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# CHANNEL CHANGES WROUGHT BY GOLD MINING: NORTHERN SIERRA NEVADA, CALIFORNIA

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**ABSTRACT:** Fluvial responses to gold mining can be determined from historic and field evidence. This study emphasizes early historic evidence of two types of mining. River mining began quickly in 1849 and by 1850 valley bottoms of the Sierra foothills were being transformed by the construction of flumes and water wheels. Excavations of alluvial beds rapidly altered main mountain channels from equilibrium gravel-bed forms and disrupted the alluvial stratigraphy of large channel reaches. This style of mining was largely complete by 1862 except in the Middle Fork American River where deep rich placers persisted until at least 1880. In the rivers to the north, river-mining operations were buried from the early 1860s through the 1870s by a tremendous volume of sediment produced by hydraulic mining of uplands. Sediment production and aggradation during this period were rapid and episodic along certain rivers, in particular, the Yuba and Bear Rivers. Aggradation extended down into main channels in the Sacramento Valley causing channel avulsions and leaving deep alluvial deposits that remain today. Most hydraulic mining was enjoined in 1884, and 20th century sediment production was modest. Knowledge of this history is essential to an understanding of current geomorphic processes, sediment budgets, and landforms in these rivers.
***KEY TERMS:*** California; Historical Mining Sediment; Fluvial Geomorphology.

## INTRODUCTION

River corridors are a valuable resource utilized for many purposes including urban and agricultural development, transportation routes, water supplies, flood conveyance, recreation, nature preserves, mineral resources, and fisheries. Growing concern over the management of these riparian environments in recent decades has led to the need for information about historical changes to the geomorphology of these fluvial systems. It is important to understand the history of mining in rivers flowing out of the northern Sierra Nevada which were very severely altered by gold-mining activities in the 19th and early 20th centuries. This paper utilizes historical information to describe the nature of channel responses to gold mining in rivers of northern California flowing out of the Sierra Nevada.

The area of concern is the Yuba, Bear, and American Rivers in the heart of the *northern mines* of the northern Sierra Nevada, California (Figure 1). Prior to mining, small tributary channels in the mountains were dominated by bedrock and bouldery alluvium with little fine-grained alluvium (Gilbert, 1917). In main mountain channels, however, depths of alluvium were substantial, as has been noted at Rattlesnake Bar on the North Fork American below the town of Auburn where alluvial depths ranged from 6 to 18 m (20-60 ft) (Lardner and Brock, 1924). For example, in an 11 km stretch of the modern Middle Fork American River the channel has lag deposits with depths to bedrock averaging 8.1 m (26.5 ft) and ranging from 5.5 to 9.6 m (18.0-31.5 ft). Based on aggregate surveys, these bars cover about 40 hectares (100 acres) and contain 7.3 million $m^3$ (9.5 million $yd^3$) of alluvium not counting about 2 m of overlying modern channel deposits (COE, 1991).

As major tributaries from the Sierra Nevada enter Sacramento Valley and approach the Sacramento and Feather Rivers, gradients and sedimentary textures decrease considerably. Contemporary descriptions indicate that pre-mining channels in the Sacramento Valley had high, steep banks with dark, fertile soils on low terraces (Hall, 1880). For example, the lower Bear River in the late 1850s had steep banks about 12 feet high (Keyes, 1878: pp. 7, 62, 144; James, 1988; 1989).

Mining technology evolved rapidly in northern California from 1849 to 1884. Three distinct forms of mining can be differentiated, but only two had substantial impacts on channels: (1) *river mining* exploited the alluvium of active channels, (2) *hydraulic mining* utilized water under pressure primarily to work upland paleochannel gravel, and (3) *tunnel* or *quartz* mining were forms of hard-rock mining that produced relatively little sediment, had little impact on fluvial systems, and are not addressed by this paper. The history and nature of the two placer technologies are outlined below, along with the corresponding character of stream responses. Both river mining and hydraulic mining were vigorously practiced in the northern mines. Stream channels in the northern mines were radically changed by the influences of hydraulic mining, and many have never fully recovered.

## RIVER MINING

Gold miners began arriving in California in large numbers in 1849. Initially they worked shallow alluvial deposits of the active channels with pans, rockers, and other simple devices. These traditional placer-mining techniques existed long before the California gold rush and were imported from Georgia, the Carolinas, and Spanish-Mexican sources. Shallow placer mining initially had little impact on channels, produced little sediment, and was short-lived along any given river. Once a new gold-bearing deposit was located, a rapid influx of miners ensued and the surface alluvium was thoroughly worked within a year or two. By 1851, newspapers were already signaling a decline in yields from shallow gravel.

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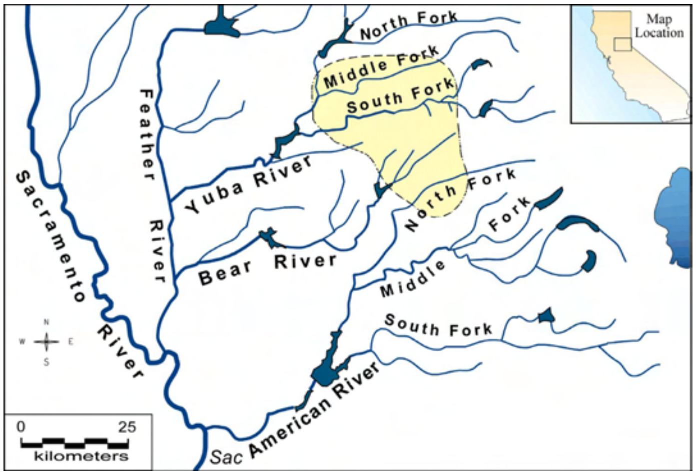


Figure 1. Map of the northern mines showing the Yuba, Bear, and American River Basins on the western side of the northern Sierra Nevada, California.

The rapidity by which placer gold was mined and exhausted can be illustrated by an examination of total gold production in California during this period (Figure 2). Gold production rose rapidly from 1848 to a peak in 1852 as mining intensified and shallow surface placers were worked over by the relatively benign placer mining methods (Loyd and Bane, 1981). Reductions in shallow placer gold production were even more precipitous than is suggested by the bold recessional curve on Figure 2. Although production by the various mining methods cannot be precisely differentiated, historical information indicates that river mining gold production declined rapidly in the late 1850s and early 1860s while hydraulic and quartz mining both grew in importance. Between 1859 and 1863, Americans had relinquished most of their claims to the American River channel bed to Chinese miners (Paul, 1947: 130). Gold production by river mining declined sharply following the 1862 flood and never recovered. Hydraulic mining also suffered a decline in the early 1860s but it rebounded later. Quartz mining began to increase productivity, and by 1860, due to improvements in hardrock mining technology and capital investments, quartz mining began to thrive (Paul, 1947: 143-144). The rapid decline in gold availability in the early 1850s created an impetus for miners to become more industrious.

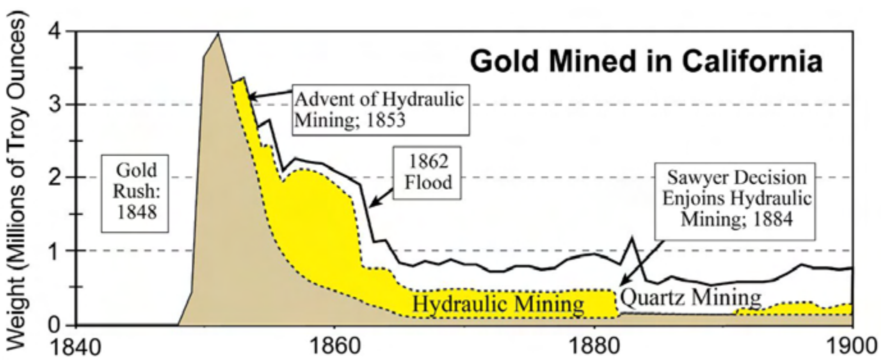


Figure 2. Nineteenth century annual gold production in California. Gold production by river and hydraulic mining is estimated based on historical information. Adapted from Loyd and Bane, 1981.

The richest placers were below channel lag gravel at the bedrock contact, which on major rivers was more than 5 m (16 ft) deep and required mining or engineering skill to extract. Hard-rock miners from the coal and iron mines of Pennsylvania and the lead mines of Wisconsin provided experience with explosives and heavy, water-powered machines. Through the 1850s as shallow placers became scarce, river mining became ever more organized and mechanized in order to exploit the deep alluvium (Figure 3).

Miners banded together into smallcompanies to build dams, flumes, longtoms, and sluices, and began mining the alluvium more deeply and extensively. As work progressed down into coarse channel-lag deposits, they diverted channels into large flumes and built water-powered pumps to lower water tables along the channels. By the late 1850s, valley bottoms with deep, rich placers had been transformed into a continuous series of canals, water wheels, and gravel pits lined by a succession of tent cities crowded with workers. Many alluvial valley bottoms were disrupted by river mining in this manner.

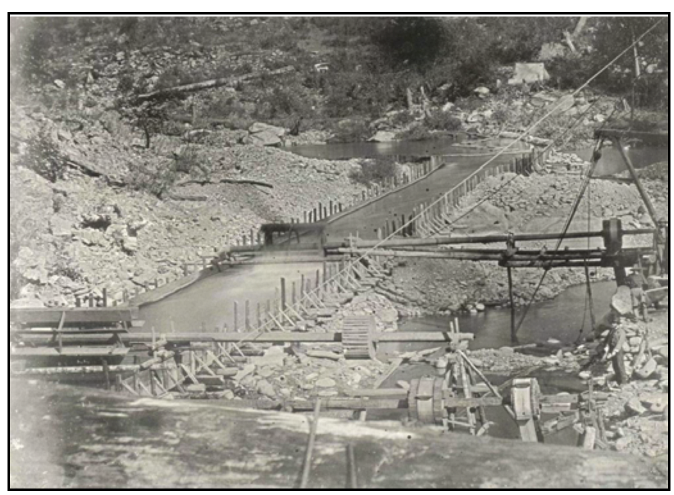

Figure 3. River mining at Grizzly Flats, South Fork American River. Daguerreotype, *ca.* 1850. Bancroft Library, MacKay Collection #81.

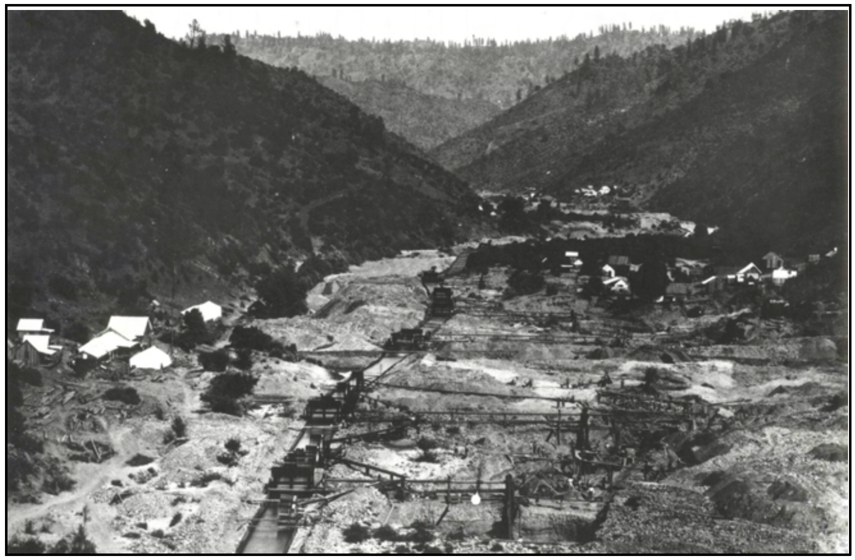

Figure 4. River mining at Kennebec Bar, Middle Fork American River, *ca*. 1858. Bancroft Library, Chs. Weed Collection.

Figure 5. Middle Fork American River, Kennebec Bar, 1992.

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Figure 6. Dutch Claim on the Middle Fork of the American River, near Poverty Bar, *ca.* 1858. Bancroft Library. Weed Collection.

River mining was extensive along the Middle Fork American River, near Auburn, where valley bottoms supported some of the densest populations in the State in 1858. At Kennebec Bar the pre-mining channel at the far left side of Figure 4 crosses the canal near the center of the photo. Water driven sump pumps allowed the mining of channel lag gravel for gold. The intense mining industry in 1858 is in stark contrast to the same site in 1992, which appears to be a pristine stretch of river (Figure 5). The lack of cultural features at the site in 1992, uncharacteristic of rivers in this region, is due to protection of the site by the Bureau of Reclamation as the potential reservoir area above the Auburn Dry Dam. The 1858 photographs and photo sites are described by Turner (1983).

Nearby at Dutch Claim on the Middle Fork American, similar river-mining operations and channel changes were active in 1858 (Figure 6). Sparse vegetation on hillslopes and valley bottoms in 1858 contrasts with the modern oak woodland and willows that have since colonized slopes and floodplains (Figure 5). Sparse vegetation less than ten years after settlement has been interpreted as a pre-settlement vegetation adjustment to frequent fires, and the dense contemporary vegetation as a result of fire suppression (Fugro-McClelland and Leiser, 1991). Deforestation was associated with mining, and more than twenty sawmills in the Middle and South forks of the American River in 1860 supplied miners with wood to replace flumes after winter floods (Lardner and Brock, 1924: 182-183). Few conifers extended down to these low elevations, so local clearance was probably limited to firewood and subsidiary construction materials to support the mines and mining communities. It is likely that much oak and brush was cleared during this period since this was the primary source of fuel and population densities were very high. Vegetation changes due to mining represent an additional potential hydrogeomorphic impact on channels through increased runoff and hillslope erosion.

In the winter of 1861-62, record floods devastated the mining communities as well as the mechanical works. Following these floods, few river-bottom communities recovered to their pre-flood level of activity since diminishing returns had already set in and the remaining gold was concentrated at deep levels. Some river-mining operations continued at least into the 1880s on the Middle Fork American River, however, and were noted by Manson (1882: 97) during his survey of the river.

## HYDRAULIC MINING

Shortly after 1850, while river mining was evolving from shallow placer prospecting, miners discovered the source of the modern placer gold in a series of upland Tertiary paleochannel gravels. These were dry deposits generally buried by thick layers of volcanic overburden, however, that could not be economically worked without moving large volumes of sediment. Between 1853 and 1854, miners of the northern mines invented *hydraulic mining*, the utilization of water under pressure, and quickly began to extract gold from upland gravel (Paul, 1947; Kelley, 1954; 1959; May, 1970; Rohe, 1985; Burgess, 1992). Immense hydraulic pits began to be excavated along ridge tops using water power in conjunction with blasting (Gilbert, 1917).

Two periods of hydraulic mining can be differentiated based on the deposits and technology utilized. Up to the 1860s, hydraulic mining exploited *upper channel gravel* or *bench gravel* which was fine, weakly cemented, and relatively easily mined (Figure 7). These deposits began to be depleted in the early 1860s, and combined with the 1861 flood, extremely dry conditions over the two succeeding years, and an out-migration of miners to the Comstock Load in Nevada, these changes led to decreased sedimentation rates (Paul, 1947: 242; 255). From 1864 onward, hydraulic mining gold production was maintained by technological innovations in spite of depletion of the upper gravel (Keyes, 1878; Paul, 1947: 293).

Stratigraphically beneath the upper gravel were the *deep gravel*, or the *blue lead*, which were rich in gold but coarse, strongly cemented, and located down in bedrock channels difficult to exhume with commonly available water pressures (Lindgren, 1911; Yeend, 1974). These deposits began to be worked in the 1870's as technologies, such as water cannons (monitors and giants), blasting with dynamite, and tunneling enhanced hydraulic mine productivity (Paul, 1947: 295; Loyd and Bane, 1981; Rohe, 1985). This later period was marked by consolidation of both hydraulic mine claims and the water companies supplying them as the industry grew capitally and mechanistically intensive (Paul, 1947: 297).

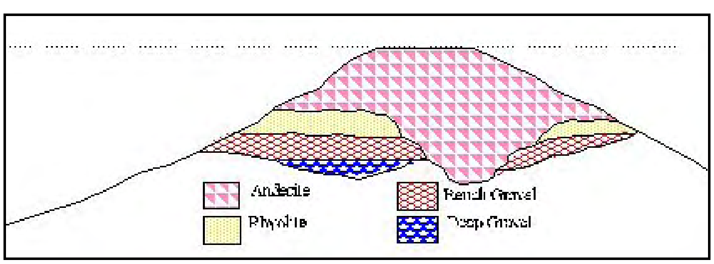

Figure 7. Auriferous channel deposits. Bench gravel above deep gravel. (Adapted from Lindgren, 1911: Fig.2)

### Sedimentation in the Mountains

By 1860, several hydraulic mines in the foothills were working the bench gravel, and large tailings deposits were already present in tributaries draining the mines. These deposits were local, however, and did not yet extend downstream due to the lack of large floods during this period. Main channel sedimentation was negligible in the mountains and below in the Sacramento Valley until the floods of December, 1861 and January, 1862. For example, in the mountains below the mines, a noticeable increase in turbidity was noted in the Bear River at Bear River Dam in 1856. After the 1861-62 floods, this turbidity increased considerably, dam and canal sedimentation began, and mining sediment began to be delivered throughout the Sacramento Valley (Keyes, 1878; Mendell, 1881). Channel bottoms were filled by graded deposits of sand and gravel, and in many cases, the pre-mining channel has not yet been re-exposed after more than 130 years (James, 1988; 1989). While these floods were devastating to downstream operations, they cleared out the tailings dumps in the canyons below the mines and restored the gradients necessary for efficient hydraulic mining. Thus, the decrease in gold production after 1862 (Figure 2) was primarily due to less river mining. Hydraulic mining rebounded in the mid to late 1860s.

The combined effects of the two stages of hydraulic mining sediment production and the reworking of sediment stored within tributaries below the mines resulted in rapid aggradation of tributaries below the mines and formation of a series of *tailings dams* at main channel confluences where gradients decreased. Many of these tailings dams formed reservoirs and released sediment episodically when breached by floods. It was argued in court by miners and mining engineers that the dams were permanent features and that no sediment could get past them to the Sacramento Valley below (Keyes, 1878). The dams failed during high flows, however, and released large pulses of sediment.

Topographic surveys conducted in 1870 and in 1879 document 30 and 42 m (96-136 ft) of aggradation in this 9-year period on tailings fans located at Little York and Steephollow Crossings, respectively, tributaries to the Bear River (Pettee, in Whitney, 1880). These are minimum depths that must be added to an estimated 15 to 23 m (50-75 ft) of mining deposits that were already at these sites in 1871 (Pettee). By the 1880s, sedimentation and devastation had become so severe that Congress directed the U.S. Army to conduct field surveys to ascertain the volume and location of sediment storage in the American, Bear, and Yuba River canyons, as well as downstream in the Feather and Sacramento Rivers. These government surveys were conducted in 1879 while mining was still active (Mendell, 1880; 1881), in 1889 shortly after hydraulic mining had ceased (Heuer, 1891), and from 1908 to 1914 (Gilbert, 1917). These surveys produced descriptions of mining sediment deposits and estimates of both sediment production and storage. In general, the main channel systems most seriously aggraded were the South Yuba, lower Yuba, Bear River, and the North Fork American Rivers. The Middle Fork Yuba had sediment deposits that rivalled the others but had been altered by an extreme dam-break flood by the time of Turner's (1891) survey. The Middle Fork American River had only modest hydraulic mining sediment deposits and river mining persisted. Very little hydraulic mining sediment was produced in the South Fork American River or in rivers to the south.

## Sedimentation in Sacramento Valley

Farmers in the Sacramento Valley were decimated by the aggradation and increased flooding caused by hydraulic mining sediment. Although frequent flooding of Sacramento Valley lowlands was common prior to channel aggradation (Gilbert, 1917; Thompson, 1960), the aggradation of channels exacerbated flooding by filling channel bottoms and decreasing conveyance of flood-waters. This was particularly true in the Yuba and Bear Rivers, and to a lesser extent, in the Feather and American Rivers. Deposition was negligible until the 1862 flood when the channel-bottom was suddenly filled (Keyes, 1878; Mendell, 1881). Channel aggradation and flooding grew worse through the 1870s and was characterized by channel avulsions in spite of the construction by farmers of levees and other engineering works intended to control sedimentation and flooding (Hall, 1880; Mendell, 1881).

The effects of channel aggradation has been documented in the lower Bear River (James, 1989; 1991). Aggradation continued unabated through the 1870s while farmers formed levee districts and vainly attempted to control the river. Discharges of the late 1870s floods were probably not considerably large, but aggradation had raised the channel bed to heights that aggravated flooding and triggered a series of channel avulsions beginning in 1870 until the channel was finally stabilized by levees and dikes in 1881 (Lardner and Brock, 1924: 33-34). By this time there were broad deposits across the valley bottom, an extensive discontinuous levee system, abandoned pre-mining channels, and a new channel resulting from the 1870s avulsions. Sloughs influenced flooding and sedimentation patterns during the aggradational period by capturing main channel flows and causing avulsions. Farmers built dams and levees only to have flood waters pass down an adjoining channel. In 1875 and 1876 for example, Yankee Slough captured flows from the Bear River above the railroad bridge and the slough became partially filled with sediment (Keyes, 1878). While farmers built levees to protect their lands, the U.S. Army concluded that levees would encourage sediment transport downstream to navigable waters of the Feather and Sacramento Rivers and opted to build brush dams to detain sediment in the lower Yuba and Bear Rivers. A brush and rock dam 1.8 m (6 ft) high built on the Bear River to impound sediment failed within a year (Mendell, 1881). About 734,710 $m^3$ of sediment was impounded behind the dam in its brief existence from 1880 to 1881 (Mendell, 1882).

The influx of fine sand and silt in the early 1880s resulted in channel narrowing near the mouths of the Yuba, Bear, and Feather rivers (Mendell, 1882). By 1879, the Feather River bed at its mouth had risen about 0.9 to 1.2 m (3-4 ft) above its pre-settlement level, and its channel near the mouth of the Bear River was obscured (Hall, 1880). In the Sacramento River between the mouth of the Feather River and the City of Sacramento, there was about 1.5 m (5 ft) of fill associated with channel narrowing. Deposits in the channel were colonized by willows, and the old high banks with riparian forest were set back from the contemporary channel margin (Mendell, 1882). Similar narrowing in lower basins has occurred in response to high suspended sediment loads from 19th century agricultural practices (Knox, 1977).

Deposits are much less extensive in the lower American River than in the Yuba or Bear because sediment production was largely restricted to the North Fork which comprises less than 20% of the basin area. Although aggradation was less, considerable channel adjustments apparently occurred in the lower American during the mining period. Levee construction and raising of streets from 1 to 5 feet in the City of Sacramento following the early 1850s floods proved inadequate to handle the aggrading channel system. Following the devastating 1861 floods, a new series of higher, set-back levees were constructed including the cut-off and reclamation of a meander bend near Sutter's Fort (Bishofberger, 1975). High terraces inset between the levees at Howe Avenue represent undocumented channel aggradation along the lower American River in which channel-bed elevations rose to a maximum level considerably higher than the surrounding floodplain and seriously diminished the flood conveyance of the levee system.

## DEGRADATION AND CHANNEL INCISION

Hydraulic mining was enjoined in 1884 and sediment production rapidly decreased, although it is unlikely that sediment loads returned to pre-mining levels for several decades. A survey in the upper Bear River from 1889 to 1890 indicates that channels had incised in the upper mining region but were aggrading near confluences of Steephollow and Greenhorn Creeks with the Bear River (Turner, 1891). Depths of channel degradation in 1890, measured from maximum heights of terraces, were less than 3 m (10 ft) except at tailings fans where they reached as much as 9.1 m (30 ft) (Turner, 1891).

There is little record of mountain channel conditions at the turn of the century. By the end of the first decade of the 20th century, data and photographs from Gilbert (1917) and topographic surveys indicate that most of the mining sediment was gone from many main mountain channels. The vast and persistent deposits remaining in the Bear River are a notable exception. Likewise, tailings below hydraulic mines have persisted in many small tributaries of the Yuba and Bear Rivers, especially in Scotchman, Humbug, Shady, Spring, Steephollow, and Greenhorn Creeks.

In the Sacramento Valley, mining sediment deposits were more persistent than in the main channels above. By 1908 low terraces had formed in the lower Yuba and Bear River "piedmont" areas (Gilbert, 1917) indicating that progressive channel incision had begun, but not to the degree that erosion had progressed in main mountain channels. The Yuba and Bear River deposits are now largely protected by levees and form vast alluvial tracts covered with orchards. Substantial channel erosion is recorded by terraces and the study of cross-section changes (James, 1991), but much of these deposits can be considered more-or-less '*permanent*' over centennial time scales.

## CONCLUSION

River mining wrought considerable changes to the stratigraphy, geomorphology, and ecology of main alluvial channels in the mountains of the northern Sierra Nevada. This form of mining was early in the gold rush and was largely concluded by 1862 due to a combination of devastating floods, diminishing returns, burial by hydraulic mining sediment, and an exodus of miners to Nevada silver strikes. In addition, river mining was primarily local in nature; while it may have been devastating to the immediate environment, these impacts were apparently not carried downstream in any great way. In contrast, hydraulic mining generated an episode of sedimentation that was catastrophic from both a geologic and environmental standpoint. Sedimentation began with the rapid aggradation of small tributaries below hydraulic mines, was introduced to main channels by floods in the winter of 1861-62, continued throughout most systems through the 1870s and 1880s, and continued to shift down-valley after that time. During the 1870s, there was a shift from mining of fine upper gravel to coarse, well-cemented lower gravel, and the character of both mining and the sediment produced changed markedly. Incision of the deposits had begun by the late 1880s and was well advanced in most mountain channels by the turn of the century. Vast deposits of mining sediment remain in tributaries below the mines, in piedmont deposits along the Sacramento Valley, and in main channels where sediment storage potential is high.

Given the extreme influence that human activity often plays upon fluvial systems, we need to develop a better understanding of historic channel changes over decadal and centennial time periods. Historic perspectives not only elucidate fundamental fluvial processes over these time scales for which systematic instrumental records are lacking, but they can also indicate temporal trends in a particular system. For example, without knowledge of progressive channel aggradation or degradation, the basic assumptions of flood hazard assessment, including sophisticated flood-frequency and channel hydraulic analyses, can be invalid. As we seek to build hydrologic data bases for a given system, there should be a serious effort to include an historical geomorphic component through the study of both documentary and stratigraphic evidence. This does not discredit conventional approaches to scientific hydrology, but encourages multi-methodological approaches that incorporate information often neglected by traditional methodologies.

## ACKNOWLEDGEMENTS

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