ONE HUNDRED AND FIFTY YEARS OF SEDIMENT MANIPULATION ON THE TRINITY RIVER, CA

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ABSTRACT

This paper explores the history of gold mining, gravel mining, and river restoration activities on the upper 42 miles of Trinity River, CA between Lewiston Dam and the North Fork Trinity River. Newly developed quantitative estimates of the sediment supply impacts associated with these activities are presented. Intensive hydraulic mining since the 1860’s has contributed vast amounts of sediment to the Trinity River. Contributions from the La Grange mine alone were sufficient to aggrade the valley bottom by over 3 feet. The longitudinal profile shows preliminary evidence of a persistent sediment wave resulting from hydraulic mining activities. Subsequent dredger mining overturned more than 70 percent of the floodplains. Historic gravel mining operations likely extracted between 60,000 and 125,000 cubic yards of gravel from the channel. A surprising result of this research is that river restoration activities over the last 40 years have extracted nearly as much gravel from the channel as they have augmented – roughly 90,000 cubic yards. Repeat bulk sampling between 2001 and 2009 showed reductions of up to 50 percent in the sand content of the substrate. Additional studies are underway to better understand the legacy impacts of mining and river restoration activities on the fluvial geomorphology and channel complexity of the Trinity River.

INTRODUCTION

While it is well known that extensive gold mining activities have occurred throughout the Trinity River watershed, their effects on sediment supply and fluvial geomorphology have not previously been quantified. The impacts of gravel mining and restoration activities on sediment supply have also not previously been quantified. Extensive research of historical and project archives went into developing both the history and sediment supply estimates for gold mining, gravel mining, and river restoration. Understanding theses impacts is the first part of larger study currently underway to link sediment supply to channel complexity to help inform river management actions.

Located in Northern California, the Trinity River is partially confined, gravel bed river, and the largest tributary to the Klamath River. Figure 1. The impacts of flow regulation since 1960 and the ensuing geomorphic change, vegetation encroachment, loss of salmon habitat, and salmon population declines are well described in the Trinity River Flow Evaluation Study and Record of Decision. (USFWS 1999; Babbit 2000). These documents also more fully explain the current restoration strategy that combines flow releases, gravel augmentation, mechanical bank rehabilitation, and watershed restoration to restore fluvial processes to build and maintain the habitat needed to support a robust public and tribal salmon fishery.

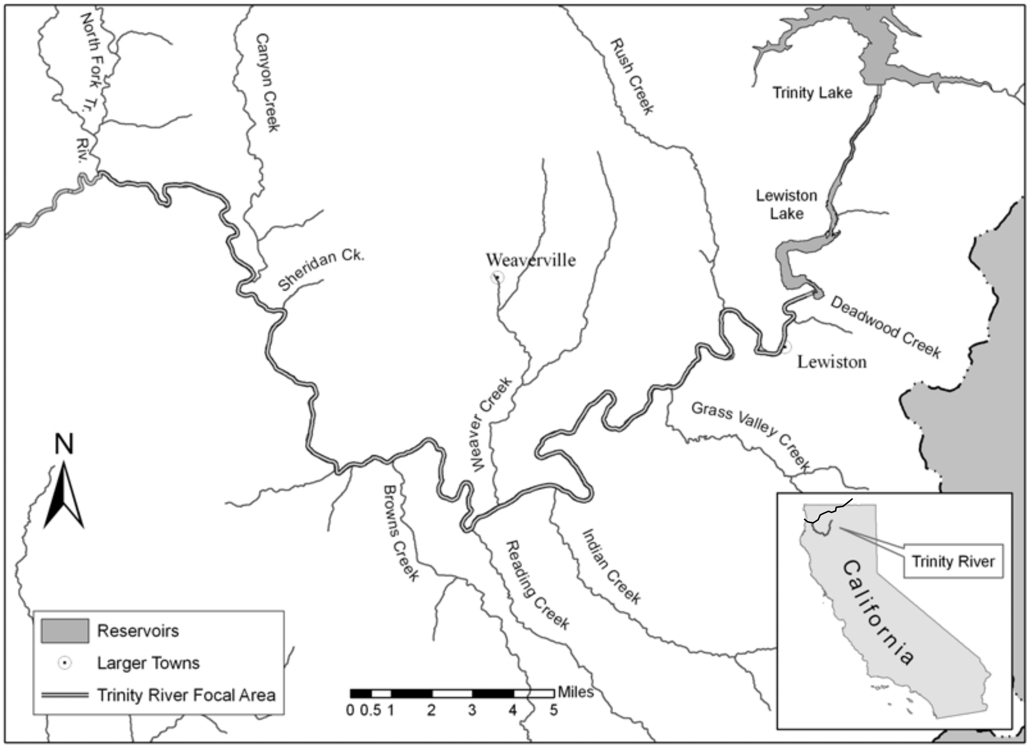

Figure 1: Trinity River Location Map

GOLD MINING HISTORY

Early Gold Mining

The second discovery of gold in California occurred in 1848 on the Trinity River at Reading Bar near Douglas City. (Brown 1916). By 1849, the California Gold Rush was in full swing and gold bearing deposits were found along every major bar on the Trinity River. The combination of mild winters of 1850 and 1851 and shallow gold deposits located in the upper two to three feet of bar deposits made the use of pick, pan, rocker, and sluice boxes effective. (Bailey 2008). As these shallow deposits were exhausted in the early 1850's and the weather became wetter, more intensive mining methods were employed, including water wheels, wing dams, and diversion dams. Water wheels, as large as 50 feet in diameter, acted as primitive dredges delivering gold bearing gravels and water to mercury-lined sluice boxes. Wing dams were placed at the head of river bars to dewater one side of the bar to allow mining. Once one side of the bar was mined, the wing dam was moved and the other side of the bar was mined. Diversion dams fully spanned the Trinity River and diverted the flow into raceways and flumes to completely dewater the mainstem to allow for mining. Diversion dams were built near Junction City, Weaver Creek, Big Flat, and Lewiston. (Hicks 1989; Bailey 2008). Diversion dams were expensive to build and temporary, washing out with the winter storms. (Hanover 1970). The largest and most famous of these was Arkansas Dam, built in 1851, four miles upstream of Junction City. After the dam washed out in the winter of 1851 and again in 1852, it was rebuilt so substantially as to withstand not only the winter storms but also contain an upstream dam break flood that occurred when the 14 foot high diversion dam at Union bar gave way. The ensuing flood wiped out every water wheel, dam, and other structures along the river in the intervening 20 miles between the dams.

(Hicks 1989). In 1857, Arkansas dam was removed by the miners so they could access the gold deposits beneath the dam. (Sedler 1891). Construction of water wheels, wing dams, and diversion dams was labor intensive and expensive. These forms of mining were becoming less profitable by the early 1860's as the gold deposits available to these methods were mining out. This era of placer gold mining ended in the winter of 1861-62 when major flood on the Trinity River washed out every flume, mine, and bridge on the river. (Bailey 2008). Ground sluicing and hydraulic mining became the dominate form of gold mining in Trinity County following the 1862 storm.

Ground Sluicing

Ground sluicing consisted of diverting large volumes of water into creeks and gulches (or over high banks) to erode the stream bed. The eroded sediment was run through sluices or into small detention basins for gold recovery. Hydraulic mining of the surrounding hillsides was often used in conjunction with ground sluicing. The largest form of ground sluicing was the "self-shooter", a reservoir with a wooden gate that automatically opened when the reservoir filled (Bailey 2008) to create a large flash flood. Reports of self shooters on Weaver Creek indicate these floods were a daily occurrence. (Hicks 1989). The larger cobbles and boulders that could not be moved by ground slicing were then stacked along the sides of the creeks to liberate the gold below. These ubiquitous tailings piles, and the vast network of water supply ditches for hydraulic mining, are still visible today along nearly every creek and gulch in the Trinity River watershed.

Hydraulic Mining

Large scale hydraulic mining became the dominate form of gold mining in Trinity County in the early 1860's through the early 1900's with small scale hydraulic mining continuing until 1970, when the Costa hydraulic mine in upper Rush Creek closed. (Trinity Taskforce 1970; Bailey 2008). Hydraulic mining uses pressured jets of water from water cannons called "monitors" to erode and wash sediment from stream banks, terraces, and hillsides into sluices for gold recovery. The resulting sediment load is tremendous, creating sediment waves that aggrade the downstream receiving water courses. The most famous sediment waves occurred in tributaries of the Sierra Nevada mountains that experienced up to 20 feet of aggradation from hydraulic mining. (Bailey 2008). The 1884 Sawyer Decision effectively stopped hydraulic mining in the Yuba River basin by the banning the discharge of mining debris to receiving streams. This ban was expanded to the entire Sacramento-San Joaquin watershed in 1893 by the Caminetti Act. (Lydon 1962). Correspondingly, hydraulic mining in the Trinity River watershed peaked during this time period, as it was not subject to these bans. State records from 1898 show 307 hydraulic mines operating in Trinity County. (Bailey 2008). This included the two largest hydraulic mines in the world during that time, the La Grange mine near Junction City and the Union Hill mine near Douglas City. (Egilbert 1913; O'Brien 1965). Other large hydraulic mines included the Sykes hydraulic mine near Trinity Center, the McMurray and Hupp Mine near Weaverville, and the Cie Fse Mine near Junction City. (Bailey 2008).

Bailey (2008) presents an excellent history of the La Grange hydraulic mine located on Oregon Mountain about 3 miles east on Junction City, California that is synopsized as follows. The La Grange mine operated from 1851 to 1942 and was the most productive hydraulic mine in America history. Large scale hydraulic mining occurred between 1862 and 1918, when landslides destroyed portions of the 26 mile long, La Grange flume that supplied 90 cubic feet per second (cfs) of water to the mine. The mine reopened in 1932 and operated through 1942 with the express purpose of excavating the cut for a new highway across Oregon Mountain. The La Grange mine operated six monitors between 6 and 9 inches in diameter. With a working head of over 600 feet, the water jets had an effective range of 250 feet, working 500-foot tall hillside cuts and pushing boulders exceeding six tons through the sluices without any operational interruptions. Debris from the La Grange mine filled Oregon Gulch before discharging into the Trinity River. In the process, the town of Oregon Gulch was completely buried, the first and only instance of town burial by mining debris in California history.

Dredger Mining

Dredger mining consists of a floating platform that works back and forth across the floodplain using a either a drag-line or a bucket-line to excavate as much as 40 feet down to bedrock, process the gravel for gold in an internal sluice or trammel, then deposit the spoils at the rear end of the dredge in the form of large tailings piles. Dredges operated on the mainstem Trinity River and most of the larger tributaries. Dredgers were massive contraptions, on the order of 150 feet long by 50 feet wide and several stories tall. (Resources Agency 1936). Smaller dredgers called "doddle-bugs" were also used to access areas with narrow floodplains. The larger dredges could chew through more than 6 acres of floodplain and process between 250,000 to 400,000 cubic yards of material a month. (Bailey 2008). In the mining process, dredgers removed the top soil and both mixed and inverted the existing floodplain sediments. The result is large tailings piles of gravel, cobble, and boulders, towering up to 40 above the surroundings. Nothing was spared, the dredgers turned over ranches, orchards, and natural floodplains alike. Between Lewiston and Junction City, California, dredger mining impacted more than 70 percent of the Trinity River floodplain. (Strearns 1969). The highest impact areas were from Trinity Center to Lewiston and from Douglas City to the North Fork Trinity River, especially near Junction City. (Bailey 2008). Like the other mining activities, dredging significantly increased turbidity levels. For instance, operation of the Fairview Dredger in 1952 muddied 120 miles of the Trinity River from Stewards Fork to Weitchpec. (Paul 1952).

Dredges were capitally intensive to build but were highly cost effective because, unlike hydraulic mining, they required no outside water supply. Dredger mining replaced hydraulic mining as the dominate form of gold mining in Trinity County in the early 1900's because it was more economical. (Bailey 2008). The first dredge on the Trinity River was the Kiser Brothers dredge that started operation in 1889 about three miles north of Lewiston. (Bailey 2008). The last large dredge to operate on the Trinity River was the Trinity Dredge in Lewiston that operated from 1912 through 1959. Operations only stopped when the Bureau of Reclamation acquired the property for operation of Trinity and Lewiston dams. (Bailey 2008).

Lode Gold Mining

Lode gold mining occurred between 1875 and 1912 in Trinity County and was focused primarily in the Deadwood district near Lewiston, California. The larger mines like Brown Bear excavated shafts over 1,000 feet deep. (Bailey 2008). A 1969 survey of rubble piles associated with 20 lode mines in the Deadwood district (about half of the total mines in the district) indicated that the 45,000 cubic yards of tailings were stable and not producing a sediment supply to the Trinity River. (Strearns 1969).

SEDIMENT SUPPLY AND GEOMORPHIC IMPACTS OF GOLD MINING

Temporal Distribution of Sediment Supply from Mining

While total sediment supply from mining activities is unknown, the temporal distribution can be assumed to roughly follow the mining production records for Trinity County (Figure 2). These records have been tallied by the State of California since 1880. Three distinct peaks are obvious. The highest peak in 1890's corresponds to increased hydraulic mining in Trinity County following the 1884 Sawyer Act and 1893 Caminetti Act that banned hydraulic mining in other parts of the state. The second peak in the 1930's represents increased dredger mining when gold prices spiked after the Great Depression. During World War II, the 1942 War Production Board Order L-208 closed non-essential gold mines to conserve equipment and manpower for the war effort. Industrial scale gold mining partially revived after the war but ended with the land acquisition and construction of Trinity and Lewiston dams in the late 1950's. (Bailey 2008). Dam construction in the late 1950's caused a spike in sand and gravel production that exceeded the economic value of gold production for the first time.

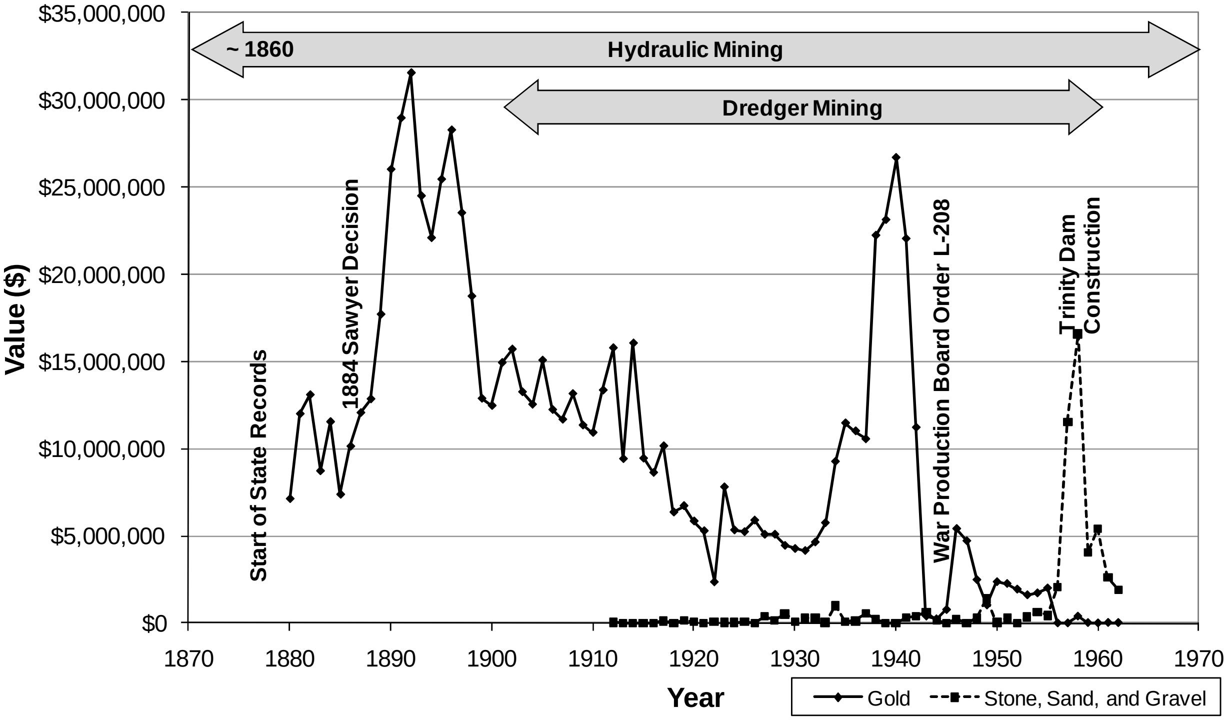

Figure 2: Mineral Production of Trinity County 1880-1962.

Source: O'Brien (1965). Original values have been adjusted for inflation using the Consumer Price index to show value in 2009 dollars.

It is interesting to note that during the mining lull in 1921, the Trinity Journal reported "Owing to the absence of hydraulic mining during the present year and the consequent clearness of the river, the salmon have been running up the Trinity and tributaries, which is something unusual. This has not happened before for a period of about 14 years. The river was freer from mud and debris last summer than for about 40 years." (Trinity Journal, Nov. 12, 1921).

Magnitude of Sediment Supply from Mining

The combination of ground sluicing and hydraulic mining deepened the tributaries, widened valleys, and washed vast amounts of sediment into the mainstem Trinity River. The total amount of sediment supplied to the Trinity River from mining activities is unknown. We do know industrial scale hydraulic mining lasted over 80 years in Trinity County (more than twice as long as other parts of California), over 300 hydraulic mines were operating in 1898 during the peak hydraulic mining period, and that two of the largest hydraulic mines in the world operated along the Trinity River. It is estimated that the La Grange mine alone produced 110 million cubic yards of sediment between the mid-1870's and its final closure in 1942. (Bailey 2008). It is useful to try to put this astronomical volume of sediment into context. To do so, the 110 million cubic yards produced by the La Grange mine will be examined from three different perspectives – sediment yield, sediment transport during large floods, and floodplain aggradation.

Sediment yield: The estimated average annual sediment yield (combined suspended sediment and bedload) for the Trinity River at Lewiston is estimated at 170 tons per square mile. (Hawley *et al.* 1969). At that rate, it would take over 1,350 years for the 719 square mile watershed above Lewiston to supply same 110 million cubic yards that that the La Grange mine produced in only 80 years of operation.

Sediment transport during large floods: The Eel River is a 3,700 square mile watershed located just south of the Trinity River. The Eel River at Scotia has an average annual sediment yield of 7,800 tons per square mile, the largest of any basin of comparable size in the United States and nearly 50 times that of the Trinity River. (Hawley *et al.* 1969). The famous 1964 storm on the Eel River was a 200 year event that peaked at over 750,000 cfs - similar in magnitude to the 1993 flood on Mississippi River near St. Louis, MO. (Sloan *et al.* 2001). This storm completely filled in the valley of the lower Eel River and passed an estimated 67 million cubic yards of sediment. (Helseth 1966). The largest flood on record in one of the most highly erosive watersheds in the country produced only 60 percent as much sediment as the La Grange mine.

Floodplain Aggradation: Assuming that only 20% of the debris from the La Grange mine was sand and gravel yields an estimate of about 22 million cubic yards of sediment that is capable of causing aggradation. Based on valley and hillslope morphology, it is estimated that roughly 6 million cubic yards of this sediment was deposited in Oregon Gulch. The remaining 16 million cubic yards is estimated to have entered the Trinity River. That volume of material would fill in the 1,000 foot wide Trinity River floodplain by over 3 feet if it were evenly distributed along the 8.5 miles between Oregon Gulch (the outlet of the La Grange mine) and the North Fork Trinity River.

The first two examples indicate the sediment supplied to the Trinity River by hydraulic mining is several orders of magnitude greater than natural processes would have produced. The floodplain aggradation example supports the notion that hydraulic mining sediments were sufficiently voluminous to produce sediment waves capable of aggrading the river channel and valley bottom by several feet. Evidence of such valley aggradation should be reflected in the longitudinal profile.

Longitudinal Profile

The longitudinal profile for the Trinity River circa 1935 is shown in Figure 3. The profile is based on 5-foot water surface elevation contours from topographic surveys conducted between 1921 and 1949 by the U.S. Geological Survey from the Pacific Ocean to the upper end of the current Trinity Reservoir. Trinity and Lewiston dams are shown for reference although they were not constructed until well after the surveys. The remainder of the profile is based on the 10 meter National Digital Elevation Model maintained by the U.S. Geological Survey. The most pronounced feature in Figure 3 is the 300 foot drop near river between Hawkins Bar and Cedar Flat. This drop is due to a geologic control imparted by the Iron Side Mountain terrain.

Figure 4 shows the longitudinal water surface profile between Lewiston Dam and the North Fork Trinity River. The profile is derived from preliminary water surface data from a 2009 airborne terrestrial LIDAR flight conducted during 300 cfs winter base flow releases between Lewiston Dam to the North Fork Trinity River. Initial inspection of Figure 4 shows what looks like a sediment wave between Dutch Creek and Coopers Bar, the area most heavily impacted by hydraulic mining, including the La Grange mine. Given the extent of the mining impacts in this area, a sediment wave is certainly plausible. Additional analysis is underway to rule out alternative explanations (e.g. geologic control) for the perceived sediment wave.

GRAVEL MINING

The peak of sand and gravel mining occurred between 1956 and 1962 during construction of Trinity and Lewiston Dams. At 29 million cubic yards and 538 foot tall, Trinity Dam is one of the largest earth filled dam in the country. (Lydon 1962). Much of the supply for dam construction came from the areas now inundated by the reservoirs. Downstream areas near Lewiston and Douglas City also provided material for dam construction, mostly from mining of dredger tailings. Gravel mining for road construction targeted both dredger tailings and in-river sources. In-river gravel mining occurred at Lewiston and near the mouths of Grass Valley Creek, Indian Creek, Weaver Creek, and Reading Creek. (O'Brien 1965; Ritter 1968). The largest of these operations was Trinity Sand and Gravel, located in Douglas City, between Weaver Creek and Reading Creek. Trinity Sand and Gravel produced an estimated 25,000 cubic yards of gravel per year between 1950 and 1980. The majority of the production came from floodplain sources but was also taken from in-channel. (Hal Goodyear, pers. comm. June 26, 2009). Assuming that 5 to 10 percent of the gravel was taken from in-channel, the estimated amount of gravel extracted ranges between 37,500 and 75,000 cubic yards over the life of Trinity Sand Gravel operations. The other in-channel gravel mining operations were temporary operations using mobile screening plants. It is assumed these operations extracted between 5,000 and 10,000 cubic yards each, for a total of 25,000 to 50,000 cubic yards. Taken together, the historic gravel mining operations likely extracted between 60,000 and 125,000 cubic yards of gravel from in-channel sources. Current sand and gravel mining operations are located in the floodplains of Weaver Creek, Oregon Gulch, and a large dredger tailing pile in Junction City. These modern operations do not impact the sediment supply of the Trinity River.

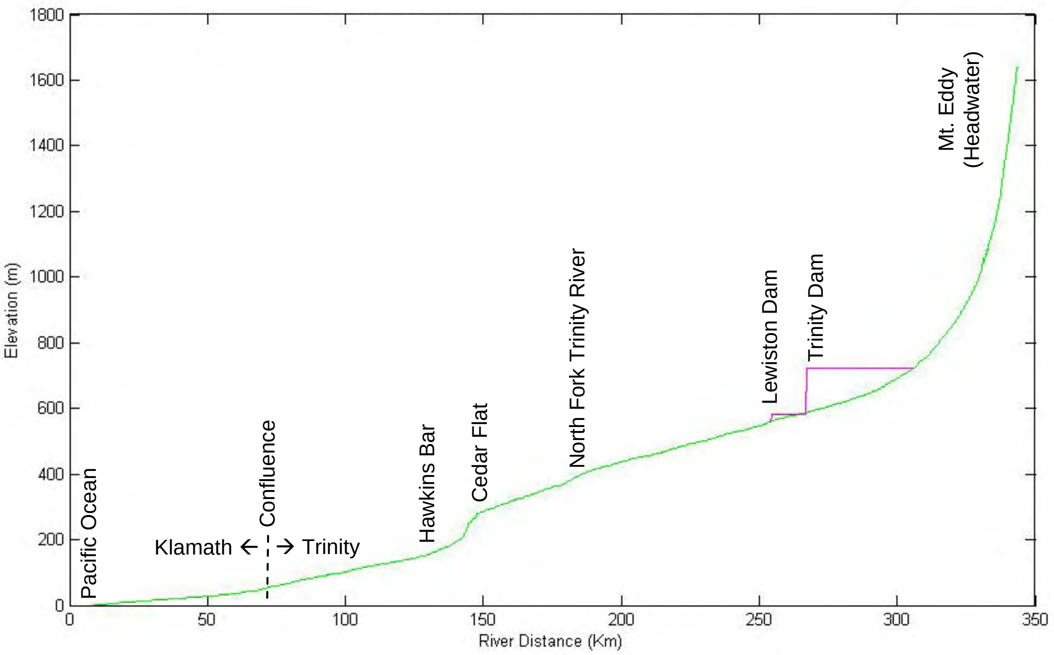

Figure 3: Trinity River longitudinal profile from the Pacific Ocean to the headwaters.

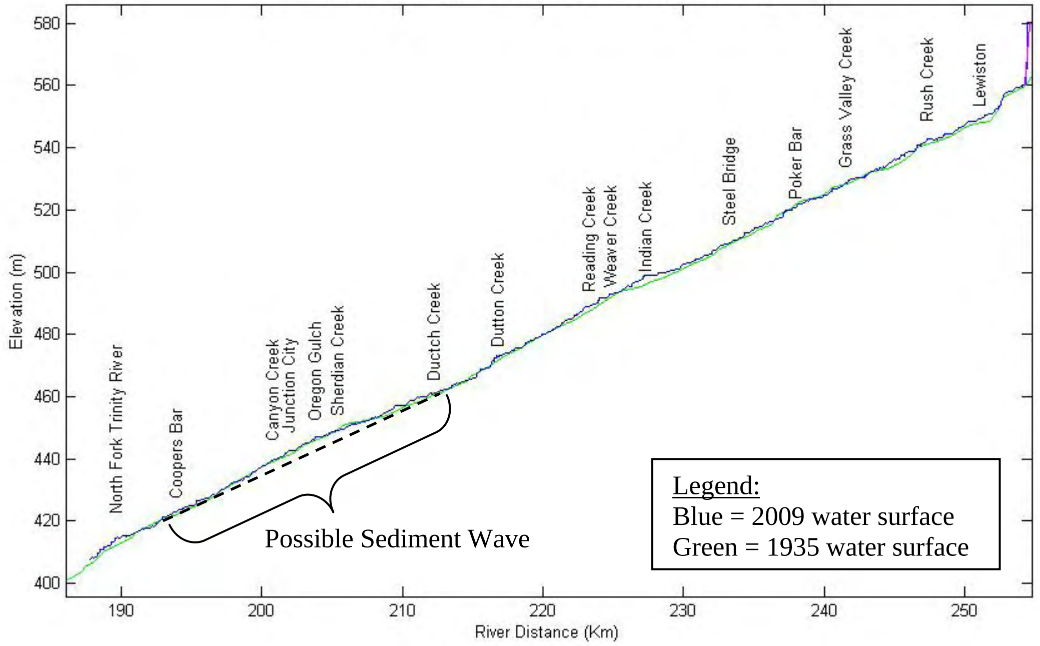

Figure 4: Longitudinal profile between Lewiston Dam and the North Fork Trinity River indicating a possible sediment wave.

RIVER RESTORATION

Spawning surveys between 1955 and 1970 show the progressive and significant loss of spawning habitat, from 50% to 80% in certain areas. By 1963, 16 out of 17 spawning riffles downstream of Trinity and Lewiston dams had decreased use. (Rogers 1972). These habitat losses were caused by a combination of delta aggradation, sand infiltration, and vegetation encroachment that occurred following flow regulation in 1960. An evolving suite of river restoration efforts to reserve the steady decline of habitat began in 1965 and continues today.

Delta Channelization

Tributary deltas, and portions of the main channel, between Lewiston Dam and the North Fork Trinity River aggraded by up to 11 feet during the 1964 storm. (Ritter 1968). The 1964 delta aggradation was due to the combination of high tributary sediment delivery and comparatively low mainstem flows. Releases from the newly constructed Trinity Dam remained at 300 cfs during the entire 1964 storm event, yet the estimated inflow was 100,000 cfs. (Strearns 1969). To put this into perspective, since 1911, the peak flow at Lewiston Dam is 71,600 cfs, recorded in 1955. The 1964 delta aggradation caused significant backwaters to develop. Several of the 17 major salmon spawning riffles were inundated by these new delta backwaters. (Rogers 1972). In an effort to recover these spawning areas, channelization of the mainstem Trinity River through tributary deltas at Rush Creek, Grass Valley Creek, Weaver Creek, and Reading Creek was conducted in 1965 (Ritter 1968) and constitutes the first restoration effort. Channelization and occasional gravel extraction continued at the Rush Creek delta in 1972, 1974, 1979, 1988, and 1989. The Rush Creek delta and associated backwater continues to be a focus of management efforts today. Figure 4 shows the growth and persistence of tributary deltas from the 1964 storm.

Construction of Artificial Spawning Riffles

The combination of mainstem flow regulation and elevated tributary sediment supply from logging and road building caused significant mainstem sand accumulation, pool filling and extensive loss of salmon habitat. (Trinity Taskforce 1970; Rogers 1972; USFWS 1999). Restoration efforts from the early 1970's through the late 1980's were focused on combating the continued loss spawning habitat due to sand infiltration. In 1971, the Forest Service tested the "riffle sifter", a large mechanical device that agitated the bed to stir up the sand then suck up the water/sand mix and use water cannon to shot it onto a nearby floodplain. The riffle-sifter was ineffective and prone to mechanical breakdown. In 1972, the first artificial spawning bed was constructed just below Lewiston Dam. (Anonymous 1976). Between 1976-77, a total 14 artificial spawning beds were constructed (including enlargement of the 1972 pilot site). The contract specifications (Reclamation 1976; 1977) describe the construction of the riffles as follows. First, a bull dozer ripped the channel bed and remove cobbles > 6 inches. Then, construct a grade control structure and place 500 to 2,000 cubic yards of spawning gravel (typically 0.5 inches to 4 inches in diameter) to build a 400 foot long artificial spawning riffle with a slope of 0.0025 upstream of the grade control structure. Finally, use cobbles > 6 inches in size to construct berms on both sides of the river to constrict the flow to an 80 foot width. These artificial riffles were designed to provide slow water velocities at low winter flow release when salmon are spawning. Consequently, the riffles had to be repaired often to replace the gravel lost during periods of modest flow releases or storm events. The artificial riffles were abandoned by 1990 and their associated grade control structures are slowly being removed as part of current restoration efforts.

Dredging for River Restoration

Pool dredging for river restoration purposes occurred from the mid 1970's through the 1991. The purpose varied from creating or enhancing holding pools for adult salmon, mechanically removing fine sediment to improve salmon spawning habitat, and mining gravel for the construction and continued maintenance of the artificial spawning riffles. Dredging was used to enhance 3 natural pools and to create 12 new pools where none previously existed. A typical constructed pool was 500 feet long and 15 feet deep. Pool dredging excavated roughly 140,000 cubic yards of sand and 90,000 cubic yards of gravel from the river. (unpublished analysis). Bed ripping was also being conducted during this time period. Bed ripping used bulldozers to loosen the top 18 inches of spawning areas and allow the river to flush the sand downstream. (DWR 1984). Bed ripping and pool dredging stopped in 1991 because it created too much turbidity. Starting in the late 1980's there was also a broader shift to use watershed restoration to control sand at it source. The primary target of watershed restoration efforts in the late 1980's through mid 1990's was the Grass Valley Creek watershed. This 36 square mile is predominately composed of highly erosive decomposed granite and was heavily logged. Between 1984 and 2009, over 240,000 cubic yards of sand were dredged from 3 sediment detention basins constructed near the mouth. (Trso 2004; unpublished analysis).The 90 foot tall Buckhorn Dam was constructed in 1991 in the upper Grass Valley Creek watershed to act as a sediment trap. Between 1991 and 2001, Buckhorn Dam has captured upwards of 92,000 cubic yards of sand and gravel. (Trso 2004).

Restoration of Fluvial Processes

By 1988, managers acknowledged that rearing habitat, not spawning habitat, was likely the limiting factor for salmon production. (Trinity Taskforce 1988). This recognition lead to a series experimental high flow releases in the 1990's, conducted in combination with "feather edge" pilot projects that removed encroached vegetation and created gently sloping gravel surfaces along the channel margins. These experiments changed the restoration paradigm and lead to the adoption of the current fluvial process based restoration strategy formally adopted by the Secretary of Interior in the 2000 Record of Decision. (USFWS 1999; Babbit 2000). Full implementation of associated management actions (flow releases, gravel augmentation, mechanical bank rehabilitation projects, and watershed restoration) began in 2005. Between 2005 and 2009, a total of 18 projects have been constructed, treating over 120 acres. Several of these projects included gravel augmentation to promote a dynamic channel via sediment transport and bar building.

Sediment Supply Impacts of River Restoration

Between 1972 and 2009, approximately 97,000 cubic yards of gravel have been augmented to the channel by restoration activities (spawning riffle construction and gravel augmentation). Pool dredging related to river restoration activities have removed an equivalent volume of gravel from the channel. Most of the gravel removed by pool dredging was sieved to between 1 inch and 4 inches and were used for in-channel augmentations in other locations. Therefore, the net impact of river restoration activities over the last 40 years on in-channel gravel supply is a slight fining of the grain size but no significant impact on total volume.

Repeat bulk sampling of the river substrate between 2001 and 2009 throughout the upper 42 miles between Lewiston Dam and the North Fork Trinity River shows a decrease across the board in the substrate sand content. The most dramatic reduction was observed at Poker Bar where the substrate content of sand (< 2 mm size fraction) dropped from 30 percent to 14.5 percent. (GMA 2010). These results indicate the watershed restoration, flushing flows (and to a certain extent pool dredging and bed ripping) have been successful in reducing the amount of sand stored in the substrate.

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