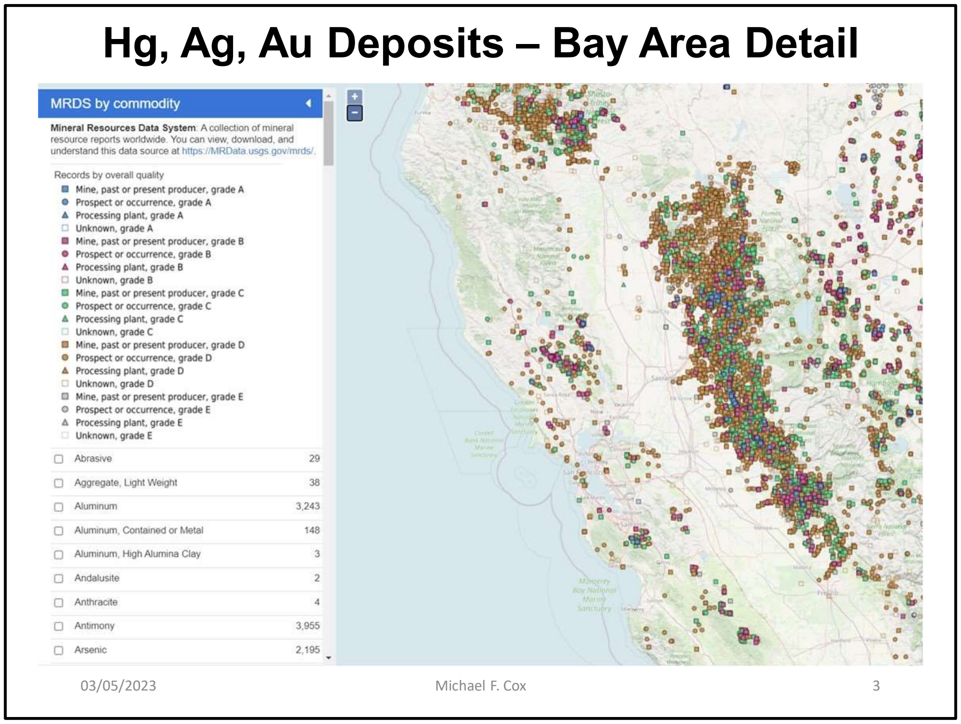
This picture is of some items I personally collected a long time ago, before the mine was a park. The beer bottle is typical of the gold rush days. Miners are a thirsty lot. The rocks are cinnabar, mercuric sulfide, HgS, the ore of mercury. The rounded rock is a creek nugget. The first peoples collected the nuggets for vermillion paint. The big rock is a piece of ore from industrialized mining prior to 1863. The smaller rock is a piece of the last ore body discovered in the district in 1989. These are icons of the mines, beginning with the first peoples and ending with mining in our industrial age.

Purpose

- Improve mercury pollution management capabilities
  - Share and discuss some history of mercury mining and use
  - Share and discuss pollution management and abatement experience
- The problem is highly fractal
  - multi-party cooperation and coordination is essential!

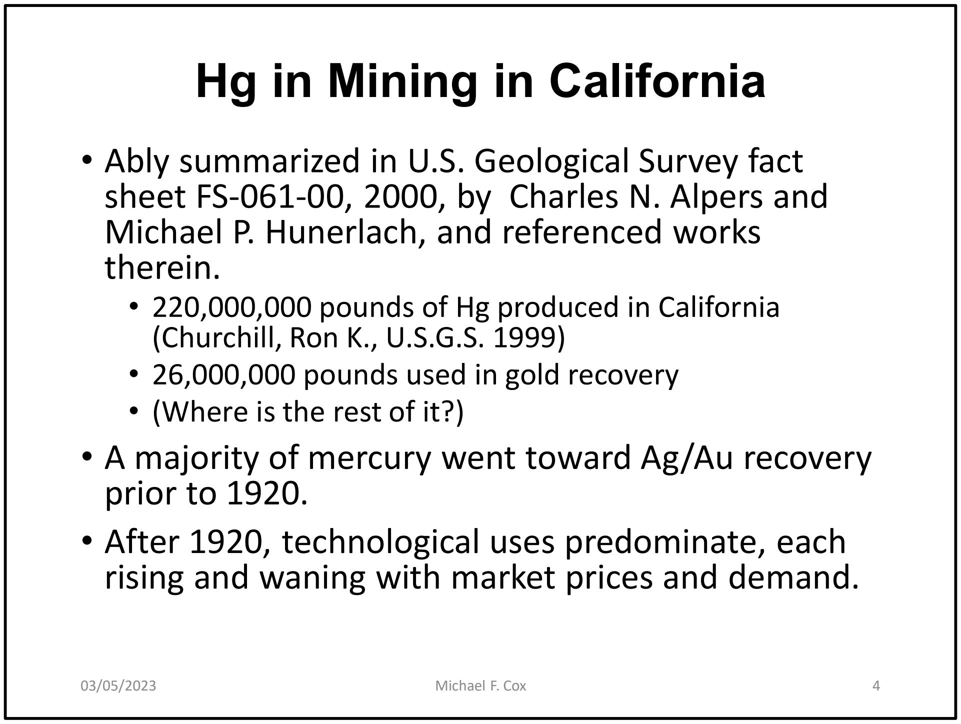
Self-explanatory. This talk will necessarily be very fast due to time limitations. There is a lot packed into it.



There are a lot of mineral occurrences, prospects, and mines in California.

This data is from the U.S. Geological Survey Mineral Resources Data System and shows everything from reported unmined occurrences to working mines and mills. California has 42,749 MRDS records (downloaded Feb. 27, 2023). 53% (22,758) of these records list gold as the first primary commodity. Many others list gold as a secondary commodity. 2% (932) of the records list mercury as the first primary commodity, and just under 2% (786) list silver.

MRDS is large, complex, and somewhat problematic. As of 2011, USGS has ceased systematic updates to MRDS, and is working to create a new database, focused primarily on the conterminous US. For locations outside the United States, MRDS remains the best collection of reports that USGS has available. For locations in Alaska, the Alaska Resource Data File remains the most coherent collection of such reports and is in continuing development.



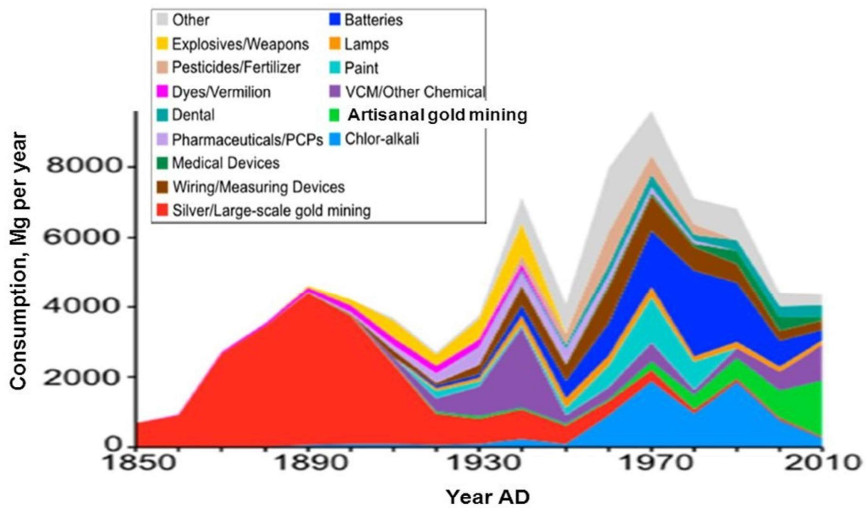
Accounting for mercury use in gold mining is not enough. What happened to the rest of the production?

Mercury Losses in Ore Processing

- Reports of state mining, mineralogy, and geology often contain data of the use of mercury in mining and associated consumption and ore losses.
- U.S. Census reports on the mercury industry also often contain valuable information.
- Losses are significant.
  - Spillage and kinetic losses
  - Mist and fume loss
  - Leakage to ground and air
  - Cooling and cleanup water discharge
  - Ore treatment carryover to tailings

Data collected for the 11th Census of the United States details mercury losses in gold mill tailings that possibly range from 50 mg/kg to 935 mg/kg. The losses can only be approximated by the mercury consumption per ton or ore treated. The division of the loss between water, sediment, and air is unknown.

Global historical use of mercury in commercial products



Horowitz et al. [2014]

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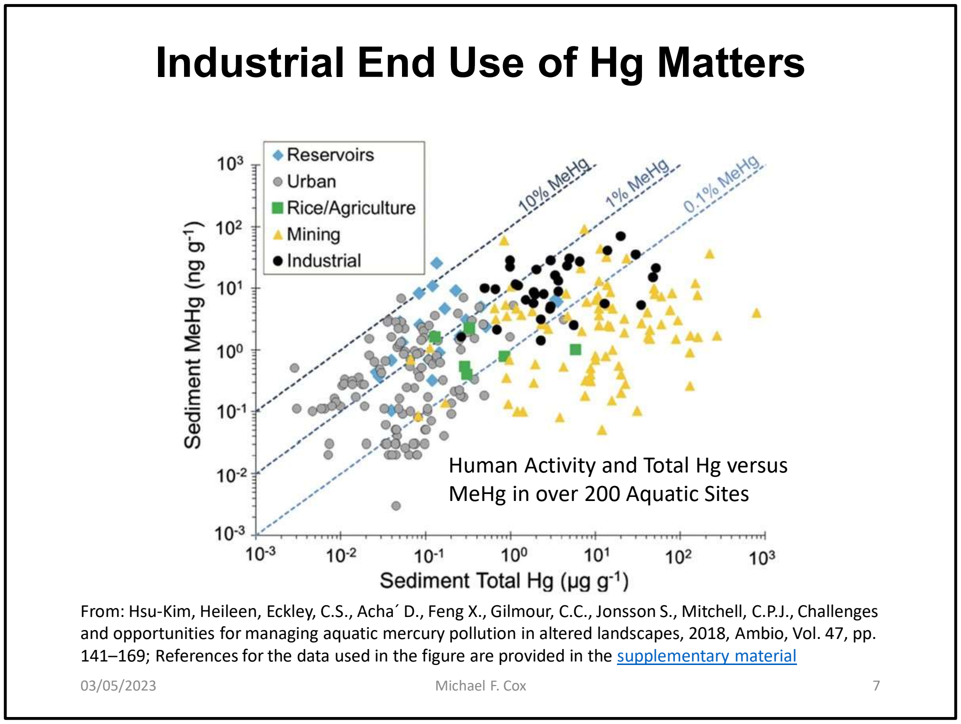
Primary mercury mining and production is a big problem in California. Industrial end use other than for amalgamation probably represents as significant a potential source of mercury pollution, if not more significant, but often these end uses are not easily regulated point sources. This does not mean the other end uses should be ignored because they can be presumed to be too small or removed from environmental circulation. A good regional Total Maximum Daily Load is deficient if it has not identified the location and condition of all site of significant mercury use and potential emissions. An example of a nuance that is being assessed is the operation of methane extraction systems at sanitary landfills. These landfills can contain buried mercury. Are incinerator mercury emission limits adequate to ensure minimal bioaccumulation over time? What about landfills of former mining waste sites using contaminated materials for daily cover?

Fun fact, the 1890 U.S. Census of mineral industries illuminates that six vermillion manufacturing companies in New York City consumed 243002 kg (535,728 pounds) of mercury in 1889 to manufacture 272177 kg (600,047 pounds) of vermillion. Added sulfur at a ratio of 1:5 by volume makes up the difference. We hope the manufacturing process created very little waste.



The figure suggests that industrial end use of mercury should not be overlooked. How many regional and local management documents, such as Total maximum Daily Load programs, have gone out seeking a more complete picture of end use?

From the authors: “Figure 1 Total Hg and MeHg contents observed at more than 200 aquatic sites that have been perturbed by anthropogenic activities. The risks of
Hg exposure at these sites generally depend on the mobilization potential of Hg from the site as well as

the potential for MeHg bioaccumulation and exposure to wildlife and humans. Supplemental information at https://link.springer.com/article/10.1007/s13280-017-1006-7#Sec10."

One good bit of news is that mercury and mercury-sulfide in sediments is not significantly mobile when removed from surface transport.

1970 Mercury in Sediments, mg/kg, SF Bay

1971, Distribution of mercury in surface sediments in San Francisco Bay estuary, California
Open-File Report 71-192, By: D. S. McCulloch, T. J. Conomos, D.H. Peterson, and K. Leong

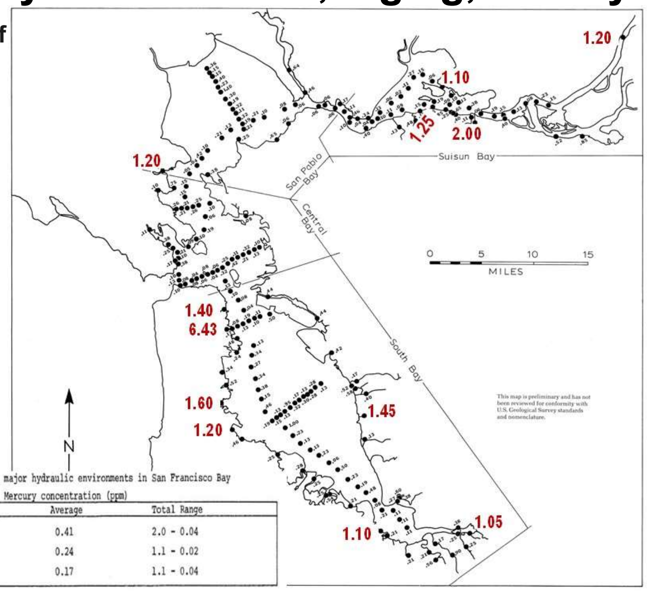


Table 2.--Concentrations of mercury in three major hydraulic environments in San Francisco Bay

	Mercury concentration (ppm)		
	Median	Average	Total Range
Tributaries and margins	0.40	0.41	2.0 - 0.04
Shoals	0.21	0.24	1.1 - 0.02
Channels	0.13	0.17	1.1 - 0.04

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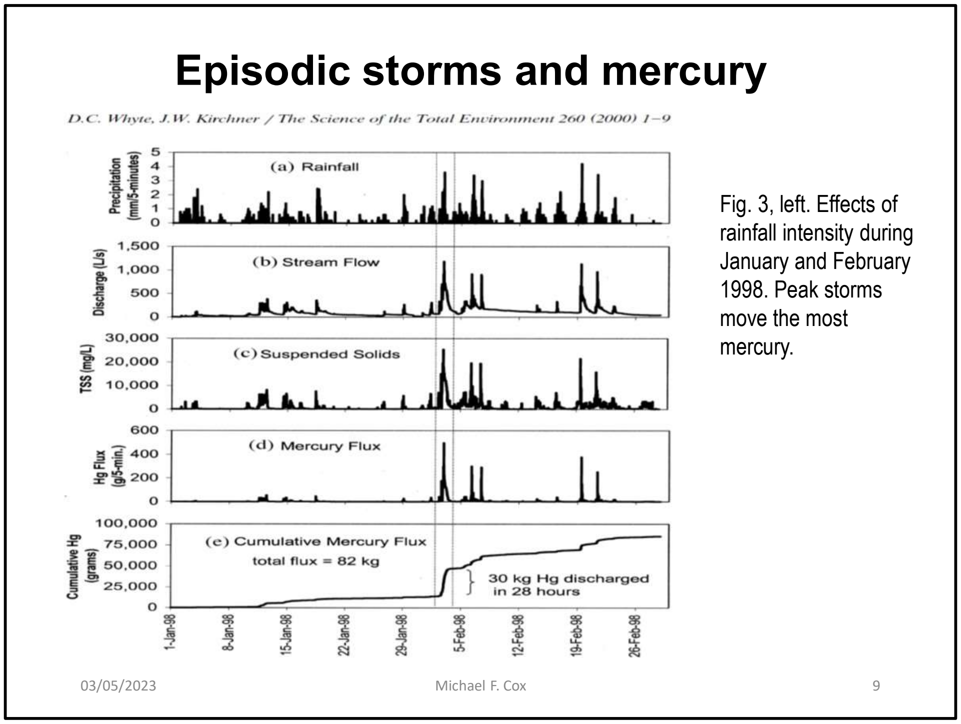
The earliest comprehensive characterization of Bay sediments for mercury was conducted by the United States Geological Survey in 1970. Bottom sediments were taken from an 8 in. x 6 in. x 4 in. deep area, air dried, and spilt into 0.1 gram aliquots for analysis by the UV-absorption vapor detection technique of W.W. Vaughan (1967) (https://www.911metallurgist.com/mercury-detector/). There are mercury anomalies at the Bay margins that are no doubt industrial signatures, whether primary mercury mining or secondary mercury use.



The time-integrated suspended solids work done by Whyte and Kirchner illuminates the need for better mass flux determinations. One reason is to better separate mining from other loads, including airborne, bed and bank, and unrecognized industrial contributions. Erosion is episodic, and so are inputs from mining and industrial activity. Smooth curves should not be expected. The idea here is to use better measurement of time-integrated flux to clarify baseline conditions and the effects of remedial action to control mine site erosion and sediment loads.

Some Au/Ag mining photos

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Rocker

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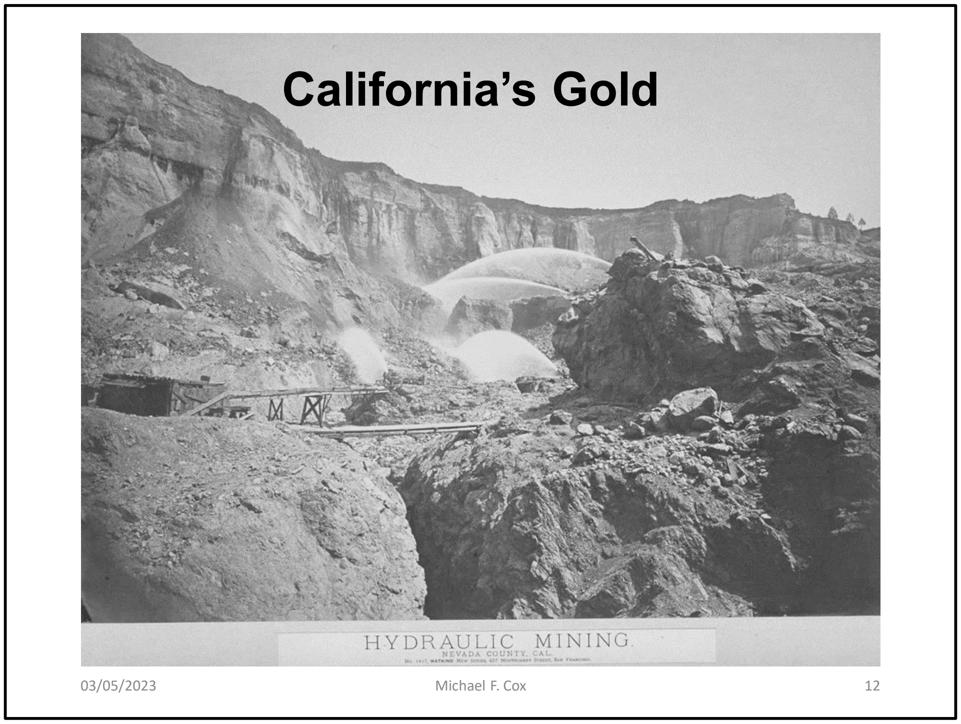
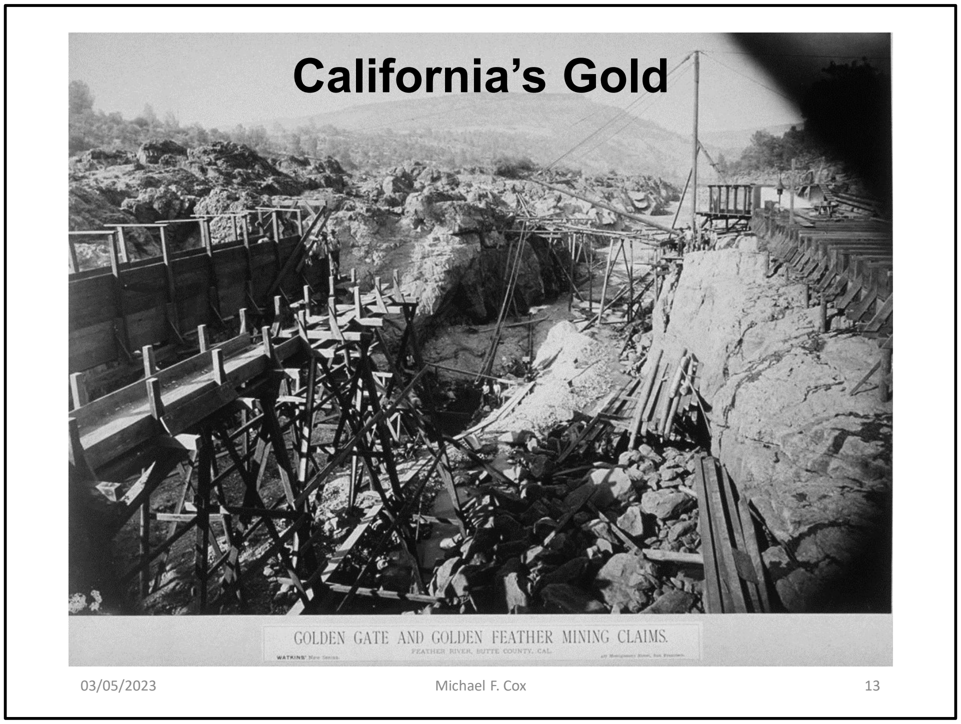
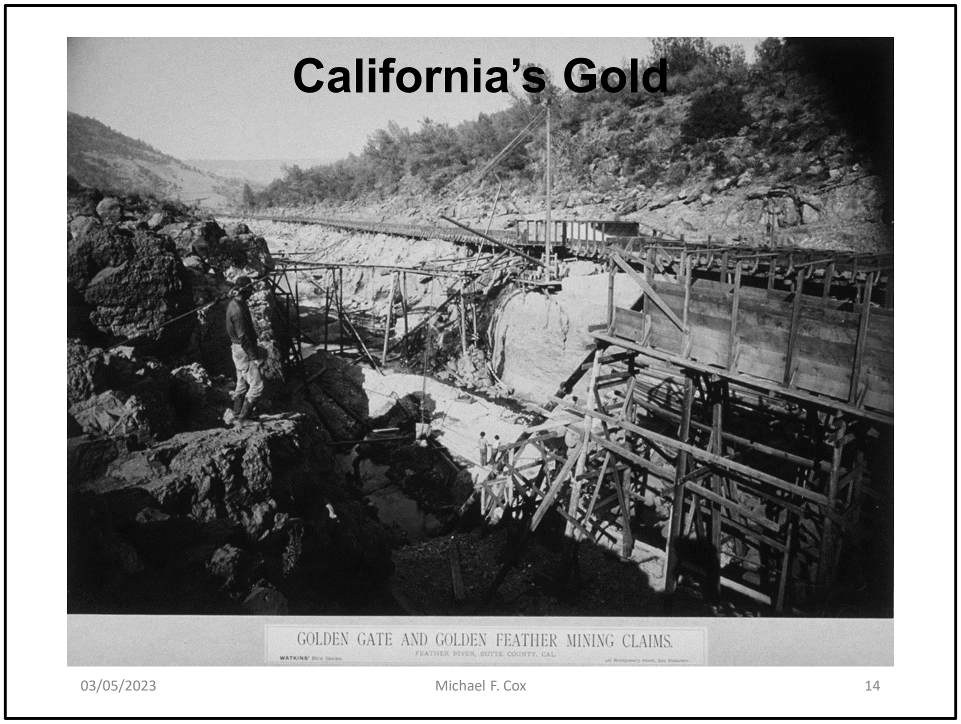


This is another photo folks think of when considering mercury pollution from gold mining. This is the infamous Malakoff mine.
Photo by Carleton Watkins, circa 1871-1876, from the Hearst Mining Collection, U.C. Berkeley.

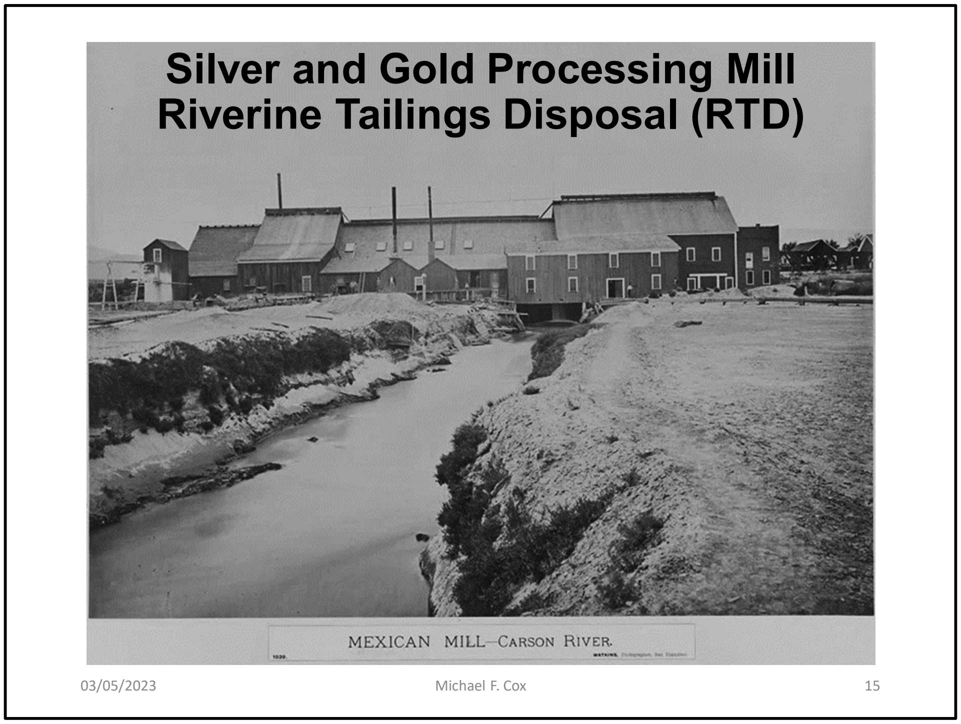


But alluvial gold mining involved a lot more than hydraulic mining. Entire rivers were moved so the beds could be worked. As well, tunnels were excavated at the sediment and bedrock interface along ancient river bottoms, sometimes at a depth of over 100 meters (300 feet). Mercury was added to the long alluvial drift tunnels to pick up fine-grained gold. Alluvial mining was effective for coarse gold, but very ineffective for fine grain gold particles. Professionals of the day often state that things were going well if half of the gold fines were recovered.

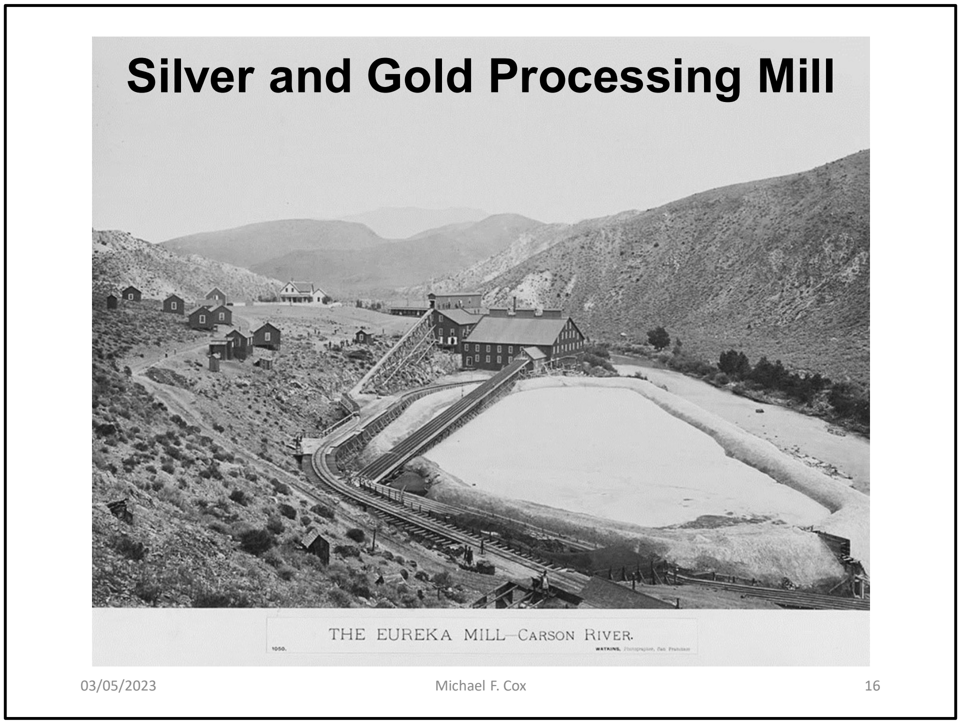
Carleton Watkins, circa 1871-1876, from the Hearst Mining Collection, U.C. Berkeley.



The miners are digging down to bedrock to get gold trapped in the irregular surfaces and crevices. Note the long wooden flume to the right. It contains the river. Carleton Watkins, circa 1871-1876, from the Hearst Mining Collection, U.C. Berkeley.



As we know, California is not the only state with gold and silver amalgamation troubles. Here is the Mexican Mill on the Carson River dumping mill tailings directly into the river. This was not an uncommon practice. RTD is an issue at many California Ag, AU, and Hg mines. Mills also suffered from inefficient fine-grain gold recoveries. Photo by Carleton Watkins, circa 1871-1876, from the Hearst Mining Collection, U.C. Berkeley.



Some mines used tailings ponds in order to conserve water for reuse. Ponds are easier to remediate as compared to eroding tailings distributed all along watershed channels, that is if the pond has not been breached.
Carleton Watkins, circa 1871-1876, from the Hearst Mining Collection, U.C. Berkeley.

Some Hg mining photos

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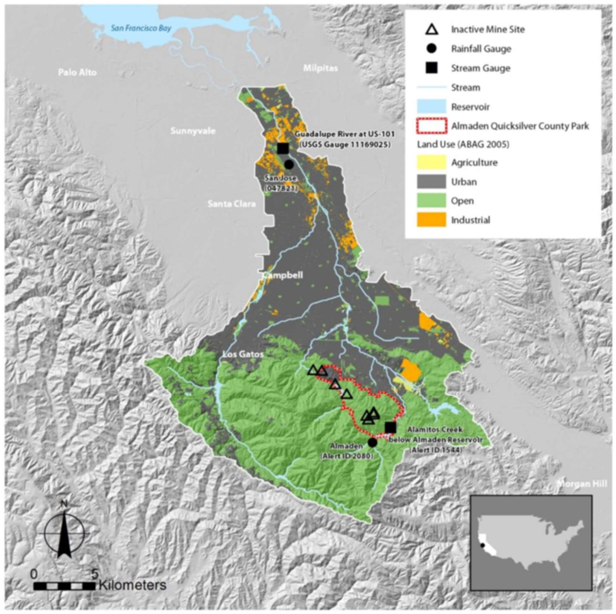

Map of the Guadalupe River watershed, main drainages, the Highway 101 (GR-101) sampling location and land-use/land cover. The Almaden Quicksilver County Park (outlined in red) is the location of a number of inactive mercury mine sites that operated from 1850-1975. Not shown are several inactive mines (Santa Teresa and Bernal) that were situated 3-4 miles northwest of the Calero Reservoir.

Source: McKee et al., 2018, Guadalupe River Mercury Concentrations and Loads During the Large Rare January 2017 Storm, Figure 1, San Francisco Estuary Institute, Contribution no, 837, February, 41 pp.

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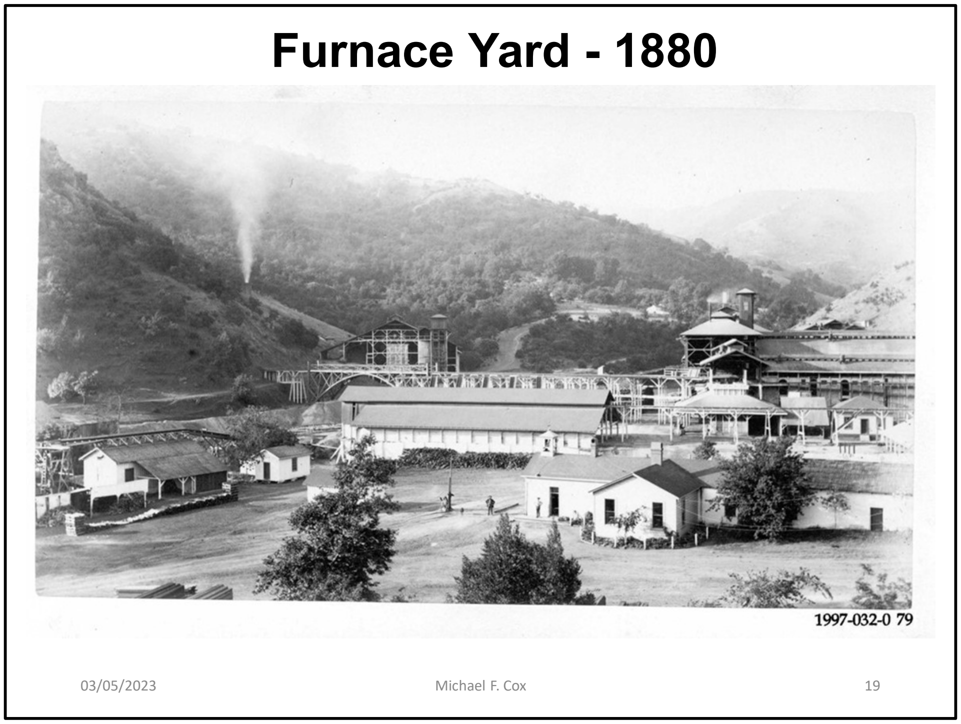
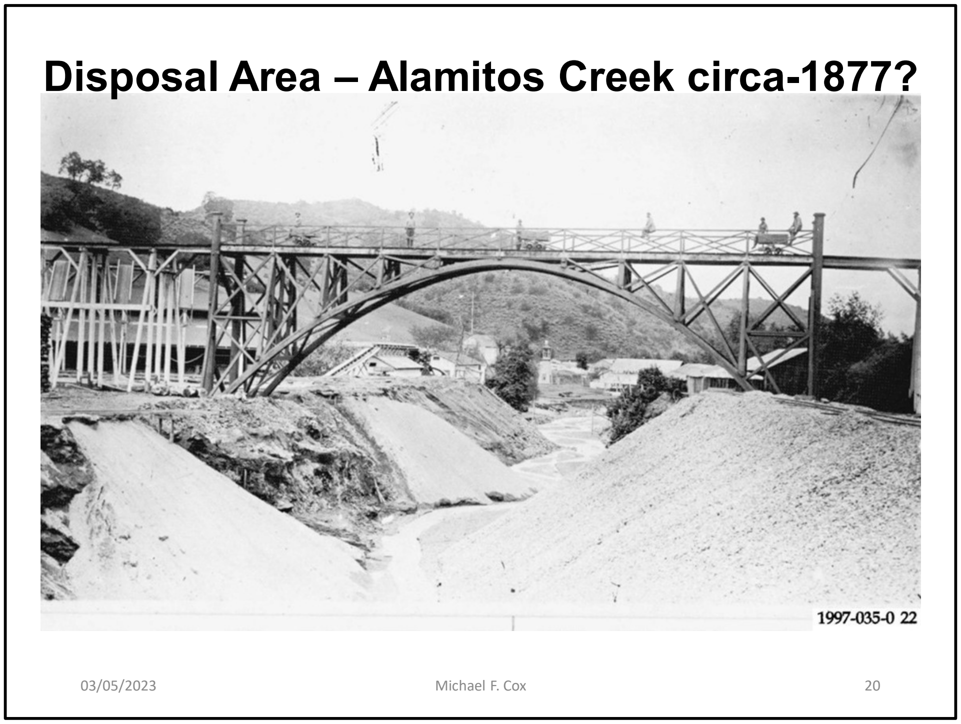
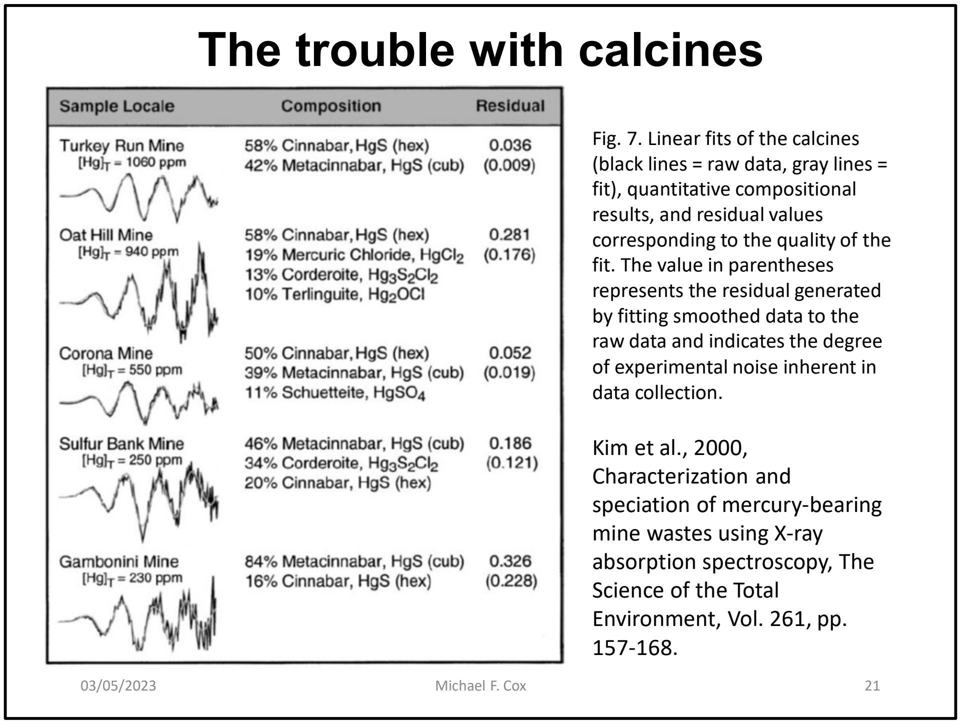
The New Almaden mine is the largest in the south-bay mining district. The Guadalupe mine is second largest. There are dozens of smaller mines and prospects. This map illustrates the principle land uses within the Guadalupe watershed and the stream monitoring locations associated with some of the studies of stormwater transport of mercury.



Mercury cannot properly sublimate and condense when water vapor is present in the chamber holding the ore to be roasted. Additionally, substantial steam in the condensers can carry out fine beads of mercury, increasing mist loss. For this reason, when furnaces were newly charged, either because they were intermittent type or were being restarted after repairs, the fire was brought up slowly so that the water vapor could be evaporated prior to then firing the ore to a cherry red color. Another possibility is the mine was using a counter-current water spray after the ore roasting chambers, as water mist does aid the condensation of hot mercury vapor, but other photos of the furnaces in operation do not show such a dramatic plume of mist. Another issue not fully investigated is the effect of wood smoke as well as whether the copious wood ash dumped out with the calcines may have some effect on trace mercury in the waste.

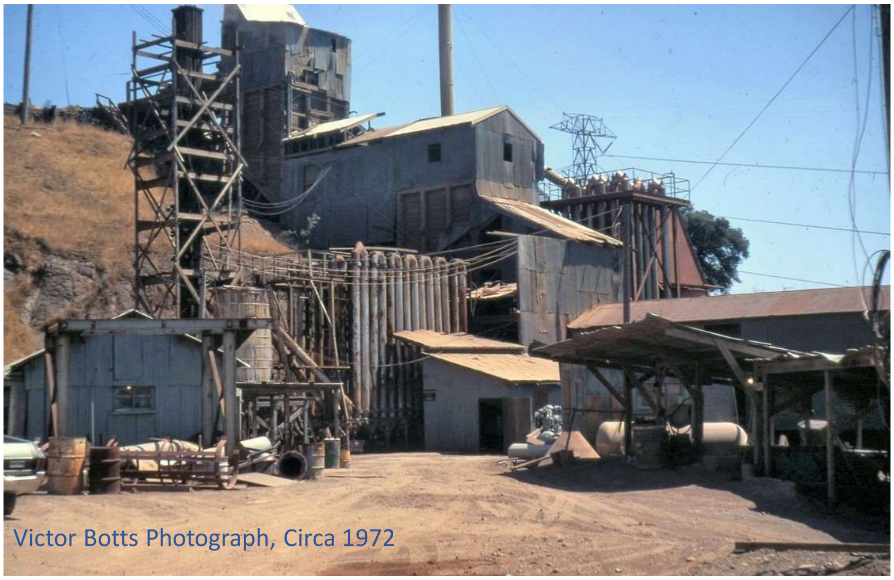


At New Almaden, the yard did not have much flat space. Most of the flat space was occupied by operational necessities. This dictated that burnt ore be piled in Alamitos Creek, to await flushing with the winter rains. This photo was taken after a long drought broke with a flood. The creek had been entirely filled in with roasted ore. The flood washed it all downstream and into the yards and fields along the creek. Over two-thirds of burnt ore from the Hacienda was washed downstream. Much of the material settled out where Alamitos Creek met the broad and flat Santa Clara Valley. This pile of alluvial gravel sat until after WW-II, when the Bay Area housing boom called for extensive sand and gravel. Quarry operators dug up and sold the calcines and the stream gravels from under the calcines. The material was wet screened to remove the fines (mud) and the material larger than 2 mm was sold. Today the mud and quarry ponds are all that remain to tell the tale.



Roasted ore contains red-ox residuals of mercury that can be more soluble and bioavailable than elemental mercury and cinnabar. The make up of waste products depends heavily on the timing of the technology used. Early mines and operations were more primitive and had higher losses. They also were mining richer ore, so in the case of mercury, the losses were substantial. On the other hand, modern mines are moving lower grades of ore in quantities that vastly eclipse 19th Century mining.

Mechanical Furnace Plant



Victor Botts Photograph, Circa 1972

With respect to mercury ore furnacing, there are a lot of issues, even with modern plants, like this, the last plant to operate at New Almaden. That said, in general, calcines from later mechanical furnaces, if operated well, have about one-tenth of the trace mercury content as calcines from a well-operated 19th-Century brick furnace.

It is important to identify dust deposits from refractory dust separation processes at mines. This is an example of dust collector wash-out at the Mine Hill rotary furnace plant, operated at the time by the New Idria Mining and Chemical Company. Chief geologist Victor Botts took this photo of a slimes containment pit excavated into the top of the calcines dump adjacent to the furnace. This area and the entire calcines pile has been graded, benched, and encapsulated in place. The clean clay soil cap is over five feet thick in the area of the pond. Notice the carry over of fuel oil and soot. Dust collector soot typically will have a much higher mercury content than roasted ore. A mechanical furnace plant that is designed and operated with care is quite capable of reducing residual mercury in the calcines to less than 20 mg/Kg. The dust collection products should never be discharged without additional treatment, as they can contain hundreds to thousands of mg/Kg of mercury.

1929 – Furnace Yard Reprocessing

Sometimes cleanup creates an inadvertent mess. After the New Almaden furnace yard shut down in 1917, miners began looking for mercury under the old furnaces. They also discovered a lot of old calcines that were made up of incompletely roasted ore. Later they also found a substantial deposit of placer cinnabar gravels. Findings at New Almaden encouraged similar efforts at other major mercury mining sites. At the Hacienda, miners dug down 5 to 10 meters (15 to 30 feet) to bedrock and found mercury saturated colluvium and alluvium layers along the way and pools of liquid mercury on bedrock. They washed and hand sorted the material to recover mercury and ore. In the process, they created a mercury blowout that should be easily seen in river and estuary sediments if cored.

1929 – Furnace Yard Reprocessing

Here miners are wet screening furnace yard material through riffle bars spaced about 1 inch (2.5 cm) apart. Using rakes, they pull out potential pieces of partially burned ore. The material passing through the screens is then sent through a sluice to try to capture any mercury and smaller pieces of partially roasted ore.

1929 – Furnace Yard Reprocessing

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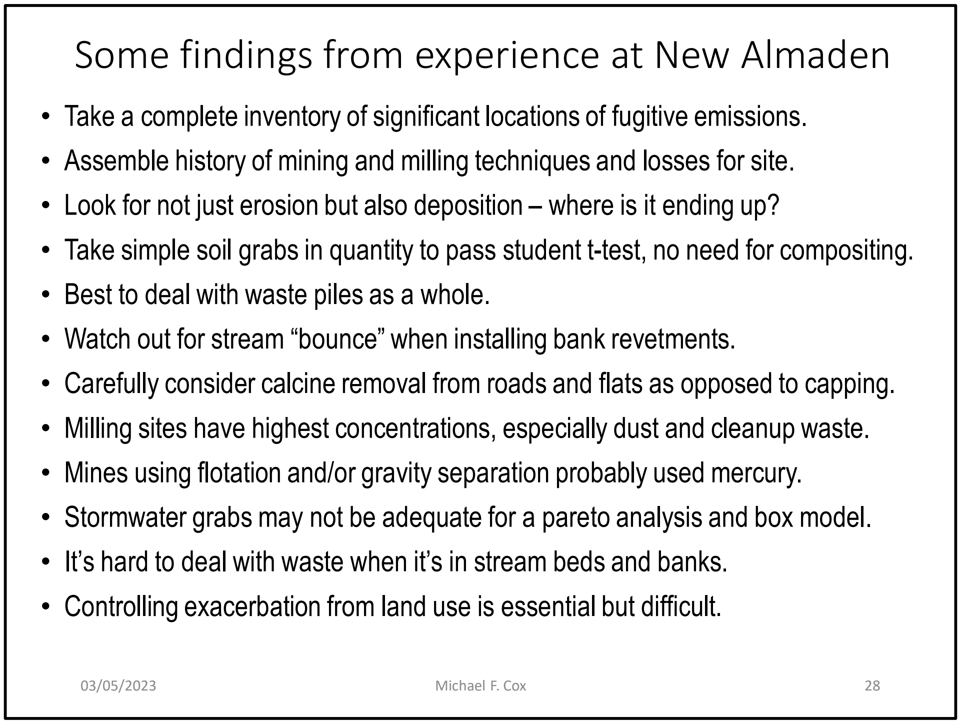
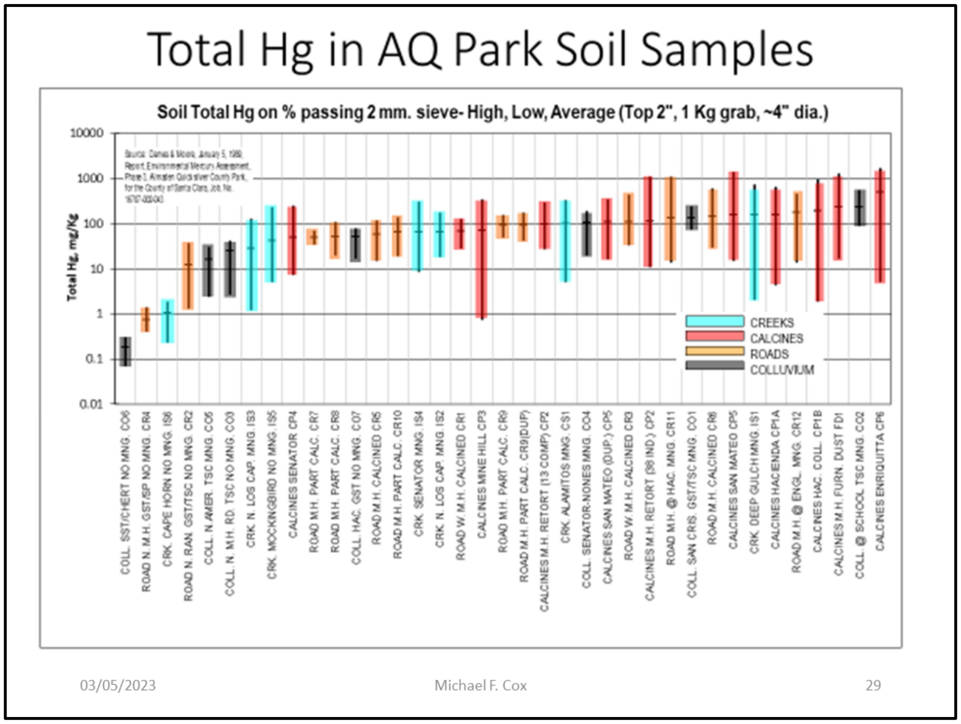
The independent operators working the yard were said to be rather sloppy according to one of the mine's old timers who was on hand. Louis Artnous, a miner born in New Almaden in March 1865, wryly commented that "more mercury went down the creek than was caught in the riffles." As well, the operation discharged pieces of partially burnt cinnabar ore too small to be captured. Of course, the discoveries at New Almaden lead prospectors to dig up the ground at other old mercury plants, including New Idria, the Guadalupe mine, and other larger mercury mines up and down the state. The digging had stopped by 1936, but it probably created somewhat of a great mercury blowout. An interesting footnote at New Almaden was the demolition of and digging under the old mine office at the Hacienda. The operators thought the office was built on old partially roasted ore waste. They found neither mercury or partially roasted ore, but they did find a spectacular deposit of placer cinnabar gravel. Again, other mines in the State starting digging to see if they might also have placer cinnabar.

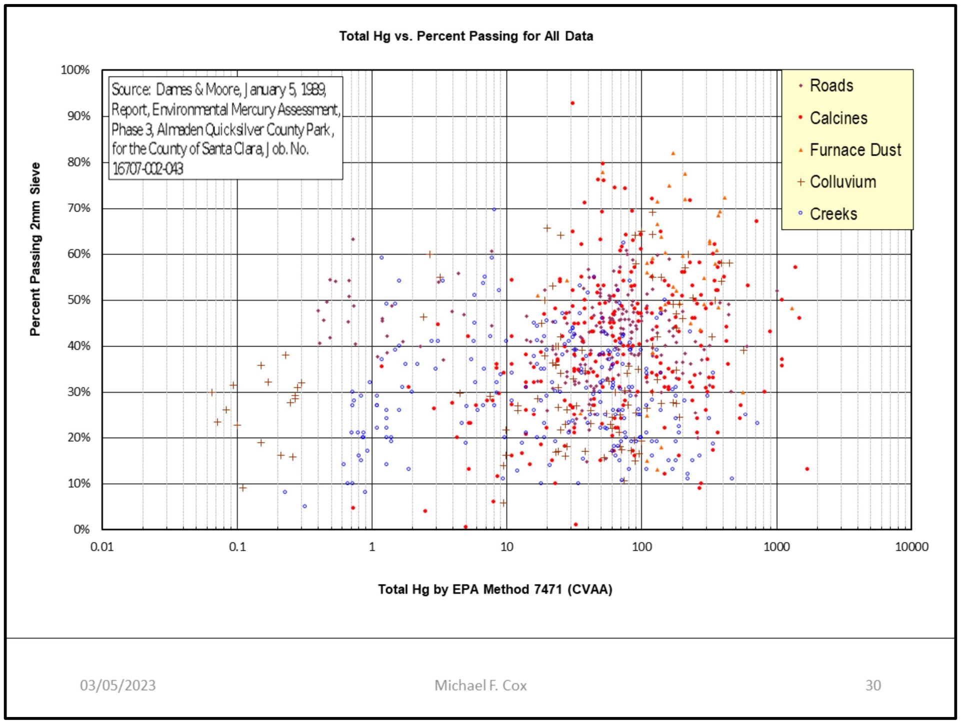
The result of repeated campaigns of colluvium excavation and washing at the Hacienda was a lot of mixed waste and a very significant mercury “blowout” to Alamitos Creek.



These are some common sense findings from the AQ work. In no particular order of importance, the remaining slides will illustrate some examples.

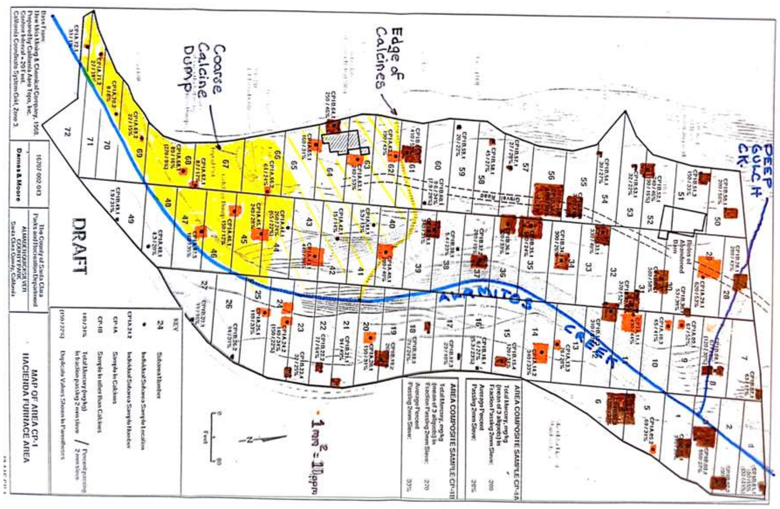


The Phase-III Environmental Characterization of the park determined these total mercury concentrations for soils and stream sediments. Because the majority of the mercury is present as cinnabar, the concentrations were not found to have the potential for excess health risk to humans except where concentrations exceeded about 400 mg/kg. These higher concentrations were associated with mercury ore roasting waste. The County elected to remove or encapsulate the major processing waste piles in the park. This turned out to be a benefit to wildlife as well, because wildlife can be sensitive to even lower trace concentrations, especially when the chemical form of the mercury is something other than cinnabar (HgS).



This plot of percent passing a 2mm sieve versus total mercury shown no apparent correlation. It also illuminates that mercury concentrations are all over the map. The variance is so great it took nearly 1,000 samples to adequately characterize just under 40 representative sampling areas in the park. Adequate means pass a student T-test at 90% confidence interval in order to determine range, mean, and median for a risk assessment. The risk assessment was largely a waste of time and money. Waste products have elevated mercury. Verify significance in terms of watershed beneficial use protection and then remove or cap and contain those that are judged to be significant.

Hacienda Furnace Yard



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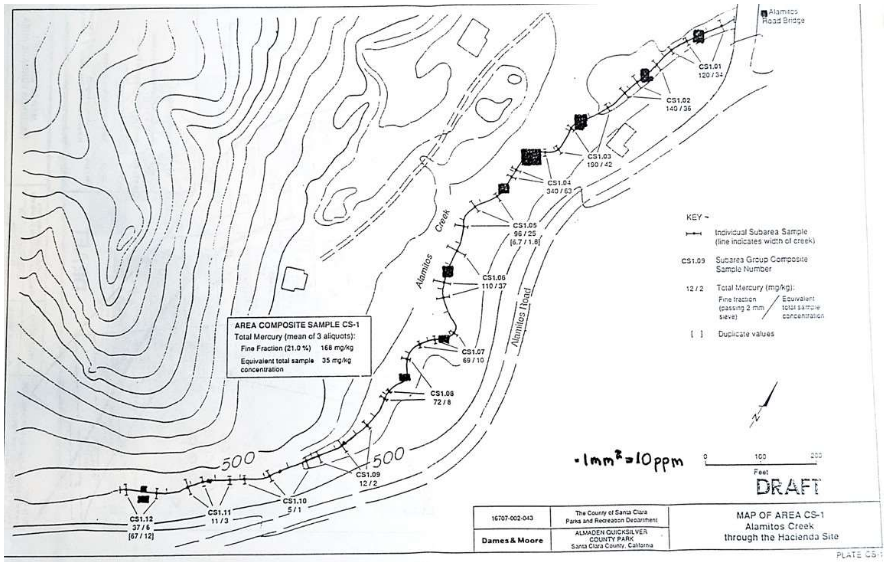
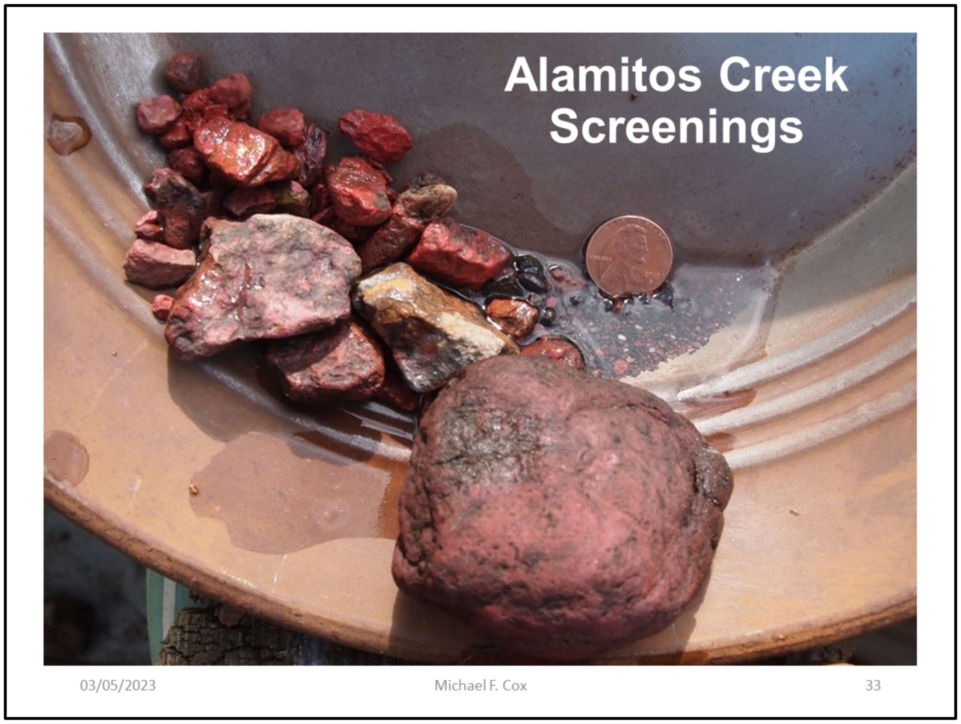
Sampling at the Hacienda furnace yard found a definite difference in the median mercury between calcines and calcines mixed with excavated soil spoils from the recovery of leaked mercury from under the old furnace beds. The soils with the highest mean concentrations were in the areas of old processing plants, both furnaces and soil washing operations.

Alamitos Creek at the Furnace Yard

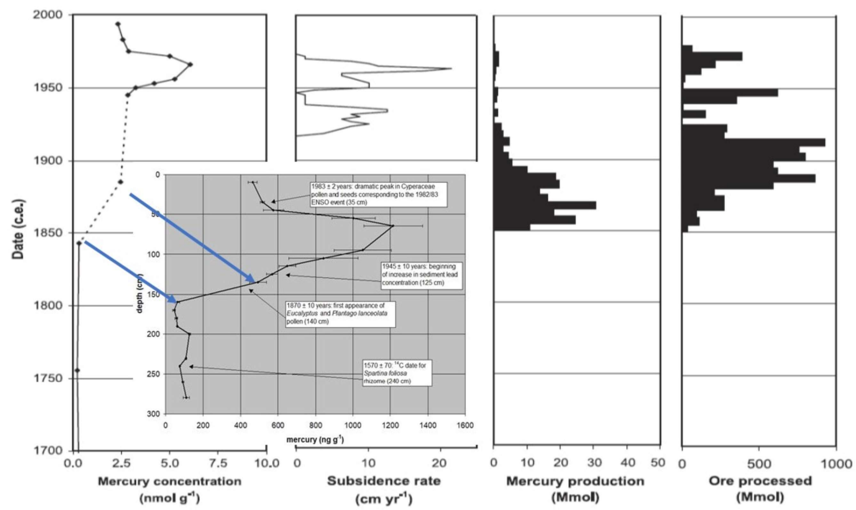


The results of bottom sediment grab samples along Alamitos Creek through the furnace yard. The small area of elevated concentration at the bottom left is below a Creekside pile of 19th-Century calcines. The creek is incised into the calcines, so the samples in this area are somewhat elevated in mercury. Normally, a significant influx of cleaner sediment from upstream would dilute and somewhat mask inputs from mining wastes. That may not be happening here because Almaden Reservoir just upstream captures all but the particles that carry over through the dam outlet and spillway. In any case, the fact that the distribution of concentrations somewhat matches the trend in the adjacent furnace yard wastes suggests the mercury is not especially mobile. The Parks Department elected to cap the entire hacienda furnace yard and to install gabion and concrete revetment along the edge of cap. One lesson learned is to evaluate the effect of bank stabilization on one side of a major drainage only. The work caused the creek to leave its bed and migrate to the south. Another issue, even larger, is what to do with the vast amount of mercury stored in the creek bottom sediments.



The legacy of the dead mercury industry at New Almaden is easily found in Alamitos Creek downstream of the mine. This is old material, released long ago but still rolling along. It is heavy. It does not dissolve. It does not move very far or disappear. Nonetheless, the trace amounts of mercury that do escape through water, air, and biota, are great enough to potential harm wildlife. This is why it is best to remove these legacy materials. The impact is not shockingly noticeable, but the impact will continue until this material is removed from the system.

It is not just cinnabar. It is many species of mercury, as demonstrated by analysis work by Chris Kim, Adam Jew, and others at the Stanford Linear Accelerator Center. There is also a great deal of finely-divided elemental mercury, as can be seen here- the bright silver spots. Notice the larger ball at the right edge of the panned material.



Total mercury with depth (age) in SF Bay mud core

Temporal total mercury profile in a piston core of tidal flat mud. From Conaway et al., 2004, Mercury deposition in a tidal marsh of south San Francisco Bay downstream of the historic New Almaden mining district, California, "Marine Chemistry," Vol. 90, pp. 175-184

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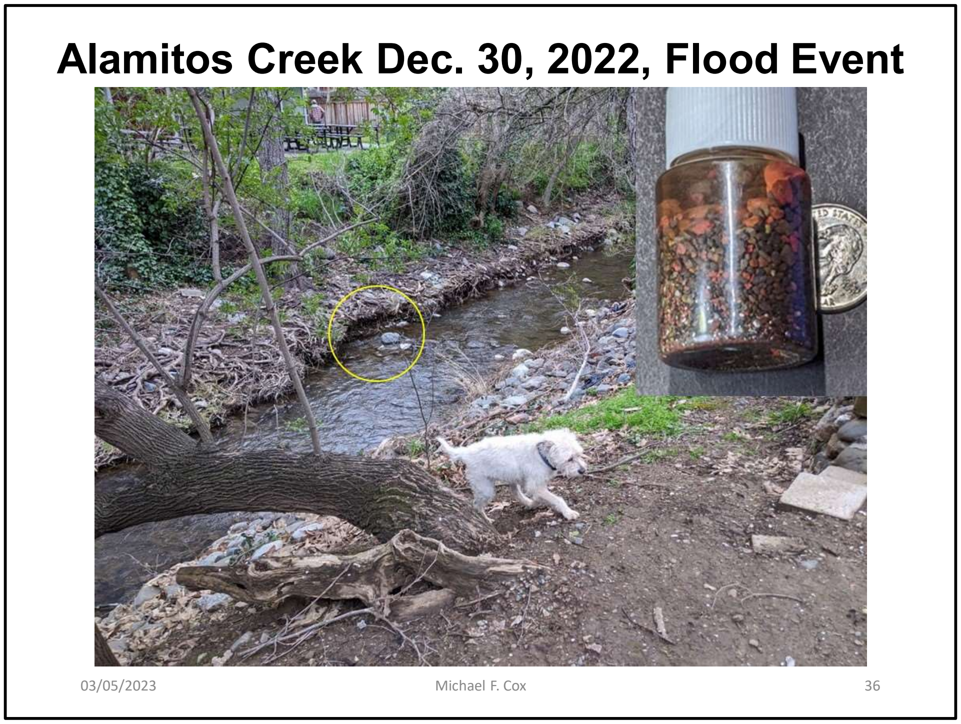
Total mercury analyses of Bay mud cores, with an inset showing additional data refinement. Additional data is needed to refine the signal timing between the arrows. The authors first contended that the lag in the base chart reflected transport delay. Then a second paper provided the inset chart and alleged a fairly continuous signal that correlates with production. There is a background mercury concentration of around one hundred billionths of a gram of mercury for every gram of sediment. Dilution and spare sampling smooth the curve. What might be expected with more tightly-spaced samples is a gradual rise from mining with spikes from several mining waste blowouts.

Diluting sediment inputs along a watershed greatly decrease the concentration in sediment. The important issue is mass movement. Small amounts of mercury in sediments at the water interface can readily methylate. Where is the source of a majority of the mass? The contention today is the upland mines are responsible for the majority of fish MeHg. This may not be correct where large stores of legacy waste are in the downstream bed and banks.



The creek cut down about 12-inches in one storm. A layer comprised of serpentinite rocks and clayey weathered serpentine soil with square nails and other iron objects is exposed at the circled area. Furnace yard soil and waste mining operations discharged significant mercury and so called half-burned rock to the creek. The material contains square nails because furnace yard buildings were demolished at the time. As well, burnt ore piles were processed along with the mercury-saturated soils from under the wrecked furnaces. Upper right are the pannings from a standard gold pan filled to about half full, perhaps 2 to 2.5 Kg of sediment and rocks.

https://www.911metallurgist.com/

- https://www.911metallurgist.com/blog/mercury-amalgamation
- https://www.911metallurgist.com/blog/gold-cyanidation-process
- https://www.911metallurgist.com/blog/flotation
- https://www.911metallurgist.com/blog/mercury-extraction-process
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Self-explanatory.

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Self-explanatory