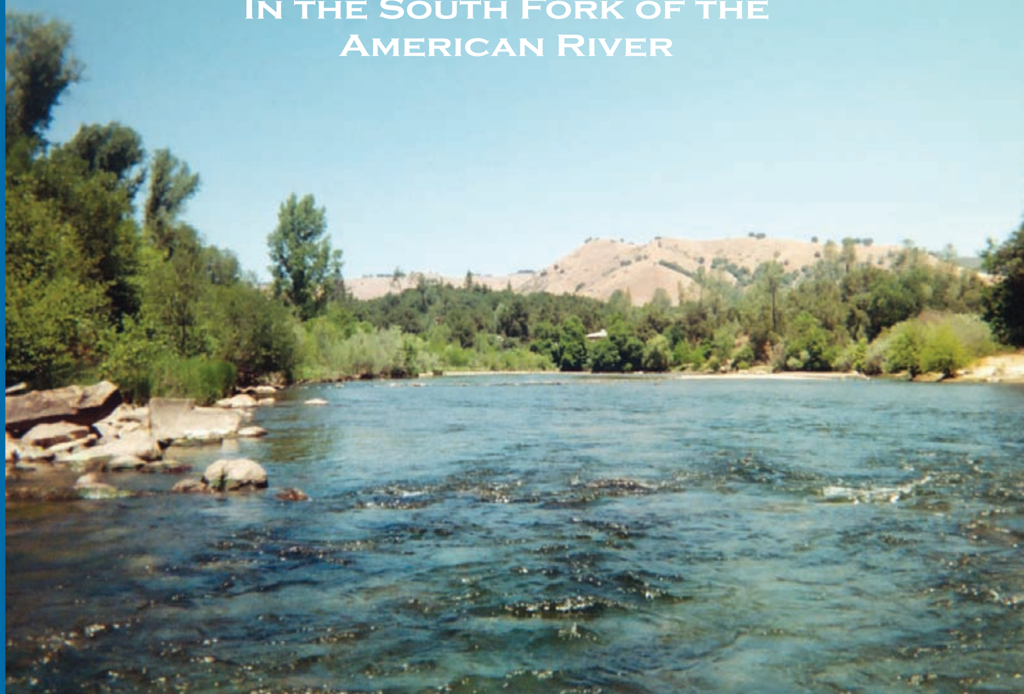
STAFF REPORT

# MERCURY

## LOSSES AND RECOVERY

### During a Suction Dredge Test In the South Fork of the American River



CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

MAY 2005

# TABLE OF CONTENTS

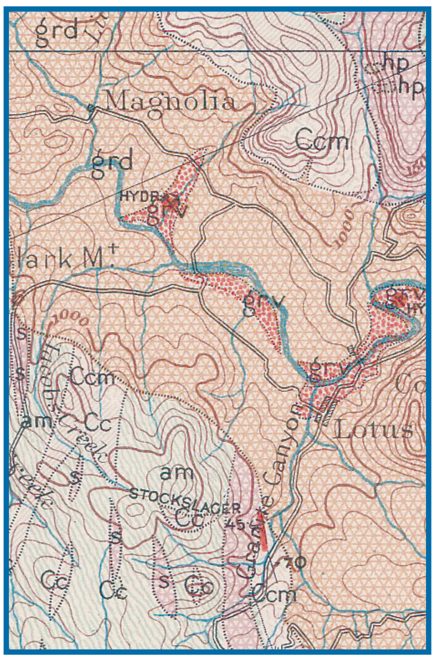



*FIGURE 1: Historical Map of Coloma, California by Waldemar Lindren (1894), United States Geological Survey Folio#3 - Placerville, California, Economic Geology - northwest (Courtesy of: Craig Couch)*

## Table of Contents

# ABOUT A KILOGRAM OF MERCURY

## Introduction

Mercury has been used widely since the dawn of recorded history for gold mining. During California's gold rush, gold miners used about 6 million kilograms or 6.6 thousand tons of mercury (Churchill, 2000) to recover over 3.6 thousand tons of gold (Bulletin 193). **The weight of mercury used is roughly equal to the total weight of a 9-mile long line of 2,750, full sized pickup trucks (note: the pick up truck line equaling gold recovered would only be 5 miles long). The miners lost about half of the mercury to the environment.**

Using historical records,Churchill (2000) estimated that total mercury losses ranged between 2.3 million and 2.6 million kilograms for placer and lode mining in the Sierra Nevada Geomorphic Province. Consequently, elemental mercury from the gold rush is still found, sometimes in amounts that constitute a local hotspot (i.e., a location where visible elemental mercury is found) in Sierra Nevada watersheds where gold mining occurred. In March 2003, a recreational gold miner reported a mercury hotspot in the South Fork of the American River near Coloma, to State Water Resources Control Board staff. It was the first time a recreational gold miner had revealed a hotspot locations to agency staff. Coloma is California's historic "Gold Discovery" site as James W. Marshall's discovery there in January 1848 initiated the 1849 gold rush. Steve Franklin, the recreational gold miner who reported the hotspot, claimed to have recovered about a kilogram of mercury while gold mining from the hotspot during January and February 2003.

**Finding a hotspot near Coloma raised questions about its potential threat to human health, effects on local fish, and threat to water quality. Moreover, its discovery presented an opportunity to test the notion that recreational gold miners effectively clean up mercury hotspots while suction dredging for gold.** There is no record of any attempts by state or federal agencies to clean up a mercury hotspot in a California river. But State and federal agencies have discussed whether encouraging or even providing support for recreational gold miners to clean up hotspots is viable and wise. The pros are that there is a potentially large, volunteer workforce. The cons are that oversight would be difficult and, up to now, no data supported the notion that suction dredges could recover mercury efficiently.

*FIGURE 2: Steve Franklin and SWRCB staff sampled the hotspot on July 8, 2003, and recovered about 125 grams of mercury in about three hours from the river using simple suction recovery tools. Mercury was visible as droplets ranging from one to ten millimeters on bedrock in the river channel. (Photo by: Rick Humphreys, DWQ)*

Recreational gold dredging on public and private lands is a moderately popular activity in California. The Department of Fish and Game (DFG) issues several thousand permits annually to recreational gold dredgers. Along with gold, recreational dredgers recover iron (nails bolts, etc.), lead

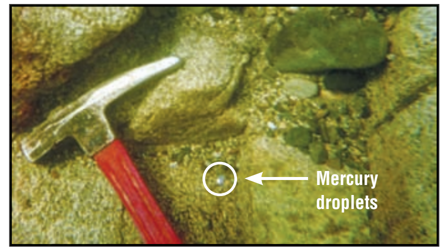



*FIGURE 3: Under water photograph showing river sediment, bedrock, and mercury droplets. (Photo by: Rick Humphreys, DWQ)*

(fishing weights, buckshot, and spent bullets) and mercury (elemental mercury, mercury/gold amalgam, and mercury stained gold). Over the past several years, United States Forest Service (USFS), Bureau of Land Management (BLM) and State agency staff have discussed setting up a mercury recovery program for recreational dredgers. Incentives (e.g., cash for mercury, free dredging permits, new areas opened for dredging) were proposed in exchange for mercury turned in by recreational dredgers. Offering such incentives was and remains controversial for a variety of reasons and a mercury recovery program was not started. **Moreover, an important drawback was that the efficiency of a standard suction dredge at recovering mercury was unknown.** Consequently, no one knew if mercury would be lost along with waste sediment from a suction dredge. Clearly, a mercury recovery program that dispersed elemental mercury back into a stream in substantial amounts would be unacceptable. The hotspot presented an opportunity to determine the mercury recovery efficiency of a suction dredge.

Studying the hotspot may also reveal bedrock characteristics and sediment transport conditions that cause hotspots, and the effects that concentrated mercury has on local fish. This report documents the results of a suction dredge test that was completed in September 2003 by State Water Board, USFS, and DFG staff.

## Hotspot Setting

The hotspot is located mid-channel in the South Fork of the American River, a few miles downstream from the Marshall Gold Discovery State Park at Coloma. Surface placers and in-river gravel accounted for most gold produced from the area during the gold rush and in-river dredging recovered more gold during the 1930s and 1940s (Bulletin 193). These historic mining operations are the likely mercury source.

The hotspot is located on the downstream side of a low bedrock hump that extends across the river channel perpendicular to its flow. Because the hotspot remains underwater under all observed flow conditions, State Water Board skin divers recorded how the mercury occurred on bedrock and in river sediment visually. The bedrock hump is shaped like a low-pitched roof. River sediment forms wedge-shaped deposits on the up and downstream sides of the hump. Easily visible, small (e.g., 1mm)

FIGURE 4: *"The hotspot is located mid-channel in the South Fork of the American River, a few miles downstream from the Marshall Gold Discovery State Park at Coloma." (Photo by: Rick Humphreys, DWQ)*

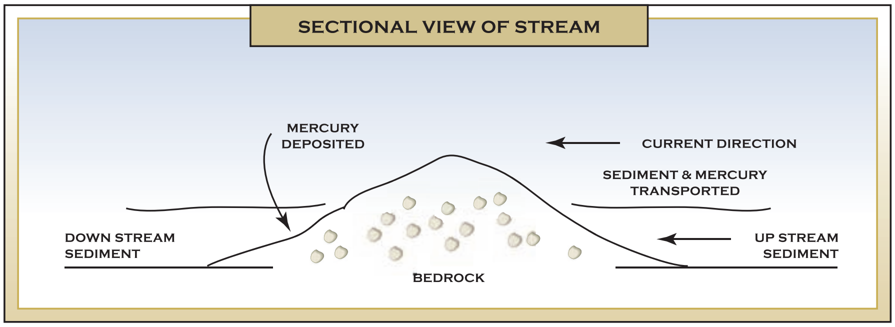



*FIGURE 5: Cross-sectional view of stream graphic showing where mercury deposits on bedrock.*

mercury droplets permeate the sediment at the thin upstream edge of the downstream wedge (see fig.2). Hand "fanning" stirs up fine-grained sediment, which is carried away by the river current. Elemental mercury, however, remains on bedrock, and continued fanning causes small mercury droplets to fall into bedrock depressions and fractures. When mercury droplets touch, they fuse into much **large** droplets (up to 25 millimeters). **Hand fanning the upstream sediment wedge also exposes elemental mercury in bedrock depressions and fractures** but in much smaller amounts than on the downstream side.

River flow at the hotspot is uncontrolled during winter and spring runoff but controlled for hydroelectric and recreational rafting purposes for the rest of the year. During controlled flow periods, flows typically range from 200 to 1,200 cubic feet per second (cfs) daily. High runoff coincides with winter storms, and these flows have ranged to 80,000 cfs as recently as 1997. Post dredge test inspections show that during low flow periods (200 cfs), sediment does not travel over the bedrock hump. But post dredge test inspections also showed that mercury had re-deposited on bedrock that had been dredged clean. Higher controlled flows may be moving sediment and mercury over the hump but attempts to observe sediment movement directly at higher flows proved too dangerous.

Mercury may concentrate at the hotspot because after it is carried over the bedrock hump during high flows, it encounters a low flow velocity zone on the downstream side of the bedrock hump. The river current on the downstream side lacks the power to move mercury anymore so it drops out on bedrock on the downstream side. If this scenario is correct, **periodic mercury recovery from this location might be practical.** A mercury removal system's design would depend on the site's the physical characteristics which are unknown. A detailed evaluation of mercury and sediment transport and flow velocity at the hotspot surface would be necessary if periodic mercury removal from this site is considered.

## Suction Dredge Test

The USFS volunteered their mineral evaluation team, based in Redding (Rich Teixeiria, Jim DeMaagd, and Tera Curren), to perform the test. According to Rich Teixeiria, the team's dredge is a Keene Engineering floating 4 inch dredge powered by a Honda 5.5 horsepower engine. It is similar to those used by recreational dredgers to recover gold (see fig.3). A single sluice box used carpet and riffles but no "miners" moss (i.e., woven nylon fabric placed between the riffles and carpet for enhanced gold recovery).

The team performed the dredge efficiency test on Sept.15, 2003. The 63.5kg sediment sample used in the test had been collected by State Water Board staff from the hotspot and characterized for grain size and mercury content. State Water Board staff analyzed the sample's grain size at the Cal Trans Laboratory in Sacramento. The sample classifies as a "clean gravel with sand" under Unified Soil Classification System. Visual inspection of size fractions showed that almost all the liquid mercury rested in the fraction that passed a 30-mesh sieve (0.6mm). The mercury content of this fraction served as a surrogate for the mercury content of the entire sample. Chris Foe of the Central Valley Regional Water Quality Control Board had two 30-mesh passing fractions of the sample analyzed for mercury by ALS Chemex Laboratory in Reno, NV. Two suspended sediment samples of the bulk sample (i.e., samples of sediment that settled out of water used for sieving after an hour) were sent to ALS Chemex Laboratory for mercury analysis. A second set of samples from archived material was sent to Frontier Geosciences in Seattle, WA after reliability problems were discovered with analyses performed on standards by ALS Chemex. During the test, the USFS team captured sediment lost off the sluice in a catch basin for later analysis. Small mercury droplets and fine, barely discernable droplets (i.e., floured mercury) were characteristic of these samples. After the test, 30 mesh and finer dredge concentrates and "waste" sediment were sent to ALS Chemex Laboratory. ALS Chemex Laboratory used an analytical method that could not quantify the high mercury concentration in the mercury-rich samples. So a second set of samples was sent to Frontier Geosciences for analyses.

*FIGURE 6. Dredging the hotspot. (Photo by: Rick Humphreys, DWQ)*

The team (USFS and State Water Board staff) dredged the hotspot the next day on Sept. 16, 2003, and DFG staff recorded the test on video.

THE MERCURY CONTENT OF THIS FRACTION SERVED AS A SURROGATE FOR THE MERCURY CONTENT OF THE ENTIRE SAMPLE.

## Results - Laboratory Data

ALS Chemex reported that the mercury content of the samples received exceeded the upper detection limit of the analysis used and did not reanalyze the samples. As a result, the Frontier Geosciences analyses were used for this report. The bulk sample mercury concentration was 1,170ppm; the mercury concentration of the sediment captured by the dredge was 1,550ppm, and the mercury concentration of the sediment lost by the dredge was 240ppm. The suspended sediment sample mercury concentration was 298ppm. Note that these mercury concentrations are quite high. **Mercury concentrations of the waste and suspended sediment are over an order of magnitude higher than the minimum concentration necessary for classification as a California hazardous waste (20mg/kg).** The suspended sediment's high mercury content is problematic because after re-suspension by dredging, it can be carried long distances by stream current.

## Results - Suction Dredge Efficiency

It is necessary to know how elemental mercury, which is a dense liquid, behaves physically when evaluating the laboratory results. During dredging, large mercury droplets were broken up into small droplets by turbulence. The phenomenon is called "flouring" and it is described as a major cause of mercury loss by historic hydraulic gold mining operations. Confounding matters is mercury's ability to form large droplets from small droplets. This causes mercury enrichment of sediment captured on the sluice because small mercury droplets that are caught in the low velocity area behind the sluice riffles fuse into large droplets just as they do on the downstream side of the bedrock hump. Sluice sediment samples had large and small mercury droplets. Such samples are subject to analytical bias from either a single large mercury droplet, or the absence of any mercury droplets.

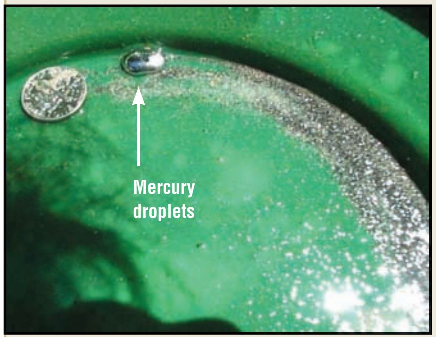



*FIGURE 7: Mercury panned from a small creek below the Sailor Flat Hydraulic Mine, Nevada County. (Photo by: Rick Humphreys, DWQ)*

Bias probably is affecting the analytical results for the efficiency test. The mercury concentration for the captured sediment is 32 percent higher than that of the parent sample, and that may be because the captured sediment sample analyzed had one or two large mercury droplets. However, in absolute terms, the mercury concentration of both samples agrees fairly well. Mercury concentrations in sediment lost by the dredge was averaged (30-mesh and finer and suspended sediment). The mercury concentration of the lost sediment fractions is about 2 percent that of the test sediment's mercury concentration. Thus, the dredge removed about 98 percent of the mercury from the test sample based on concentration. Unfortunately, a mass balance of sediment captured and lost, as part of the test was not performed because we did not have an accurate total mass for the lost fraction.

The test showed that a typical suction dredge set up to recover gold recovered about 98 percent of the mercury in the high-mercury, test sediment sample. However, the loss was in sediment that had high mercury content and is easily transported away by the river.

## Results - In-River Test

The team dredged about four yards or about 5,900 kilograms (6.5 tons) of sediment from the hotspot. Team members used special care to find and dredge large liquid mercury droplets as well as mercury-laden sediment from the site. During clean up after the test, team members noted large mercury droplets captured on the sluice. From the 30-mesh passing fraction, SWRCB staff separated about 0.5kg liquid mercury (see fig. 4). The remaining 2.2kg of sediment retained a substantial amount of liquid mercury as small (e.g., 1mm) and fine droplets of floured mercury, which floated on water used to immerse the sediment. Separating residual mercury from the sediment by physical means proved impossible. The mercury content of a 1.1kg sample was determined directly heating the sample and recovering the mercury vapor (i.e., retorting). The retorted sample contained 20gm of mercury or 1.8 percent. The dredge concentrate contained 540gm of mercury (liquid mercury + retorted mercury/ 1.1kg x 2), which accounted for about 20 percent of the sample mass (540gm mercury/2.7kg sieved sample x 100). Note that the mercury concentration of captured sediment from the in river test is about ten times higher than that reported for the efficiency test. The difference likely reflects the success of the dredge team in finding and dredging up mercury droplets during the in river test.

*FIGURE 8: Jim DeMaagd and Rich Teixeiria setting up the dredge. (Photo by: Rick Humphreys, DWQ)*

# CONCLUSIONS

## Conclusions and Recommendations

1. A suction dredge set up to recover gold recovered liquid mercury from the mercury hotspot. The dredge recovered about 98 percent of the mercury in a test sediment sample enriched in mercury. Mercury concentrations in the fine and suspended sediment lost from the dredge were more than ten times higher than that needed to classify it as a hazardous waste.

2. Lost sediment with high mercury levels is, in effect, mercury recycled to the environment. Floured mercury in fine sediment and mercury attached to clay particles in suspended sediment may be carried by the river to environments where mercury methylation occurs and where fish have high mercury concentrations. The consequences of having floured mercury added to biologically active areas where mercury methylation already occurs are currently unknown because the methylation potential of floured elemental mercury is unknown. But tests are underway at the DFG laboratory at Moss Landing to determine the methylation potential of floured mercury in sediment samples from this hotspot.

3. It is unacceptable to encourage suction dredgers to "clean up" in stream mercury hotspots because dredges release too much mercury in easily transportable forms. There may be other reasons to discourage suction dredging of mercury hotspots once the bioavailablity of floured mercury becomes known. It would be advisable for land management agencies to contact dredgers through their clubs and discourage them from trying to dredge liquid mercury from in-river hotspots on public lands. Removing mercury with hand-operated suction tubes, or better yet, reporting hotspot locations to land management agencies is a better strategy.

4. It might be possible to design a shore-based recovery system for the Coloma hotspot and recover mercury annually. Such a system would need to minimize mercury loss. Recovery equipment would need to be held in storage during nonuse and operated by trained staff. Proper permits (e.g., in stream alteration, and, mercury disposal or recycling) would be needed. Such a project is more complex and costly in time, money, and commitment than previously considered projects. Developing such a system might result in technical advances that could be applied to dredges used by gold dredgers.

5. The sediment transport parameters that cause mercury to concentrate should be characterized. Such a characterization at Coloma might be useful for predicting where other hotspots are located in the South Fork of the American River and other watersheds, and it would provide the data for a recovery project described above.

6. The hotspot's effect on fish and invertebrates in this segment of South Fork of the American River should be determined.

*FIGURE 9. Liquid mercury (about 0.5kg) separated from sediment captured by the dredge. (Photo by: Rick Humphreys, DWQ)*

*FIGURE 10: Under water diver searches for Mercury. (Photo by: Rick Humphreys, DWQ)*

# ...REMOVING MERCURY WITH HAND-OPERATED SUCTION TUBES, OR BETTER YET, REPORTING HOTSPOT LOCATIONS TO LAND MANAGEMENT AGENCIES IS A BETTER STRATEGY.

## References

*Contributions of Mercury to California's Environment from Mercury and Gold Mining Activities - Insights from the Historical Record.* Unpublished report, 18 pages. Ron Churchill, California Geological Survey, Division of Mines and Geology, 2000.

*Gold Districts of California, Bulletin 193, Sesquicentennial Edition.* William B. Clark, 1963 with some revisions through 1969. California Geological Survey, Division of Mines and Geology, 1998.

*Laboratory Classification of Soils, Unified Soils Classification System*, Geotechnical Branch, Division of Research and Laboratory Services, Bureau of Reclamation Engineering and Research Center Denver Colorado, 1986.



## Acknowledgements

Special thanks to Steve Franklin for reporting the hotspot and to Bill Center for granting us access to the area and use of his camp at Lotus. Thanks to Janine Clayton (USFS) for making the USFS minerals evaluation crew available. Thanks also to Chris Foe of the Central Valley Regional Water Quality Control Board and Mark Stephenson (DFG) for arranging laboratory analyses, and Chris Foe and Dr. Charles N. Alpers for their reviews. Finally, thanks to dredge crewmembers Rich Teixeiria, Tera Curren, Jim DeMaagd, Dominic Gregorio, and Janna Herren for making the project a success.

STAFF REPORT PREPARED BY:
Rick Humphreys,
Division of Water Quality,
California Water Boards

EDITING
Liz Kanter,
Office of Public Affairs,
California Water Boards

LAYOUT AND DESIGN:
Maria Bozionelos,
Division of Water Rights,
California Water Boards

Printed on recycled paper.