	% Difference	Classification††
1852-53	N/A	N/A	N/A	Flood
1857	N/A	N/A	N/A	Flood
1861-62	92.55*	N/A	N/A	Flood
1871	N/A	N/A	N/A	Flood
1878	N/A	N/A	N/A	Flood
1879	N/A	N/A	N/A	Flood
1880	37.79	-0.92	98	Normal
1881	32.12	-6.59	83	Flood
1882	41.16	2.45	106	Normal
1883	34.21	-4.5	88	Normal
1884	24.43	-14.28	63	Drought/Flood
1885	21.65	-17.06	56	Drought
1886	42.13	3.42	108	Normal
1887	44.49	5.78	115	Normal
1888	34.63	-4.08	89	Normal
1889	34.24	-4.47	88	Normal
1890	74.39	35.68	192	Flood
1891	36.57	-2.14	94	Normal
1892	37.17	-1.54	96	Normal
1893	50.46	11.75	130	Flood
1894	54.71	16	141	Normal
1895	47.55	8.84	123	Normal
1896	51.27	12.56	132	Normal
1897	50.01	11.3	129	Normal
1898	35.43	-3.28	92	Normal
1899	35.48	-3.23	92	Normal
1900	50.71	12	131	Normal
1901	51.59	12.88	133	Normal
1902	48.06	9.35	124	Normal
1903	52.21	13.5	135	Flood
1904	66.45	27.74	172	Normal
1905	31.03	-7.68	80	Normal
1906	39.42	0.71	102	Flood
1907	53.03	14.32	137	Flood
1908	32.88	-5.83	85	Normal
1909	43.94	5.23	114	Flood
1910	39.21	0.5	101	Normal
1911	32.45	-6.26	84	Normal
1912	40.86	2.15	106	Normal
1913	34.29	-4.42	89	Normal
1914	38.36	-0.35	99	Normal
1915	40.96	2.25	106	Flood
1916	41.46	2.75	107	Normal

Year	Rainfall (in)	Mean Difference† (in)	% Difference	Classification††
1917	30.2	-8.51	78	Normal
1918	25.51	-13.2	66	Normal
1919	39.49	0.78	102	Normal
1920	25.5	-13.21	66	Normal
1921	46	7.29	119	Normal
1922	34.88	-3.83	90	Normal
1923	26.37	-12.34	68	Normal
1924	20.59	-18.12	53	Drought
1925	43.85	5.14	113	Normal
1926	23.95	-14.76	62	Drought
1927	50.48	11.77	130	Flood
1928	30.48	-8.23	79	Normal
1929	28.76	-9.95	74	Normal
1930	24.73	-13.98	64	Drought
1931	20.73	-17.98	54	Drought
1932	36.24	-2.47	94	Flood
1933	35.44	-3.27	92	Normal
1934	21.39	-17.32	55	Drought
1935	40.52	1.81	105	Normal
1936	33.49	-5.22	87	Normal
1937	30.39	-8.32	79	Flood
1938	58.03	19.32	150	Normal
1939	29.48	-9.23	76	Normal
1940	41.13	2.42	106	Normal
1941	47.89	9.18	124	Normal
1942	41.73	3.02	108	Normal
1943	41.11	2.4	106	Normal
1944	28.07	-10.64	73	Normal
1945	43.93	5.22	113	Normal
1946	39.3	0.59	102	Normal
1947	22.83	-15.88	59	Drought
1948	42.45	3.74	110	Normal
1949	32.24	-6.47	83	Normal
1950	40.59	1.88	105	Normal
1951	46.72	8.01	121	Flood
1952	47.28	8.57	122	Flood
1953	47.91	9.2	124	Flood
1954	43.52	4.81	112	Flood
1955	32.68	-6.03	84	Flood
1956	45.37	6.66	117	Flood
1957	37.9	-0.81	98	Flood
1958	48.06	9.35	124	Flood
1959	33.42	-5.29	86	Flood
1960	33.18	-5.53	86	Flood
1961	45.05	6.34	116	Flood
1962	30.71	-8	79	Flood
1963	42.17	3.46	109	Flood

Year	Rainfall (in)	Mean Difference† (in)	% Difference	Classification††
1964	37.67	-1.04	97	Flood
1965	40.05	1.34	103	Flood
1966	34.03	-4.68	88	Flood
1967	43.63	4.92	113	Normal
1968	29.52	-9.19	76	Normal
1969	45.29	6.58	117	Flood
1970	38.13	-0.58	99	Flood
1971	50.65	11.94	131	Flood
1972	37.97	-0.74	98	Flood
1973	36.08	-2.63	93	Normal
1974	51.05	12.34	132	Flood
1975	40.13	1.42	104	Flood
1976	34.8	-3.91	90	Normal
1977	19.17	-19.54	50	Drought
1978	35.96	-2.75	93	Normal
1979	23.2	-15.51	60	Drought
1980	36.59	-2.12	95	Normal
1981	30.28	-8.43	78	Normal
1982	48.1	9.39	124	Flood
1983	63.83	25.12	165	Flood
1984	44.01	5.3	114	Normal
1985	36.33	-2.38	94	Normal
1986	39.95	1.24	103	Flood
1987	25.49	-13.22	66	Normal
1988	32.2	-6.51	83	Normal
1989	35.77	-2.94	92	Flood
1990	29.34	-9.37	76	Normal
1991	23.15	-15.56	60	Drought
1992	29.26	-9.45	76	Normal
1993	39.38	0.67	102	Flood
Mean = 38.71				

† Mean Difference = difference between annual rainfall maximum and the mean for the period of record

†† Flood classification based on: 1) newspaper accounts; 2) an historical analysis of flooding on the Arcata Bottoms (Haynes, 1986); and 3) USGS gauging records showing peak discharges greater than 30,000 cfs ("Damage from inundation begins when flows of the Mad River below the confluence with the North Fork reach a magnitude of about 30,000 cfs" from Draft Environmental Impact Statement, Butler Valley Dam and Blue Lake Project, U. S. Army Engineer District, San Francisco, California, November 1972, p. 33). Drought classification based on 65% of mean annual precipitation from 1880 to 1993 after "The Delineation of Sovereign Lands and Areas Subject to Public Trust Easement on the Russian River", Prepared by Trinity Restoration Associates, Inc., Arcata, California, January, 1993).

* 92.55 inches measured at Fort Gaston (near Hoopa) between December 22, 1861 and February 8, 1862

Appendix F:

Peak discharges and partial duration flows for the Mad River at Arcata, USGS Gauge# 4810

Water Year	Discharge (cfs)	Date	Partial Duration Q's	Ranked Year	Peak Discharge
1911	14,800	1/19/11		1977	3,360
1912	21,200	1/25/12		1991	8,700
1913	17,800	12/16/12		1981	10,800
1951	35,000	2/4/51		1987	11,000
		10/28/50	29,000	1979	14,600
		12/3/50	26,600	1911	14,800
		12/14/50	14,800	1973	14,800
		1/18/51	27,800	1968	15,800
		1/21/51	33,100	1976	16,500
1952	42,100	2/1/52		1913	17,800
		12/1/51	20,900	1985	18,200
		12/27/51	27,400	1990	18,400
		12/29/51	15,800	1980	19,500
		2/18/52	15,600	1988	19,700
1953	75,000	1/17/53		1912	21,200
		12/7/52	22,200	1978	21,900
		12/10/52	16,200	1984	21,900
		1/9/53	25,200	1962	23,500
		1/20/53	16,700	1961	24,200
1954	30,600	11/23/53		1957	24,500
		1/17/54	27,900	1989	26,000
		1/28/54	22,700	1963	28,900
1955	48,300	12/31/54		1971	29,200
1956	77,800	12/22/55		1954	30,600
		12/6/55	16,400	1967	30,900
		12/19/55	29,800	1969	32,700
		1/15/56	36,800	1959	33,700
		1/22/56	20,400	1970	34,500
		2/21/56	39,200	1983	34,800
1957	24,500	2/24/57		1951	35,000
		12/11/56	17,100	1966	35,800
		2/25/57	19,700	1982	37,200
		3/5/57	18,300	1964	39,200
		3/11/57	21,100	1974	41,300

Water Year	Discharge (cfs)	Date	Partial Duration Q's	Ranked Year	Peak Discharge
1958	44,900	11/13/57		1952	42,100
		12/21/57	23,600	1975	43,400
		12/28/57	15,800	1958	44,900
		1/29/58	31,500	1960	48,000
		2/12/58	30,600	1955	48,300
		2/15/58	20,300	1986	49,000
		2/19/58	19,200	1972	54,400
		2/24/58	30,300	1953	75,000
1959	33,700	1/12/59		1956	77,800
		1/9/59	19,900	1965	81,000
		1/27/59	20,200		
		2/15/59	26,500		
1960	48,000	2/8/60			
1961	24,200	2/11/61			
		11/25/60	16,600		
		12/17/60	14,700		
		1/13/61	15,300		
1962	23,500	12/19/61			
1963	28,900	12/2/62			
		10/12/62	26,000		
		11/26/62	19,100		
		1/31/63	15,000		
		4/6/63	16,200		
		4/12/63	16,000		
		4/15/63	14,900		
1964	39,200	1/20/64			
1965	81,000	12/23/64			
		12/10/64	16,600		
		1/6/65	15,800		
		1/24/65	15,100		
1966	35,800	1/4/66			
1967	30,900	12/5/66			
1968	15,800	1/15/68			
1969	32,700	1/20/69			
1970	34,500	1/24/70			
1971	29,200	1/16/71			
1972	54,400	3/2/72			
1973	14,800	1/16/73			
1974	41,300	1/16/74			
1975	43,400	3/18/75			
1976	16,500	2/28/76			
1977	3,360	3/9/77			
1978	21,900	1/17/78			
1979	14,600	1/11/79			

Water Year	Discharge (cfs)	Date	Partial Duration Q's	Ranked Year	Peak Discharge
1980	19,500	1/14/80			
1981	10,800	1/28/81			
1982	37,200	12/19/81			
1983	34,800	12/16/82			
1984	21,900	12/11/83			
1985	18,200	11/12/84			
1986	49,000	2/18/86			
1987	11,000	2/2/87			
1988	19,700	12/10/87			
1989	26,000	11/22/88			
1990	18,400	1/8/89			
1991	8,700	3/4/91			

Appendix G:

Recurrence interval/exceedence probabilities, lower Mad River

Peak Q	Rank	T	Probability
81,000	1	45.00	0.02
77,800	2	22.50	0.04
75,000	3	15.00	0.07
54,400	4	11.25	0.09
49,000	5	9.00	0.11
48,300	6	7.50	0.13
48,000	7	6.43	0.16
44,900	8	5.63	0.18
43,400	9	5.00	0.20
42,100	10	4.50	0.22
41,300	11	4.09	0.24
39,200	12	3.75	0.27
37,200	13	3.46	0.29
35,800	14	3.21	0.31
35,000	15	3.00	0.33
34,800	16	2.81	0.36
34,500	17	2.65	0.38
33,700	18	2.50	0.40
32,700	19	2.37	0.42
30,900	20	2.25	0.44
30,600	21	2.14	0.47
29,200	22	2.05	0.49
28,900	23	1.96	0.51
26,000	24	1.88	0.53
24,500	25	1.80	0.56
24,200	26	1.73	0.58
23,500	27	1.67	0.60
21,900	28	1.61	0.62
21,900	29	1.55	0.64
21,200	30	1.50	0.67
19,700	31	1.45	0.69
19,500	32	1.41	0.71
18,400	33	1.36	0.73
18,200	34	1.32	0.76
17,800	35	1.29	0.78
16,500	36	1.25	0.80
15,800	37	1.22	0.82
14,800	38	1.18	0.84
14,800	39	1.15	0.87
14,600	40	1.13	0.89
11,000	41	1.10	0.91
10,800	42	1.07	0.93
8,700	43	1.05	0.96
3,360	44	1.02	0.98

Appendix H:

Notes on air photo observations of channel changes from Sweasey Dam to the Hammond Bridge (1941/42-1992)

Channel Changes from Sweasey Dam to the Hatchery (1941/42-1992)

[Channel Changes: 1941/42 to 1948]

Sweasey to Hatchery

-- veg area on bars has increased; veg line nr. Canon Ck. has filled in, increased in length along terrace along RB of Mad and along RB of Canon Ck. @ mouth
-- channel width has decreased slightly, veg encroachment onto bars
-- debris flow/landslide visible on LB @ approx. RM 11.5 (?)
-- RB erosion just US of the Hatchery, just DS of pipeline crossing
-- at pipeline crossing US of Hatchery, may have been rip rapped along LB to protect pipe; lots of boulders in 58 & 62 photos observed along LB
-- 5 longitudinal bars observed in 48

[Channel Changes: 1948 to 1954]

Sweasey to Hatchery

-- single channel, migrated to LB @ Canon Ck; confluence has migrated to L side of channel (possible downcutting along LB?)
-- channel mostly along LB at Camp 4 Flat
-- slide scar from 48 photo still visible, healing up
-- slight widening of channel just US of hatchery site (LB erosion of veg)

[Channel Changes: 1954 to 1958]

Sweasey to Hatchery

-- boulders and footbridge still visible
-- channel has migrated toward RB at Camp 4 Flat along with confluence of Canon Ck.
-- slide still visible, healing
-- single strand channel abv Hatchery, mostly along RB
-- lots of boulders visible in channel on 58 photos (better photos than before)

[Channel Changes: 1958 to 1962]

Sweasey to Hatchery

-- dam nearly filled with sediment in 58 photo, filled by 62
-- channel essentially same/similar @ mouth of Canon Ck in both photos; single thread along RB
-- some woody debris visible in channel (trees along banks, protruding, etc.)
-- debris flow scar still visible, healing in '62 photo

[Channel Changes: 1962 to 1966]

Sweasey to Hatchery

-- rocks DS of dam more exposed in channel
-- RB erosion evident in places (veg. changes apparent)
-- gravel bars appear rockier/larger grained; lots of boulders in channel
-- rocks at pipeline/footpath crossing is gone (or underwater)

-- channel widening at Camp 4 bend; mouth of Canyon Ck. has been eroded away; RB DS of Camp 4 bar shows evidence of bank erosion - veg. line bet. channel and rd. is gone
-- rocks along channel DS appear similarly exposed in both years (no noticeable changes in bed elevation)
-- LB is overshadowed by trees and their shadows; difficult to see changes along the bank
-- watershed is heavily logged to NW of Canyon Ck., SW of Hatchery
-- point bar on RB US of Hatchery has eroded significantly (where pipeline crosses to LB)
-- significant widening of channel, retreat of LB just abv. Hatchery, RB has grown

[Channel Changes: 1966 to 1970]

Sweasey to Hatchery
-- Canon Ck. photos in 1970 not available from county
-- DS north bend, bar in 1970 shows veg growth; channel narrowing
-- bars in 66 photos scoured clean of beg; growing back in 1970 photos
-- no bank erosion noted

[Channel Changes: 1970 to 1974]

Sweasey to Hatchery
-- no photos of dam/Canon Ck.
-- channel DS appears wider, no boulders/rock outcrops visible in channel
-- bars appear scoured of veg, very few plants seen on bars in channel

[Channel Changes: 1974 to 1981]

Sweasey to Hatchery
-- no photos available for 1981

[Channel Changes: 1981 to 1988]

Sweasey to Hatchery
-- very extensive logging in watershed by 88 (> 50 - 60 % or more), lots of roads observed
-- 74 photo set incomplete; parts of watershed observed don't show logging on SW side of river
-- channel is devoid of veg on bars in 88; very few (to no) rocks observed; channel appears filled with finer grained sediment - no rock/boulder outcrops seen (except 2 large rocks DS of Sweasey)

[Channel Changes: 1988 to 1992]

Sweasey to Hatchery
-- (photos not available)

Channel Changes from the Hatchery to Blue Lake Bridge (1941/42-1992)

[Channel Changes: 1941/42 to 1948]

Hatchery to Blue Lake Bridge
-- RB erosion just DS of Hatchery site; river has migrated away from LB to RB through this reach; moves back to LB abv Guynup's

-- LB erosion @ field abv Guynup's, trees along LB disappear in spots
-- channel just abv bridge splits into 2 threads; one thread shows a longitudinal bar
-- RB DS of inflection shows erosion, meander growth & lengthening of channel; sinuosity increase
-- LB erosion @ West End Rd. bridge, bridge replaced bet. 1942-48
-- active mining (@ least 3 pits visible on bar where Hatchery Rd. crosses main fork (1 pit US of rd., 2 DS)
-- 3 old main fork channels visible cutting through rip. forest US of Hatchery Rd. bet. main fork and N. Fork

[Channel Changes: 1948 to 1954]

Hatchery to Blue Lake Bridge

-- RB erosion DS of Hatchery site (continued erosion), meander is growing, migrating DS
-- LB erosion @ Guynup
-- more RB erosion abv present Emerson bar site, just US of county bridge; meander is growing outward, moving toward N. Fork

[Channel Changes: 1954 to 1958]

Hatchery to Blue Lake Bridge

-- channel is very, very straight from Hatchery to Blue Lake until it makes a right angle left turn toward county bridge
-- channel flows along LB most of the way until below Guynup's
-- RB erosion (continues) toward N. Fork, channel has widened
-- rip veg along revetment has been removed from US of bridge to DS end; revet. extended US along N. Fork

[Channel Changes: 1958 to 1962]

Hatchery to Blue Lake Bridge

-- main fork avulsion observed US of Blue Lake bridge; RB erosion toward N. Fork occurred until an old channel was encountered (seen on '58 photo), then stream captured by N. Fork channel US of Blue Lake bridge; as evidence of human induced avulsion
-- confluence moved US to just below US end of revetment; channel shorter
-- gravel pits observed on upper Simpson bar, @ old National Guard pool site where Hatchery Rd crosses old, abandoned channel
-- line of logs, trees, debris across channel observed, may have been put in to prevent people from driving US (John Murray, pers. comm.)

[Channel Changes: 1962 to 1966]

Hatchery to Blue Lake Bridge

-- bank erosion along RB DS of Hatchery; channel has migrated toward Simpson property; gravel pit observed in 63 photo wiped out by 64 flood by 66 (may have helped capture channel)
-- channel appears to have overflowed onto LB floodplain bet. upper Simpson bar and N. Fork
-- LB erosion at Guynup property, veg. line along LB shrinks
-- channel has widened at confluence with N. Fork, rip. veg. along both banks washed away
-- gravel pit observed on Emerson bar in 66 photos

[Channel Changes: 1966 to 1970]

Hatchery to Blue Lake Bridge

-- Hatchery built between 66 & 70, some construction still going on in 1970 photo
-- no bank protection along Hatchery; rip veg removed along LB
-- extensive mining along LB processing plant at Guynup's (299 is being widened east of Blue Lake)
-- veg growing up on bars that aren't mined (across/east of Emerson)
-- at Emerson bar, channel has migrated toward LB (erosion), may have captured a pit observed in 66 photo (flows through same location)
-- confluence has migrated DS as a result of LB erosion, channel migration
-- small trench leads into pit

[Channel Changes: 1970 to 1974]

Hatchery to Blue Lake Bridge

-- RB erosion on upper Simpson, pit in 70 photo appears to have captured channel causing meander migration toward RB
-- LB bar accretion at same spot; LB protection at Hatchery observed
-- mining at Guynup
-- channel is braided at Guynup to Emerson, has moved toward LB where trench is seen in 1970 photo
-- last bit if rip veg cleared along North Fork revetment
-- some skimming on Emerson bar

[Channel Changes: 1974 to 1981]

Hatchery to Blue Lake Bridge

-- rip veg above upper Simpson removed from RB terrace (across from Hatchery)
-- RB erosion just DS along upper Simpson bar
-- pit visible in 74 photo across from Guynup stockpile, cuts back into RB; water in pit
-- by 81 rip veg has grown into area where pit was observed (75 flood may have trapped and deposited material in pit); channel is braided/trenched along this reach at Guynup's
-- extensive mining along Guynup bar - roads onto bar, stockpile seen
-- rip veg cleared at organic farm on west side of Hatchery rd. (in old river bed - 58 and earlier)
-- river hugs LB at Emerson bar in 81, not braided as in 74; LB erosion next to Hatchery rd. just US of bridge
-- rip veg has encroached along RB US of confluence by 81 (not very thick, though)

[Channel Changes: 1981 to 1988]

Hatchery to Blue Lake Bridge

-- RB erosion DS of Hatchery at upper Simpson
-- single thread through Guynup property by 88
-- LB erosion (> than RB erosion mentioned above) US of Emerson bar, channel has migrated to RB at Emerson bar, eroding RB; sinuosity increased
-- Guynup diversion ditch observed in 88 photo from upper Simpson (RB to LB) at "Mt. Guynup"
-- mining on Guynup bar, rds. observed on Emerson - mining (?)

[Channel Changes: 1988 to 1992]

Hatchery to Blue Lake Bridge

-- diversion of portion of flow toward LB by Guynup visible in both photos (not being done today)
-- bank erosion along RB visible (bank closer to tree line in 92) at upper Simpson bar
-- LB erosion visible DS at next bend, river closer to Hatchery Rd.
-- RB erosion just abv confluence with N. Fork
-- mining of gravel on Guynup and Emerson bars
-- stream braided at Guynup's, small channel created by Guynup (single channel in 88 photo)
-- no veg changes on bars
-- slightly more sinuous in 92 than 88

Channel Changes from Blue Lake Bridge to the A&MRR Bridge (1941/42-1992)

[Channel Changes: 1941/42 to 1948]

Blue Lake to A&MRR Bridge

-- 2 abandoned channels visible DS of Hatchery Rd.
-- no evidence of bank protection along RB of N. Fork; rip. veg. all along RB
-- veg line along Leavey property is v. thin in both photos
-- 2 channels below confluence in 42 photos, 1 in 48 photo
-- @ Blue Lake bar river becomes braided by 48; one channel cuts through center of bar, shortening river
-- in 42 photo same bar is a half wavelength US, smaller channel is along LB, runs down to Leavey's property
-- rip rap appears along RB @ Christie bar, wing dams protrude into channel, rip veg in 42 is now gone
-- 2 creeks along RB DS of Christie flow together, then along RB parallel to Mad R., confluence is just US of A&MRR bridge (approx. 600 ft)
-- rd. onto Johnson/Lower Simpson bar, possibly some gravel extraction
-- just DS of Christie bar, meander growth, LB & RB erosion (c. 400 ft), rip veg eroded back
-- LB DS is in same position, then next RB meander has straightened and moved toward LB, shortening channel (c. 600 ft of LB erosion); river has lengthened, sinuosity increased until last bend abv A&MRR bridge
-- cut banks and point bars evident
-- dunes visible along LB US of A&MRR bridge (indicates net deposition)

[Channel Changes: 1948 to 1954]

Blue Lake to A&MRR Bridge

-- RB erosion toward N. Fork; channel has moved toward Blue Lake bar, away from Leavey' property, no longer along LB (straightening and widening of channel)
-- channel has migrated away from RB toward center of active channel just below sewage treatment ponds
-- bend at Christie's has been cut off, straightening channel which now flows along center of active channel
-- large portion of rip veg along LB eroded away
-- confluence with creeks abv A&MRR br. (RB) has migrated US
-- revetment seen along Macintosh mill @ Blue Lake, some rip veg removed

[Channel Changes: 1954 to 1958]

Blue Lake to A&MRR Bridge

-- National Guard swimming hole observed; roads on bar DS of county bridge lead to swimming hole; discussion with John Murray indicates the Nat. Guard dammed the river, creating the swimming hole -- examination of the photos shows the river isn't dammed, but a pit was dug next to the stream and water was diverted into it
-- rip veg DS on RB bet 54 channel and an old channel has been completely wiped out and eroded away
-- confluence with N. Fork has migrated US
-- huge area on LB DS of Leavey's eroded away (in 55?), channel back toward stream's center
-- large portion of rip veg forest on US side of Christie bar eroded away
-- channel forms a single thread, meandering pattern through Blue Lake valley
-- active channel has widened significantly; very little (if any) veg on bars
-- channel flows along LB abv A&MRR bridge, Johnson/Lower Simpson bar has grown
-- LB erosion abv bridge

[Channel Changes: 1958 to 1962]

Blue Lake to A&MRR Bridge

-- rip veg forest eroded along RB of main fork before avulsion
-- rip veg has grown up in old channel by 62 (starting to fill in)
-- woody debris in old, abandoned channel observed in 58 photos
-- pit mining on Blue Lake bar observed in 58 & 62
-- LB erosion across from Blue Lake bar toward Leavey property
-- RB erosion toward Christie property and toward sewage treatment ponds as meander growth occurs; wing dams along RB washed away
-- mechanical manipulations of channel observed, two sediment berms pushed into channel near Christie bar; pit next to one
-- LB erosion on next bend DS
-- RB erosion DS end of Christie bar, meander has migrated DS, straightened slightly
-- lower Simpson/Johnson bar disappears as channel migrates to RB above A&MRR bridge
-- no longitudinal bars observed

[Channel Changes: 1962 to 1966]

Blue Lake to A&MRR Bridge

-- LB erosion DS of bridge; meander loop starting to cut into LB toward Leavey's
-- skimming on Blue Lake bar in 62 photo, river has migrated that way wiping out Blue Lake bar by 66
-- Christie bar migrates US along RB; extensive mining on the bar
-- 299 built bet. 62 and 66, crosses Christie property
-- channel shows braided quality - effects of 64 flood
-- significant channel widening bet. Blue Lake bar and A&MRR bridge; both LB and RB erosion
-- 3 rip. veg. islands survived 64 flood at Christie bar
-- rocks visible along RB US of A&MRR bridge in both photos
-- river has moved toward and flows along RB abv. A&MRR by 66

[Channel Changes: 1966 to 1970]

Blue Lake to A&MRR Bridge

-- LB erosion observed, meander growth DS of bridge
-- RB erosion toward Blue Lake bar and sewage ponds
-- some channel widening near sewage ponds (to southwest), rip veg/RB erosion toward ponds
-- channel is braided DS of sewage ponds
-- bank erosion along Leavey's; rip veg and farmland eroded
-- channel still mostly clear of rip veg from 64 flood
-- extensive mining, operations observed on Christie bar, equipment visible
-- not as much equipment seen by 70 on Christie bar, some pits visible near channel, mining appears less extensive on Christie bar by 70; gravel stockpiled on the bar
-- channel shows LB erosion at farm above A&MRR bridge

[Channel Changes: 1970 to 1974]

Blue Lake to A&MRR Bridge

-- Blue Lake bar continues to grow as LB erodes and meander migrates
-- RB eroded toward sewage ponds even further, very close to ponds
-- bar at Leavey's accretes
-- channel still very braided from Blue Lake bar to between Christie and Johnson bar (DS end of Christie)
-- mining on Christie bar/Blue Lake bar/Johnson-Simpson bar (lots of skimming across river on LB)
-- trenching on US end of Christie bar (3 long trenches split flow into 3 threads); river diverted and shortened slightly

[Channel Changes: 1974 to 1981]

Blue Lake to A&MRR Bridge

-- very little (if any) erosion on LB at Leavey's between 74 and 81; rip veg along this LB reach has been cleared between agricultural land and close to LB (from ag. land side)
-- mining on Blue Lake bar, very little rip veg observed in both photos (74 & 81)
-- no mining on next bar DS on LB - minor amounts of rip veg on bar, mostly clear in both 74 & 81
-- construction of RB revetment/bank protection for sewage ponds observed in 74 photo, channel appears to be diverted (3 trenches observed along LB bend); (construction observed in one photo, not the other; no dates on photos to determine month, day)
-- mining at Christie bar observed; several pits/skimmed surfaces seen in 74
-- channel is braided, anastomozing at Christie bar in 74, recovering by 81 with one area on DS end of Christie bar showing 2 channels (4 in 74) - one channel is main channel, other is filled with water, connected with main channel at DS end
-- rip veg growing in on Christie bar by 81
-- extensive mining of gravel on lower Simpson/Johnson bar (LB side of river) - large increase in area mined between the two 74 photos! - several new skimmed areas observed; bar still being mined in 81 - rds. from both sides of river lead down onto bar; 2 strands in 81 photo (perhaps LB strand captured)

[Channel Changes: 1981 to 1988]

Blue Lake to A&MRR Bridge

-- Blue Lake bar - channel is very braided along point bar; single channel in 88
-- veg slightly thicker on Christie bar
-- active mining on Christie bar, channel is very braided
-- LB erosion at Leavey's - rip veg line gone, eaten back to ag. field/pasture
-- channel migrates toward LB at Christie bar, meander growth
-- channel migrates toward LB at lower Simpson bar, accretion on RB

[Channel Changes: 1988 to 1992]

Blue Lake to A&MRR Bridge

-- channel braided DS of bridge along LB bend, part of channel is along bank, other smaller channels flow across nose of point bar
-- channel has migrated toward Blue Lake bar by 92, away from LB; possibly capturing area skimmed by gravel mining
-- Blue Lake bar shows active mining
-- Christie bar mining evident, RB erosion on US side of bar; LB has migrated toward Christie bar (on RB), captured by skimming on bar; trenching seen, channel has straightened DS of Christie bar
-- channel hugs RB just abv A&MRR bridge; has migrated since 88 from LB

Channel Changes from the A&MRR Bridge to the 299 Bridge (1941/42-1992)

[Channel Changes: 1941/42 to 1948]

A&MRR to 299

-- no pond/lake on Lindsay Ck (shows up in 58 photo as lumber mill pond with lots of timber floating in it -- area not covered in 54 photo)
-- channel has migrated toward RB @ Essex bar where extensive mining is observed (multiple roads onto bar, equipment visible, little to no veg on Essex bar and next one DS along RB, which is also being mined)
-- opposite Essex bar channel has migrated (500-600 ft) toward RB away from RR trestle (channel captured by pits in stream?)
-- channel has shortened
-- rip veg removed on R bar abv 299 (some appears cleared by farmer abv, some appears cleared by mining activity on bar)
-- eastbound 299 span is new since 1942 photo (bridge @ an oblique angle to river)
-- boulders observed US of 299
-- banks do not appear steep (when viewed in stereo) along the reach

[Channel Changes: 1948 to 1954]

A&MRR to 299

-- channel migration back toward center of active channel at Essex bar
-- 1954 photos don't show much detail - washed out

[Channel Changes: 1954 to 1958]

A&MRR to 299

-- Lindsay Ck. appears to flow US under A&MRR bridge, then into Mad R. (which changes over LB)
-- active mining at Essex, pits and diversions visible, channel along LB, but not where it was in 42
-- no mining seen on bar just US of 299 (RB) although a road drops down onto the bar
-- rocks in stream abv 299 visible; channel appears slightly wider through the reach

[Channel Changes: 1958 to 1962]

A&MRR to 299

-- gravel extraction observed in RB bar just US of Essex bar in 62
-- channel has migrated away from this bar between 58 & 62 (thus allowing mining)
-- LB erosion just DS on Pump Station 4 bar (US of Pump Station 4) no wing dams observed here, probably put in shortly after since dirt rd. is being washed away along with terrace just above Pump Station 4
-- v. extensive channelization and mining at Essex bar; berm in channel diverts water away from bar also into pools on bar
-- wing dams appear on 1974 photos at Pump Station 2 (no coverage with 1970 photos) on LB extensive mechanical manipulation in 74 photo; HBMWD shop observed on LB; intake not observed
-- bar on RB just above 299 shows extensive mining, pits down to - and below water level seen, channel braided and migrating toward RB, may have been captured by trenches/pits, water flows into one pit along RB
-- rock/boulder outcrop (c. 1000 ft. US) barely visible in 58, very prominent by 62, even more so by 70; rock diverts flow partly toward RB as exposure increases; rip veg removed and part of terrace being mined

[Channel Changes: 1962 to 1966]

A&MRR to 299

-- Pit mining DS of confluence with Lindsay Ck. in 62 photo; by 66 river occupies a channel along RB, perhaps captured by pits (@ least 2)
-- wing dams along LB, US side of park @ Pump Sta. 4 1st appear on 66 photos; river has migrated to RB (possible because of these?)
-- extensive in-channel work around pump stations, Pump Sta. 5 appears by 66
-- rocks seen DS of Lindsay Ck. confluence, not visible in 62 photos (river on other side of channel - rocks are part of bar)
-- rocks visible at mouth of Warren Ck. (also visible on 62 photos)
-- channel has migrated toward RB at Essex plant, away from park @ Pump Sta. 4
-- bar bet. Pump Sta.'s 1&2 appears to be devoid of veg. - not a terrace yet
-- gravel mining on bar just US of 299 on RB in both photos, more extensive in 66
-- small longitudinal bar immediately US of 299 in center of channel on 62 photo, not seen on 66 photo
-- rip. veg. on RB abv. 299 & USGS gaging station removed by roadbuilding to gravel operation
-- rocks @ USGS cableway visible on RB
-- DS span of 299 bridge appears by 66

[<u>Channel Changes: 1966 to 1970</u>]

<u>A&MRR to 299</u>

-- extensive in-channel mechanical manipulations around the Pump Stations, water diverted to Pump Stations 1-5 in 1970 photo (all 6 added by 62); veg has grown in somewhat by 1970 photo
-- terrace shows mining on RB above USGS gaging station in 1970 photo
-- large rock US of 299 along LB is visible

[<u>Channel Changes: 1970 to 1974</u>]

<u>A&MRR to 299</u>

-- river still being diverted to Ranney collector, braided between A&MRR and Essex bar
-- mining on Essex bar continues
-- rock outcropping on LB above 299 visible
-- bar opposite rock has received recent flow, is scoured of veg
-- rocks US of 299 in channel visible (USGS control)

[<u>Channel Changes: 1974 to 1981</u>]

<u>A&MRR to 299</u>

-- no diversions observed of river to Ranney collectors
-- Essex bar shows no mining in 81; no flow over Essex bar
-- no flow over bar DS of Essex on RB in 81
-- rock US of 299 on LB quite visible in 81; 74 shows gravel around rock, doesn't protrude as much; flow diverted by rock (around it)
-- wing dams visible at Pump Stations 2 & 5 - difficult to see in 81 due to scale differences
-- intake DS of Pump Station 1 observed (LB) - rip veg cleared, river diverted to that side

[<u>Channel Changes: 1981 to 1988</u>]

<u>A&MRR to 299</u>

-- wavelength decreases between Essex and A&MRR bridge by 88
-- river diverted to LB and intake DS of Pump Station 1
-- flow along RB above 299, hits big rock, then flows right; boulders visible above 299

[<u>Channel Changes: 1988 to 1992</u>]

<u>A&MRR to 299</u>

-- channel appears to maintain same pattern, no changes observed
-- veg on bars has increased, slightly thicker in 92

Channel Changes from the 299 Bridge to the Hammond Bridge (1941/42-1992)

[Channel Changes: 1941/42 to 1948]

299 to 101

-- channel braided @ Spini's L bend in 48, 2 lines of veg along RB seen in both photos @ Spini's
-- road from 299 br. drops down onto bar on L side of channel; pit seen @ DS L hand bend in river; gravel may have been used in bridge construction (?)
-- some veg on bar has been removed by 48, one line of trees seen just DS @ pit protruding from LB into channel (confines channel in 1942 photo)
-- instream bar observed @ Shaw's Crossing (US side); not seen in 48 photo
-- across from Graham bar, RB erosion evident, bank has retreated toward farmland, LB just DS has also eroded (even more significantly); bank protection evident in 48 photo; bank has retreated c. 450 ft max; next bend shows RB erosion (c. 300-400 ft)
-- rip veg has grown toward river on L bar US of 101
-- channel just US of piers abv 101 has migrated to RB (c. 600 ft)

101 to Hammond

-- no mining on Dutra bar
-- no changes observed, veg/channel appear similar

[Channel Changes: 1948 to 1954]

299 to 101

-- veg line along RB at Spini's still visible
-- channel has migrated toward RB, single channel in 54, not braided
-- rocks/boulders visible at Shaw's Crossing and just US
-- RB erosion across from Graham bar
-- mining evident along LB in channel at Graham bar (REA); channel is along RB (eroding as abv)
-- lots of pools visible along L side of channel
-- veg at Spini's L bend is now gone (washed away by 53 flood?)
-- further LB erosion DS of REA, rip veg line retreats/gone
-- further RB erosion south of Azalea rd. (c. 250-300 ft)
-- channel back to LB abv piers abv 101

101 to Hammond

-- veg gone on RB abv Hammond, but not DS of Hammond, appears cleared by farmers, not bank erosion

[Channel Changes: 1954 to 1958]

299 to 101

-- some of veg line at Spini's RB bar eroded
-- rocks at Shaw's Crossing exposed
-- trenching in channel at Graham bar extend for > than 1,000 feet; 1 bridge seen in 54 photo
-- further LB erosion
-- trenches extend for c. 1 mile down the bend to south of Azalea rd.

101 to Hammond
-- wing dams put in on LB DS of 101, rip veg gone, possibly eroded in '55 flood
-- RB erosion on bend just US of Hammond bridge

[Channel Changes: 1958 to 1962]

299 to 101
-- very little mining on Spini bar (LB) in 58; 62 extensive mining, large pits down to water surface observed (& below)
-- rocks visible at Shaw's Crossing; appear to protrude more than in 58 and 48 (not seen in 48, but channel appears to have more water in it); these rocks are at mouth of ck. just US of crossing
-- extensive trenching along Graham bar by REA continues; some trenches extend for > than 2,000 ft.; 2 long trenches in channel, one on inside bend, one on outside bend; trenches/pits below water level observed for > 2,000 ft.; culverts at REA seen; large berm between bars; flow is along inside trench, shortening channel
-- rip veg has grown up along inside bend of right bar (south of Azalea rd.)
-- RB just above 101 has eroded back, rip veg gone, 5 wing dams observed diverting flow away from right bank, bridge on north-bound lane still being repaired, traffic diverted to south-bound land, bridge completed by 62; rip veg has grown in by 62 photo
-- 101 widened to 4 lanes between Arcata and McKinleyville (gravel may have been taken from Graham bar)

101 to Hammond
-- wing dams along LB still observed
-- rip veg growing back along RB just above Hammond bridge

[Channel Changes: 1962 to 1966]

299 to 101
-- RB eroded @ Spini's, veg. disappears
-- bank erosion also along LB @ left hand bend, channel widening
-- rocks at Shaw's Crossing show on both photos
-- REA's culverts visible
-- extensive trenching from US of REA to left hand bend abv. 101 bridge, river splits into several strands and pools
-- extensive erosion of bar DS on LB @ big left hand bend in river, veg. disappears on left bar and begins to grow on RB where trenching was formerly done
-- farmer has cleared some of veg. on RB
-- channel has shortened and migrated toward LB @ this bend; spur along LB protruding into channel was eroded away
-- trenching just south of Azalea Rd. in channel in 62 photo, gone by 66
-- skimming on LB bar @ same left hand bend
-- US of 101 approx. 200 ft a road is visible extending down into channel - gravel skimming? same rd. appears on 66 photo - equipment and mining visible in channel

101 to Hammond
-- wing dams DS on LB disappear by 66, LB is diked/revetted
-- extensive gravel mining at next RB bend
-- LB opposite is diked/revetted
-- rip. veg. removed along both dikes
-- rip. veg. on next L bend and bar is eroded (approx. 1/3 less by 66 photos)

-- some channel widening
-- 101 bypass of McKinleyville appears on 66 photo
-- gravel from Dutra's bar used for this (RB, DS of 101)

[Channel Changes: 1966 to 1970]

299 to 101

-- mining on Spini bar (LB)
-- rocks at Shaw's Crossing visible
-- RB rip forest removed, trench replaces forest; appears removed by gravel harvesting; rip forest on RB just DS has grown up thicker
-- rip veg on RB US of 101 has grown in, fairly thick by 1970

101 to Hammond

-- Dutra bar being mined at least down to water surface in large pits
-- rip veg along north bank (RB) at Hammond cleared/removed by 1970
-- wing dams visible in 66 and 70 photos on RB just US of Hammond

[Channel Changes: 1970 to 1974]

299 to 101

-- mining on Spini bar
-- RB erosion just DS of 299 visible (no rd. down to bar along RB yet)
-- channel is along RB in both photos at Spini's
-- large rock (barely visible in 62, visible in 66, 70) protrudes from channel in 74 with other rocks around it visible (O'Neill's rock); same rock not visible in 58 photo - sand/gravel bar observed where outcrop should be
-- trenching less extensive at REA/Graham bar than in 70 (doesn't extend as far DS)
-- rip forest south of Azalea and North Bank rds. increased in area
-- channel still braided along Graham bar and DS to left bend
-- rip veg along LB filling in

101 to Hammond

-- mining still occurring on Dutra's bar, to a lesser extent
-- rip veg between Dutra and Hammond almost completely gone; LB is similar to 70

[Channel Changes: 1974 to 1981]

299 to 101

-- mining on Spini bar, river along RB in 74, moves toward center of channel by 81
-- rock at Shaw's Crossing visible, flow around rock on both sides in 74, mostly to LB in 81
-- trenches in 74, some skimming in 81, but not as much mechanical manipulation of channel (no trenches)
-- rip veg on longitudinal bar (Graham bar) beginning to grow back; rip forest on RB getting thick

101 to Hammond

-- "Mt. Dutra" shrinks, pit almost completely gone along with stockpile; rip rap along RB observed in 74 photo at this bend
-- rip veg slightly thicker at left US of Hammond

[Channel Changes: 1981 to 1988]

299 to 101

-- channel braided, flows along L and RB at Spini in 88
-- rock at Shaw's Crossing visible, flow is to L of rock
-- single channel DS of Graham bar, rip veg on longitudinal bar filling in, overflow channel along RB is dry, veg is encroaching
-- culverts at REA visible

101 to Hammond

-- Dutra's bar shows no mining at all
-- no other changes observed

[Channel Changes: 1988 to 1992]

299 to 101

-- channel is braided on Spini's bar, scoured clean of veg, multiple threads in 88; 92 shows 2 threads, R channel has migrated away from RB compared to 88
-- rip veg has grown up (slightly) in 92 on longitudinal bar at Spini's
-- rocks at Shaw's Crossing visible, flow is to L of big rock
-- rip veg on bar across from REA thicker in 92; (86? overflow channel filling in?)
-- rip veg along RB at Spini's has grown up

101 to Hammond

-- very little (if any) changes observed

Appendix I:

Active channel centerline measurements (ft.), lower Mad River, 1855 to 1992

Year	Sweasey to Hatchery	Hatchery to Blue Lake bridge	Blue Lake to A&MRR	A&MRR to 299	299 to 101	101 to Hammond
1855	N/A	15,571	14,666	9,447	18,359	9,887
1865	22,928	7,558*	14,397	10,204	16,768	9,595
1886	21,110	14,472	14,451	9,718	7,770	9,231
1898	25,831**	9,753	15,546	9,498	9,996	8,805
1916	21,719	9,042	16,930	9,845	10,471	9,358
1921	28,521	7,667	15,239	9,647	11,510	9,157
1933	N/A	N/A	N/A	9,764	13,360	9,575
1941/42	29,638	6,861	16,926	10,536	12,853	9,587
1948	30,367	6,642	16,977	10,177	13,600	9,535
1954	29,875	7,192	15,897	10,198	13,796	9,454
1958	30,080	7,555	15,778	10,323	13,590	9,373
1962	30,032	7,521	14,497	9,964	13,753	9,758
1966	29,771	8,043	15,333	9,740	13,038	9,498
1970	29,974	8,923	14,381	9,855	11,952	9,787
1974	29,473	8,450	14,474	9,943	12,342	9,515
1981	N/A	8,555	14,777	10,095	12,359	9,877
1988	N/A	8,760	15,598	9,910	13,035	9,713
1992	29,768	8,885	16,514	10,239	12,936	9,712

* -- poor / inadequate data / map interpreted incorrectly
** -- questionable data, channel may be mismapped

Appendix J:

Active channel width measurements (ft), lower Mad River, 1855 to 1992

Year	Sweasey to Hatchery	Hatchery to Blue Lake bridge	Blue Lake to A&MRR	A&MRR to 299	299 to 101	101 to Hammond
1855	N/A	278	919	748	438	521
1865	N/A	565**	553	419	888	611
1886	576	581	659	673	582	488
1898	573*	475	940	750	692	890
1916	282	445	490	626	516	515
1921	286	1,365	1,528	643	721	871
1933	N/A	N/A	N/A	372	352	360
1941/42	387	578	564	397	349	318
1948	192	458	749	365	416	274
1954	227	666	1,006	423	448	299
1958	249	844	1,453	426	451	292
1962	261	1,170	1,403	354	432	284
1966	302	1,988	1,511	523	461	449
1970	283	605	1,532	459	495	359
1974	323	634	1,664	381	438	298
1981	N/A	474	1,259	423	416	335
1988	N/A	736	1,064	391	351	345
1992	318	495	675	379	333	301

* -- questionable data, channel may be mismapped
** -- poor / inadequate data / map interpreted incorrectly

Appendix K:

Active channel area measurements (acres), lower Mad River, 1855 to 1992

Year	Sweasey to Hatchery	Hatchery to Hatchery Road bridge	Blue Lake to A&MRR	A&MRR to 299	299 to 101	101 to Hammond
1855	N/A	99	310	162	185	118
1865	N/A	98**	183	98	342	135
1886	279	193	219	150	104	104
1898	340*	106	335	164	159	180
1916	141	92	191	141	124	111
1921	187	240	534	142	190	183
1933	N/A	N/A	N/A	83	108	79
1941/42	213	91	219	96	103	70
1948	140	70	292	85	130	60
1954	156	110	367	99	142	65
1958	172	146	526	101	141	63
1962	181	202	467	81	84	64
1966	206	367	532	117	136	98
1970	194	124	506	104	137	81
1974	219	123	553	87	124	65
1981	N/A	93	427	98	118	76
1988	N/A	148	381	89	105	77
1992	217	101	256	89	99	67

* -- questionable data, channel may be mismapped
** -- poor / inadequate data / map interpreted incorrectly

Active channel area measurements (ft^2), lower Mad River, 1855 to 1992

Year	Sweasey to Hatchery	Hatchery to Blue Lake	Blue Lake to A&MRR	A&MRR to 299	299 to 101	101 to Hammond
1855	N/A	4,321,990	13,483,178	7,063,829	8,042,508	5,146,407
1865	N/A	4,269,764**	7,960,659	4,274,811	14,883,830	5,862,508
1886	12,161,927	8,401,262	9,525,246	6,539,449	4,518,482	4,509,313
1898	14,794,758*	4,629,596	14,612,304	7,122,893	6,918,999	7,832,120
1916	6,129,645	4,021,215	8,353,848	6,162,099	5,402,815	4,823,772
1921	8,159,045	10,466,968	23,279,997	6,199,871	8,298,032	7,975,505
1933	N/A	N/A	N/A	3635982	4,696,046	3,450,960
1941/42	9,274,416	3,963,960	9,539,640	4,181,760	4,486,680	3,049,200
1948	6,095,216	3,043,390	12,713,064	3,710,824	5,662,304	2,615,906
1954	6,785,784	4,791,600	15,986,520	4,312,440	6,185,520	2,831,400
1958	7,481,729	6,377,593	22,919,586	4,396,200	6,133,118	2,735,104
1962	7,867,972	8,799,120	20,342,520	3,528,360	5,924,160	2,768,429
1966	8,977,023	15,986,520	23,173,920	5,096,520	5,967,720	4,268,880
1970	8,469,034	5,400,189	22,037,146	4,518,738	5,915,988	3,509,290
1974	9,531,469	5,357,880	24,079,363	3,789,720	5,401,440	2,831,400
1981	N/A	4,051,080	18,600,120	4,268,880	5,140,080	3,310,560
1988	N/A	6,446,880	16,596,360	3,876,840	4,573,800	3,354,120
1992	9,453,912	4,399,560	11,151,360	3,876,840	4,312,440	2,918,520
mean†	8,215,173	6,237,979	17,921,782	4,141,557	5,427,568	3,108,437

* -- questionable data, channel may be mismapped

** -- poor / inadequate data / map interpreted incorrectly

† -- mean for 1941/42 to 1992 (aerial photo measurements)

Appendix L:

Medial bar measurements (feet) lower Mad River, 1941/42 to 1992

Year	Location	Length	Width	L/W Ratio	Mean for Each Year	Number of Bars Observed
1941/42	blw Sweasey Dam	350	112	3.1	4.8	10
	US Cañon Ck.	931	192	4.8		
	Cañon Ck.	1644	199	8.3		
	Hatchery to BL	946	175	5.4		
	Blue Lake to A&MRR	1510	503	3.0		
	Blue Lake to A&MRR	897	202	4.4		
	Blue Lake to A&MRR	552	193	2.9		
	bet. 299 & 101	1204	245	4.9		
	blw Hammond	1878	897	2.1		
	blw Hammond	824	94	8.8		
1948	blw Sweasey Dam	340	108	3.1	4.3	11
	US Cañon Ck.	913	184	5.0		
	Cañon Ck.	1658	209	7.9		
	abv Hatchery	811	163	5.0		
	abv Hatchery	521	89	5.9		
	Hatchery to BL	933	185	5.0		
	Blue Lake to A&MRR	818	332	2.5		
	Blue Lake to A&MRR	724	130	5.6		
	Blue Lake to A&MRR	1650	615	2.7		
	299 to 101	223	131	1.7		
	299 to 101	2032	515	3.9		
1954	abv Cañon Ck	906	214	4.2	3.1	5
	blw Cañon Ck	449	92	4.9		
	blw Cañon Ck	753	246	3.1		
	abv Hatchery	810	497	1.6		
	abv A&MRR	1122	537	2.1		
1958	@ Cañon Ck	675	206	3.3	4.4	7
	blw Cañon Ck	470	133	3.5		
	DS Cañon Ck	533	123	4.3		
	DS Cañon Ck	371	72	5.2		
	DS Cañon Ck	471	97	4.9		
	DS Cañon Ck	595	195	3.1		
	blw N. Fork	595	92	6.5		
1962	blw Sweasey Dam	629	204	3.1	2.9	3
	DS Cañon Ck	205	68	3.0		
	DS Cañon Ck	464	171	2.7		
1966	DS Cañon Ck	504	75	6.7	5.8	6
	DS Cañon Ck	552	152	3.6		
	DS Cañon Ck	812	197	4.1		
	abv Blue Lake br.	647	114	5.7		
	DS of Blue Lake revet.	680	84	8.1		

Year	Location	Length	Width	L/W Ratio	Mean for Each Year	Number of Bars Observed
	REA man made bar	1629	245	6.6		
1970	Cañon Ck	2558	325	7.9	5.4	19
	DS of bend	865	150	5.8		
	just DS of bend	528	146	3.6		
	big bar @ Hatchery	1293	317	4.1		
	sm bar @ Hatchery	592	126	4.7		
	Guynup bar	497	63	7.9		
	Guynup bar	365	56	6.5		
	DS of Blue Lake br	764	127	6.0		
	DS of Blue Lake br	280	127	2.2		
	DS of Blue Lake br	663	91	7.3		
	DS of Blue Lake br	500	61	8.2		
	bar bet Blue Lake & A&M	5939	1327	4.5		
	bar bet Blue Lake & A&M	3662	878	4.2		
	bar bet Blue Lake & A&M	245	95	2.6		
	bar bet Blue Lake & A&M	697	287	2.4		
	DS of 299	592	92	6.4		
	REA man made bars	1958	552	3.5		
	REA man made bars	2610	335	7.8		
	DS of 101	716	118	6.1		
1974*	US of Blue Lake br	1877	248	7.6	4.4	4
	DS of Blue Lake br	1464	412	3.6		
	Pmp Sta 5 man made	1408	505	2.8		
	REA man made bar	2371	665	3.6		
1981*	Guynup bar	1546	284	5.4	4.0	2
	US of A&MRR br	937	354	2.6		
1988	DS of Blue Lake br	1713	439	3.9	4.1	3
	US of A&MRR br	2166	417	5.2		
	DS of 299 @ Spini	1917	606	3.2		
1992	just DS of Hatchery	1437	216	6.7	4.8	4
	Guynup bar	680	152	4.5		
	US of 299	968	193	5.0		
	DS of 299 @ Spini	1381	464	3.0		
	Mean =	1091	268	4.6	Total =	74

* = incomplete data above Hatchery

Appendix M:

Sinuosity measurements, lower Mad River, 1855 to 1992

Year	Sweasey to Hatchery	Hatchery to Blue Lake bridge	Blue Lake A&MRR	A&MRR to 299	299 to 101	101 to Hammond
1855	N/A	1.84†	1.03†	1.05†	1.58†	1.08†
1865	0.79†	0.89†	1.01†	1.14†	1.44†	1.05†
1886	0.73†	1.71†	1.01†	1.08†	0.67†	1.01†
1898	0.89†	1.15†	1.09†	1.06†	0.86†	0.96†
1916	0.75†	1.07†	1.19†	1.10†	0.90†	1.02†
1921	0.98†	0.91†	1.07†	1.07†	0.99†	1.00†
1933	N/A	N/A	N/A	1.09	1.15	1.05
1941/42	1.02	0.81	1.19	1.17	1.11	1.05
1948	1.05	0.79	1.19	1.13	1.17	1.04
1954	1.03	0.85	1.12	1.14	1.19	1.03
1958	1.04	0.89	1.11	1.15	1.17	1.02
1962	N/A	0.89	1.02	1.11	1.18	1.07
1966	N/A	0.95	1.08	1.09	1.12	1.04
1970	1.03	1.06	1.01	1.10	1.03	1.07
1974	1.01	1.00	1.02	1.11	1.06	1.04
1981	N/A	1.01	1.04	1.12	1.06	1.08
1988	N/A	1.04	1.09	1.10	1.12	1.06
1992	1.03	1.05	1.16	1.14	1.11	1.06

N/A -- Air Photos not available
† -- Accuracy of maps uncertain

Appendix N:

Geomorphic variables (ft), Blue Lake valley, lower Mad River, 1941/42 to 1992

Year	Meander #	River Mile	Wave-length	Amplitude	Radius of Curvature	Notes
1941/42	1	10	3770	107 / 284	105 / 251	
	2	9	5301	619 /547	916 / 376	
	3	8.5	1984	436 / 60	300 / N/A	
	4	7.5	2891	71 / 1145	182 / 750	
	5	7	3130	1047 / 72	600 / N/A	
	6	6.5	2373	87 / 441	N/A / 292	
	7	6	2081	329 / 121	262 / 175	
1948	1	10	3611	233 / 287	197 / 304	
	2	9.25	2797	630 / 251	361 / 178	
	3	8.5	2780	212 / 947	158 / 473	
	4	7.75	4535	435 / 1229	617 / 721	
	5	7	3063	1086 / 613	615 / 417	meander #7 has disappeared,
	6	6.5	2481	378 / 858	214 / 441	channel has straightened
1954	1	9.75	3537	490 / 300	423 / 241	
	2	9	3873	1261 / 314	569 / 358	
	3	8.25	2029	289 / 248	306 / 276	
	4	8	1503	155 / 116	140 / 121	
	5	7.25	3445	301 / 1131	221 / 565	
	6	6.75	3784	954 / 300	572 / 343	
	7	6.25	2644	474 / 155	294 / 173	
1958	1	9	3144	757 / 1149	455 / 710	
	2	8	3918	662 / 626	532 / 590	
	3	7.5	3754	509 / 1125	340 / 679	
	4	6.5	4287	795 / 551	477 / 762	
1962	1	7.5	5211	973 / 1095	766 / 1081	channel is very straight
	2	6.5	1765	591 / 22	345 / N/A	between Hatchery & Blue Lake
1966	1	9.75	3519	699 / 170	413 / 202	channel begins to meander
	2	9.25	2758	62 / 301	312 / 316	between Blue Lake & Hatchery;
	3	8.5	4425	868 / 400	647 / 676	also braided upstream of
	4	7.75	3073	494 / 126	510 / 305	A&MRR bridge
1970	1	9.75	3234	417 / 363	313 / 256	
	2	9.25	2948	238 / 274	198 / 230	
	3	8.5	4132	642 / 791	525 / 656	
	4	7.75	4297	1043 / 711	631 / 834	braided ds

Year	Meander #	River Mile	Wave-length	Amplitude	Radius of Curvature	Notes
1974	1	9.75	3455	596 / 197	580 / 181	reach straightens down to BL
	2	8.5	4928	876 / 1331	568 / 778	
	3	7.5	6140	967 / 576	533 / 650	braided blw #3
1981	1	9.5-9.75	3913	813 / 246	472 / 256	
	2	9	2384	180 / 176	190 / 232	
	3	8.5	3727	569 / 1424	334 / 834	
	4	7.25-7.5	4618	1150 / 575	767 / 391	
	5	6.75	3462	191 / 527	178 / 318	
	6	6.25	2425	452 / 65	422 / N/A	
1988	1	9.5	4828	565 / 830	422 / 711	
	2	8.5	4813	827 / 1163	743 / 849	
	3		5835	1107 / 1144	1183 / 901	
	4		1966	764 / 104	390 / 92	
	5		2351	104 / 294	119 / 321	
1992	1	9.5	4937	620 / 857	506 / 740	
	2	8.5	4797	820 / 1062	679 / 825	
	3	7.25-7.5	5599	1440 / 552	1196 / 534	
	4	6	5177	847 / 70	829 / N/A	reach straightens

Appendix O:

Tree Ring Study at the A&MRR Bridge, Lower Mad River
October 26, 1993

Objectives: 1) to use an incremental borer to sample an alder tree growing on one of the bridge abutments in order to age date the tree; 2) to measure the net degradation of the channel below the tree; 3) to combine the two measurements in order to estimate net change in depth through time at the abutment.

Notes: I made the following assumptions: 1) the tree was at the bed surface when it first took root; 2) net change in elevation is recorded by the difference in elevation between the base of the tree and the present bed surface over the number of years the tree has been growing (age of the tree).

Results: Four cores were taken. The number of rings ranged from 42 to 20 (cores were photographed and saved). The ranges obtained resulted from the selection of core locations (see figure O-1 below). Core #1 yielded an age of approximately 40 years for the tree. Core #2 yielded an age of approximately 20 years since it was taken much higher in the tree. I assumed the tree was browsed back by animals when the bed surface permitted access to the tree (similar to what I've observed on the Trinity River during riparian monitoring studies). Core #3 yielded an age of approximately 19 years (cored into root system below base of trunk). Core #4 yielded an age of approximately 30 years. It was taken higher up on the trunk than core #1. I was unable to determine exactly where the center ring of core #4 was since the core came out damaged, so the age obtained is just an estimate. I used the 40 year age since the core was undamaged, the center ring was easiest to see, and since it was reasonable to assume that where the core was taken accurately measured the oldest part of the tree.

Since the tree started growing (40 years ago), the bed has dropped 6.9 feet (210 cm) (see figure O-2). The rate of bed lowering was determined by using the following relationship: 6.9 feet/40 years.

Lowering rate at the A&MRR bridge = 0.17 = 0.2 feet/year

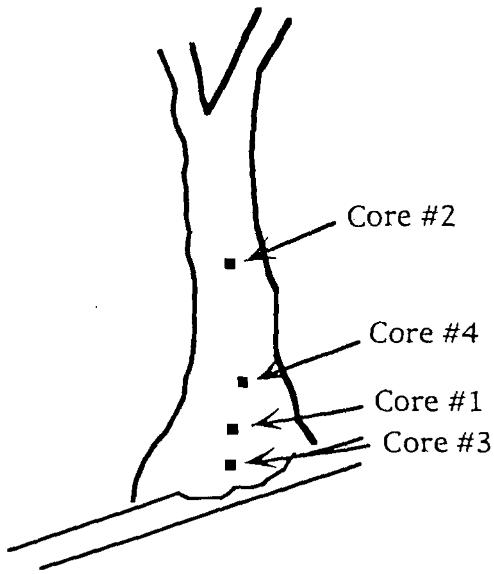


Figure O-1: Tree ring core locations in the alder tree on right A&MRR bridge abutment, Mad River.

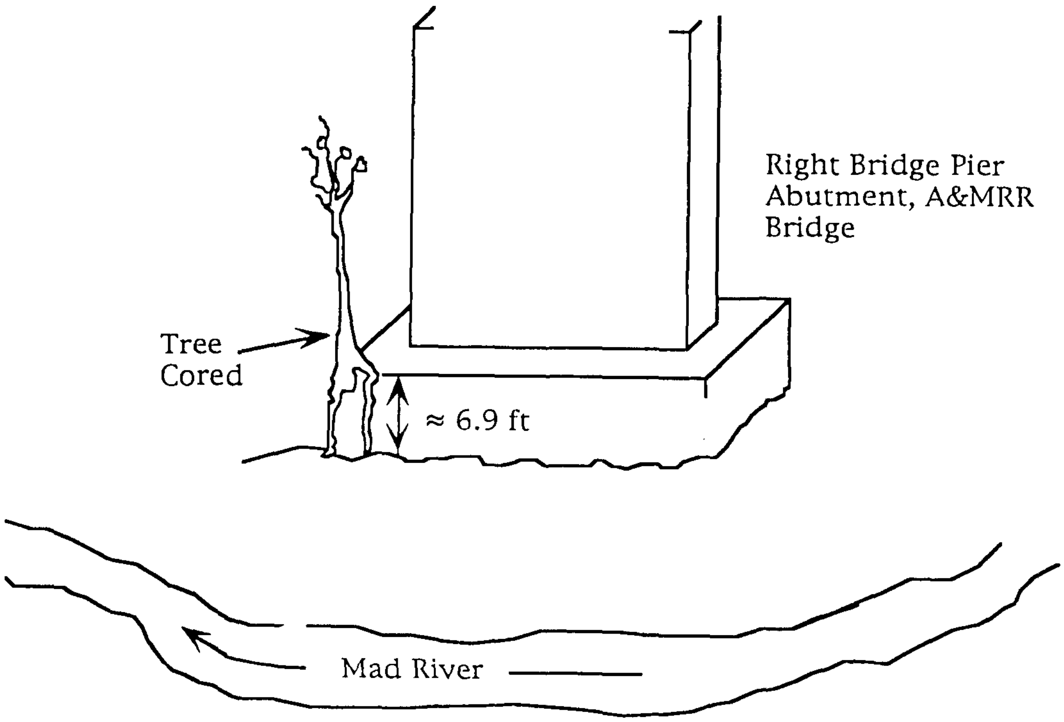


Figure O-2: Net bed lowering at the right bridge pier abutment, A&MRR bridge, Mad River.

Appendix P:

Bed Elevation Analysis of Bridge Photo @ USGS Cableway, Lower Mad River

Objectives: To determine bed elevation changes through time at the USGS cableway, upstream of the highway 299 crossing by comparing photogrammetric data with cross-section surveys done in 1978 and 1993.

Findings: Analysis of the bridge crossing photo at the present USGS cableway, taken between 1906 and 1932 (when the bridge was constructed, then removed -- see below) indicates net bed lowering of 20 to 25 feet over the last 61 to 87 years. Bed lowering rate estimates range from 0.23 feet per year to 0.41 feet per year. Minimum lowering rate = 0.3 feet/year (rounded).

Total lowering amounts were estimated under the following assumptions:

Assumptions:

1. camera lens axis was horizontal when photo was taken
2. vertical distortion under measurement location (from bridge to bed surface) is 4% maximum (= -0.8 to -1.0 ft)
3. railing height is 36 to 44 in., based on observations of railing (probably constructed from 1" X 8" boards -- the typical mill dimension of that period (Aldaron Laird, pers. comm.)), estimated height of carriage wheels, estimated height of horse's belly, estimated height of person's torso
4. bottom of bridge beam = BM elevation located on RB abutment (= 58.373 ft. in 1931)
5. bridge beam is horizontal
6. atmospheric and earth curvature distortions are negligible over the distances measured
7. photographic paper distortions are negligible over the distances measured

Methods:

The principle point on the photo was located by drawing lines through fiducial marks plotted on a mylar overlay of the photo. I was not able to determine the focal length of the camera since the point at which the tripod was set up is, today, overgrown with vegetation, completely obscuring the view toward the old bridge site. I used an optical micrometer to measure the height of the railing closest to the principle point from the top of the railing to the bridge deck (15 units). I then measured the height of a similar feature directly above the channel center (11 units). The distance directly down to the top of the bed below this point was measured (174 units). The distance between the BM elevation (bridge beam bottom) and the top of the bed was determined by dividing that distance by the length of the railing (assumed to be between 36 and 44 in.) and was determined to be 6.73 units. I multiplied this value by 3.0 ft. (36 in.) and 3.7 ft. (44 in.) to obtain a range of distances (20.2 ft. to 24.7 ft. below the bridge) representing the bed elevation differences at the time the photo was taken.

I calculated 27% shortening due to parallax distortion between the principle point and the center of the bridge along the horizon line ((1-(11/15))*100). Maximum radial distortion was estimated at 4% from the principle point to the top of the bed (assuming a constant distortion rate along the distance from the principle point to the bed surface = distortion rate along the horizon line between the principle point and the center of the bridge). This would give an error of -0.8 ft. to -1.0 ft. from the point on the bridge along the horizon line to the point on the bed surface directly below the center of the bridge. I calculated true bed elevations by subtracting the elevation differences, adjusted by -1.0 ft. (to include potential error resulting from distortions mentioned above) from the BM elevation and obtained values of 39.173 ft. to 34.673 ft., rounded to 39 ft. and 35 ft. above sea level.

The bridge was built between 1905-06 and was completed by September 1, 1906 (Arcata Union, September 1, 1906). It was removed in 1932 as reported in the Blue Lake Advocate: "The bridge is to be moved to a point downstream from the present railroad bridge over Mad River, on the Blue Lake road." ("Smith Bros. Low Bidders For Moving Bridge", *Blue Lake Advocate,* September 24, 1932) giving a minimum time span of 61 years. To assess net bed elevation changes through time I used a total geodetic station to survey a cross section along the centerline between the still-present abutments. Results show the thalweg elevation was 10.543 ft. (Net elevation changes were estimated using the range of estimates for the height of the railing (3.0 ft. and 3.7 ft.)). I subtracted the thalweg elevation from the true bed elevations determined above. Results indicate a change in elevation of 29 to 24 ft. (39.173 - 10.543 = 28.630; 34.673 - 10.543 = 24.130) over a minimum time range of 61 years (when the bridge was removed) and a maximum of 94 years (when horse and buggy travel was common). I should also note the cross section was measured down to the thalweg, while the photo measurement was made to the top of the bed below the bridge. The photo was taken during low flow conditions and I assumed the thalweg was no more than 3-4 feet below the point measured. This would have given a net difference of approximately 20 to 25 feet over the time span mentioned above.

Using these estimates, I calculated net bed lowering rates for 61 and 87 years:

Over 61 years:	0.33 ft./yr. for 20 ft. elev. change
	0.41 ft./yr. for 25 ft. elev. change
Over 87 years:	0.23 ft./yr. for 20 ft. elev. change
	0.29 ft./yr. for 25 ft. elev. change

Bed lowering rate ranges from 0.23 to 0.41 ft./yr (0.07 to 0.12 m/yr).

Appendix O:

Geomorphic variables (ft), Graham bar, lower Mad River (1941/42 to 1992)

Year	River Mile	Wavelength	Amplitude	Radius of Curvature	Notes
1941/42	2.5	2925	1750 / 229	814/350	upstream meander
		2225	99 / 335	N/A /298	downstream meander
		5804	2271 / 746	910/625	large meander
1948	2.5	4597	902 / 1795	718/1197	w/o small meander
		5804	2291 / 966	800/1241	large meander
1954	2.5	2705	1194 / 833	695/641	w/o small meander
		5804	1760 / 952	1096/1267	large meander
1958	2.5	2762	784 / 812	656/574	w/o small meander
		5804	1551 / 952	1264/ N/A	2nd meander irreg.
1962	2.5	2777	964 / 687	678/389	
		5804	1624 / 882	1142/ N/A	2nd meander irreg.
1966	2.5	5804	1987 / 675	1202/937	large meander
1970	2.5	5804	1971 / 420	1004/ N/A	2nd meander irreg.
1974	2.5	5804	1663 / 966	991/1187	meander growth
1981	2.5	5804	1894 / 973	1297/1014	large meander
1988	2.5	5804	1988 / 1084	1143/1001	large meander
1992	2.5	5804	1907 / 871	1174/844	large meander

Appendix R:

Lower Mad River Bridge Pier Study above 101
September 29, 1993

Objective: 1) To measure the amount of bed lowering at two bridge piers approximately 700 feet above the U.S. Highway 101 bridge; 2) to measure the distance from the top of the pier to the original bed elevation for scaling purposes.

Methods: 1) I used a tape measure to determine the distance from the bottom of the cement within the bridge pier casings (assumed poured onto the top of the bed at the time of construction) to the water surface (see figure R-1). Then I determined the distance down to the thalweg and added the two together. I took 5 measurements from the upstream pier and 6 measurements from the downstream pier to obtain an average depth for each. 2) I used a tape measure to determine the distance from the top of the pier to the water surface. I then subtracted the elevation difference between the water surface and the bottom of the cement to obtain the original distance from the river bed to the bottom of the bridge for scaling purposes on an old photo of the bridge I obtained from Don Tuttle at the Humboldt County Public Works Department (Natural Resources Division).

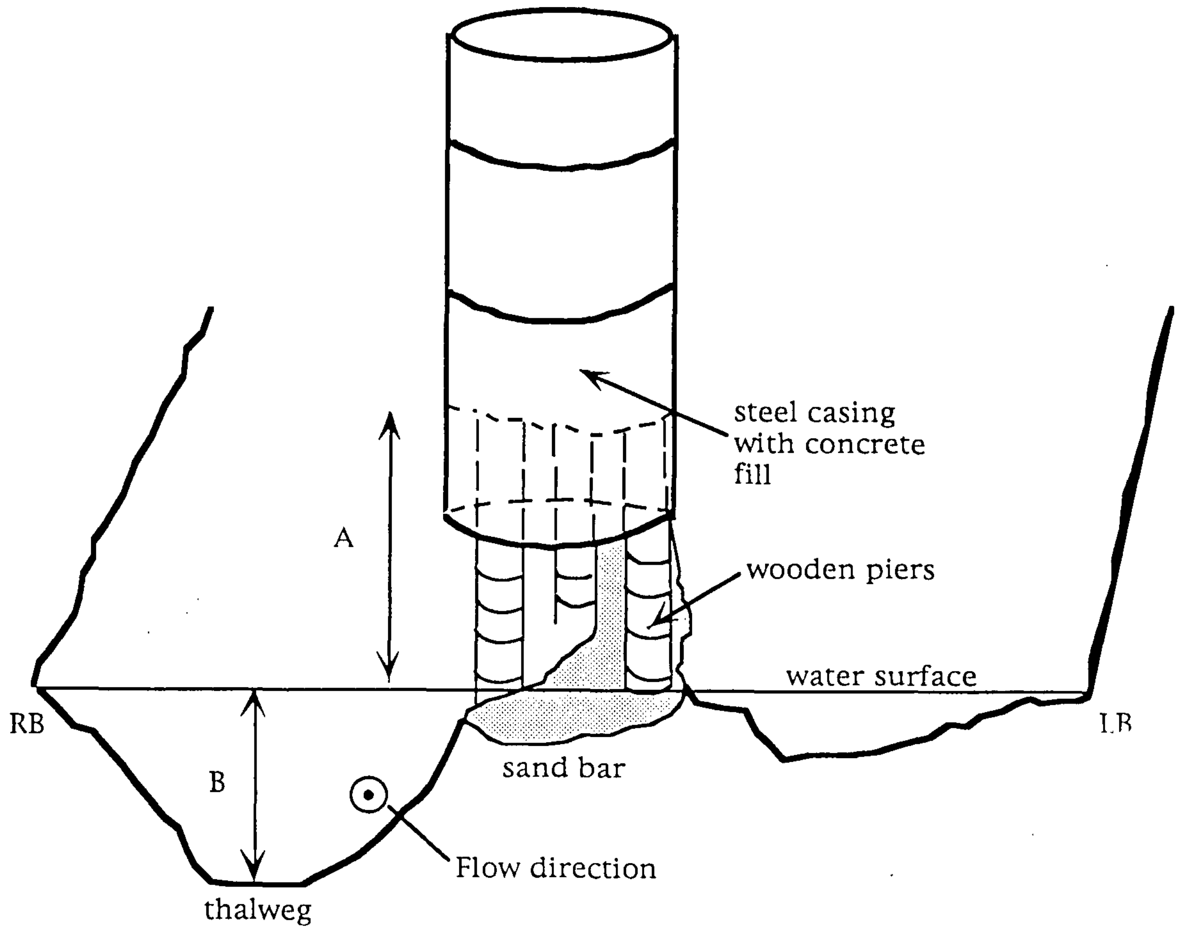
Notes: The upstream pier is supported by 5 pilings driven into the bed; the downstream pier is supported by 6 pilings. Each pier appears to have been constructed by: 1) driving the pilings into the bed; 2) encasing the pilings with steel, riveted jackets or sleeves; which then 3) acted as concrete forms into which the concrete and gravel mixture was poured; 4) casings were either removed or have fallen off (upstream pier still has 2, downstream pier one jacket). I found a reference that described this type of construction on the A&MRR bridge (built in 1896): "Piles were driven into the river gravel and capped for the false-work", ("1896 Railroad Bridge Collapse", Blue Lake Advocate, Sept. 13, 1896; see also "Early Days of Humboldt", Mrs. Eugene F. Fountain, Historian, Blue Lake Advocate, April 11, 1957). The distance between the top of the bed and the bottom of the poured concrete was measured to estimate bed degradation (net change) since the piers were constructed.

Results: Measurements are tabulated and given in table R-1. Mean minimum lowering since the bridge piers were constructed ranged from 7.2 feet (upstream pier) to 7.4 feet (downstream pier). The bridge was constructed in 1891 and removed in 1931: "The bridge was erected about forty years ago, and served until about a year ago when the state highway built a new structure a few hundred yards down the river." ("Old Mad River Bridge Is Sold For $85", *Blue Lake Advocate,* May 16, 1931). I made the assumption that the bed surface was at an elevation equal to that of the bottom of the concrete poured into the piers when they were constructed. (Note: this is a minimum estimate since there is no way of knowing how much material was excavated during construction of the bridge piers.) Based on this assumption a minimum lowering rate can be estimated. In 103 years the bed has lowered approximately 7.2 feet giving a lowering rate of 0.07 = 0.1 feet/year.

Table R-1 -- County bridge pier measurements upstream of 101

Piling	1	2	3	4	5	6	Ave. ht. (cm)	Mean of inside & outside piers (cm)	Total Bed Lowering (Ft)	
upstream										
inside (cm)	248	235	232	228	229	NA	234			
outside (cm)	245	155	197	188	244	NA	206	220	7.2	
										Ave = 7.3 ft
downstream										
inside (cm)	219	219	217	254	258	255	237			
outside (cm)	209	164	205	219	241	251	215	226	7.4	

Note: Maximum water depth along XS perpendicular to piers is 142 cm (55.9 in or 4.7 ft).



(A = ~7.3 feet B = 4.7 feet)

Figure R-1: Diagram of bridge pier and channel bed relationships (not drawn to scale).

Appendix S:

Lower Mad River bed elevation study at the 101 bridge
June 7, 1995

Objective: 1) To measure the bed elevation at the U.S. Highway 101 bridge; 2) to compare the measurement to photogrammetric measurements from an historic photo (figure 35) of the bridge taken in 1929 in order to determine bed elevation changes.

Assumptions: 1) photo distortions are minimal since the area analyzed is very close to the photo's principal point; and 2) the bed elevation at the base of the right bridge pier fairly accurately represents lowering over the rest of the bed.

Methods: 1) With a weight tied to the end of a string, I lowered the string until it touched the bed surface, below the water level; 2) I marked the spot on the string that corresponded to the base of the bridge so that I could compare the same point on an old photo of the bridge taken in 1929 which I obtained from Don Tuttle at the Humboldt County Public Works Department (Natural Resources Division); 3) I then measured the length of the string with a tape measure to determine the distance below the base of the bridge; 4) the distance on the photograph was determined by first measuring the distance between two piers on the photo and the same distance on the ground; 5) the distance above the bed was also measured on the photo and I then solved for the unknown; 6) finally I compared the two measurements to determine bed elevation change between 1929 and 1995.

Results: Measurements are tabulated and given in table S-1. The bed surface in the photo is visible at the base of the right bridge pier where the field measurement was taken (figure S-1). The bridge was constructed in 1929 (Don Tuttle, Humboldt County Public Works, pers. comm., 1994). In 66 years the bed has lowered approximately 14 feet giving a lowering rate of 0.21 feet/year. This is consistent with other bed elevation changes measured along the reach.

Table S-1: Photogrammetric and field measurements, 101 bridge

	Length of a*	Length of b*	Distance between bed and bridge (ft)
1929 Photo	1.94 in	0.34 in	26 ft
Field Data	150 ft	40 ft	40 ft

* see figure S-1 below

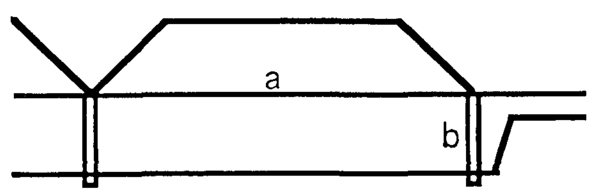


Figure S-1: 101 Bridge measurement locations (a = truss span length; b = base of bridge to bed surface)

Appendix T:

Riparian zone areas (acres) lower Mad River, 1941/42 to 1992

Year	Sweasey to Hatchery	Hatchery to Blue Lake bridge	Blue Lake to A&MRR	A&MRR to 299	299 to 101	101 to Hammond
1941/42	328	527	925	205	250	141
1948	292	457	796	172	267	125
1954	320	436	746	180	266	103
1958	294	515	858	186	275	119
1962	N/A	415	943	173	233	126
1966	N/A	382	805	195	233	164
1970	328	319	784	174	264	155
1974	369	257	726	185	248	125
1981	N/A	228	746	189	210	150
1988	N/A	296	779	164	263	131
1992	374	255	809	161	263	130

Note: Measurements include active channel areas.

Riparian zone areas (ft^2) lower Mad River, 1941/42 to 1992

Year	Sweasey to Hatchery	Hatchery to Blue Lake bridge	Blue Lake A&MRR	A&MRR to 299	299 to 101	101 to Hammond
1941/42	14,294,796	22,974,139	40,258,458	8,908,745	10,873,302	6,134,139
1948	12,709,854	19,924,668	34,667,869	7,502,215	11,630,456	5,465,446
1954	13,933,512	18,985,653	32,474,349	7,838,558	11,595,367	4,474,081
1958	12,812,533	22,453,564	37,392,196	8,113,941	11,963,482	5,182,718
1962	N/A	18,087,421	41,055,708	7,519,249	10,146,931	5,484,757
1966	N/A	16,647,621	35,050,034	8,502,894	10,167,018	7,154,888
1970	14,288,938	13,905,430	38,510,996	7,590,958	11,499,255	6,746,976
1974	16,077,332	11,189,706	35,986,185	8,040,356	10,784,798	5,424,123
1981	N/A	9,934,998	32,481,482	8,241,965	9,167,417	6,535,041
1988	N/A	12,881,237	32,169,306	7,164,837	11,437,496	5,691,998
1992	16,289,080	11,114,995	30,905,399	7,026,676	11,438,059	5,658,396

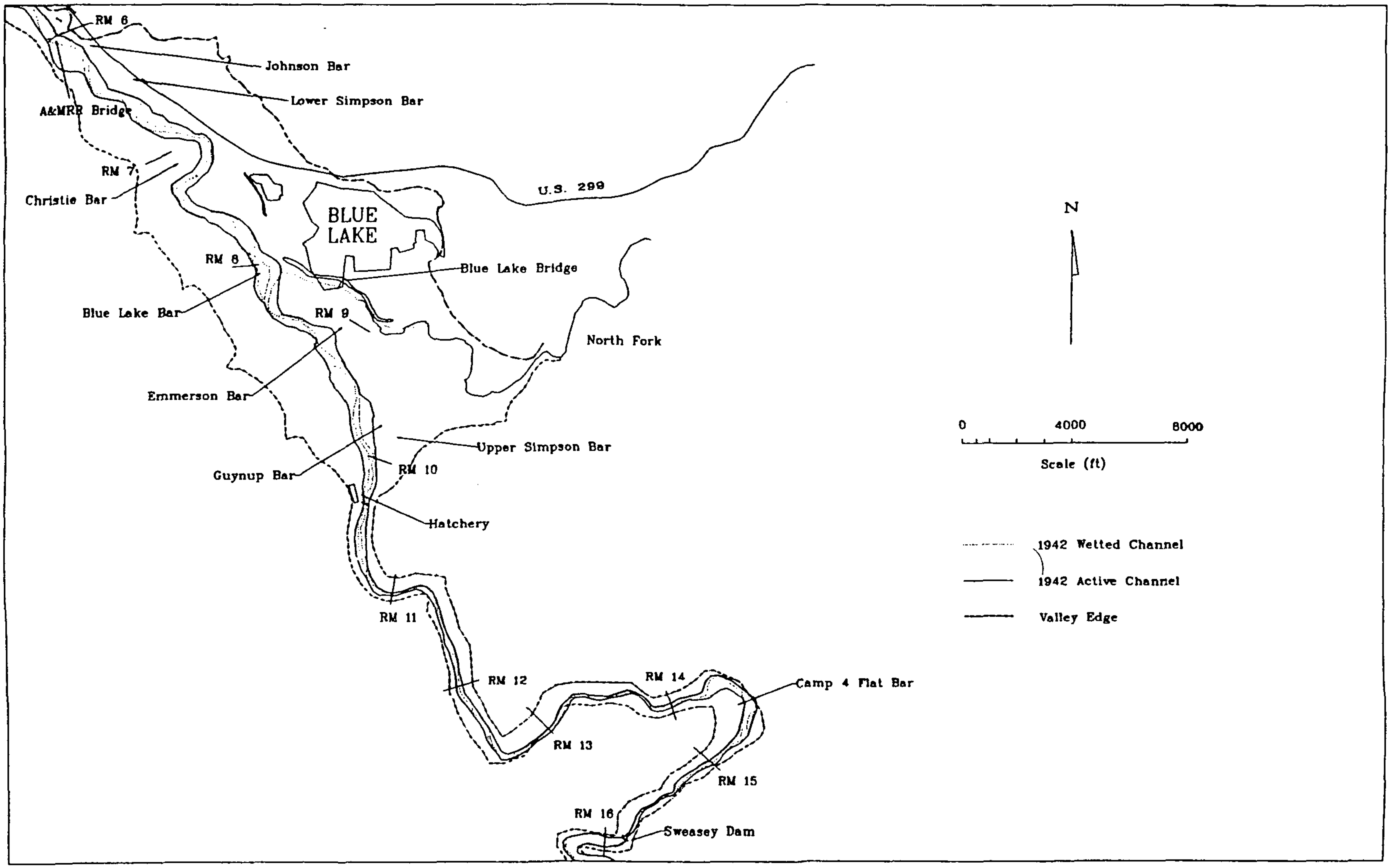
Note: Measurements include active channel areas.

Appendix U:

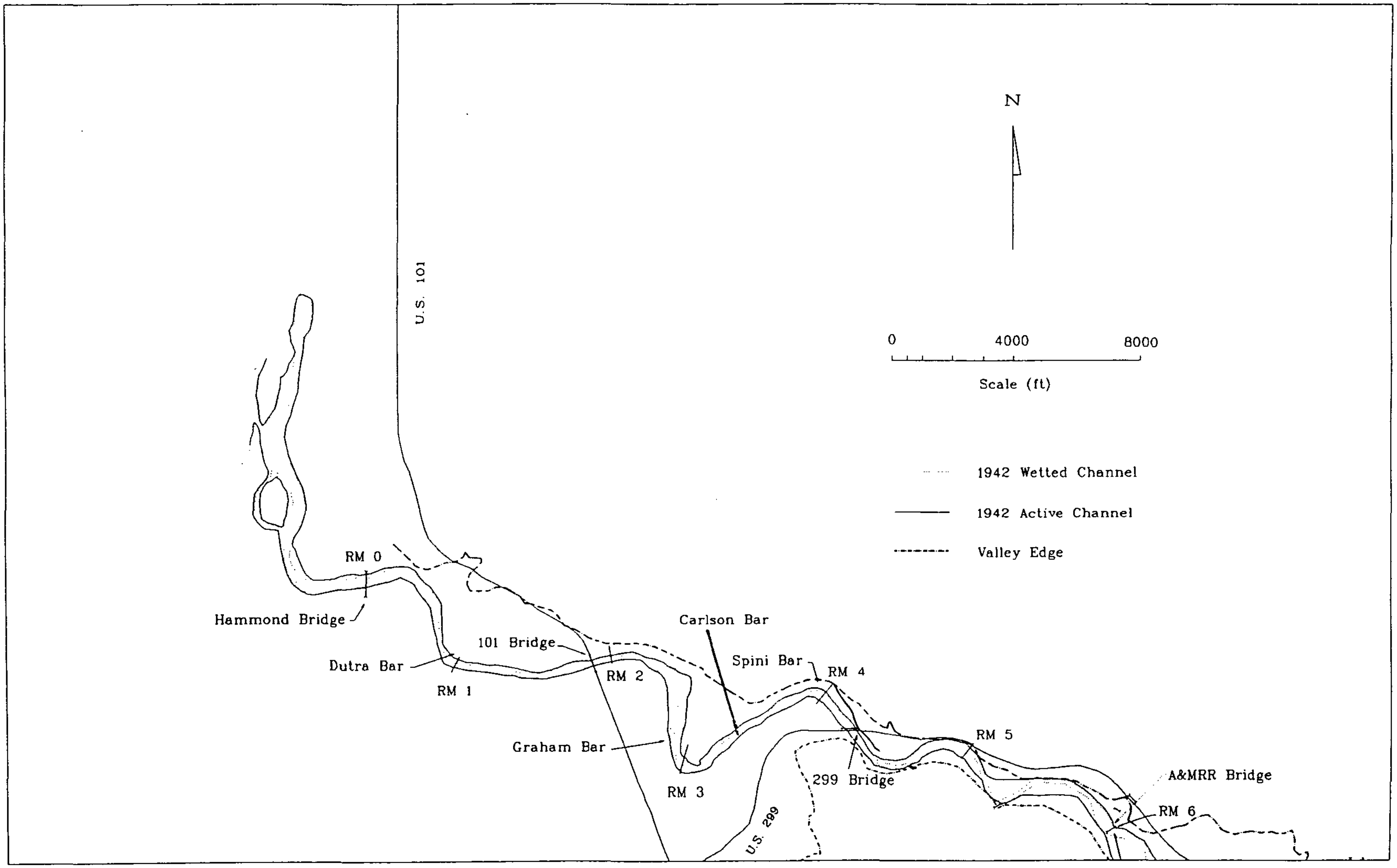
Digital map archive showing the active channel, wetted channel, and valley edge for each layer, 1941/42 to 1992, (produced from digitizing air photos).

Maps cover the following years:

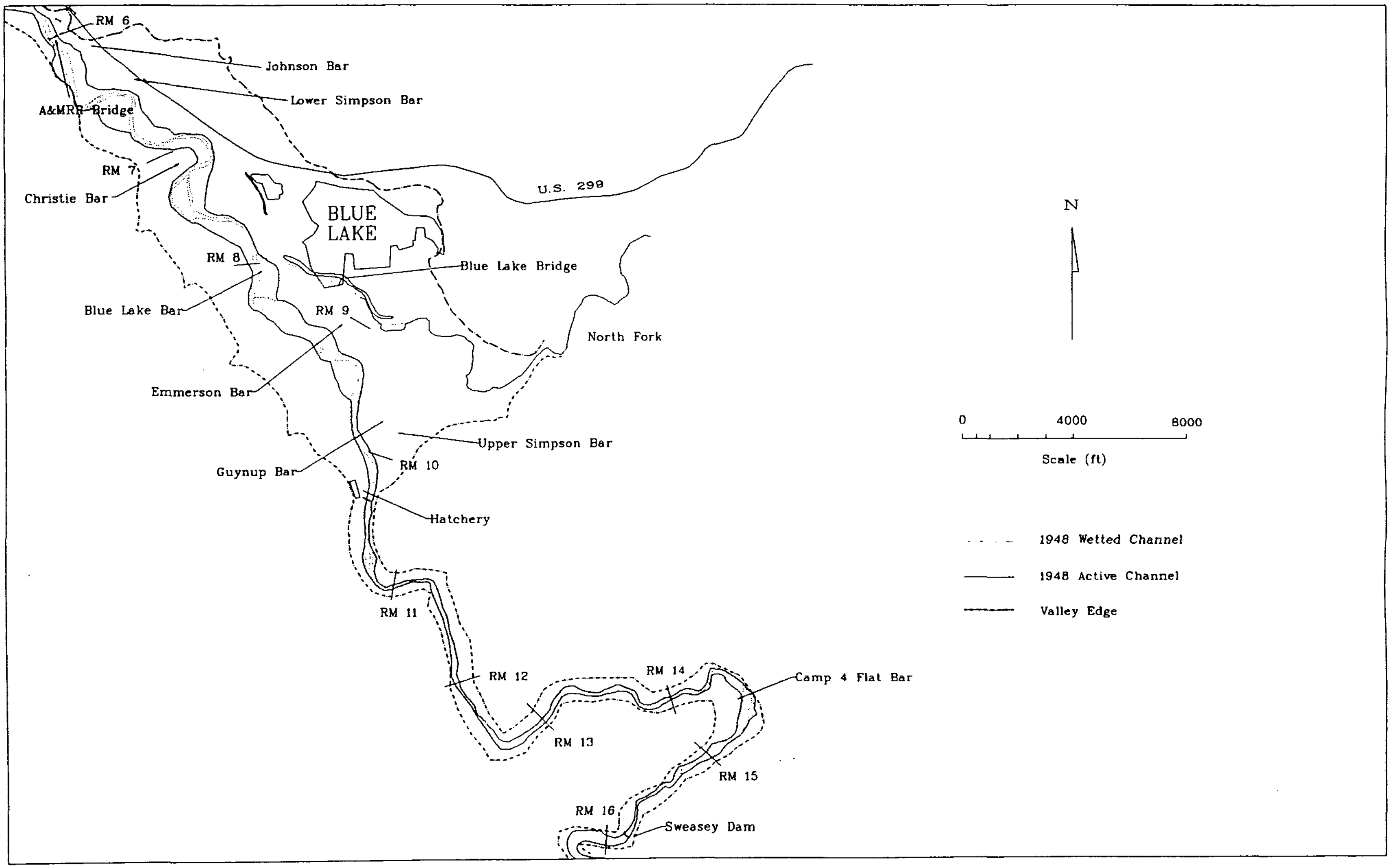
1) 1942/42
2) 1948
3) 1954
4) 1958
5) 1962
6) 1966
7) 1970
8) 1981
9) 1988
10) 1992



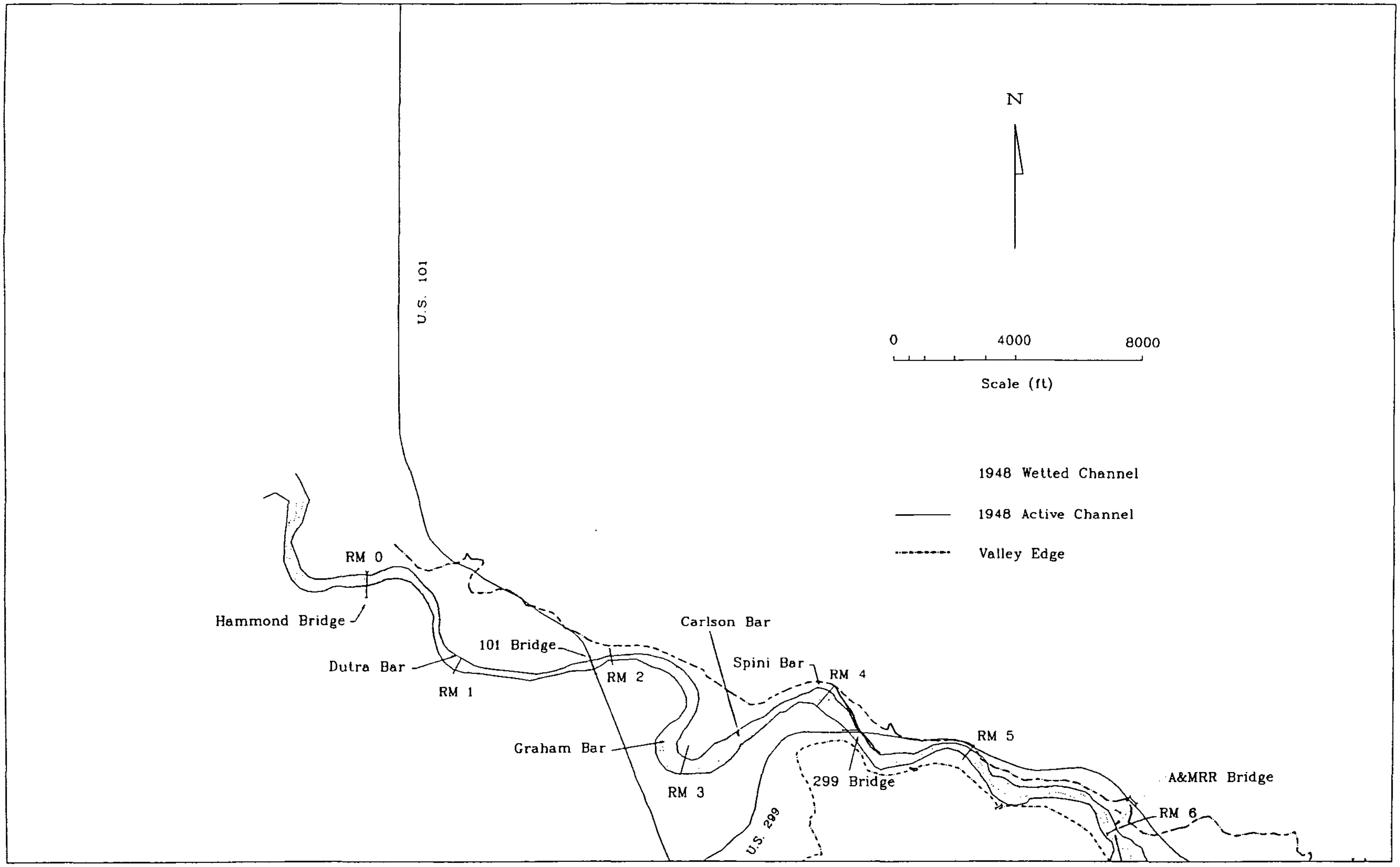
Mad River, Sweasey to A&MRR, 1942



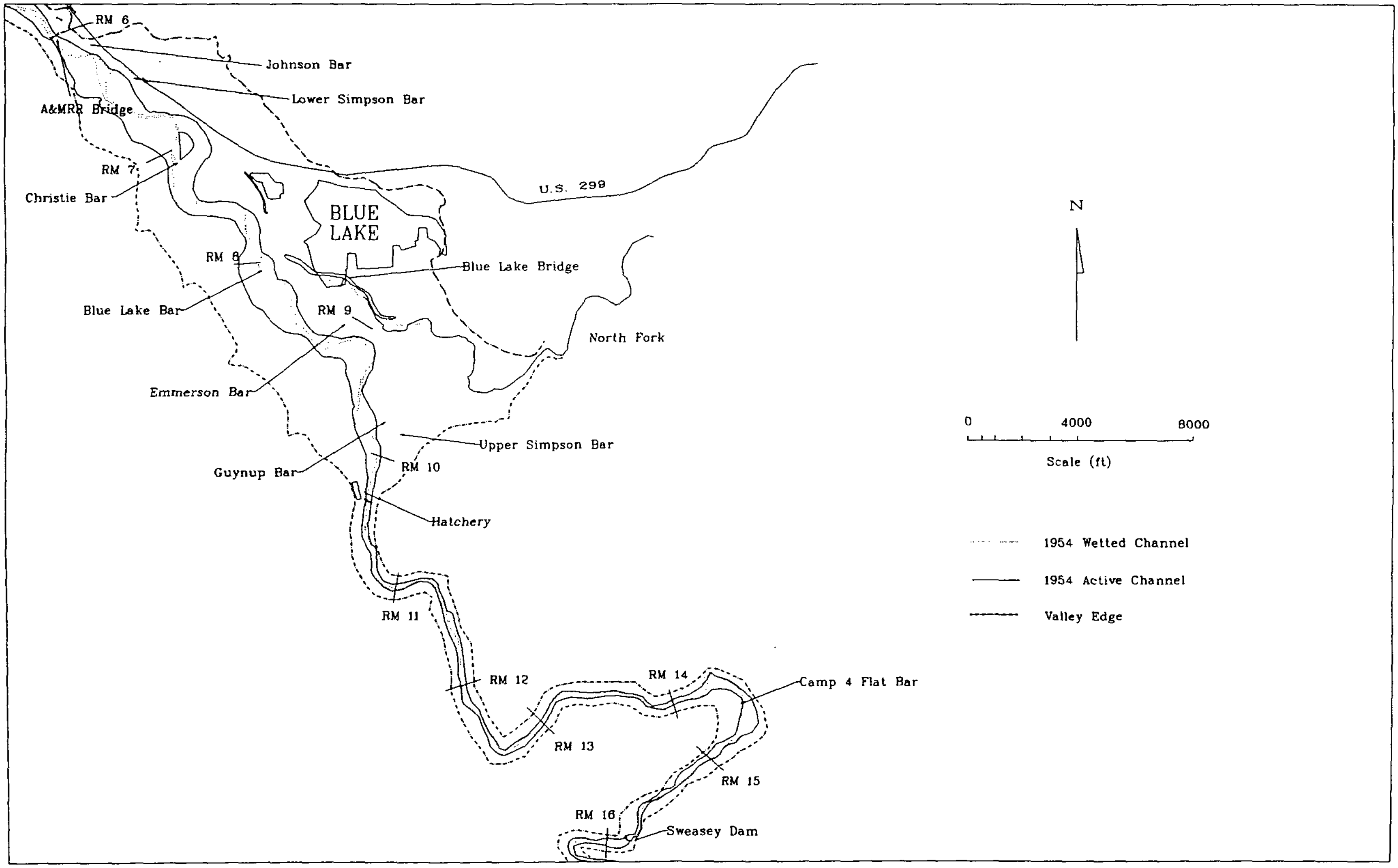
Mad River, A&MRR to Hammond, 1941/42



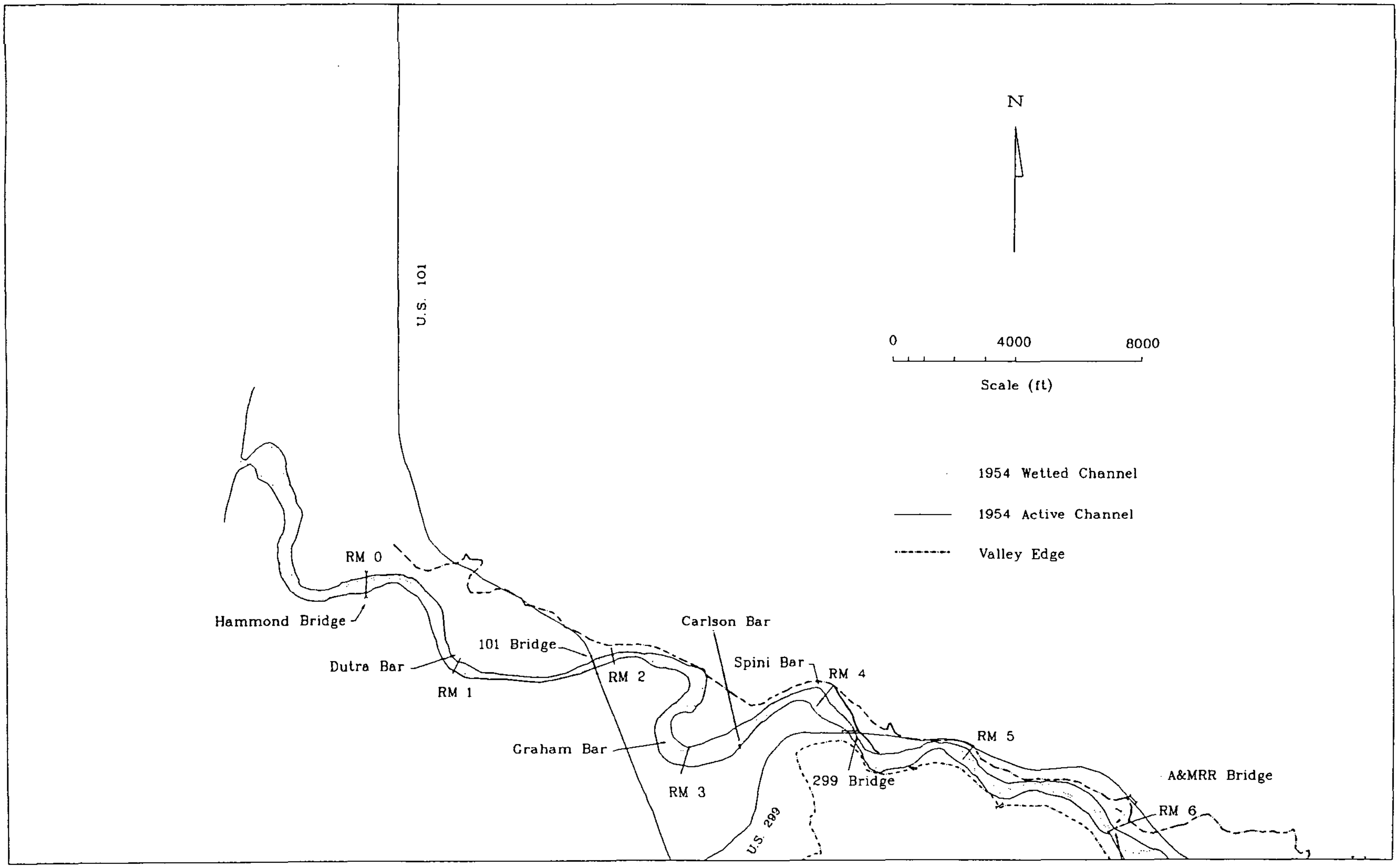
Mad River, Sweasey to A&MRR, 1948



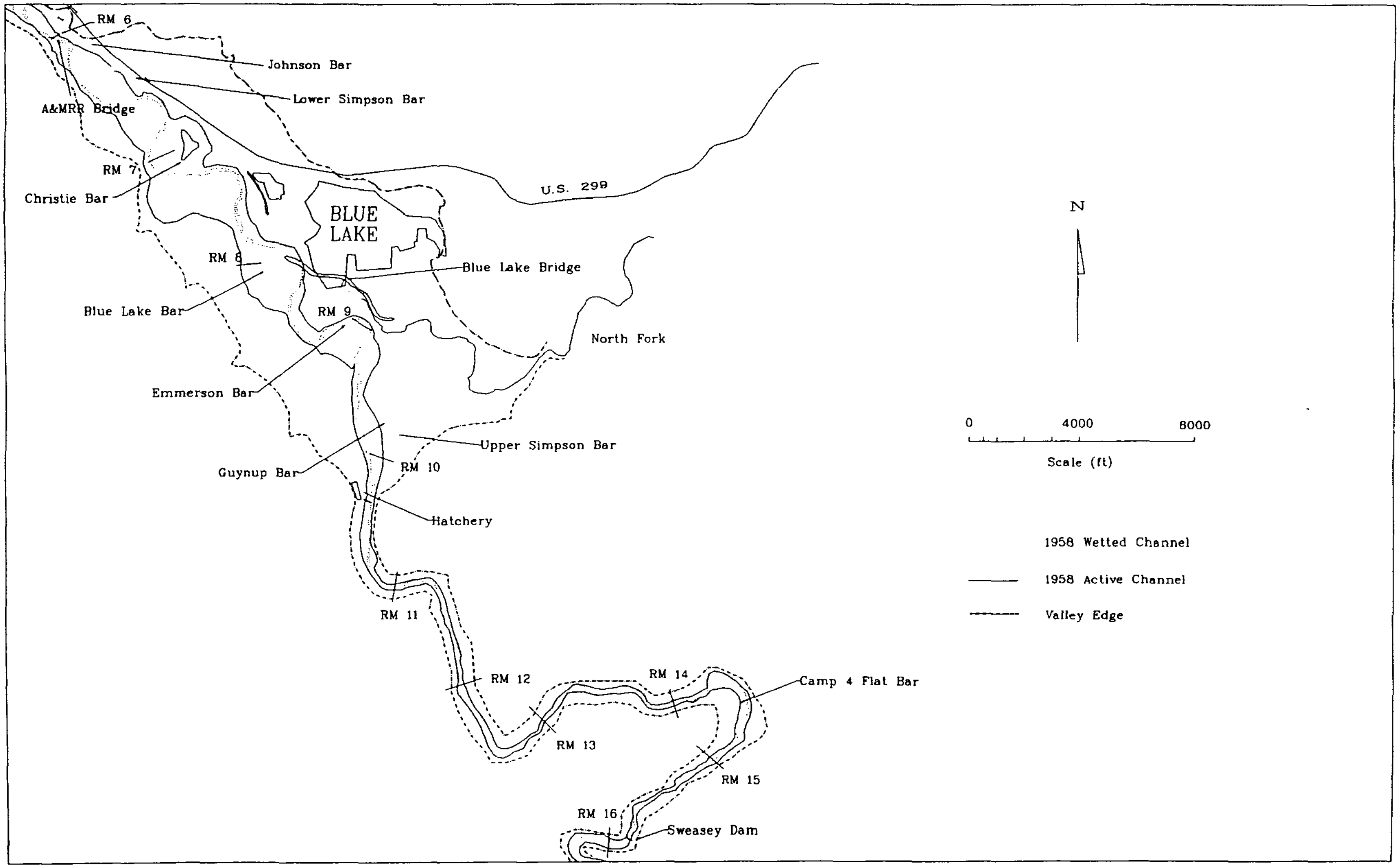
Mad River, A&MRR to Hammond, 1948



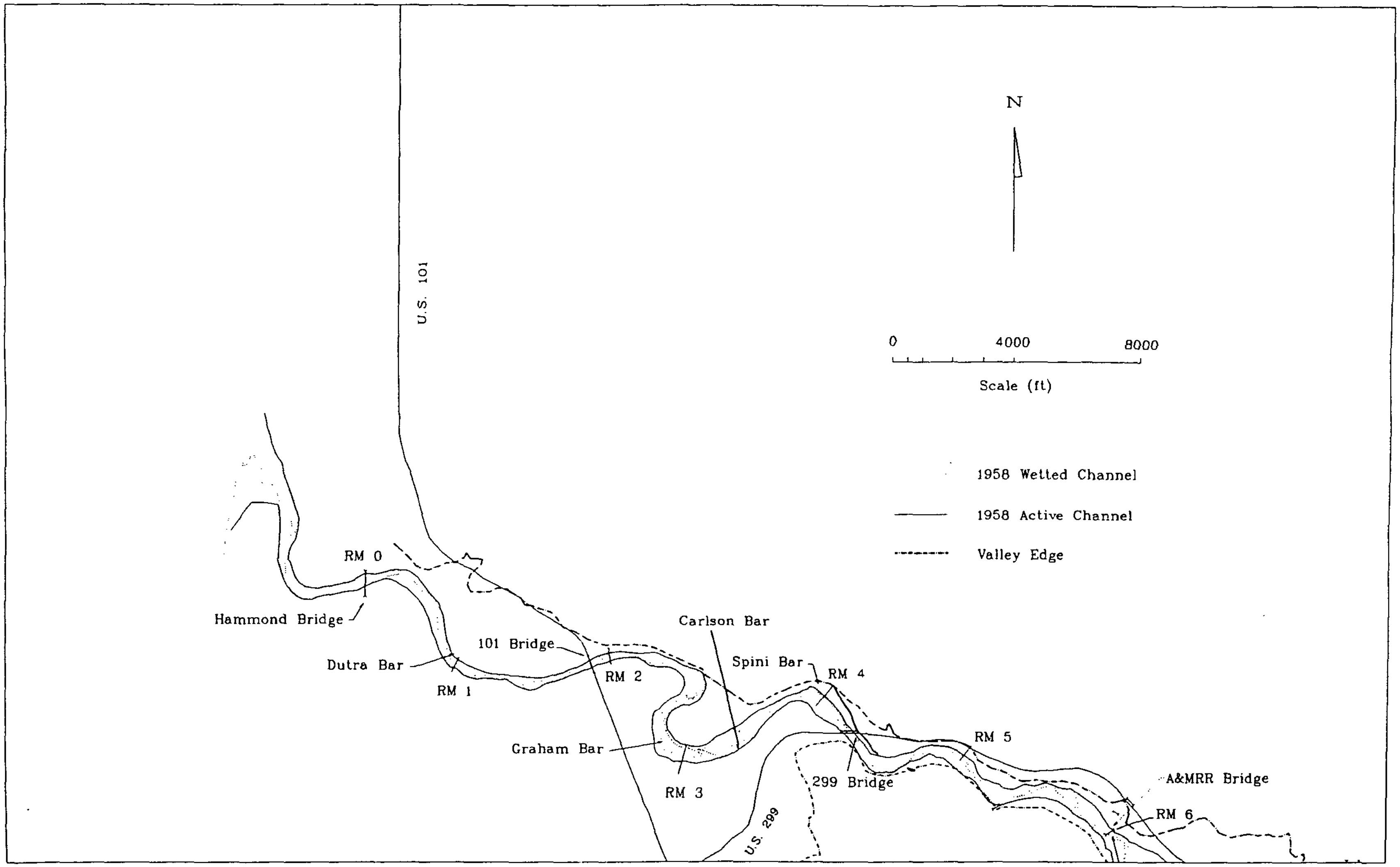
Mad River, Sweasey to A&MRR, 1954



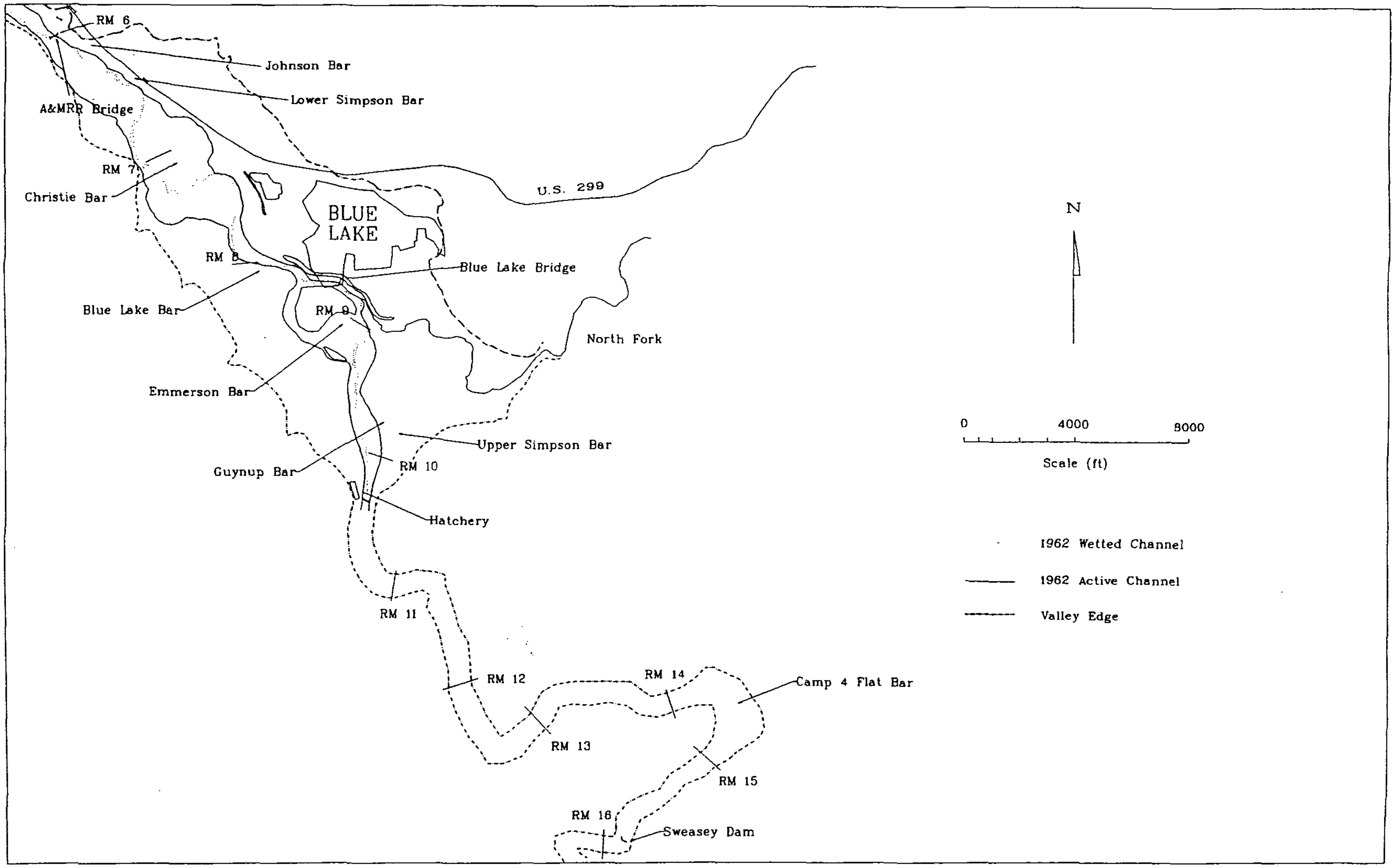
Mad River, A&MRR to Hammond, 1954



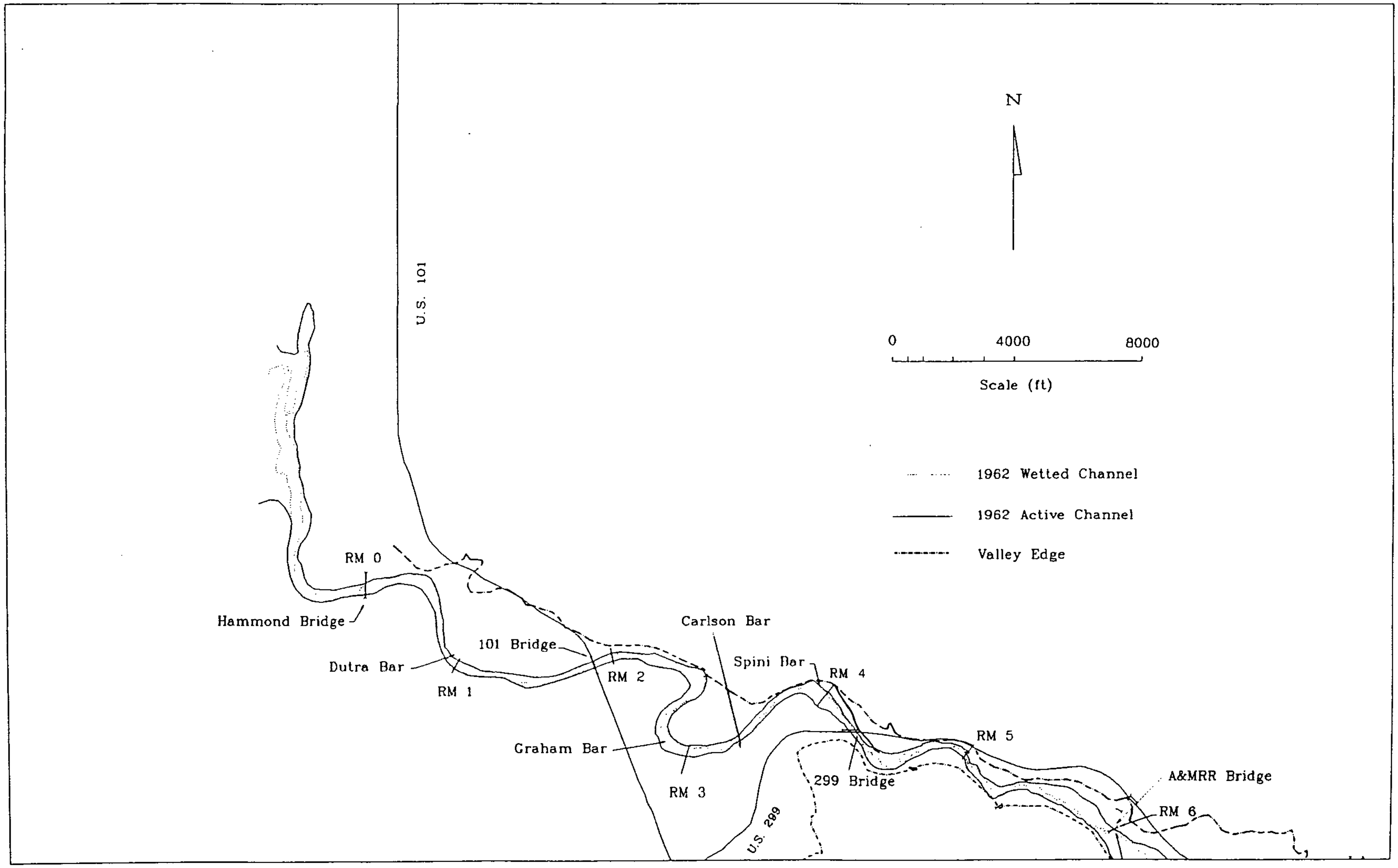
Mad River, Sweasey to A&MRR, 1958



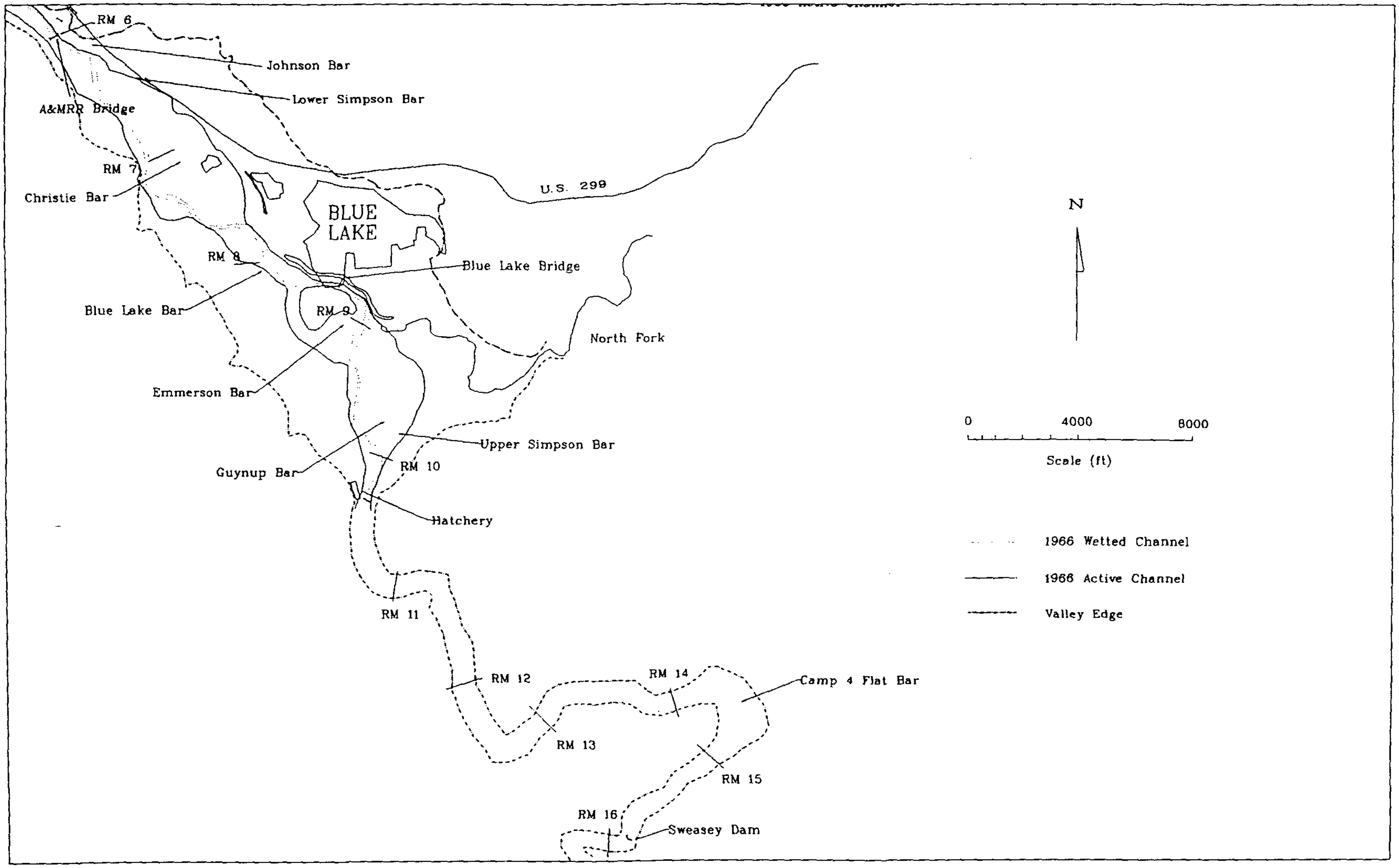
Mad River, A&MRR to Hammond, 1958



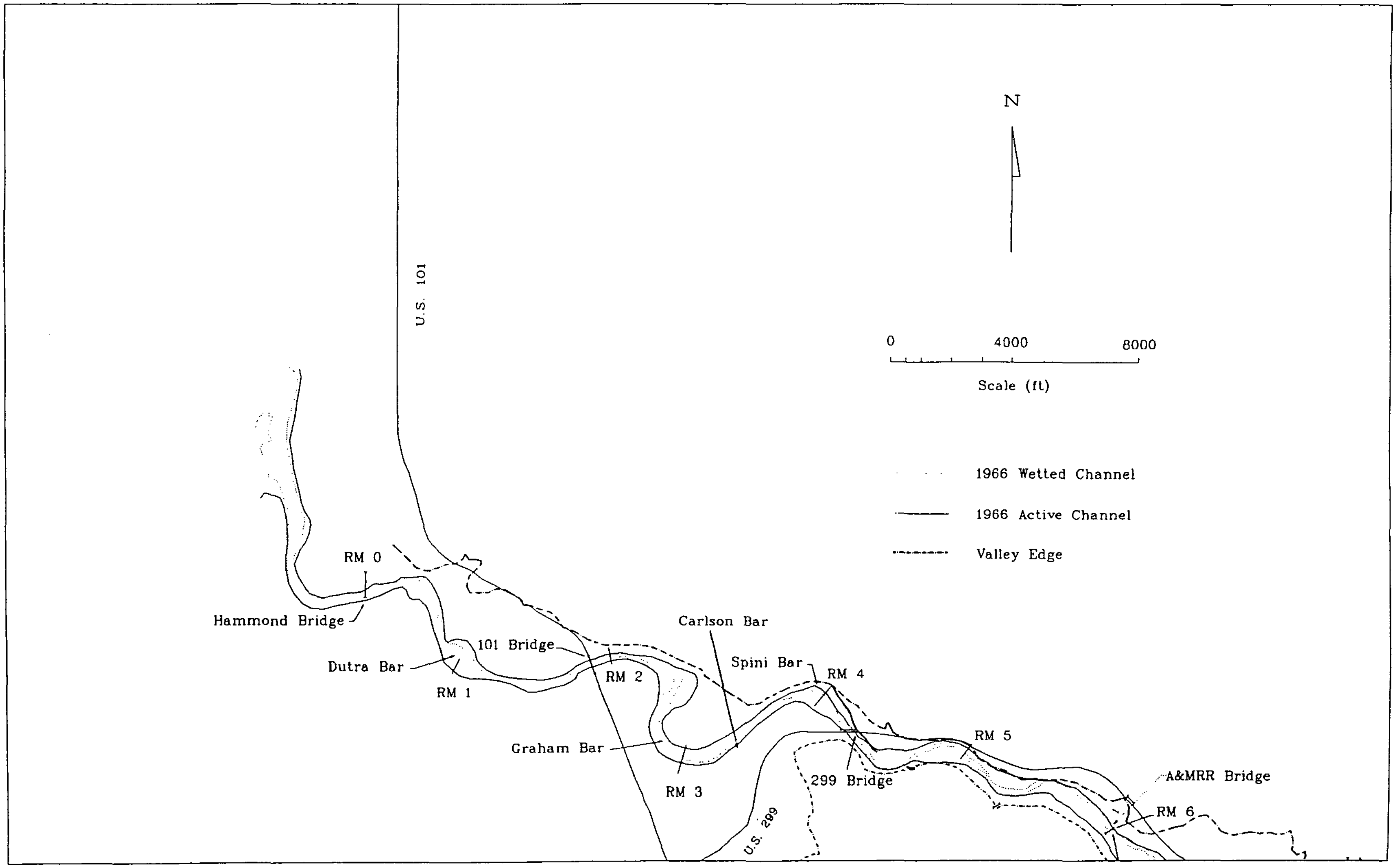
Mad River, Sweasey to A&MRR, 1962



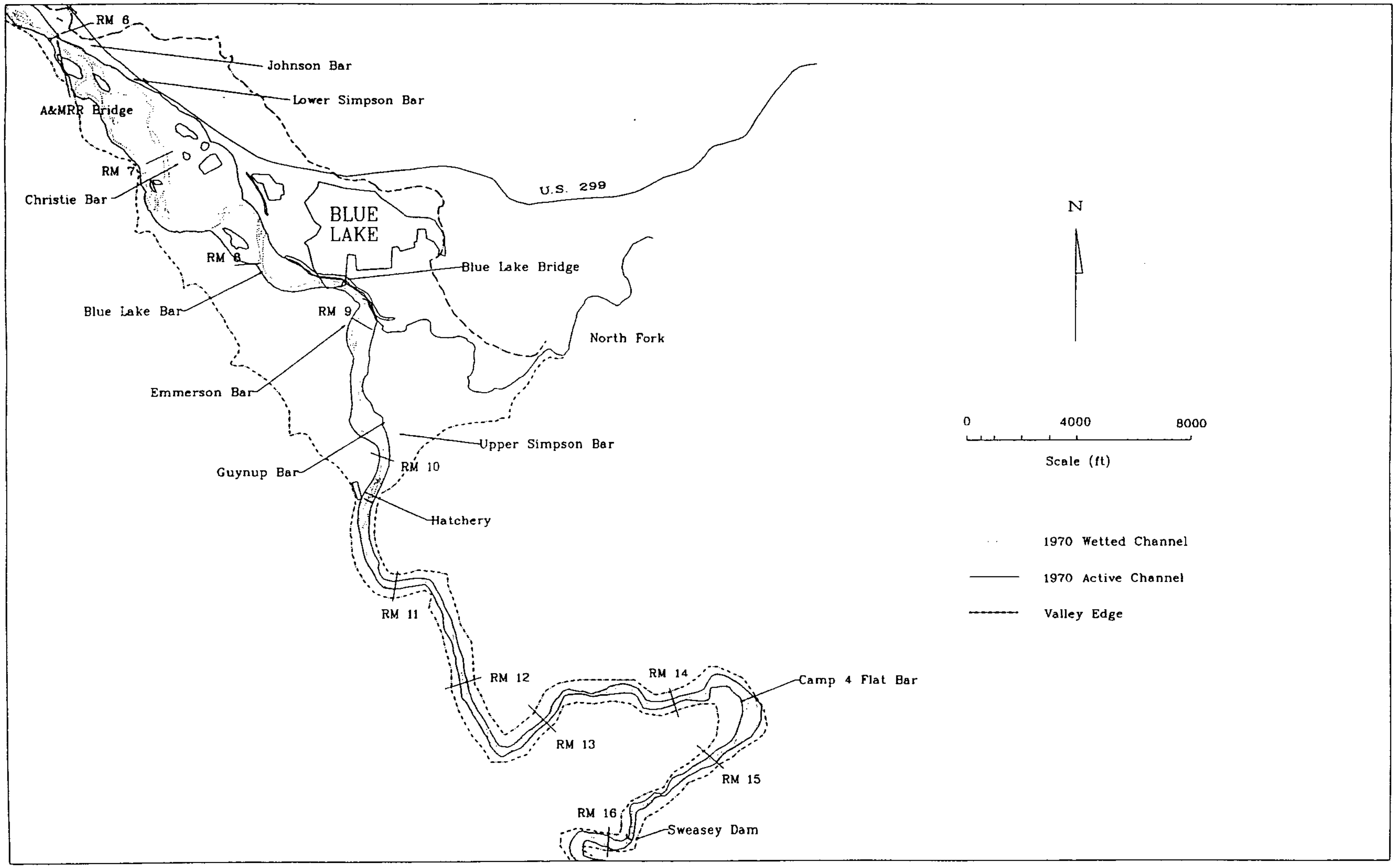
Mad River, A&MRR to Hammond, 1962



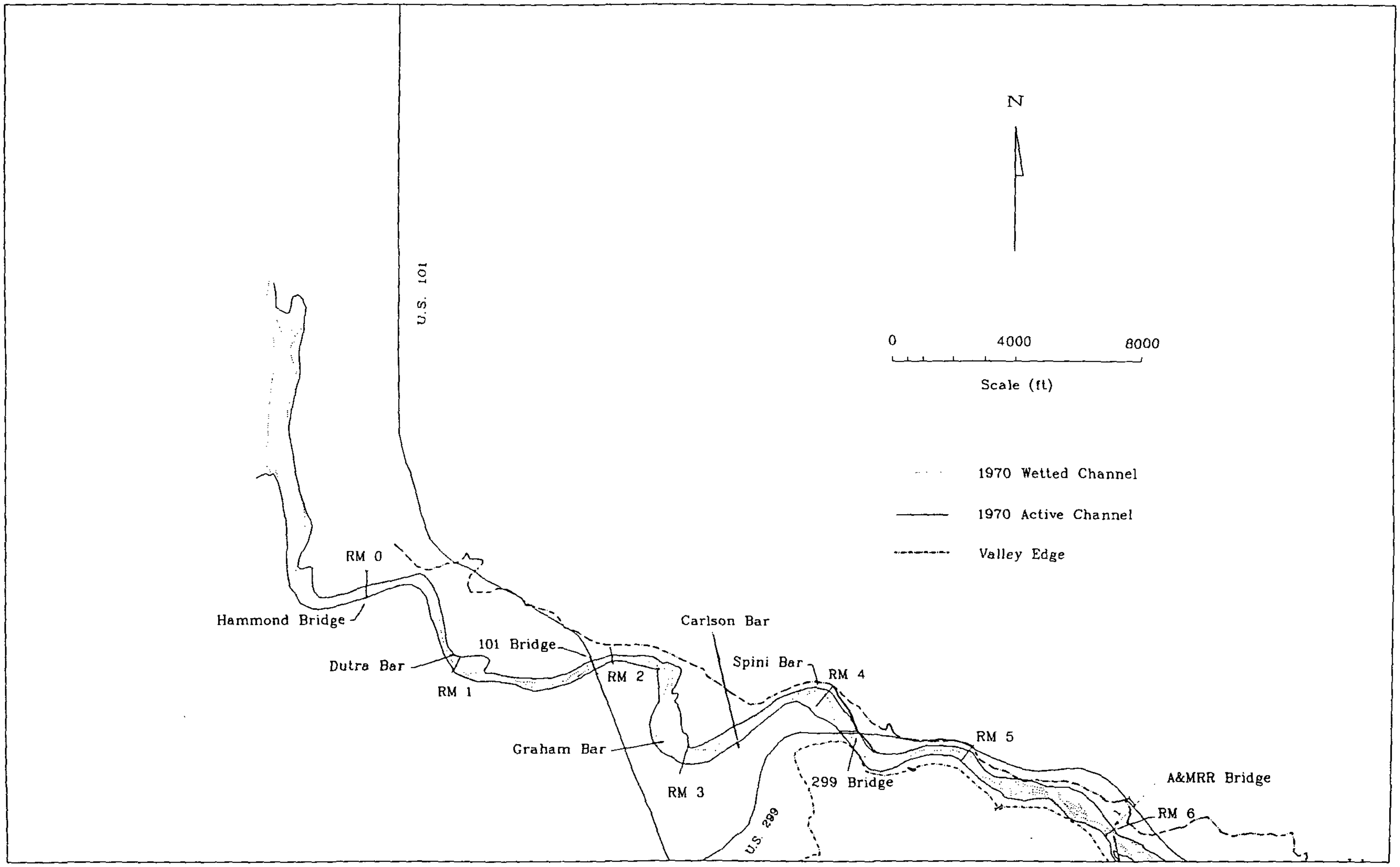
Mad River, Sweasey to A&MRR, 1966



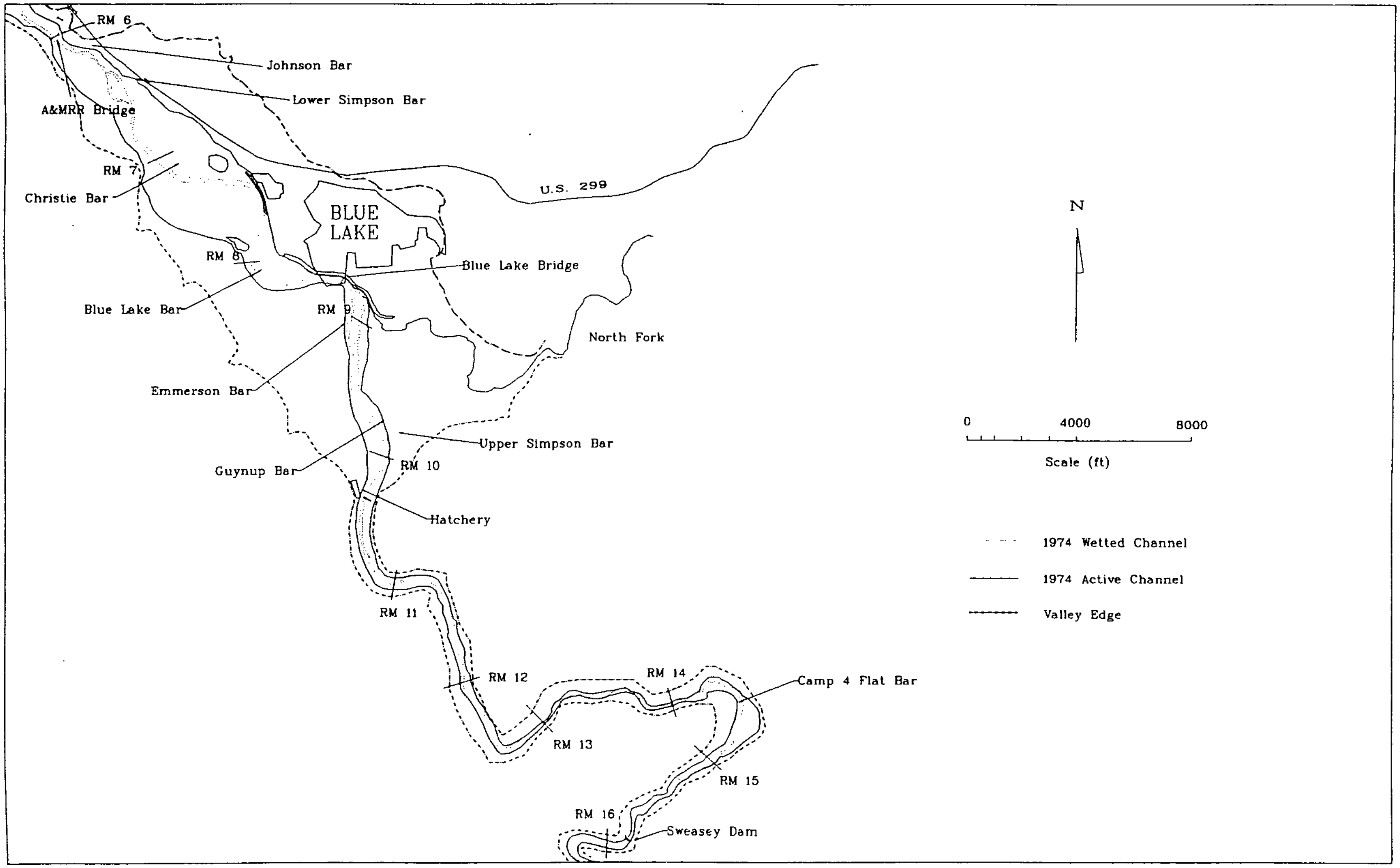
Mad River, A&MRR to Hammond, 1966



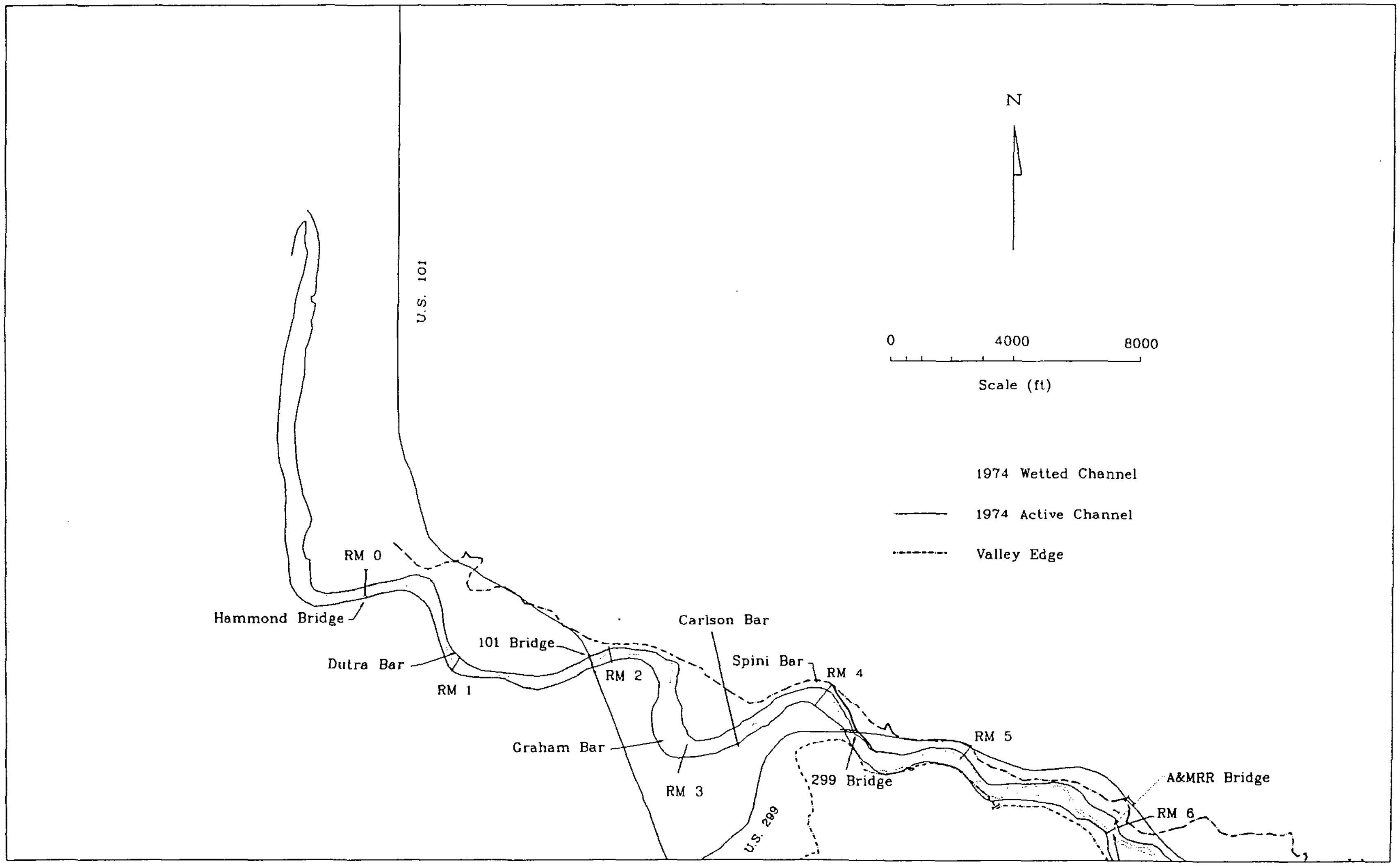
Mad River, Sweasey to A&MRR, 1970



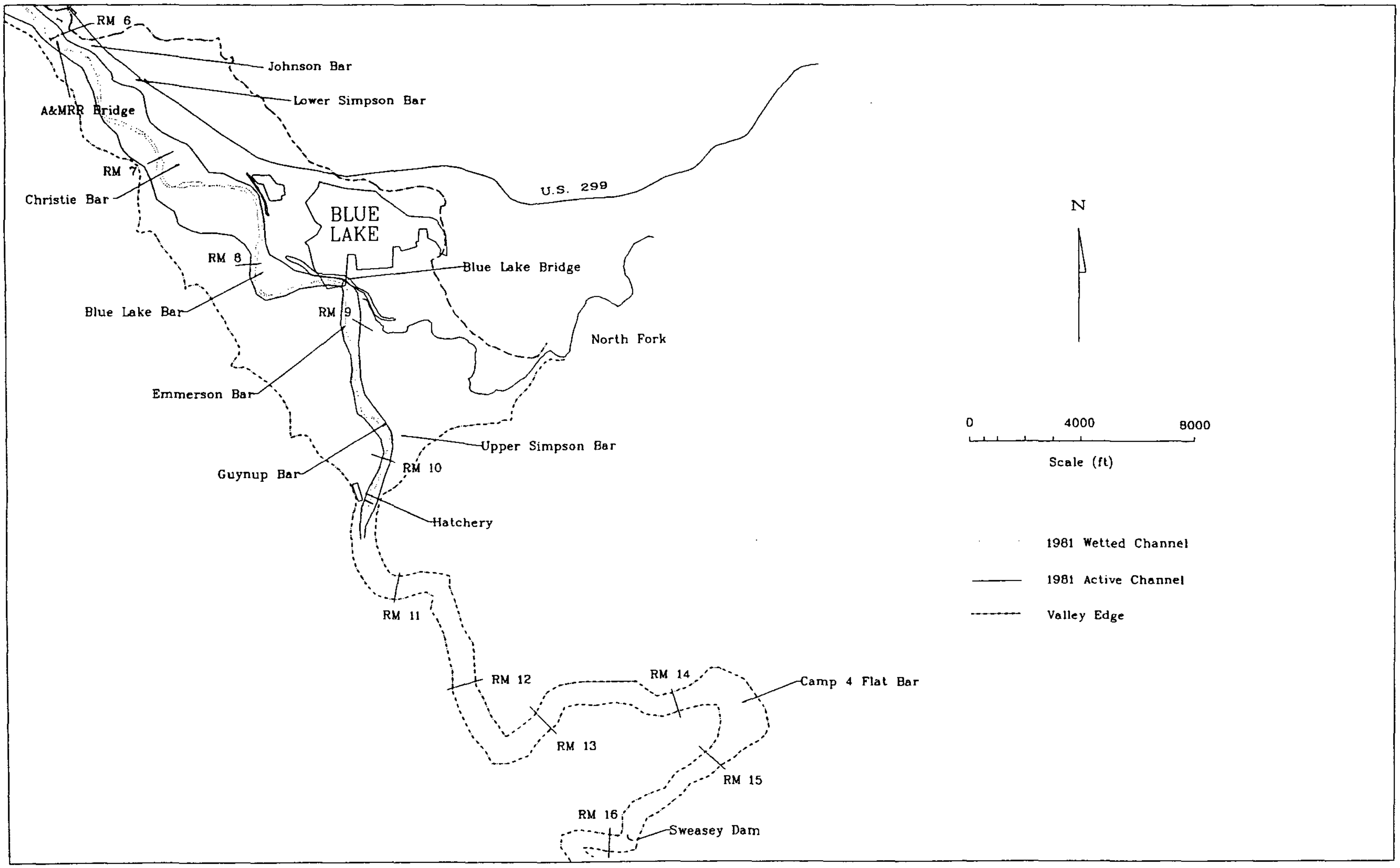
Mad River, A&MRRto Hammond, 1970



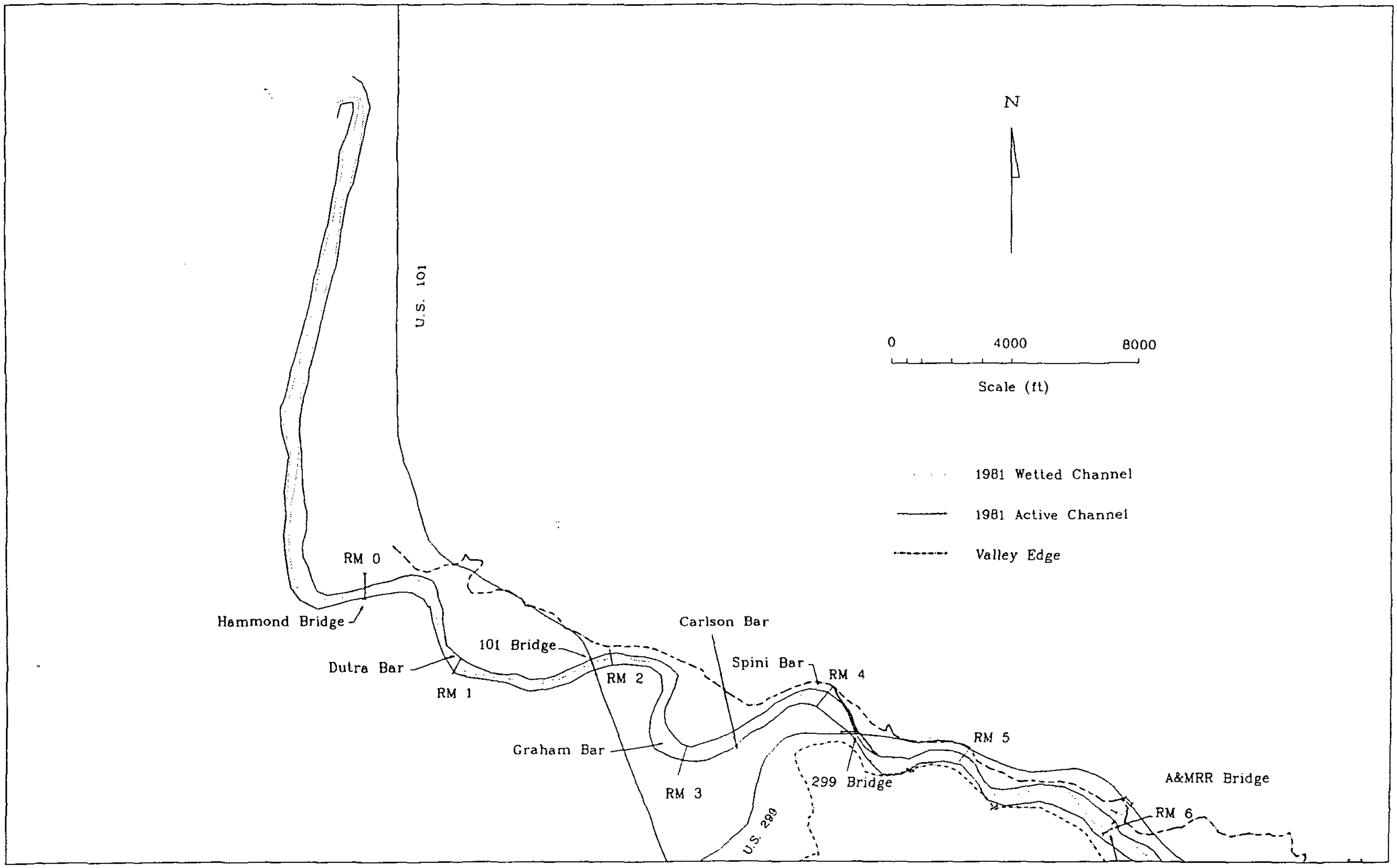
Mad River, Sweasey to A&MRR, 1974



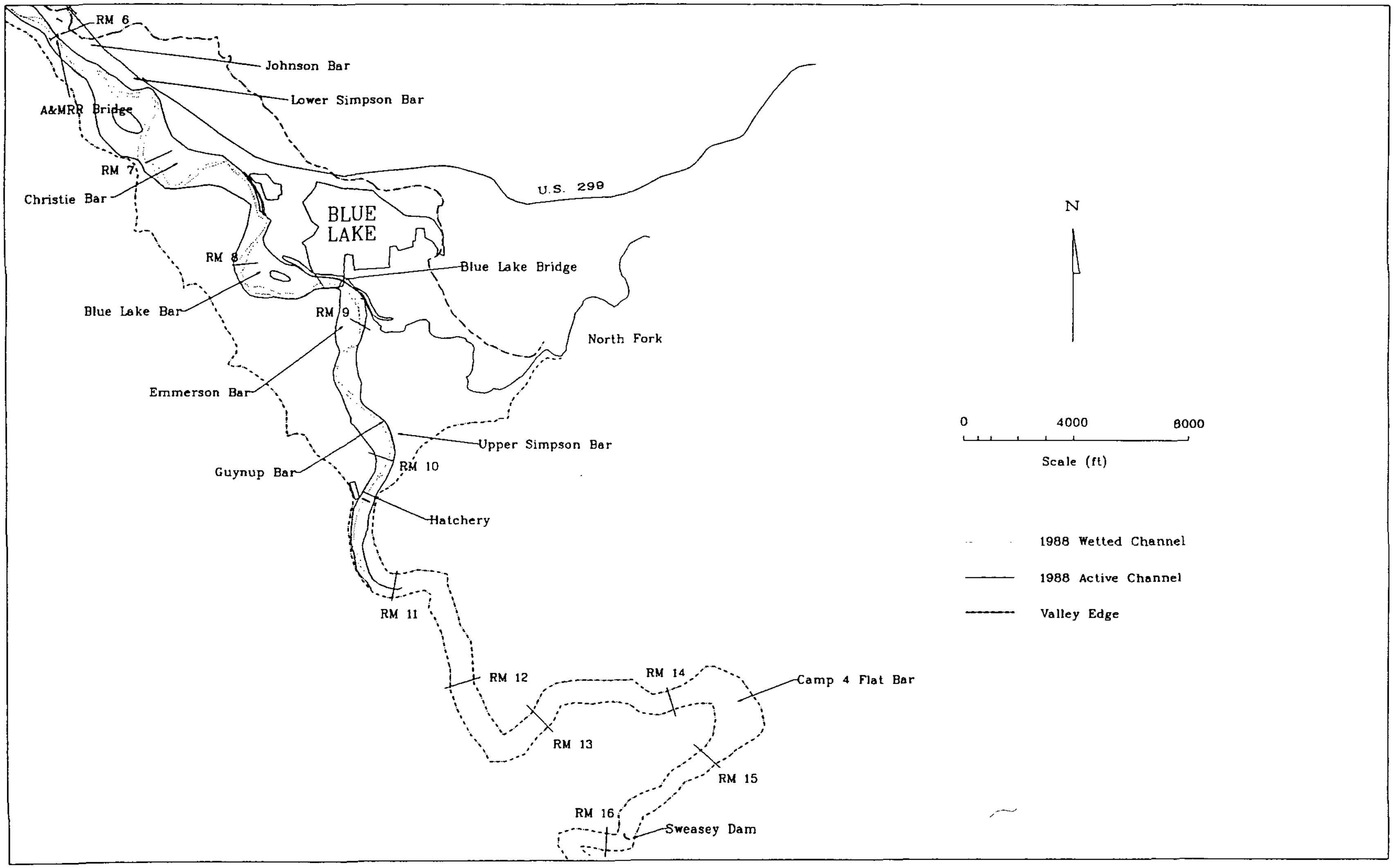
Mad River, A&MRR to Hammond, 1974



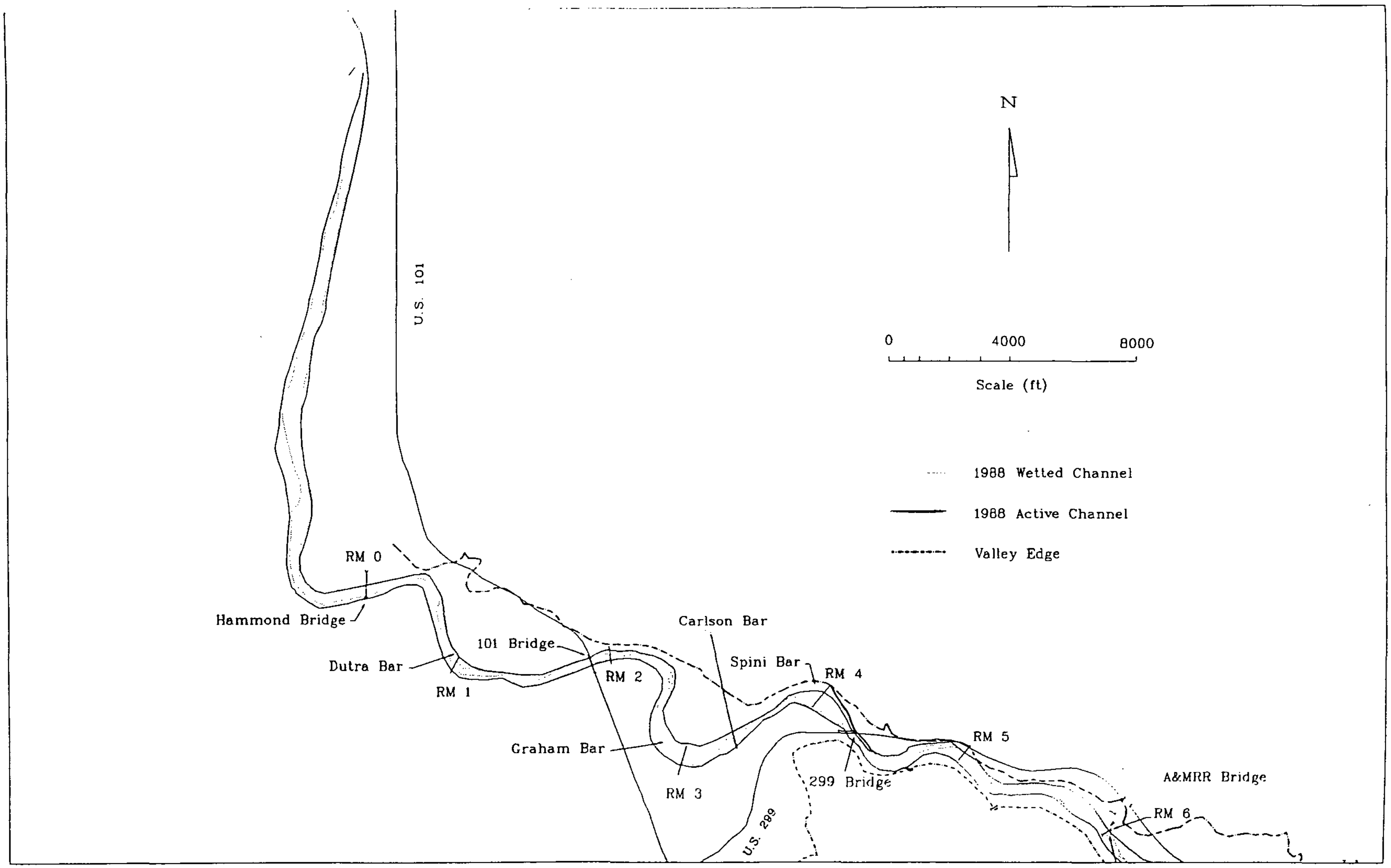
Mad River, Sweasey to A&MRR, 1981



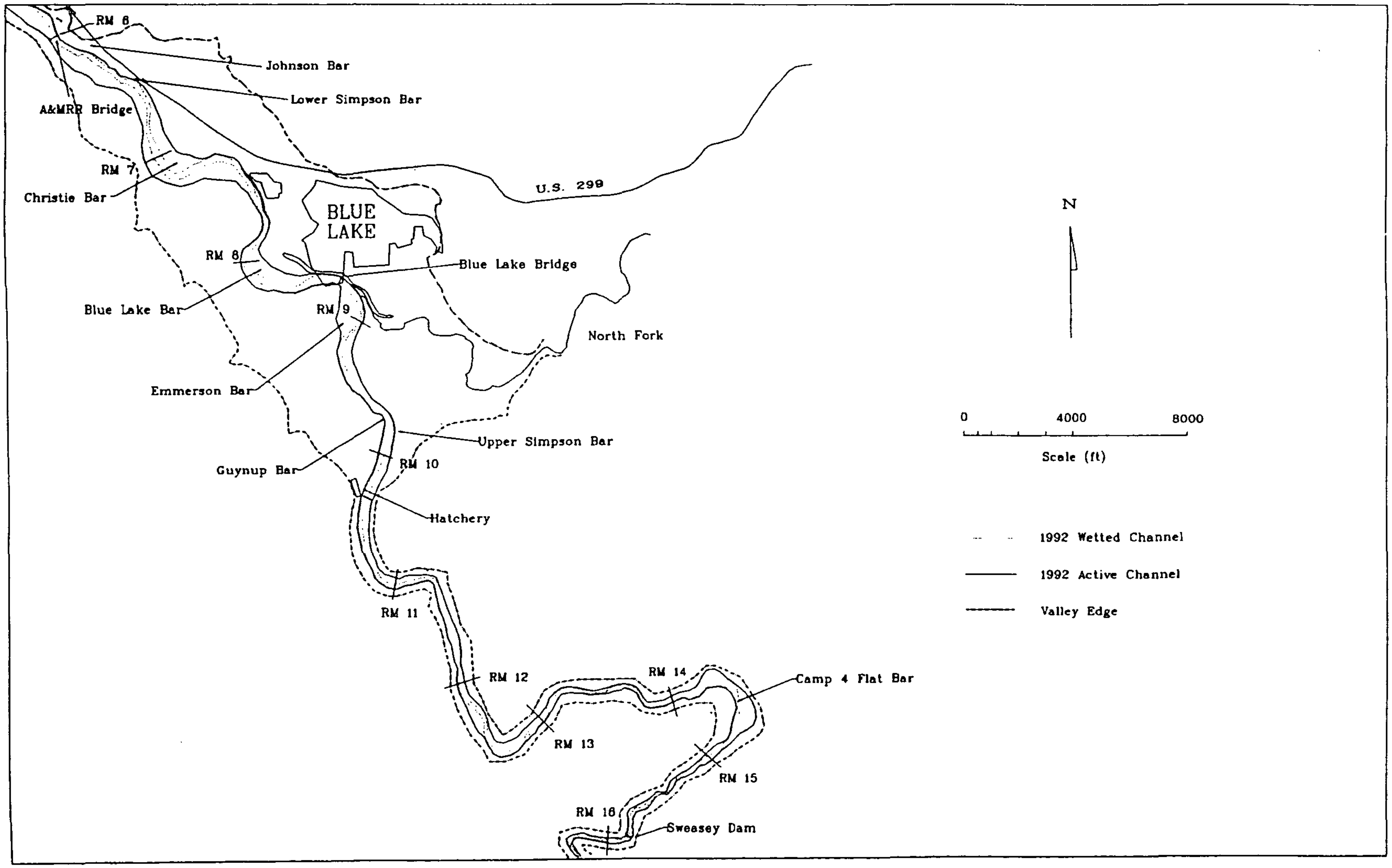
Mad River, A&MRR to Hammond, 1981



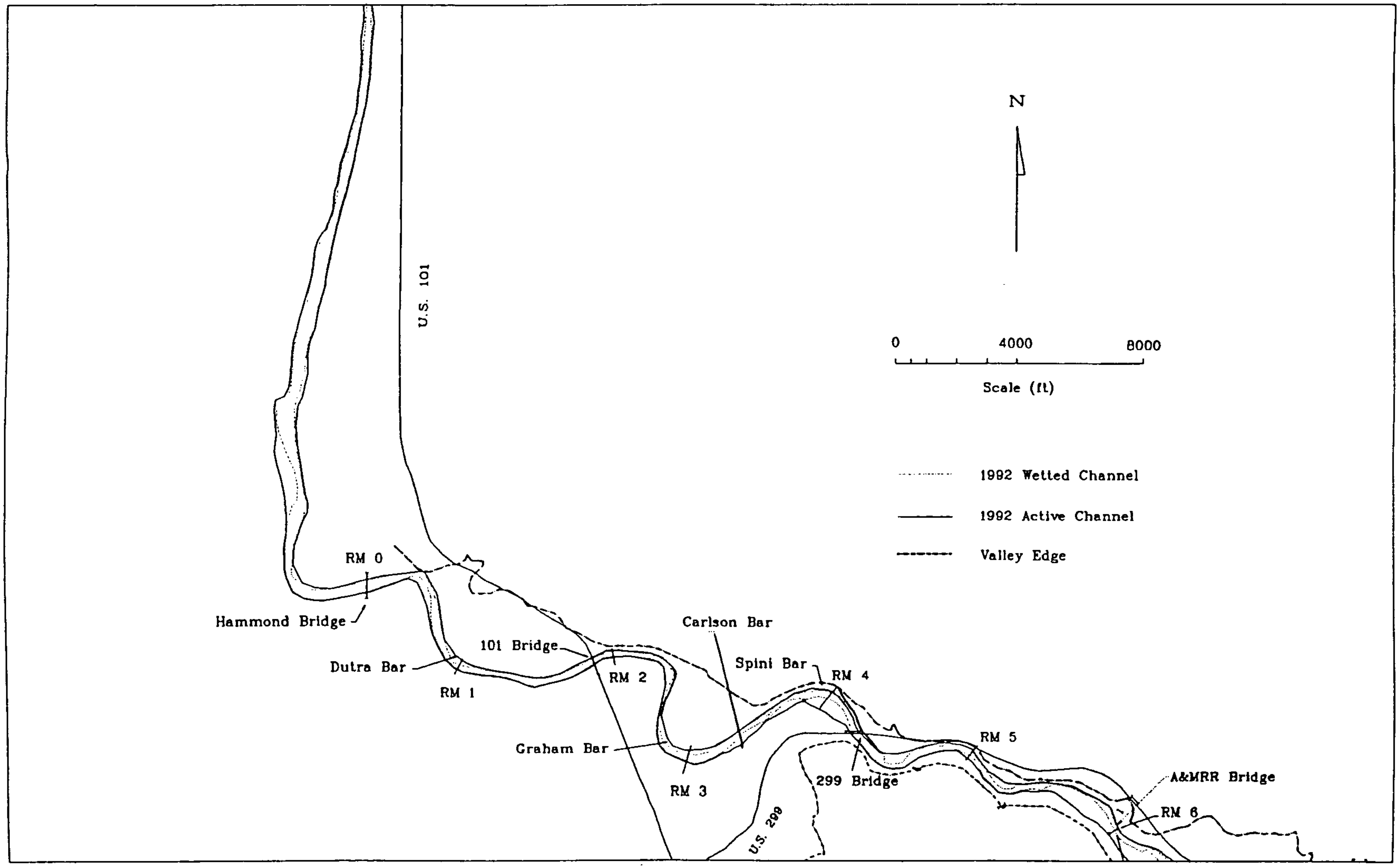
Mad River, Sweasey to A&MRR, 1988



Mad River, A&MRR to Hammond, 1988



Mad River, Sweasey to A&MRR, 1992



Mad River, A&MRR to Hammond, 1992