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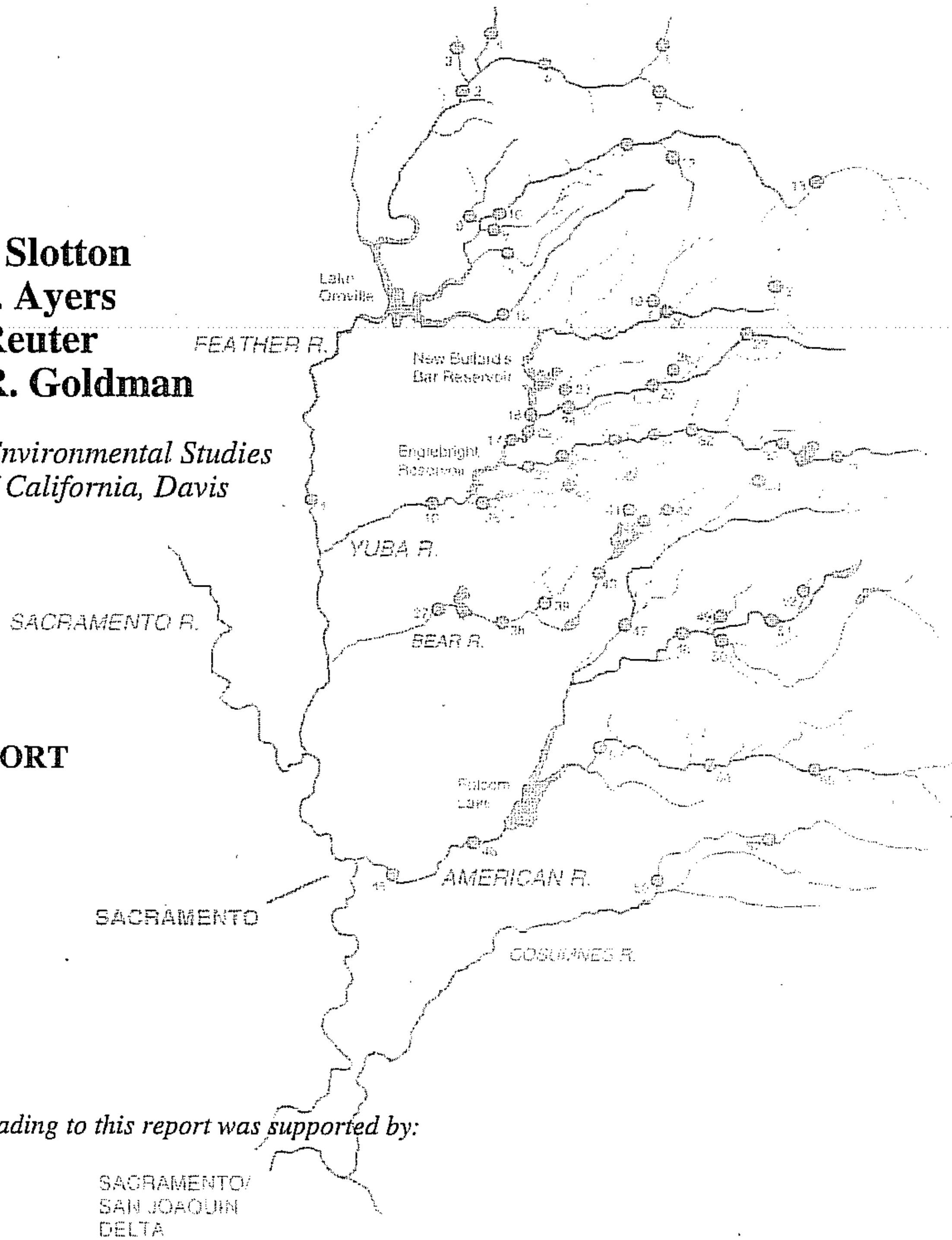
GOLD MINING IMPACTS ON FOOD CHAIN MERCURY IN NORTHWESTERN SIERRA NEVADA STREAMS

(1997 REVISION)



By

Darell G. Slotton
Shaun M. Ayers
John E. Reuter
Charles R. Goldman

Division of Environmental Studies
University of California, Davis

FINAL REPORT

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ABSTRACT / EXECUTIVE SUMMARY

In this research, we investigated mercury levels in aquatic invertebrates and trout within the historic gold mining region of the northwestern Sierra Nevada, in order to determine the localized biological impacts of mining-derived mercury. These organisms were used as indicators of specifically the bioavailable fraction of mercury, that portion which can enter, transfer through, and be concentrated by the food web. The biota samples were used to determine relative "hot spots" of mercury contamination and to rank the various streams and rivers as to relative bioavailable mercury levels. Trout mercury was investigated also from a health perspective, for comparison with existing mercury guidelines.

Fifty-seven sites were sampled throughout the region during the three years of this study. A clear signature of mining-derived mercury was found, with notably elevated levels in the aquatic food webs of the South and Middle forks of the Yuba River, the mid-section of the Middle Fork of the Feather River, Deer Creek, the North Fork of the Cosumnes River, and tributaries throughout the Bear River drainage. Mercury was low throughout most of the American and Feather River watersheds and in many tributaries away from the most intensively mined stretches of rivers. Elevated mercury regions did not demonstrate a point source signature. Where biotic accumulations of mercury were elevated, this elevation was generally distributed across many miles of stream or river. The elevated bioavailable mercury regions could thus be localized to specific tributaries or series of river miles, but not to highly localized "hot spot" point sources. This is consistent with the historic widespread use of mercury throughout the gold mining region and its subsequent redistribution downstream.

Mercury concentrations in trout, while variable, were found to be uniformly below existing health standards, indicating the lack of a direct health hazard within the region itself. Foothill reservoirs were found to operate as interceptors of bioavailable mercury, in addition to trapping much of the sediment-associated inorganic load. Significantly lower bioaccumulated levels were found throughout the food web below several reservoirs, as compared to upstream. Concentrations of mercury in aquatic indicator organisms increased in a predictable pattern with increasing trophic feeding level. Aquatic invertebrate samples can be used to determine relative mercury presence and bioavailability, to predict mercury levels in co-occurring trout, and to integrate localized bioavailable mercury conditions over the lifetime of the respective organisms.

LIST OF TABLES

ACKNOWLEDGMENTS

We are grateful to the many agency personnel who were generous with their time and conversation and who helped direct our site selection process in the early stages of the project. We also appreciate being provided access to several otherwise difficult to reach sites. In particular, we thank staff of: the Foresthill Ranger District in the American River watershed, the North Yuba Ranger Station in the Yuba River watershed, various stations in the Feather River area, the Yuba Water Agency, the University of California Agricultural Field Station at the lower Yuba River, the Central Valley Regional Water Quality Control Board, and the California Department of Fish and Game. The State Toxic Substances Monitoring Program supplied much parallel and related data and, in large part, provided the basis for this work. Special thanks go to our colleague, Dr. Michael Brett, who played an important role in the development of this project and who provided helpful suggestions throughout the data reduction and interpretation process.

INTRODUCTION: PROBLEM AND RESEARCH OBJECTIVES

Mercury pollution of aquatic systems is a major concern of researchers and regulatory agencies on both a regional and global scale. In its methylated form, mercury is readily concentrated and transferred through aquatic food chains, where it can become a significant neurological toxicant to higher trophic level consumers, including man. The primary pathway into humans is fish consumption. Much of the current mercury research is focused on the pervasive problem associated with low level atmospheric deposition of industrially-derived mercury across wide areas which have low pH and poorly buffered surface waters. In these regions, mercury can accumulate to dangerous levels in fish with even trace level inputs (e.g. the Northeast United States, Southeast Canada, Scandinavia and much of Western Europe). While the high alkalinity waters of the western U.S. render atmospheric sources of mercury relatively insignificant, California has historically been impacted by large-scale bulk contamination of mercury. This has been the result of extensive mercury mining in the Coast Range of Central California, the use of very large amounts of mercury in Sierra Nevada streams and rivers for gold mining, and the subsequent movement of mercury from both of these areas into downstream rivers and lakes, foothill reservoirs, and ultimately the Delta/Bay ecosystem. In this work, we investigated regional patterns of mercury accumulation in aquatic biota collected in the historic and current gold mining region of the northwestern Sierra Nevada. While some attention has been devoted to mercury accumulation in downstream sinks, little or no research has focused on probable upstream source regions associated with current and, primarily, historic use of mercury for gold mining. It has been estimated that over 3 million kilograms of mercury were lost into Sierra Nevada streams in the course of the California Gold Rush (CVRWQCB 1987).

Previous biological sampling efforts in these streams, as part of the State's Toxic Substances Monitoring Program (TSMP 1990, 1991, 1992), have been limited and most of this was done prior to the 1986 floods and the resurgence of small scale mining. Indeed, much of the routine sampling for the TSMP program is conducted on the lower reaches of the stem rivers and in foothill reservoirs. Mining, on the other hand, is concentrated along mid-elevation stretches of northern Sierra Nevada rivers, namely the forks of the upper Feather, Yuba, and American Rivers, the Bear River, Rubicon River, Cosumnes River, and the Mokelumne River. These rivers have been sampled sporadically by the Toxic Substances Monitoring Program (TSMP 1990, 1991, 1992). However, site selection and the species composition of the fish collected indicates that this work was generally carried out in regions well downstream of the reaches where gold mining is prevalent. We feel our data constitutes a valuable contribution to the Program's data base and its objective of identifying human health risks and major sources of toxic substances.

In this research, we utilized exclusively biotic samples. In-stream aquatic insect species were sampled as bioindicators of relative mercury bioavailability at each of the sites and as surrogates for fish, which were not available at many of the sites. The invertebrate mercury data also provided information on the transfer of mercury through the stream food web. Fish were of interest for their specific mercury concentrations, from a health perspective, as well as also being indicators of relative mercury availability. We chose rainbow trout as one focus of the survey because this species is the dominant vertebrate in many of these rivers, and because mercury bioaccumulation in this species represents perhaps the main vector of human exposure to mercury in this region. Other fish were sampled when available.

Sampled trout were generally representative of individuals taken by fishermen. While a range of sizes and ages were taken, the focus was on three year olds, typically 9-12 inches in length. Trout of this size class dominate angling catches, are the major contributors to in-stream reproductive success of this species, and are the group most heavily relied upon by the Department of Fish and Game in both research and policy making (Harry Rectenwald, Calif. Dept. of Fish and Game, personal communication). Stream aquatic insects were taken from a variety of trophic levels whenever possible, as described below in the methodology section.

The first two years of the work reported here were sponsored by the University of California Water Resources Center. Thirty-five individual sampling sites were studied in 1993 and 1994 and reported on in Slotton *et al.* 1995a. The Sacramento Sanitation District sponsored U.C. Davis follow-up work in 1995, sub-contracted through Larry Walker and Associates. As part of the 1995 continuation work, biota mercury was investigated at 22 additional sites, completing a comprehensive network of 55 sites throughout the Sierra Nevada drainage of the Sacramento River (plus 2 sites on the Cosumnes River of the San Joaquin drainage). The 1995 biological work was conducted in parallel with mercury mass balance and water quality studies which were performed by Larry Walker and Associates. The results of that project are presented in a separate report. The report that follows focuses specifically on the U.C. Davis biological mercury project that was conducted in the gold mining region of the nothwestern Sierra Nevada between 1993 and 1995. This report is a December 1996 revision of the original University of California Water Resources Center publication, including the additional (1995) data and new discussion as appropriate.

Table 1. U.C. Davis Sierra Nevada Gold Region Biotic Mercury Sites

FEATHER RIVER DRAINAGE

1. Lower Feather River below Lake Oroville, near Live Oak (11/17/95).
2. North Fork Feather River at Belden (10/26/94).
3. Yellow Creek (tributary to N Fk Feather R), 2 miles above confluence (6/11/94).
4. Caribou Branch of North Fork Feather River, 4 miles above confluence (10/27/94).
5. East Branch of North Fork Feather River, 10 miles above confluence with Caribou Branch (10/26/94).
6. Indian Creek, tributary to E Branch N Fk Feather River, 7 miles above confluence (9/27/94).
7. Spanish Creek, tributary to E Branch N Fk Feather River, 2 miles above confluence (9/26/94).
8. South Branch Middle Fork Feather River, at M Fk Feather River (11/21/95).
9. Little North Fork Middle Fork Feather River, at M Fk Feather River (11/21/95).
10. Middle Fork Feather River, 15 miles upstream of Lake Oroville at Milsap Bar (11/21/95).
11. Middle Fork Feather River, 1 mile below Nelson Creek (9/22/94).
12. Nelson Creek, tributary to Middle Fork Feather River, 1 mile above confluence (9/21/94).
13. Upper Middle Fork Feather River, 3 miles upstream of Clio (9/23/94).
14. Fall River, tributary to lower Middle Fork Feather River, 3 miles above confluence (11/20/95).
15. South Fork Feather River above Lake Oroville (11/20/95).

YUBA RIVER DRAINAGE

16. Lower Yuba River below Englebright Reservoir, at University of California field station (12/16/93).
    * Additional, seasonal collections in 1995: (4/24/95, 6/30/95, 8/15/95, 11/16/95, 2/16/96).
17. Combined North and Middle Forks Yuba River, just above Englebright Reservoir.
    * 1995 seasonal collection site #2: (4/24/95, 6/30/95, 8/15/95; no inverts available 11/95 and 2/96).
18. North Fork Yuba River constrained (low) flow beneath New Bullard's Bar Reservoir (3/15/94).
19. Canyon Creek, tributary to N Fk Yuba, just above confluence (11/6/93).

Table 1. (continued)

42. Steephollow Creek (Bear River tributary), above Rollins Reservoir (10/13/95).

43. Bear River above Rollins Reservoir and flow diversion from S Fk Yuba (10/13/95).

44. Bear River headwaters near Lake Spaulding (10/24/95).

AMERICAN RIVER DRAINAGE

45. Lower American River at Howe Avenue (12/16/94).

46. Lower American River 1 mile below Lake Natoma (12/16/94).

47. North Fork American River in vicinity of Humbug Bar (11/19/93).

48. Middle Fork American River below Oxbow Reservoir (2/25/94).

49. North Fork of the Middle Fork American River, 1 mile above confluence (3/2/94).

50. Rubicon River, tributary to Middle Fork American River, just above confluence (2/1/94).

51. Middle Fork American River at "End of the World" (2/1/94).

52. Duncan Creek, tributary to Middle Fork American River, 3 miles above confluence (11/16/93).

53. South Fork American River, above Folsom Lake (12/16/94).

54. South Fork American River, below Slab Creek Reservoir (12/20/93).

55. South Fork American River, 1 mile upstream of Pacific (4/11/94).

Additional Sites Outside the Sacramento River Drainage

56. North Fork Cosumnes River above M Fk Cosumnes confluence (7/30/95)

57. North Fork Cosumnes River at Mt Aukum Road (12/20/93).

Several fish collection techniques were investigated initially, including gill netting, electroshocking, and angling. We determined that angling was the most effective method for taking a cross section of trout sizes from clear, fast moving Sierra foothill rivers and streams. To guard against potentially taking seasonal migrant fish from downstream reservoirs, fish sampling was largely confined to the months of August through December. Stocked individuals were rarely taken and were easily differentiated from native fish by their characteristic fused and bent fin rays. We sampled exclusively native fish for mercury content, with the emphasis on rainbow trout. The attempt was made to collect trout across a range of sizes and ages at each site, permitting the construction of site-specific fish size vs mercury regressions. These relationships were used to normalize trout mercury content at each site to a standard, inter-comparable size of trout. We chose a standard size of 250 g for normalization. This size was typical of 2-3 year old, 9-12 inch long trout which represent the majority of "keeper" fish taken by the angling public. Fish were weighed and measured in the field. At sites where stomach contents were assessed, this was also done in the field. Stomach contents were obtained with a stainless steel scalpel and were removed to an acid-cleaned jar with teflon-lined cap. Items were identified and percent volumes assessed, following standard fisheries sampling protocol.

Sample Preparatory Techniques

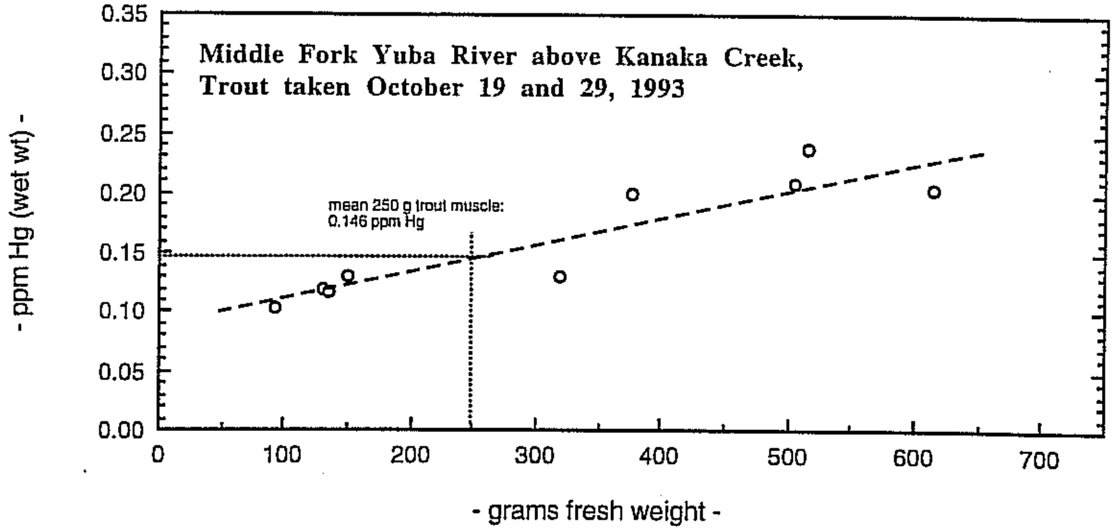
Stream insects were analyzed for mercury in homogenized composite samples of multiple whole individuals. Typically, ≥ 10 individuals were composited for each of the trophic levels through small-item predators (stoneflies), and 2-5 individuals of the top predator insect group such as hellgrammites, based on availability. Samples were pooled by taxa into separate jars. The insects were maintained live on ice. Within 24 hours of collection, the contents of each jar were carefully cleaned and sorted. This was accomplished by resuspending the jar contents in a tray of clean water and, with teflon-coated forceps, individually rinsing and shaking each individual insect in the clean water to remove any extraneous material. Insects were keyed to at least the family level, using a variety of aquatic insect texts and manuals (McCafferty 1981, Merrit and Cummins 1984, Pennak 1978, Thorp and Covich 1991) . Trophic feeding category of organisms was determined based on the recommendations of Merrit and Cummins (1984). In uncertain cases, the magnified examination of mouthparts was used to help make this determination. Cleaned insects were placed in well rinsed jars and frozen. At the onset of sample analysis, the jar contents were dried at 50-60 °C for 24 hours and then ground with teflon coated instruments or glass mortar and pestle to a homogeneous powder. The resulting powder was dried a second time to constant weight before analytical sub-samples were taken for digestion. All aquatic insect mercury analytical work was performed with dry powdered sample, both to ensure homogeneity of sample hrs, potassium permanganate is added for additional oxidation and digest stabilization. This portion of the digest procedure is performed at 80-95 °C with the tubes refluxing, uncapped. The resulting digests can be diluted or not, depending on the mercury concentrations and required level of detection, and are stable indefinitely, both before and following detection. Detection utilizes typical cold vapor atomic absorption techniques with a mercury lamp of 253.7 nm wavelength. The method differs from standard flow-through systems which reduce the entire digest in a one-time detection. A long path length, minimum volume gas cuvette and holder have been manufactured for positioning in the beam path and a specialized injection port allows direct introduction of reduced mercury in vapor. Reduction of digest mercury is performed inside a 12 cc calibrated syringe on a 2.0 cc aliquot of digest together with 2.0 cc of stannous chloride/hydroxylamine sulfate/sodium chloride reductant. A 6.00 cc airspace is utilized for partitioning of the volatile reduced mercury within the syringe and, after partitioning is complete, this airspace is injected directly into the low volume cuvette mounted in the beam path for detection. The amount of digest and, thus, proportion of sample detected is accurately determined through difference, with the digest tubes weighed to $\pm$ 0.001 g both before and immediately after removal of the analytical aliquot. Weight of total digest is initially determined by weighing the empty tube and then the full tube of digest. Level of detection was approximately 0.01 mg kg^{-1} (ppm).

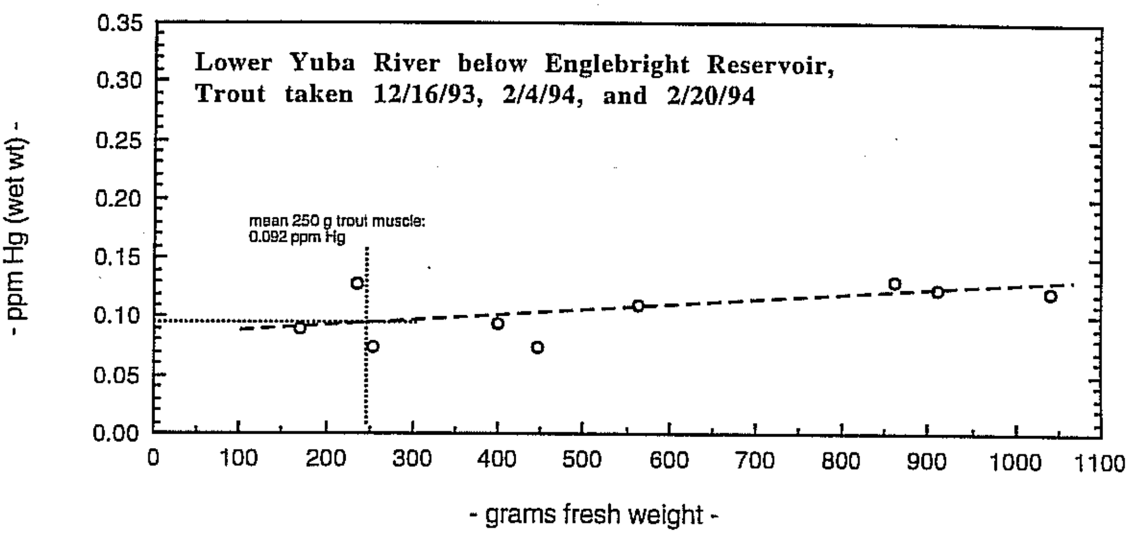
QA/QC was quite extensive, with approximately 16 of the 40 tubes in each run dedicated to this purpose. QA/QC samples in each run included a set of 8 aqueous mercury standards, a minimum of 3 certified reference material samples in an appropriate matrix, and duplicate and spike recovery samples each at a ratio of approximately 10%. QA/QC samples passed through all phases of the digest and were treated identically to analytical samples. Replication was typically $\leq$ 5% difference between duplicates, recoveries of certified reference materials were uniformly within 20% of certified values, spike recoveries were within 20% of predicted concentrations, and standard curves generally had R^2 values in excess of 0.98.

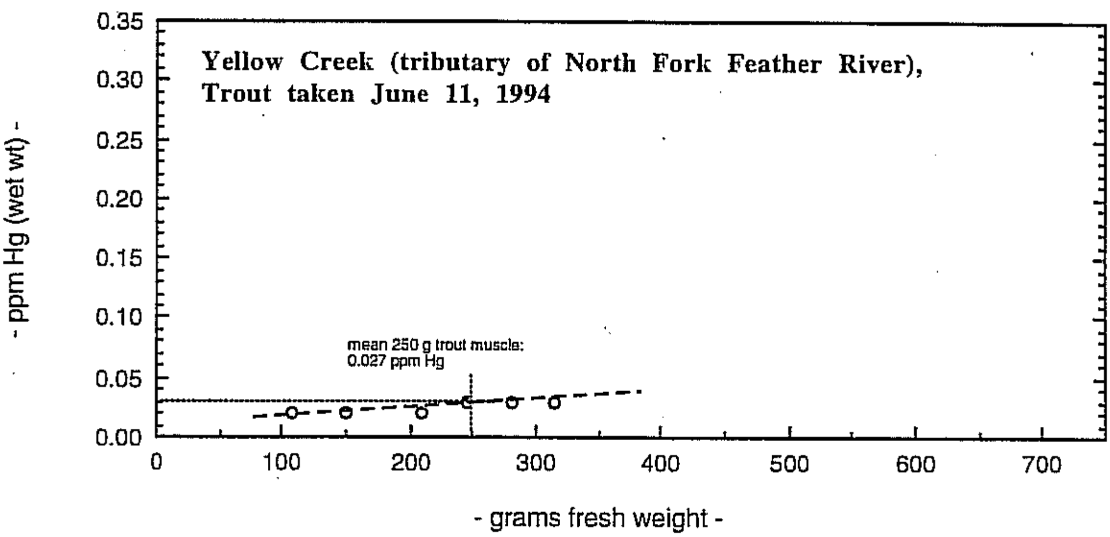
Data Reduction

In order to reduce the fish muscle mercury concentration data to a single, inter-comparable number for each site, we developed trout size vs mercury concentration curves for the fish taken at each location. Data for fish weights and corresponding mercury concentrations were plotted for each sample set. Based on a visual line of best fit, a graphic relationship between trout size and mercury concentration was estimated for each site. This approach was taken for the following reasons: (1) obvious outlier individuals could be omitted when they were clearly of different origin than the rest of the fish in a set, typically due to recent migration from an adjoining stream with

Fig. 2. Examples of Fish Size vs Mercury Concentration Normalization







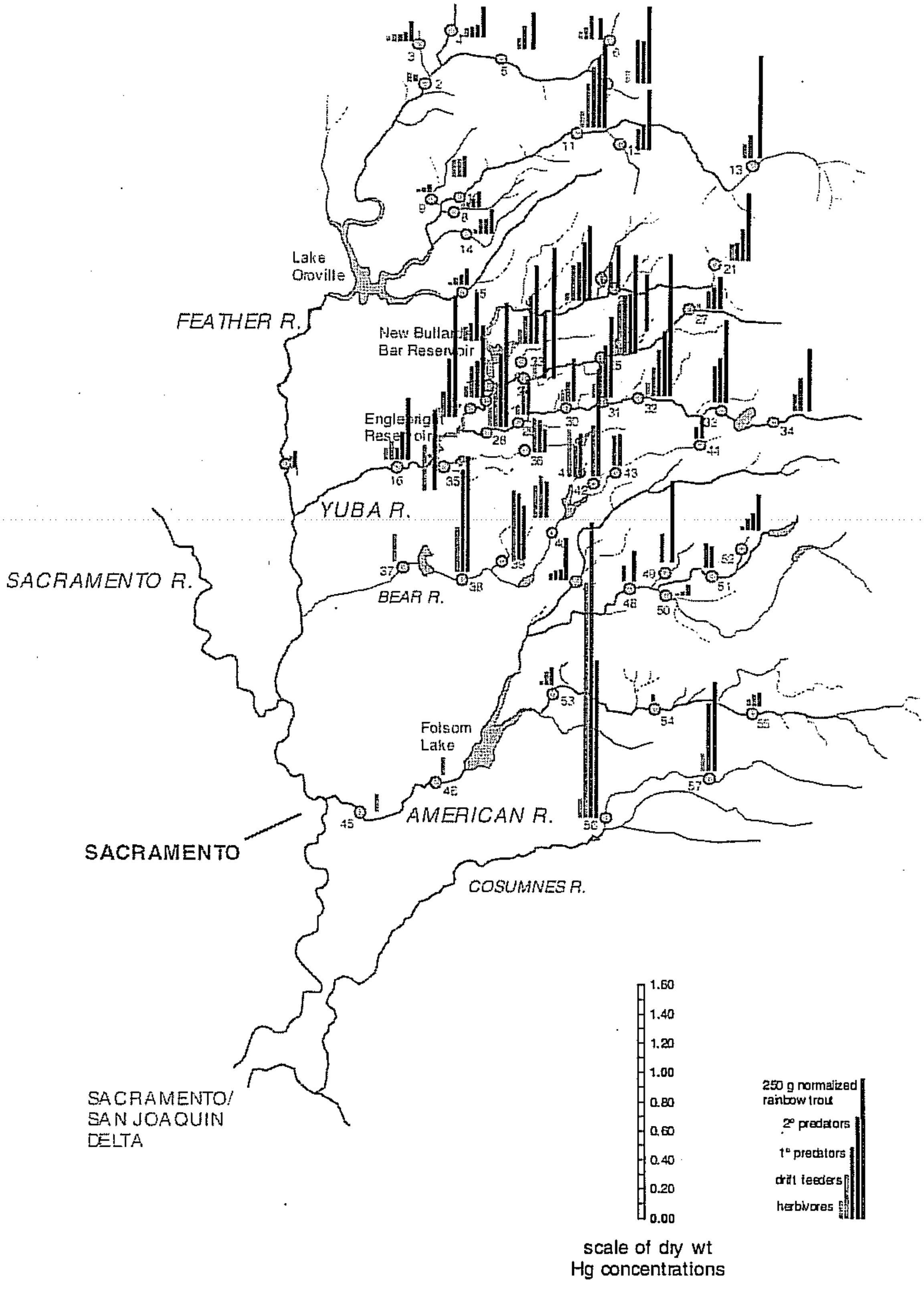


Fig. 3. Superimposed Sierra Nevada biotic mercury data for all major trophic categories

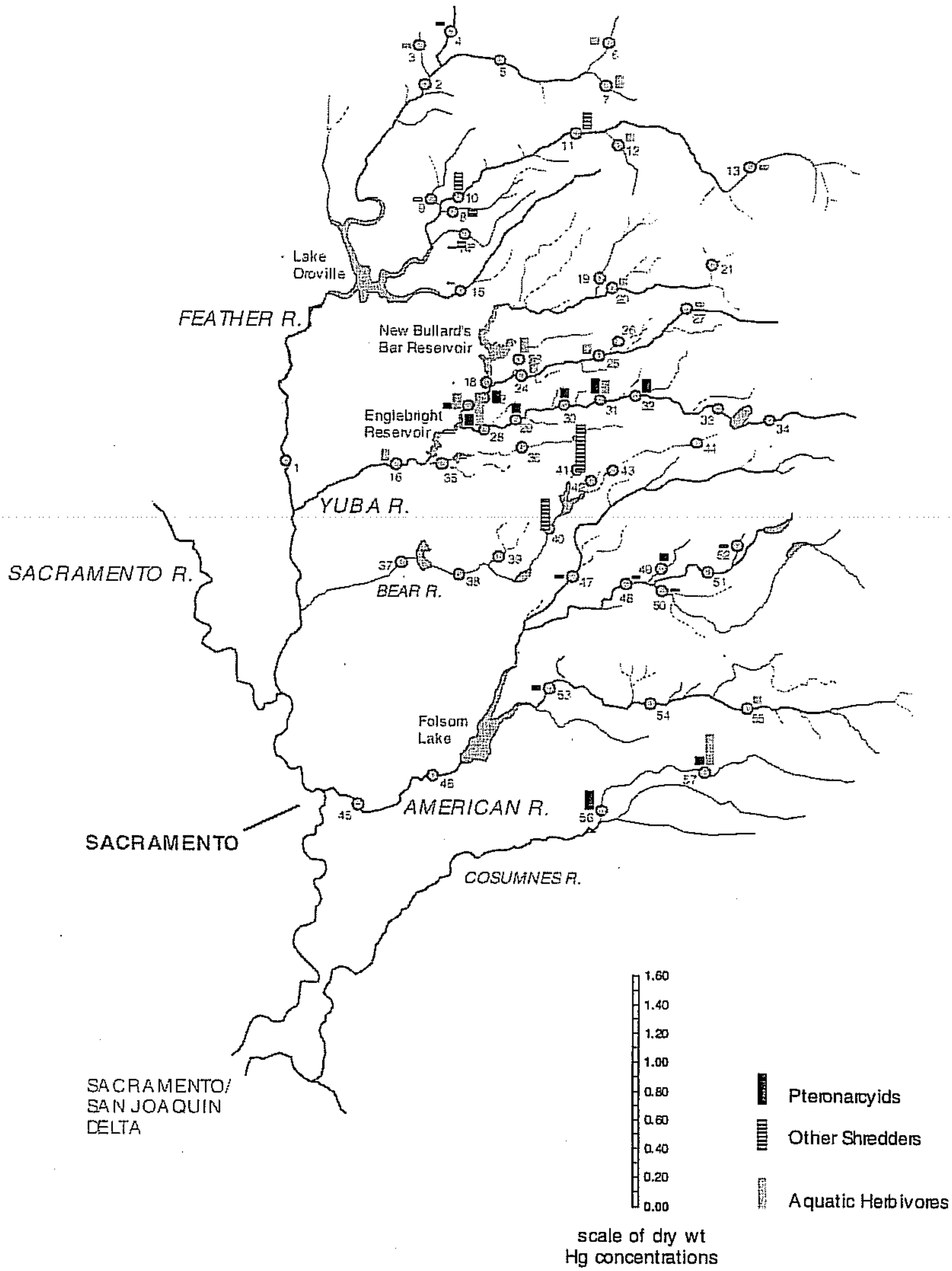


Fig. 5. Mercury in Herbivorous Stream Invertebrates (dry weight ppm)
(Shredders of terrestrial vegetation vs consumers of aquatic plants and algae)

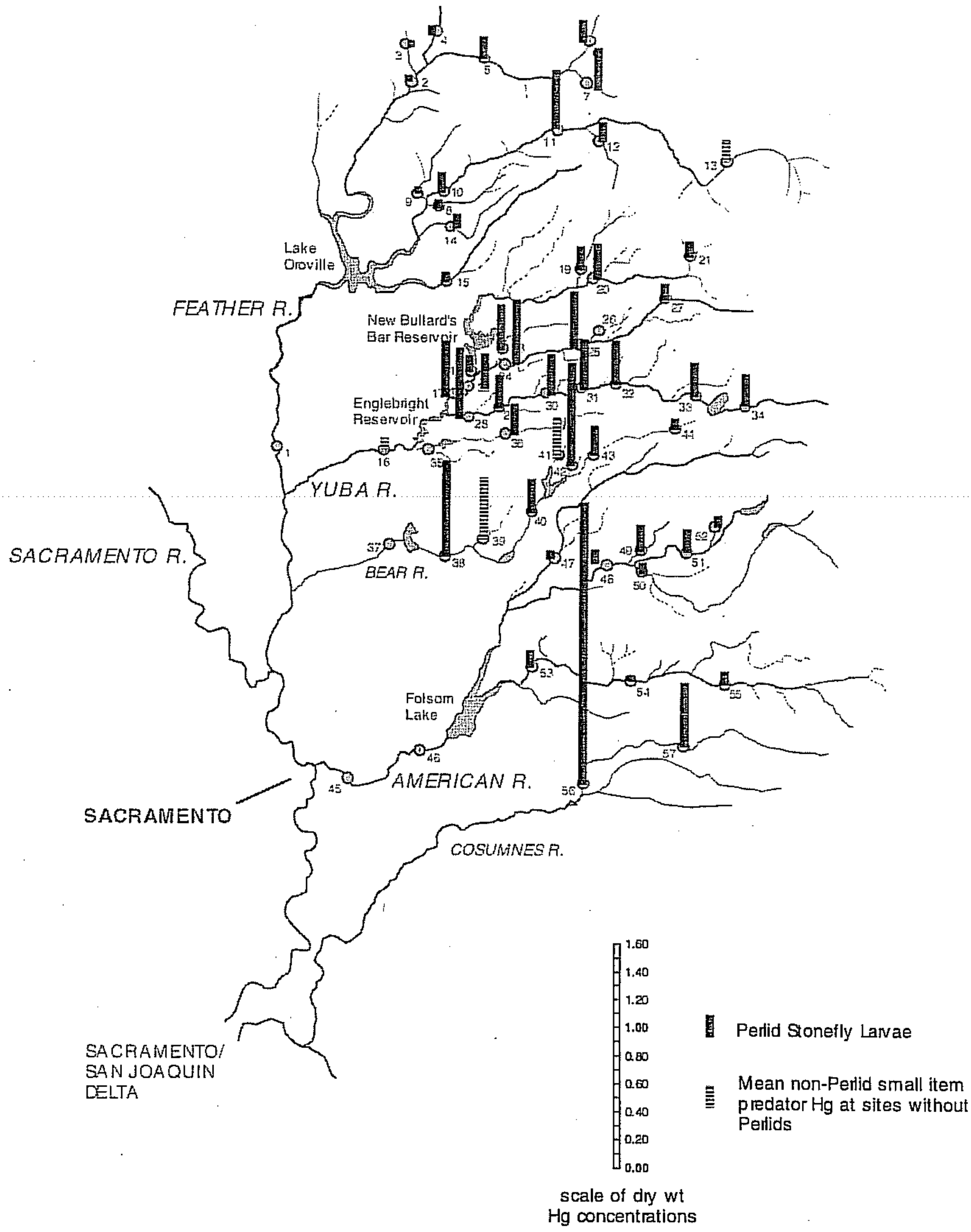


Fig. 7. Mercury in Perlid Stonefly and Other Small Item Predator Larvae
(dry weight ppm)

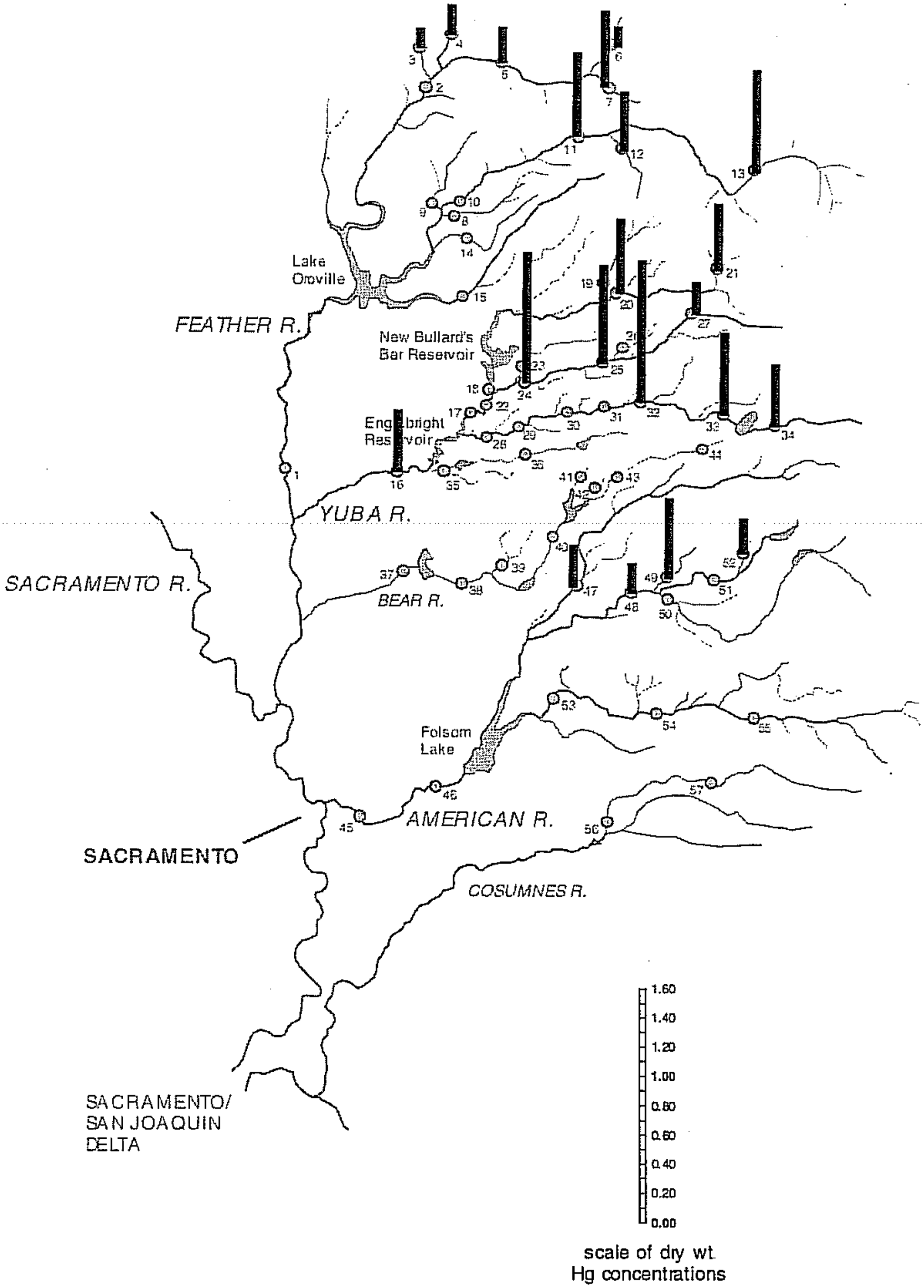


Fig. 9. Mercury in Normalized 250 g Rainbow Trout Muscle
(dry weight ppm, comparable to dry wt invertebrate data)

Table 2. Biota Mercury Data For All Northwestern Sierra Nevada Project Sites (all as dry wt ppm)

Identification	trophic level	Hg
1. Lower Feather River at Live Oak. (11/17/95)		
Hydropsychidae (net caddis)	drift feeder	0.08
Gomphidae (dragonfly nymph)	large predator	0.10
2. North Fork Feather River at Belden. (10/26/94)		
Hydropsychidae (net caddis)	drift feeder	0.05
Perlidae-Gold sp (Callineuria)	small predator	0.04
3. Yellow Creek (trib. of North Fk Feather R.), 2 miles above confluence. (6/11/94)		
(Large Mayflies)	herbivore	0.03
Hydropsychidae (net caddis)	drift feeder	0.04
Rhyacophyllidae (pred. caddis)	small predator	0.04
Perlidae (golden stonefly)	small predator	0.03
Corydallidae (hellgrammite)	large predator	0.05
Tipulidae (cranefly)	large predator	0.06
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.12*
(trout diet)	(trout diet)	0.05
4. Caribou Branch North Fork Feather River, 4 miles above confluence. (10/27/94)		
Pteronarcyidae	leaf shredder	0.02
Hydropsychidae (net caddis)	drift feeder	0.05
Perlidae-Dark sp (Hesperoperla)	small predator	0.06
Gomphidae (dragonfly)	large predator	0.08
Corydallidae (hellgrammite)	large predator	0.07
Tipulidae (cranefly)	large predator	0.09
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.20*
(trout diet)	(trout diet)	0.06

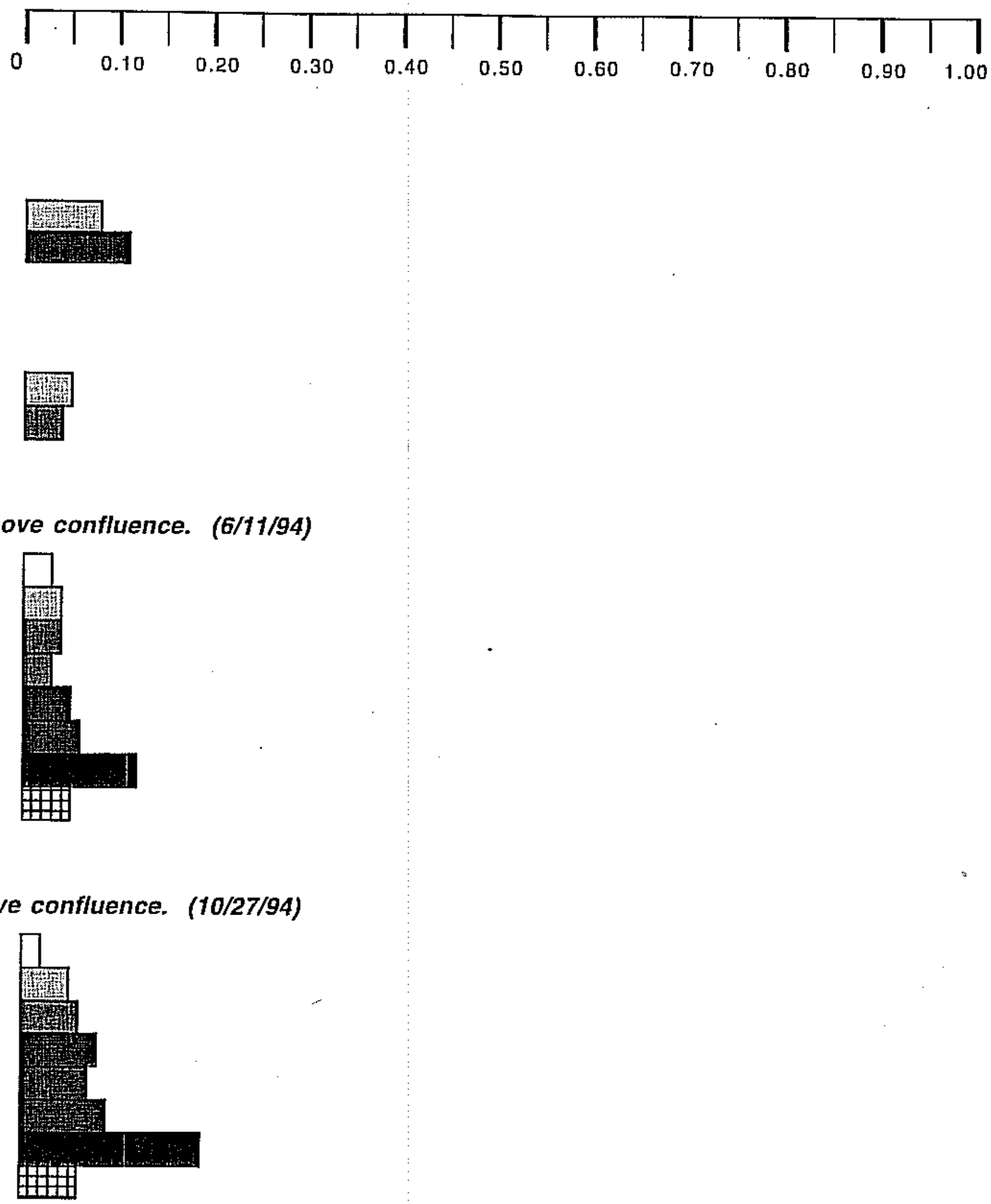


Table 2. (continued)

identification	trophic level	Hg
8. S Branch M Fk Feather at M Fk Feather. (11/21/95)		
Peltoperlidae (lg/giant)	herb/detritiv	**0.04**
Hydropsychidae (giant)	drift feeder	**0.03**
Perlidae--Callineuria (med/Lg)	small predator	**0.05**
Perlidae--Hesperoperla (lg)	small predator	**0.06**
Hellgrammite (med/lg)	large predator	**0.11**
9. Little N Fk M Fk Feather at M Fk Feather R. (11/21/95)		
Peltoperlidae (med/lg/giant)	herb/detritiv	**0.02**
Hydropsychidae (giant)	drift feeder	**0.00**
Perlidae (lg/giant)	small predator	**0.05**
10. M Fk Feather River at Milsap Bar. (11/21/95)		
Peltoperlidae (med/lg)	herb/detritiv	**0.11**
Hydropsychidae (med)	drift feeder	**0.11**
Hydropsychidae (giant)	drift feeder	**0.08**
Perlidae--Callineuria (lg)	small predator	**0.10**
Perlidae--Hesperoperla (lg)	small predator	**0.18**
11. Middle Fork Feather River, 1 mile below below Nelson Ck. (9/22/94)		
Pteronarcyidae	leaf shredder	**0.10**
Hydropsychidae (net caddis)	drift feeder	**0.28**
Rhyacophyllidae (pred. caddis)	small predator	**0.25**
Perlidae (golden stonefly)	small predator	**0.40**
Gomphidae (dragonfly)	large predator	**0.24**
Corydalidae (hellgrammite)	large predator	**0.47**
Tipulidae (cranefly)	large predator	**0.69**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.56***
(trout diet)	(trout diet)	**0.08**

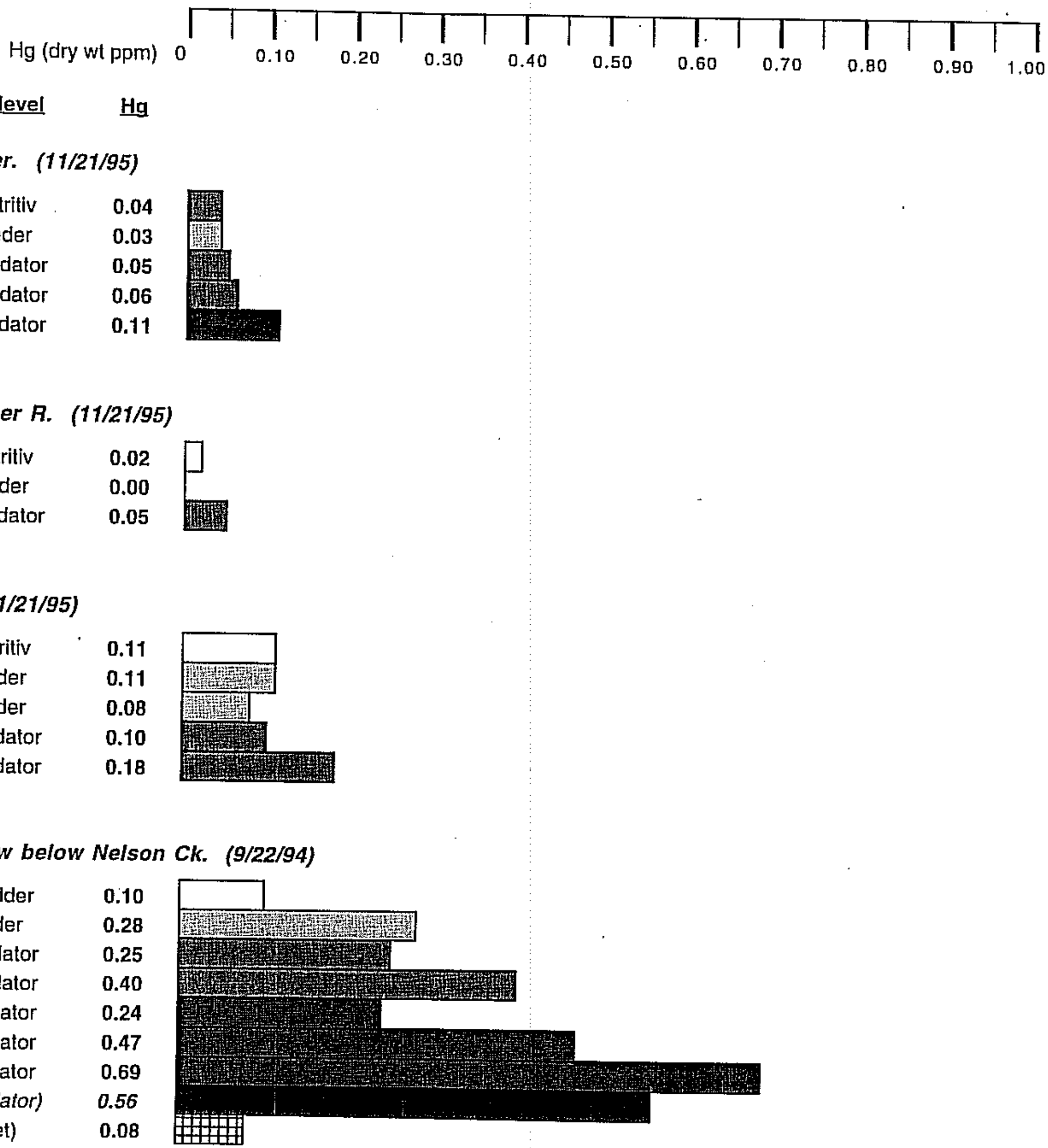


Table 2. (continued)

identification	trophic level	Hg
15. South Fk Feather River. (11/20/95)		
Mayflies (lg)	herbivore	0.02
Hydropsychidae (giant)	drift feeder	0.00
Peltoperlidae (giant)	herb/detritiv	0.04
Perlidae-Callineuria (lg)	small predator	0.06
Perlidae-Callineuria (giant)	small predator	0.07
Perlidae-Hesperoperla (lg)	small predator	0.06
Hellgrammite (sm)	large predator	0.12
Hellgrammite (med)	large predator	0.09
16. Lower Yuba River below Englebright Reservoir, at University of California field station. (12/16/93)		
Ephemerellidae (mayfly)	herbivore	0.07
Hydropsychidae (net caddis)	drift feeder	0.12
Perlodidae (stonefly)	small predator	0.07
Tipulidae (cranefly)	large predator	0.18
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.42*
17. North Fk / Middle Fk Yuba River below Colgate inflow. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	0.04
Mayflies	herbivore	0.10
Hydropsychidae	drift feeder	0.16
Perlodidae-sm	small predator	0.13
Perlidae-lg	small predator	0.39
Hellgrammites-lg	large predator	0.97
Hellgrammites-giant	large predator	0.68

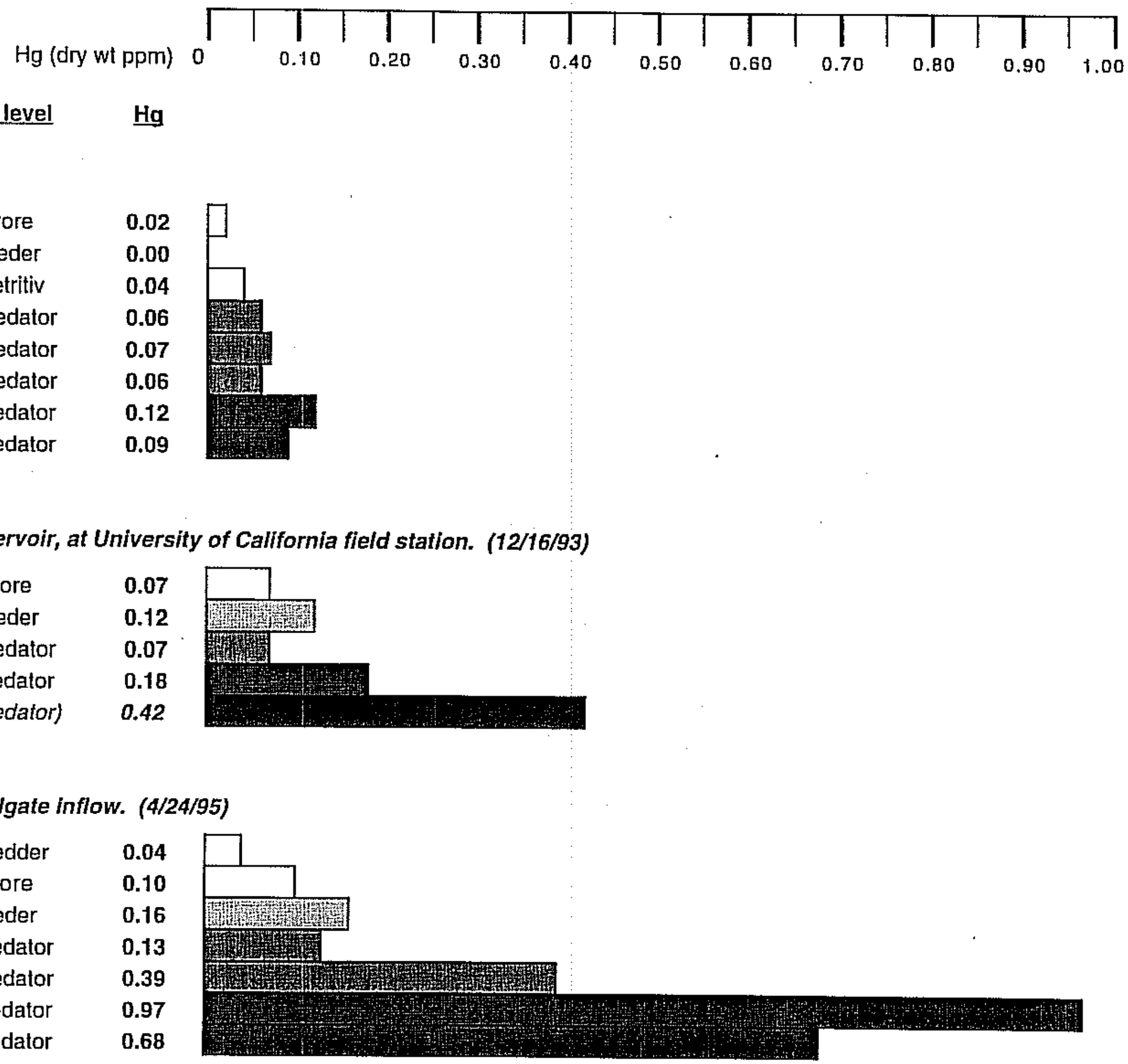


Table 2. (continued)

identification	trophic level	Hg
22. Middle Fork Yuba River, just upstream of Colgate inflow. (11/16/95)		
Pteronarcyidae (sm)	leaf shredder	0.04
Pteronarcyidae (Lg)	leaf shredder	0.11
Hydropsychidae	drift feeder	0.20
Perlodidae (med/Lg)	small predator	0.18
Perlidae (Lg)	small predator	0.25
Damsel nymphs	small predator	0.27
Hellgrammites (sm/Med)	large predator	0.57
Hellgrammites (Lg/giant)	large predator	0.41
23. Oregon Creek at Middle Fk Yuba. (11/9/95)		
Ptilodactylidae (lg)	herbivore	0.09
Hydropsychidae	drift feeder	0.17
Perlidae-Callineuria (med/Lg)	small predator	0.32
Tipulidae (lg)	large predator	0.53
24. Middle Fork Yuba River, just upstream of Oregon Creek and Highway 49 crossing. (10/21/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.10
Perlidae (golden stonefly)	small predator	0.45
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.87*
Mean 250 g Squawfish	*(fish predator)*	*1.87*
25. Middle Fork Yuba River, 1 mile upstream of Tyler Foote crossing. (10/19/93)		
Pteronarcyidae (giant stonefly),1 yr	leaf shredder	0.05
Pteronarcyidae; large (2 yr)	leaf shredder	0.06
Hydropsychidae (net caddis)	drift feeder	0.33
Perlidae (golden stonefly)	small predator	0.38
Gomphidae (dragonfly)	large predator	0.39
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.66*

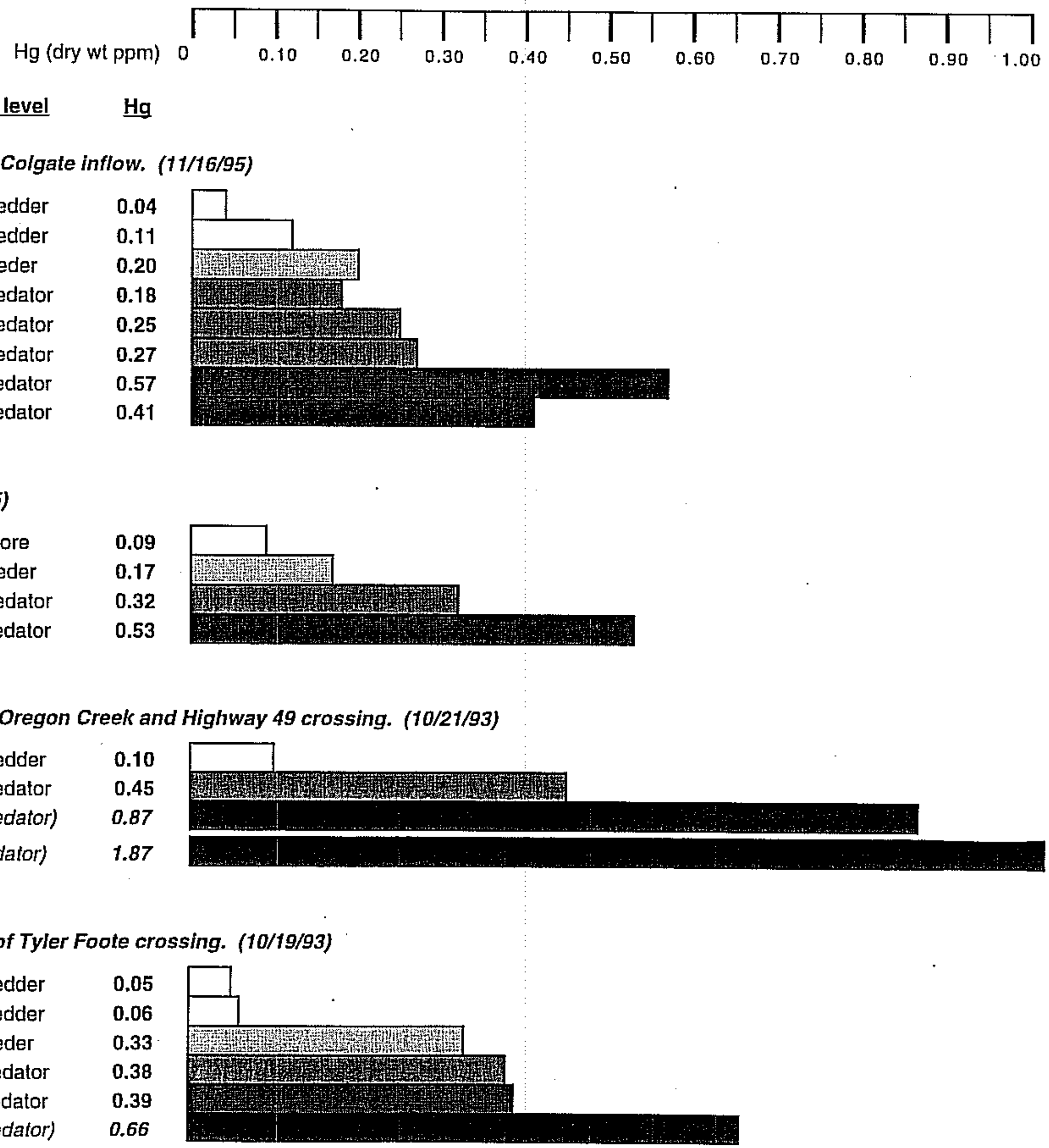


Table 2. (continued)

identification	trophic level	Hg
31. South Fork Yuba River at Edward's Crossing. (10/4/95)		
Mayflies	herbivore	0.08
Pteronarcyidae-sm	leaf shredder	0.09
Pteronarcyidae-lg	leaf shredder	0.09
Hydropsychidae-sm/med	drift feeder	0.25
Perlidae-sm	small predator	0.28
Perlidae-med	small predator	0.32
Perlidae-large	small predator	0.37
Hellgrammite-med	large predator	0.55
32. South Fork Yuba River, 1 mile downstream of Washington. (11/12/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.08
Hydropsychidae (net caddis)	drift feeder	0.18
Perlidae (golden stonefly)	small predator	0.30
Corydalidae (hellgrammite)	large predator	0.44
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.94*
33. South Fork Yuba River below Lake Spaulding. (10/24/95)		
Perlidae (m/Lg)	small predator	0.24
Gomphidae (med)	large predator	0.24
Tipulidae (med/lg)	large predator	0.31
Hellgrammites (sm/med)	large predator	0.32
34. South Fork Yuba River 2 miles above Lake Spaulding. (10/25/95)		
Hydropsychidae (giant)	drift feeder	0.11
Perlidae (med/lg)	small predator	0.22

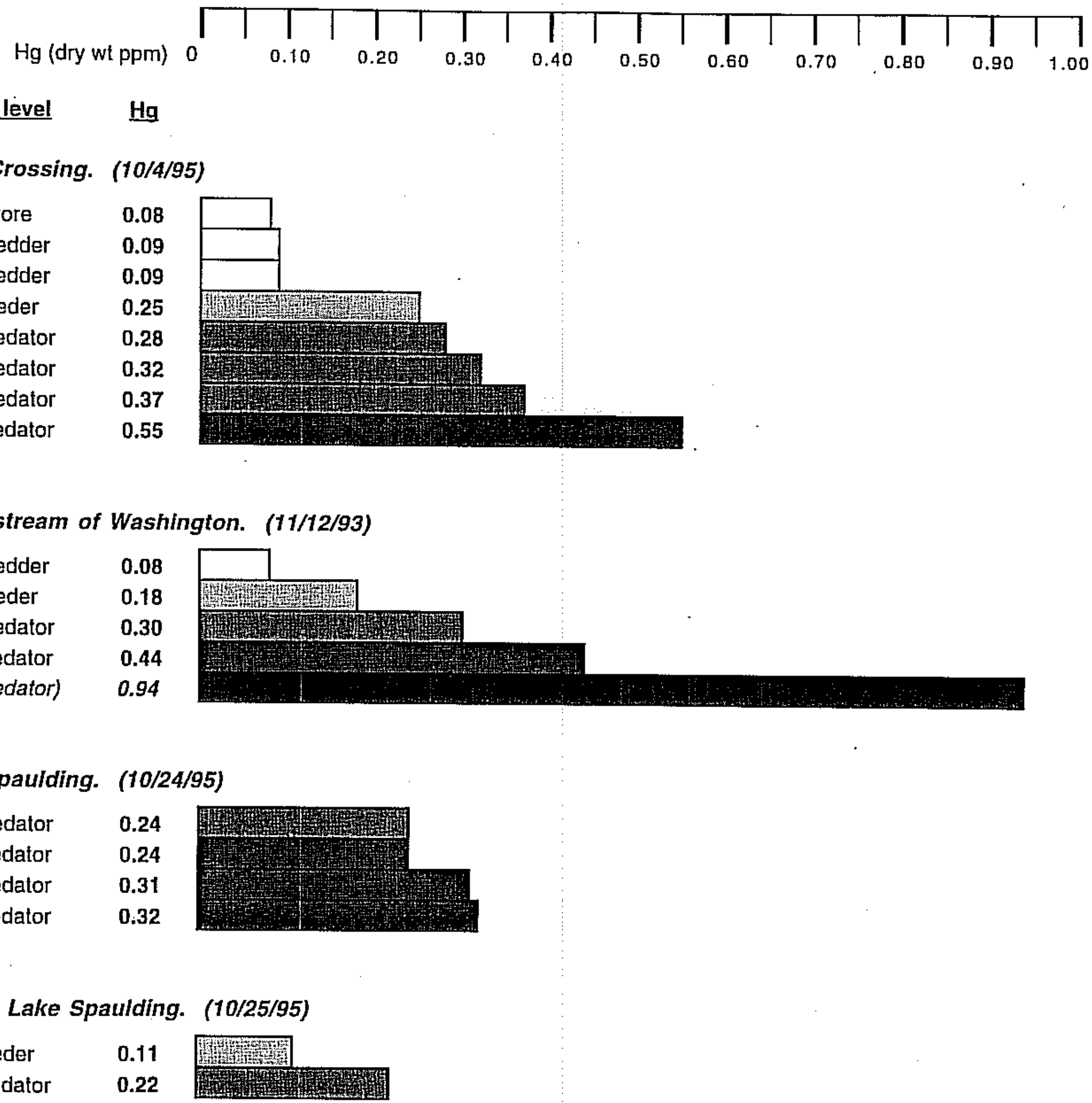
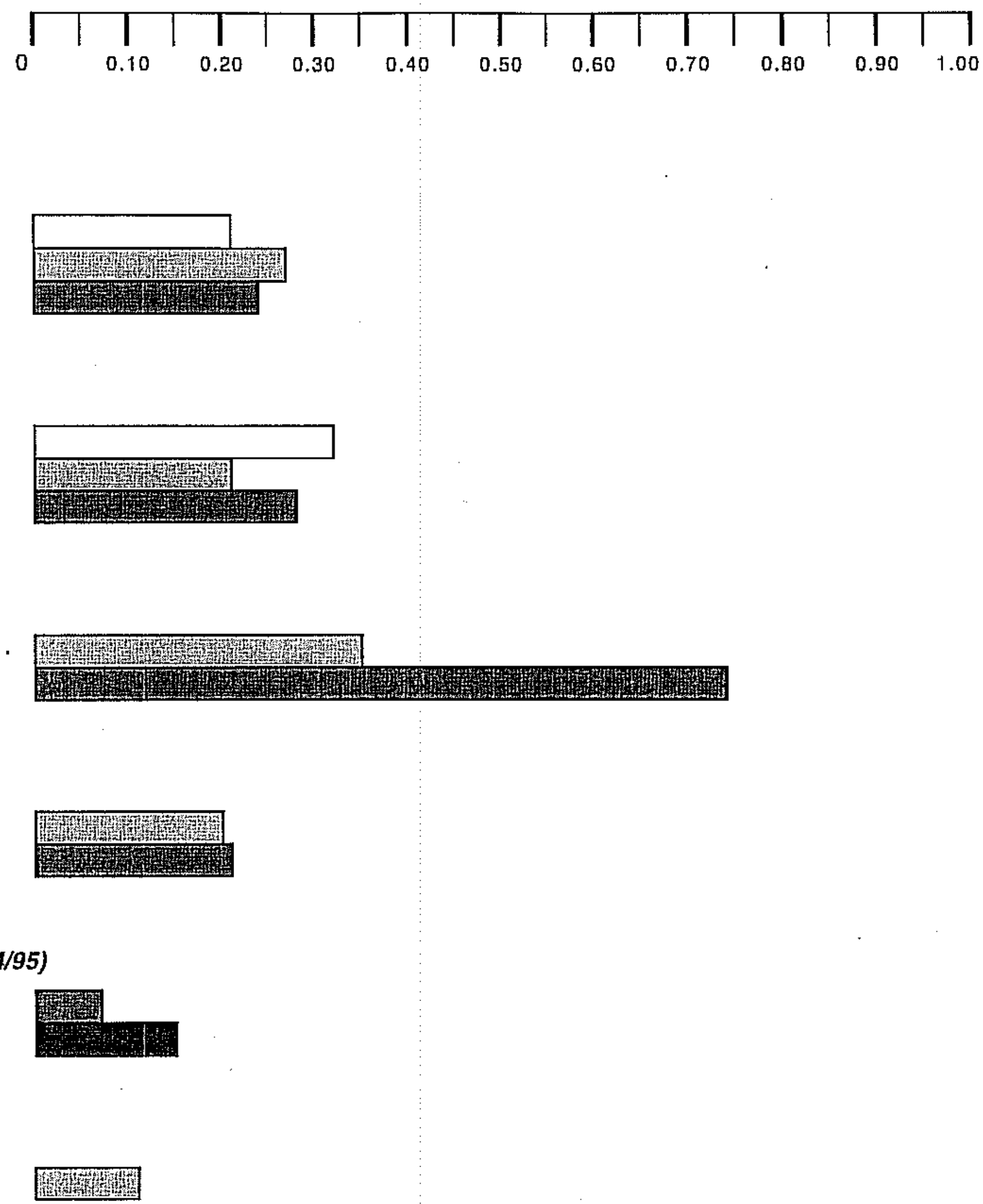


Table 2. (continued)



identification	trophic level	Hg
40. Bear River below Rollins Reservoir. (10/12/95)		
Peltoperlidae (med/lg)	small predator	**0.21**
Hydropsychidae	drift feeder	**0.27**
Perlidae-Hesperoperla (Med/lg)	small predator	**0.24**
41. Greenhorn Creek (Bear River trib). (10/13/95)		
Peltoperlidae (med/lg)	small predator	**0.32**
Hydropsychidae	drift feeder	**0.21**
Damselfly Nymphs	small predator	**0.28**
42. Steephollow Creek (Bear River trib). (10/13/95)		
Hydropsychidae	drift feeder	**0.35**
Perlidae (med/lg)	small predator	**0.74**
43. Bear River above Rollins Reservoir. (10/13/95)		
Hydropsychidae	drift feeder	**0.20**
Perlidae-Callineuria (med/Lg)	small predator	**0.21**
44. Bear River headwaters near Lake Spaulding. (10/24/95)		
Perlidae (med/Lg)	small predator	**0.07**
Hellgrammites (lg)	large predator	**0.15**
45. Lower American River at Howe Avenue. (12/16/94)		
Hydropsychidae (net caddis)	drift feeder	**0.11**

Table 2. (continued)

identification	trophic level	Hg
51. Middle Fork American River at "End of World". (2/1/94)		
Perlidae (golden stonefly)	small predator	0.16
Corydalidae (hellgrammite)	large predator	0.14
52. Duncan Creek, tributary to Middle Fork American River, 3 miles above confluence. (11/16/93)		
Peltoperlidae (stonefly)	herbivore	0.02
Hydropsychidae (net caddis)	drift feeder	0.05
Perlidae (golden stonefly)	small predator	0.07
Corydalidae (hellgrammite)	large predator	0.11
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.24*
53. South Fork American River above Folsom Lake. (12/16/94)		
Pteronarcyidae	leaf shredder	0.03
Hydropsychidae (net caddis)	drift feeder	0.08
Perlodidae- Osobenus	small predator	0.07
Perlidae-Gold sp (Callineuria)	small predator	0.10
Perlidae-Dark sp (Hesperoperla)	small predator	0.14
54. South Fork American River below Slab Creek Reservoir. (12/20/93)		
Perlidae (golden stonefly)	small predator	0.04
55. South Fork American River, 1 mile upstream of Pacific. (4/11/94)		
Heptageneidae (mayfly)	herbivore	0.03
Ephemerellidae (mayfly)	herbivore	0.05
Ptilodactylidae (lg aq beetle nymph)	herbivore	0.07
Hydropsychidae (net caddis)	drift feeder	0.07
Perlidae-Gold sp (Callineuria)	small predator	0.08
Perlidae-Dark sp (Hesperoperla)	small predator	0.09

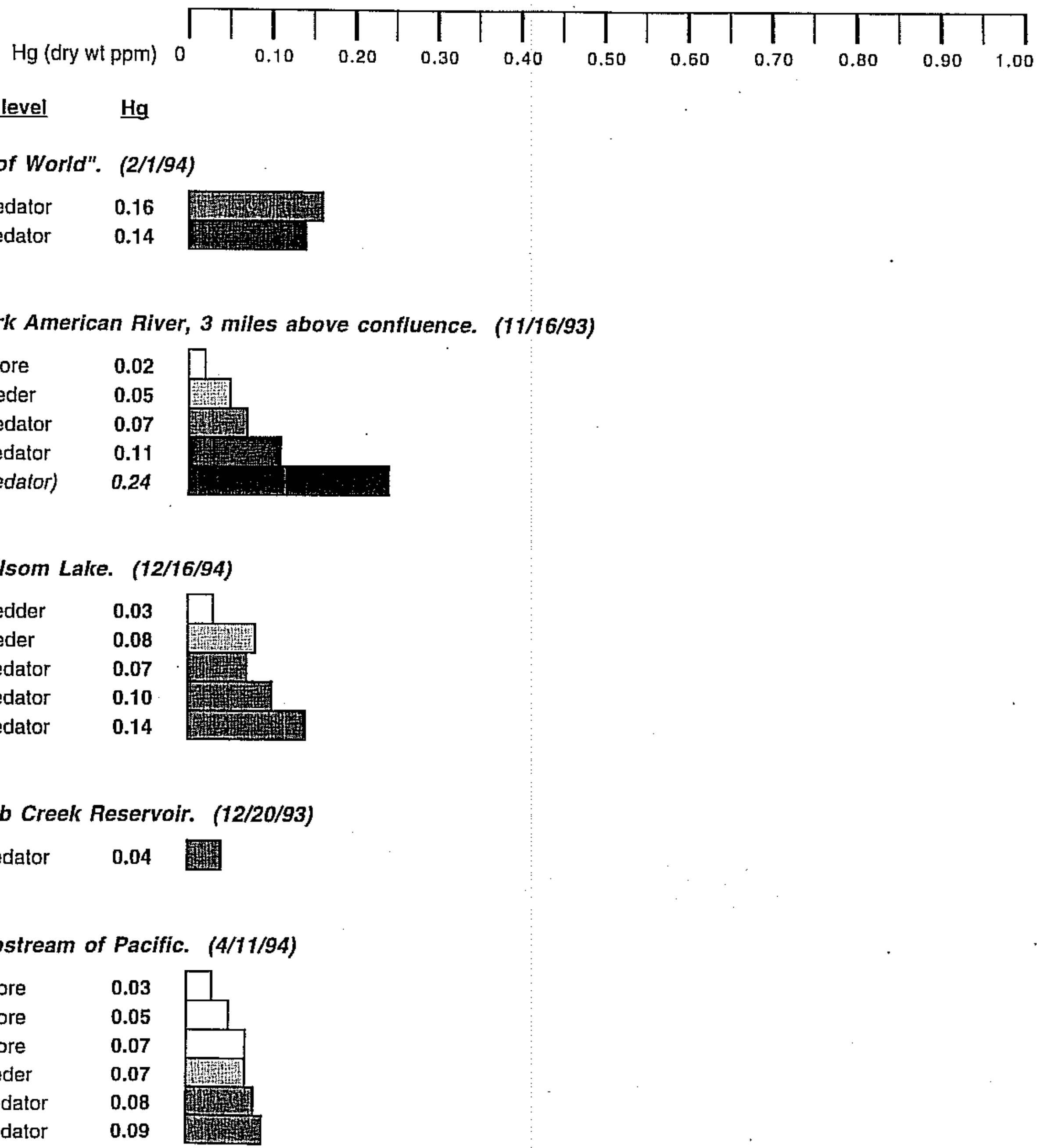


TABLE 3. Mercury Data From Individual Fish

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
2. Yellow Ck (off N Fk Feather River), 6/11/94				
107 g	197	f	0.02	
150 g	230	m	0.02	
210 g	257	f	0.02	
245 g	270	f	0.03	
280 g	285	f	0.03	
280 g	288	m	0.03	
315 g	297	f	0.03	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.03***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.12***	
3. Caribou N Fk Feather River, 10/27/94				
75 g	190	m	0.03	
115 g	223	f	0.03	
120 g	223	m	0.02	
210 g	266	m	0.04	
240 g	274	m	0.04	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.04***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.20***	
4. E Branch N Fk Feather River, 10/26/94				
75 g	193	m	0.04	
160 g	248	m	0.03	
207 g	266	f	0.04	
423 g	348	m	0.05	
515 g	370	f	0.07	
627 g	385	f	0.12	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.05***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.24***	
5. Indian Ck (Trib, E Branch N Fk Feather River), 9/27/94				
151 g	242	f	0.03	
153 g	243	f	0.02	
335 g	304	m	0.03	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.03***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.14***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
16. Lower Yuba below Engelbright Reservoir,12/16/93				
170 g	235	f	**0.09**	0.11
235 g	274	m	**0.13**	0.09
255 g	272	f	**0.07**	0.08
400 g	314	f	**0.10**	0.09
440 g	329	m	**0.07**	0.08
565 g	370	m	**0.11**	0.06
860 g	408	f	**0.13**	0.09
910 g	417	m	**0.12**	0.08
1040 g	434	m	**0.12**	0.07
normalized 250 g trout muscle (wet wt ppm Hg):			***0.09***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.42***	
20. North Fork Yuba River Near Canyon Creek, 11/5/93				
145 g	236	f	**0.14**	0.16
200 g	270	f	**0.09**	0.08
300 g	306	f	**0.10**	0.10
320 g	314	f	**0.11**	0.13
340 g	311	m	**0.10**	0.07
normalized 250 g trout muscle (wet wt ppm Hg):			***0.11***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.50***	
19. Canyon Creek at N Fk Yuba,11/6/93				
305 g	294	m	**0.11**	0.10
21. Downie River (tributary of N Fk Yuba), 11/2/93				
55 g	176	m	**0.04**	0.04
85 g	195	m	**0.06**	0.04
150 g	239	f	**0.08**	0.06
155 g	243	m	**0.06**	0.05
410 g	356	f	**0.15**	0.13
465 g	348	m	**0.07**	0.06
normalized 250 g trout muscle (wet wt ppm Hg):			***0.10***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.45***	

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
32. South Fork Yuba at Washington, 11/12/93				
20 g	112	?	**0.14**	(not analyzed)
70 g	183	f	**0.13**	0.11
70 g	186	?	**0.12**	0.14
85 g	195	?	**0.12**	0.15
90 g	200	m	**0.11**	0.13
90 g	201	?	**0.11**	0.13
90 g	207	f	**0.12**	0.16
100 g	205	?	**0.11**	0.12
135 g	234	m	**0.10**	0.12
140 g	230	m	**0.13**	0.15
150 g	237	f	**0.11**	0.13
230 g	274	f	**0.22**	0.22
310 g	305	f	**0.26**	0.35
450 g	345	f	**0.30**	0.48
normalized 250 g trout muscle (wet wt ppm Hg):			***0.21***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.94***	
33. South Fork Yuba below Lake Spaulding, 10/24/95				
Rainbow Trout				
22 g	131		**0.04**	
75 g	180		**0.06**	
85 g	190		**0.08**	
130 g	228		**0.11**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.12***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.56***	
Brown Trout				
125 g	224		**0.07**	
190 g	248		**0.07**	
34. South Fork Yuba above Lake Spaulding, 10/24/95				
Brown Trout				
99 g	208	f	**0.06**	
101 g	211	f	**0.09**	
155 g	247	f	**0.08**	
189 g	264	f	**0.06**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.09***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.43***	
40. Bear River below Rollins Reservoir, 10/13/95				
101 g	209		**0.16**	

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
52. Duncan Creek (tributary of Middle Fk American R.), 11/16/93				
Rainbow Trout				
35 g	149	m	**0.02**	0.02
55 g	170	f	**0.02**	0.02
80 g	186	f	**0.03**	0.04
85 g	195	f	**0.03**	0.03
100 g	205	m	**0.03**	0.03
100 g	215	m	**0.04**	0.05
120 g	223	m	**0.03**	0.03
170 g	246	m	**0.04**	0.05
normalized 250 g trout muscle (wet wt ppm Hg):			***0.05***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.24***	
Brown Trout				
55 g	173	m	**0.03**	0.04
110 g	214	f	**0.04**	0.04
135 g	230	m	**0.05**	0.04
150 g	237	m	**0.04**	0.05
54. South Fk American River Below Slab Creek Reservoir, 12/20/93				
Rainbow Trout				
86 g	197	m	**0.07**	0.06
Brown Trout				
83 g	207	m	**0.06**	0.06

Trout stomach contents were analyzed for mercury at a subset of the sampling sites. These data are displayed in Table 2 together with other trophic mercury data for each site. The food item mercury data was generally reflective of corresponding stream invertebrate mercury levels. In the several cases where food item mercury was considerably lower than corresponding stream invertebrate mercury, it was noted that terrestrial insects dominated the stomach contents. The diets of insectivorous rainbow trout and young brown trout naturally demonstrate temporal shifts in the percentage of terrestrial forms, in conjunction with changes in availability.

Stream Invertebrates

Aquatic invertebrates were taken at each of the 57 sites. Approximately 250 separate invertebrate composite samples were collected, identified, processed, and analyzed for mercury in the research reported here. The sites varied considerably in invertebrate diversity and types present. The most consistently available groups were drift feeding caddisfly nymphs of the family Hydropsychidae (omnivores), stonefly nymphs of the family Perlidae (small-item predators), and hellgrammites of the family Corydalidae (large-item predators). The lowest trophic feeding level of stream invertebrates taken, herbivorous species, were represented by a variety of families, with Pteronarcyid stoneflies being the most frequently taken. A variety of mayfly species represented this trophic level at a number of sites. Additional herbivores included large beetle larvae of the family Ptilodactylidae. The omnivore/drift collector feeding level was represented exclusively by Hydropsychid caddis nymphs, which were widespread throughout much of the region. The invertebrate small-item predator trophic level included Rhyacophyllid caddis nymphs, Perlodid stoneflies, and damselfly nymphs in addition to the Perlid stoneflies which were most generally available. In addition to Corydalid hellgrammite nymphs, the larger-item invertebrate predator trophic level also included large predaceous dipteran larvae of the family Tipulidae and Gomphid dragonfly nymphs.

The invertebrate mercury data are presented in Table 2 and Figures 5-8. The table includes data from each of the samples, while averaging techniques were utilized to derive single trophic level values in the map figures. The averaging methods used are described above in the Methods section. Mercury was detected at ≥ 0.01 mg kg^{-1} (ppm) in all invertebrate samples taken throughout the Sierra Nevada gold country. Inter-site mercury differences were generally consistent among all invertebrate (and trout) trophic levels, with low mercury sites demonstrating low biotic Hg levels throughout the food web and sites with high biotic Hg in one group typically having elevated Hg levels in all co-occurring organisms.

Similar to the trout results, notably elevated mercury in stream invertebrates was found at sites along the Middle and South Forks of the Yuba River, and the Middle Fork of the Feather relatively low mercury watersheds. Deer Creek was unique in demonstrating significantly higher biotic mercury accumulation below a reservoir (Lake Wildwood) as compared to above (Site 35 vs 36). While both sites were relatively elevated, the higher levels found below Lake Wildwood may result from historic downstream movement of gold mining mercury in this small drainage. The lack of significant modern barriers to downstream mercury migration may be of particular concern on the Cosumnes River (Sites 56 and 57), where the very highest levels of biotic mercury accumulation were observed.

Trophic level relationships to mercury accumulation

A pattern of increasing mercury concentrations in progressively higher trophic levels was found at the majority of sites (Figure 3, Table 2). In Figures 11 and 12 we summarize the food-chain mercury data from 19 sites where trout were sampled, normalized to 250 g rainbow trout muscle concentrations at each of the sites. In Figure 11, the normalized invertebrate data are plotted with 95% confidence intervals for trophic guilds vs trout, and in Figure 12 the dominant single family or genus of each guild is used. The means and confidence intervals are similar with either analysis.

A relatively predictable pattern results, with the highest trophic level stream invertebrates having mercury concentrations approximately half those seen in normalized 250 g trout from the same sites. Among the invertebrates, herbivorous species as a group consistently had the lowest mercury concentrations (averaging 14% of those found in co-existing trout). Low mercury levels in herbivore species was not a function of age and, thus, time of exposure. Similar low concentrations were found in Pteronarcyid stoneflies up to three years old, as well as in annual mayflies. Predaceous invertebrates accumulated considerably higher concentrations. Relatively small predators such as nymphs of Perlid stoneflies, Rhyacophyllid caddisflies, and damselflies had mercury concentrations averaging 38% of the concentrations in corresponding normalized trout muscle, while the largest invertebrate predators, characterized by the large-jawed hellgrammites, averaged 47% of trout concentrations. Hydropsychid caddis nymphs, which were an important component of the invertebrate biomass at many of the sites, averaged 31% of corresponding trout in their mercury levels. This was lower than that of the larger invertebrate predators but considerably higher than the mercury concentrations seen in herbivores, suggesting that these nymphs, which feed by capturing drift in their nets, consume primarily other invertebrates rather than algal material. We believe that relative mercury concentrations in aquatic species may offer a useful tool for determining relative, time-integrated trophic feeding level.

In Figures 13-19, mercury concentrations in different trophic categories and types of invertebrates are plotted against corresponding trout mercury to determine relative correlations.

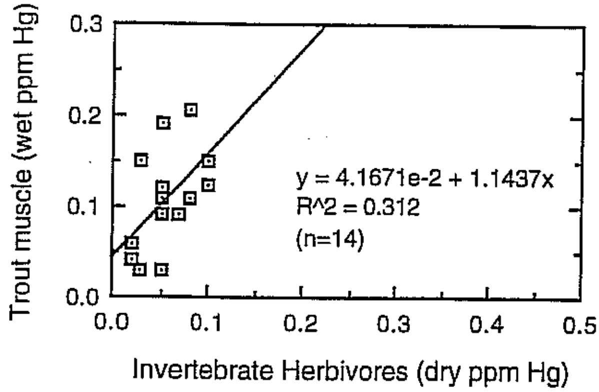


Fig. 13. Invertebrate Herbivores vs Trout

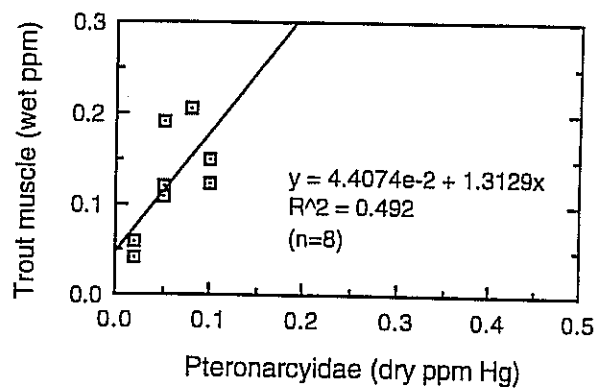


Fig. 14. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Trout

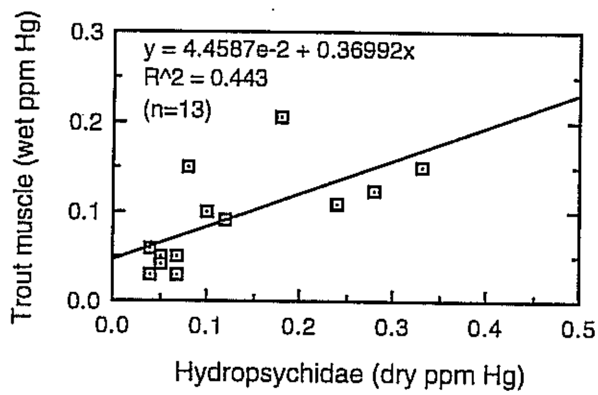


Fig. 15. Hydropsychidae (Net Collector Caddis) vs Trout

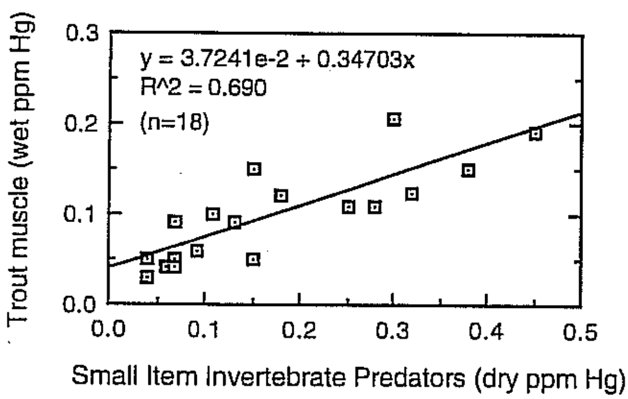


Fig. 16. Small Item Invertebrate Predators (Perlid Stoneflies, etc.) vs Trout

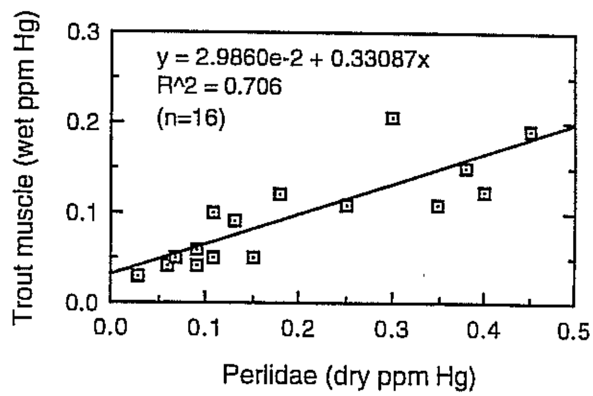


Fig. 17. Perlid Stoneflies vs Trout

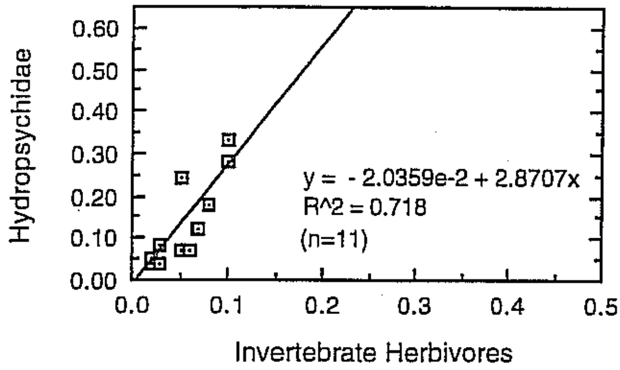


Fig. 20. Invertebrate Herbivores vs Hydropsychidae (Net Collector Caddis)

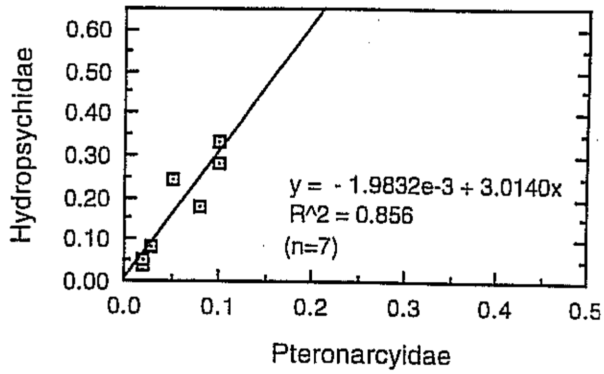


Fig. 21. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Hydropsychidae (Net Collector Caddis

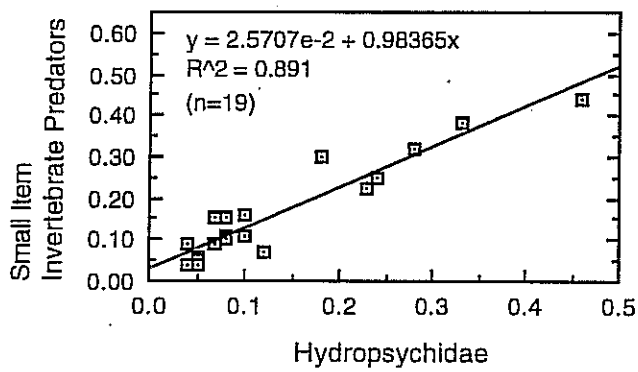


Fig. 22. Hydropsychidae (Net Collector Caddis) vs Small Item Predators (Perlid Stoneflies, etc.)

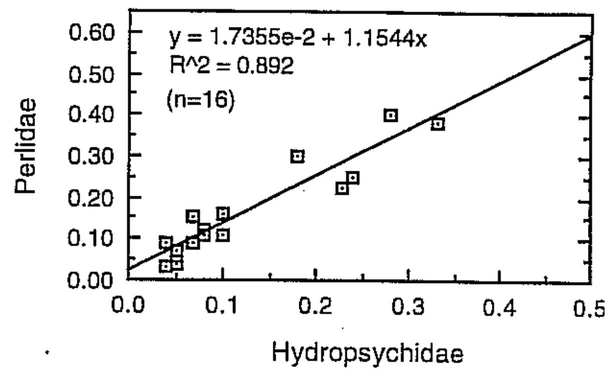


Fig. 23. Hydropsychidae (Net Collector Caddis) vs Perlidae (Predaceous Golden Stoneflies)

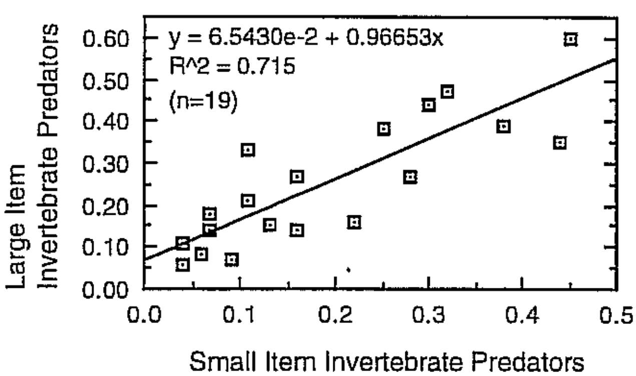


Fig. 24. Invertebrate Small Item Predators (Perlid Stoneflies, etc.) vs Large Item Predators (Hellgrammites, etc.)

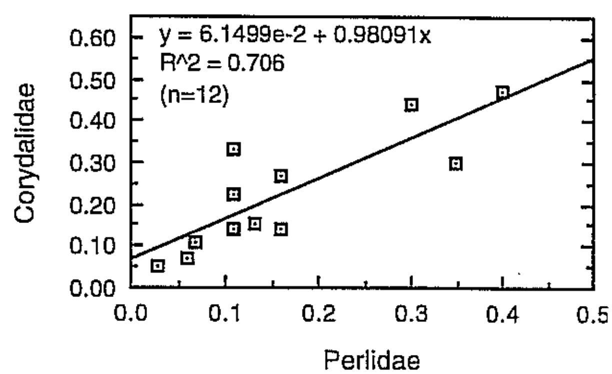


Fig. 25. Perlid Stoneflies vs Corydalid Hellgrammites

Interestingly, the R^2 correlation coefficients between invertebrates and trout taken from the same sites increased steadily with increasing invertebrate trophic feeding level. Herbivores, as a group, demonstrated the weakest correlation with corresponding trout ($R^2 = 0.31$). Hydropsychid caddis nymphs had a stronger correlation ($R^2 = 0.44$). Small predaceous invertebrates such as Perlid stoneflies had considerably tighter correlations with trout ($R^2 = 0.69$), while the highest trophic level invertebrates, characterized by Corydalid hellgrammites, demonstrated the strongest correlations with corresponding trout ($R^2 = 0.78$). Correlations between individual invertebrate family or genus and trout (figures 11, 14, and 16) were generally not significantly stronger than those using grouped trophic guild members, though this may be partially a function of lower sample size for particular invertebrates.

In Figures 20-31, correlations in mercury concentration between invertebrates are plotted, first between adjacent trophic feeding levels (Figures 20-25) and finally between more distantly separated groups (Figures 26-31). As a set, these inter-invertebrate correlations were all quite high. R^2 correlation coefficients of 0.72-0.98 were found between adjacent trophic levels (Figures 20-25) and coefficients of 0.50-0.97 were found between non-adjacent but co-occurring trophic levels (Figures 26-31).

<u>Biotic time series data</u>

A series of 5 separate collections were made throughout 1995 and early 1996 at 3 index stations, to address the question of potential seasonal shifts in biotic mercury accumulation. Data are presented in Table 4. These sites corresponded to those also used for the intensive temporal series of water collections by Larry Walker and Associates, and were all adjacent to Englebright Reservoir. One site was located below the reservoir on the Lower Yuba River (Site 16), while the other two were situated immediately above the reservoir along the two major inflowing tributaries. Site 17 was an index station located just below the Colgate powerhouse on the Middle Fork Yuba River. The Colgate powerhouse is where the majority of flow from the North Fork Yuba River is diverted into the Middle Fork, piped from the bottom of New Bullards Bar Reservoir. The North Fork flow typically dominates the total flow at this point, though releases can be erratic. The final index station (Site 28) was located along the South Fork Yuba River at Bridgeport, just above Englebright Reservoir.

Sampling for this temporal series of invertebrate bioindicator collections occurred on April 24, June 30, August 15, and November 16 in 1995, and February 16, 1996. Composite collections of 3-7 different types of benthic invertebrates were made on each of the five dates at the lower Yuba site (16) and the site on the South Fork Yuba (28). However, at Site 17 below the Colgate powerhouse, only Hydropsychid caddisfly larvae were present on the August sampling

Table 4. (continued)

identification	trophic level	Hg (dry wt ppm)
16*. Lower Yuba River at UC field station. (11/16/95)***		
Hydropsychidae	drift feeder	**0.225**
Perlodidae-med/Lg	small predator	**0.155**
Perlidae-Hesperoperla-med/Lg	small predator	**0.218**
Perlidae-Hesperoperla-giant-2 yr	small predator	**0.169**
16**. Lower Yuba River at UC field station. (2/16/96)***		
Mixed Mayflies	herbivore	**0.080**
Hydropsychidae-med/lg	drift feeder	**0.211**
Perlodidae	small predator	**0.094**

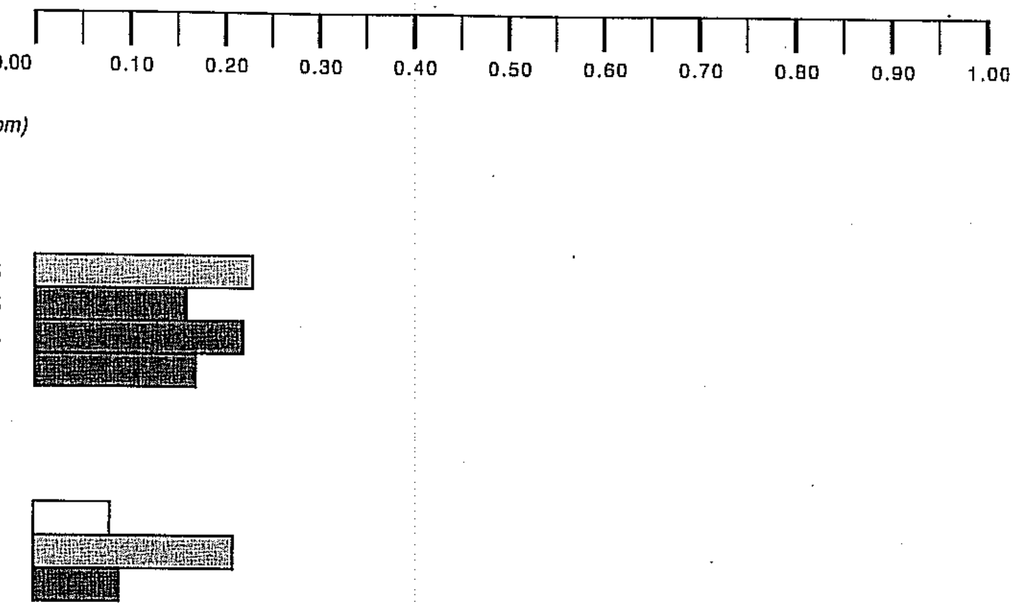
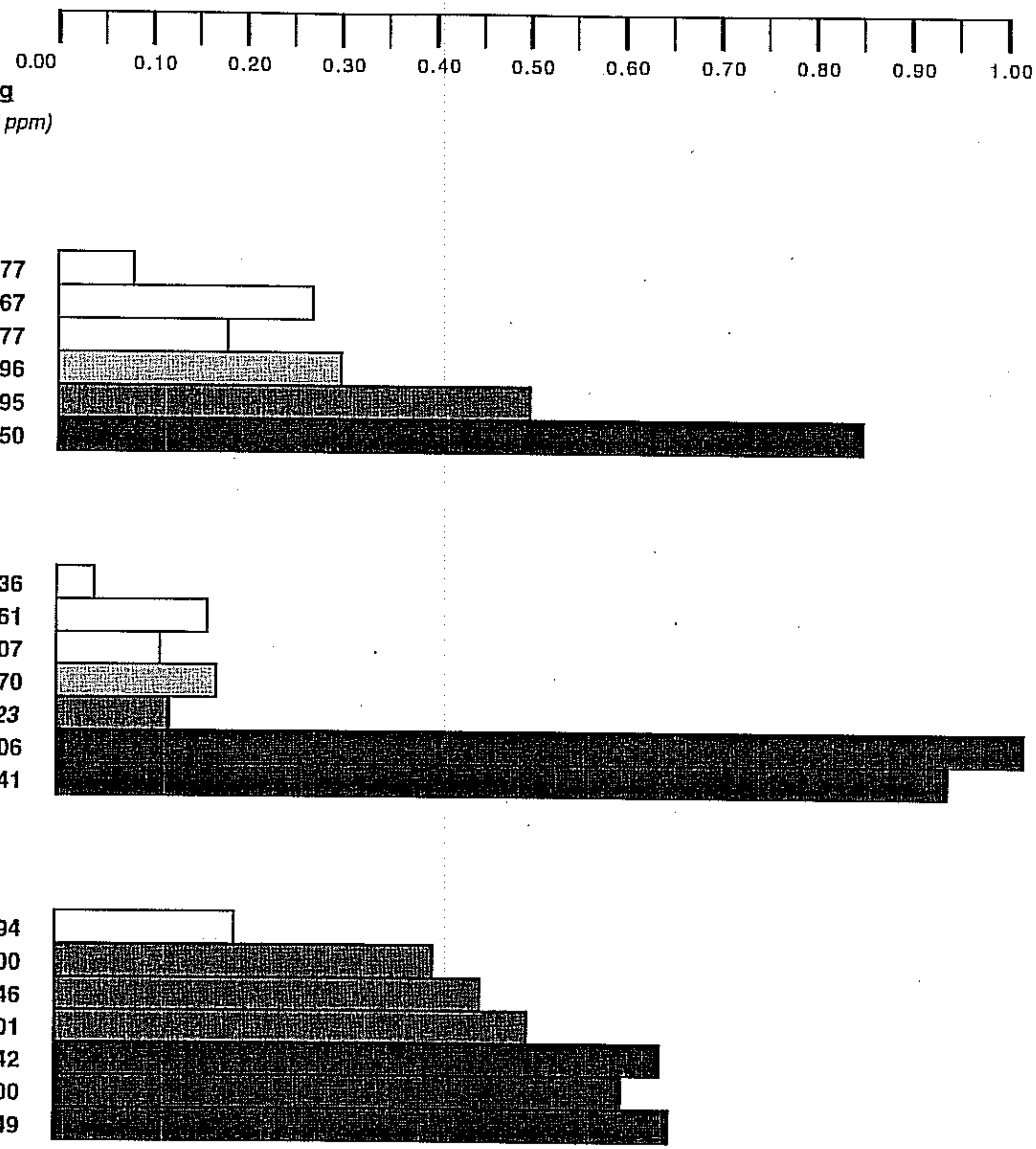


Table 4. (continued)

identification	trophic level	Hg (dry wt ppm)
28. South Fork Yuba River at Bridgeport. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	0.077
Mayflies	herbivore	0.267
Ptilodactylidae	herbivore	0.177
Hydropsychidae	drift feeder	0.296
Perlidae	small predator	0.495
Hellgrammites-lg	large predator	0.850
28. South Fork Yuba River at Bridgeport. (6/30/95)*		
Pteronarcyidae	leaf shredder	0.036
Mayflies	herbivore	0.161
Ptilodactylidae	herbivore	0.107
Hydropsychidae	drift feeder	0.170
Perlodidae-sm	Sm. Stoneflies	*0.123*
Hellgrammites-lg	large predator	1.306
Hellgrammites-giant	large predator	0.941
*28**. South Fork Yuba River at Bridgeport. (8/15/95)*		
Mixed Grazers	herbivore	0.194
Perlidae-sm/med	small predator	0.400
Perlidae-Heperoperla-med/lg	small predator	0.446
Perlidae-Heperoperla-lg/giant	small predator	0.501
Hellgrammites-sm/med	large predator	0.642
Hellgrammites-med/lg	large predator	0.600
Hellgrammites-lg/giant	large predator	0.649



date and, on subsequent samplings, the site was essentially barren. We attributed this to the unnatural mid-summer releases of very cold North Fork Yuba water from the base of New Bullards Bar Reservoir and the erratic flow regime, which varied between zero and very high flows from this cold source. When the flows from New Bullards Bar Reservoir were high, the water beneath the Colgate powerhouse was very swift and cold; when that source was shut down, the flow returned to that of the relatively warm, low flow Middle Fork Yuba. Our unsuccessful collection attempts (despite considerable sampling effort) from mid-summer through the winter indicate that the conditions at this site were too erratic to maintain a diverse community of typical benthic invertebrate fauna.

Comparing the entire data sets for each site, it is apparent that the below-reservoir site on the Yuba River (Site 16) was consistent in demonstrating significantly lower levels of mercury accumulation, throughout the trophic levels, than the sites above the reservoir. Because of a shift in species present at this site over time, it is difficult to draw conclusions with regard to potential seasonal changes in mercury accumulation here. Hydropsychid caddisfly larvae, which were present in all Lower Yuba collections, suggest a possible increase in mercury accumulation at the Lower Yuba site in the fall and winter, as integrated by the November 1995 and February 1996 samples (0.21-0.23 ppm Hg Nov-Feb vs 0.08-0.14 ppm Hg Apr-Aug). However, other sampled species did not follow any particular trend. Except for a single somewhat anomalous data point for Tipulid dipteran larvae in June 1995 (0.49 ppm), all Lower Yuba benthic invertebrate indicator samples contained ≤ 0.27 ppm mercury.

In contrast, composite samples of benthic invertebrates from the inflowing tributaries to the reservoir consistently demonstrated significantly elevated levels of mercury accumulation in most trophic levels. All samples of second order predatory invertebrates from these sites were found to contain more than 0.30 ppm mercury, with individual composites ranging to over 1.30 ppm. Comparative trout were not present at the reservoir inflow sites, though trout collected below the reservoir were far lower in mercury than were trout taken at sites where they were present further up the Forks of the Yuba within the historic gold mining region.

After seeing firsthand the large variation in flow conditions, we hesitate to form conclusions on potential temporal trends for the North Fork/Middle Fork Yuba reservoir inflow site below the Colgate powerhouse (17). Diverse samples were only available for the first two collections (April and June), during which time mercury levels appeared to drop fairly uniformly. However, because of the unique conditions at this site brought on by flow manipulations, it is unclear whether this apparent trend might be a function of different proportions of Middle Fork Yuba water being present at different times or if the invertebrates taken below the powerhouse on one or both of the significant collections might actually represent drift from the Middle Fork.

Table 5. Methyl Mercury / Total Mercury Split Data (dry weight ppm Hg)

ENGLEBRIGHT SERIES

	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
4/24/95																		
Lower Yuba	.032	.054	60.3%				.050	.141	35.5%	.085	.113	75.4%						
Colgate							.106	.163	65.0%							0.821	0.971	84.6%
S Fk Yuba				.051	.077	66.0%	.172	.296	58.0%				.442	.495	89.2%	0.611	0.848	72.0%
6/30/95																		
Lower Yuba							.077	.082	94.2%									
Colgate							.070	.094	74.5%									
S Fk Yuba																1.096	1.306	83.9%
8/15/95																		
Lower Yuba	.063	.080	78.5%				.118	.129	91.9%							0.190	0.273	69.6%
Colgate							.052	.078	66.4%									
S Fk Yuba																0.346	0.600	57.6%
11/16/95																		
Lower Yuba							.144	.225	63.8%	.154	.155	99.2%	.189	.218	86.6%			
Colgate																		
S Fk Yuba										.110	.149	73.9%	.192	.216	88.5%	0.336	0.369	91.1%
M Fk Yuba				.114	.115	99.6%	.128	.204	62.8%	.177	.177	100.4%	.239	.246	97.4%	0.311	0.411	75.6%

Fig. 32. Mean Methyl Mercury Percentages (Of Total Mercury) In Major Sierra Nevada Stream Macro-Invertebrates

(multi-individual composite samples x n composite collections with 95% confidence intervals)

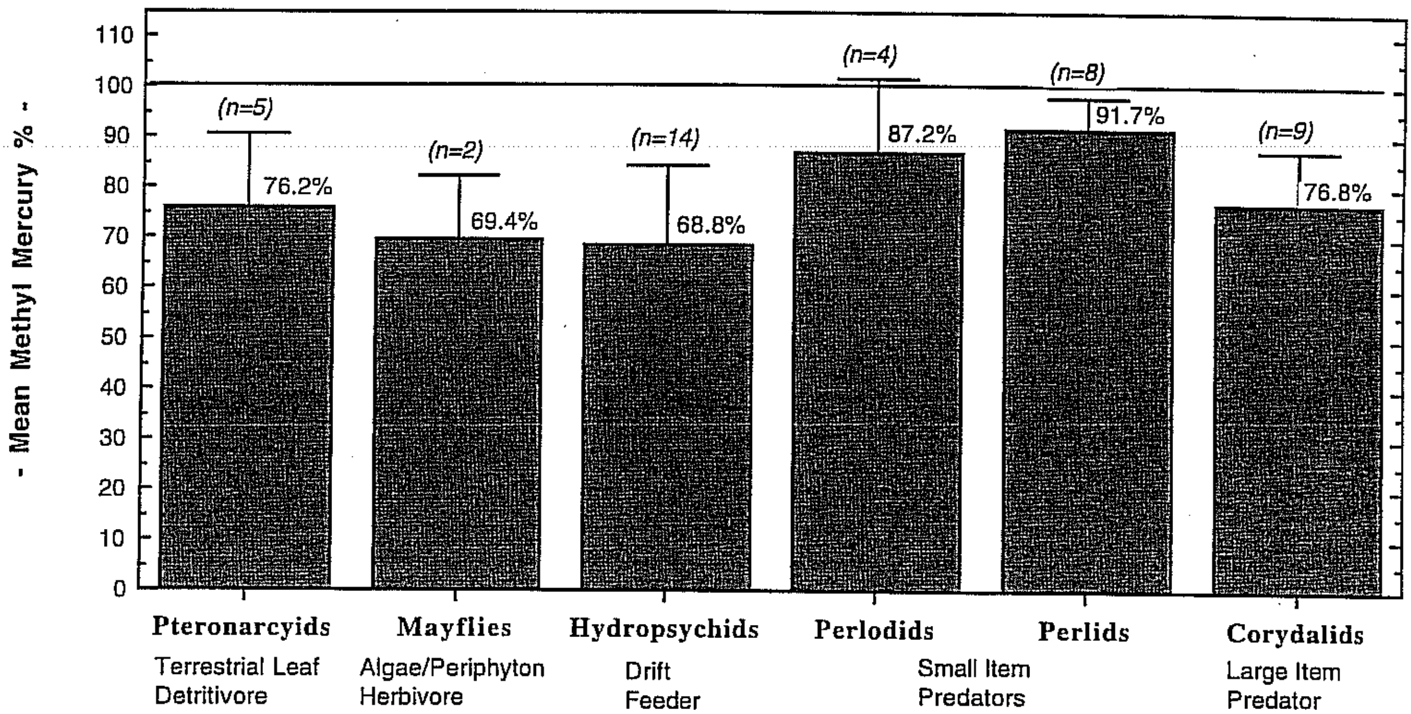


Table 6. Englebright Reservoir Fish Muscle (Filet) Mercury Concentrations (fresh/wet weight ppm Hg, July 1996)

Identification	Weight (g)	Length (mm)	Weight (lbs)	Length (inches)	Muscle Hg (wet wt ppm)
Hardhead	1,160	440	2.55	17.3	0.47
Carp	2,350	540	5.17	21.3	0.88
Sacramento Sucker	870	410	1.91	16.1	0.57
Sacramento Sucker	1,020	450	2.24	17.7	0.68
Sacramento Sucker	1,110	470	2.44	18.5	0.50
Sacramento Sucker	1,150	460	2.53	18.1	0.41
Sacramento Sucker	1,460	523	3.21	20.6	0.89
Smallmouth Bass	330	280	0.73	11.0	0.52
Largemouth Bass	390	315	0.86	12.4	0.64

Only the bass in the collection were upper level predators. However, the two individuals sampled in this collection were quite small and young. Comparably sized bass from other systems characteristically contain lower mercury accumulations than co-occurring larger adults (TSMP 1990, Slotton 1991, Slotton *et al.* 1996). The relatively elevated levels in the young smallmouth (0.52 ppm) and largemouth (0.64 ppm) bass taken in this collection are consistent with the other Englebright data in suggesting that there is a considerable amount of fish uptake of mercury in this system. However, a more comprehensive sampling should be undertaken before drawing any firm conclusion on this matter, particularly from a regulatory standpoint.

While similar fish could not be collected at both the reservoir and river sites upstream or downstream, the data indicate a significant general increase in mercury bioavailability to fish within the reservoir, even as compared to the most highly elevated upstream stretches of the Yuba River tributaries. What is most interesting is the consistently low levels of mercury accumulation, across a wide range of sizes and ages, in rainbow trout taken below Englebright Reservoir (Site 16).

having the greatest mercury concentrations that offer the most realistic options for effective mitigation work.

One important conclusion of the survey work is that the elevated mercury regions did not demonstrate a point source signature. Where biotic accumulations of mercury were elevated, this elevation was generally distributed across many miles of stream or river. The elevated bioavailable mercury regions could thus be localized to specific tributaries or series of river miles, but not to highly localized "hot spot" point sources. This is consistent with the historic widespread use of mercury throughout the gold mining region and its subsequent redistribution downstream.

Fish mercury concentrations in relation to environmental and health concerns

While these data clearly indicate the differences in relative mercury bioavailability among the various streams of the region, the absolute concentrations in rainbow trout were all well below existing health criteria. Even at the highest mercury sites, the normalized 250 g rainbow trout, fresh weight, filet muscle mercury levels were less than 50% of the 0.5 ppm guidelines suggested by the California Department of Health Services and the Academy of Sciences, and ≤ 21% of the existing U.S. FDA fish criterion of 1.0 ppm. The entire data set for 250 g normalized rainbow trout ranged between 0.03 and 0.21 mg kg^{-1} (ppm). Larger fish ranged higher but were still all within the 0.5 ppm guidelines. We conclude that there is relatively little direct health hazard associated with the consumption of rainbow trout from these Sierra Nevada streams and rivers. The notably elevated levels of mercury in edible muscle of fish from within Englebright Reservoir suggests that a problem may exist in some of the foothill reservoirs--one that may warrant additional study. The fact that this elevated mercury phenomenon was not additionally found downstream of the reservoir indicates that the foothill reservoir habitat may be trapping bioavailable mercury in addition to the bulk, inorganic mercury which deposits there with sediment.

Influence of reservoirs on downstream biotic mercury

It was expected that mercury bioavailability might be relatively low in the rivers and streams of this region, despite the presence of still considerable amounts of inorganic mercury from the gold mining era. This is because methyl mercury, the predominant form of mercury that enters and moves through the food web, requires a biological process, bacterial methylation, for the bulk of its production (Gilmour *et al.* 1992). The opportunity for bacterial mercury methylation or even the presence of significant bacterial populations is minimized in the fast moving, cold, clear water habitat typical of many of these Sierra Nevada foothill streams. However, once transported to calmer waters such as downstream reservoirs, turbid valley rivers, the Sacramento/San Joaquin Delta, and San Francisco Bay, the potential for bacterial methylation of mercury derived from the ecological research, an interesting aspect of this work is the finding that relative mercury concentrations in aquatic species may offer a useful tool for determining the relative, time-integrated trophic feeding habits of specific aquatic species.

Correlations between the mercury contents of biota of different trophic levels were similar, whether identical types of organism were used for the comparison or a variety of representatives of each trophic guild. This suggests that when identical invertebrate species are not available between sites, a variety of species within the same trophic feeding guild may be utilized as comparative general indicators of relative mercury bioavailability.

Inter-trophic mercury correlations between various groups of co-existing invertebrates were found to be uniformly stronger than mercury concentration correlations between invertebrates and corresponding trout. This is likely due to the relative site fidelity of stream invertebrates, as compared to trout, which can wander extensively throughout their lifetime accumulation of mercury.

Correlations between mercury in stream invertebrates and mercury in co-occurring trout were stronger with increasing invertebrate trophic level. Predatory invertebrate species such as Perlid stoneflies and Corydalid hellgrammites were found to be the best indicators of corresponding trout mercury levels. The excellent correspondence between larger, predaceous invertebrates and co-occurring trout may be a function of similar diet and, particularly in the case of the large hellgrammites, similar ages and thus similar periods of mercury integration. Mercury in smaller, younger organisms such as most mayflies, Hydropsychid caddis nymphs, and young predators may not correlate as well with trout mercury, but may instead be a better indicator of shorter term conditions of mercury bioavailability. Under potentially dramatic seasonally or annually changing conditions of mercury bioavailability, changes will be far less pronounced in older organisms as compared to more ephemeral species, for which the most recent time period represents a larger proportion of the entire lifetime accumulation (Slotton *et al.* 1995b). Thus, different organisms may be utilized for different types of information. Trout mercury is of direct interest for health reasons and provides a general indicator of regional, long-term mercury availability. Larger predaceous species may be utilized as surrogates for trout. The larger/older invertebrates of all types provide localized, long-term integration of relative mercury availability, when same types are compared. Finally, smaller/younger invertebrates can potentially be used as integrators of mercury conditions over shorter time scales. Ongoing research by our U.C. Davis Heavy Metals Limnology Group is investigating all of these areas.

Future Considerations

Stream invertebrates appear to be appropriate indicators for determining relative, time-integrated mercury bioavailability between sites throughout the Sierra Nevada gold region.

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APPENDIX C

CONTROL STRATEGY EVALUATIONS

Mercury control strategy alternatives selected as potentially appropriate for the study area were evaluated using the following criteria. Criteria and subjective rankings are summarized in Table C-1. A summary of the results of control strategy evaluations is presented in Table C-2. Individual evaluations and discussion of the selected control strategies are presented following Table C-2.

Accessibility of Mercury: Where (and in what form and concentrations) is mercury accessible in the study area? Is mercury localized and concentrated or diffuse and widely distributed? For the purpose of source control evaluations, mercury present in the study area was partitioned into the following categories:

- Elemental mercury (i.e. quicksilver), present primarily among streambed sediments near or downstream from historical mining areas.
- Particulate (sediment-bound) inorganic mercury associated with riparian zone or instream sediments.
- Particulate and dissolved mercury in the water column.
- Mercury in biota.

Source Data Sufficiency: Are available data for mercury sources sufficient to implement the control strategy? Are additional data required?

Limitations of Controls: What are the primary factors limiting the effectiveness of the control strategy? How severely do these factors limit effectiveness?

Potential Benefits of Control Strategy: What are the expected benefits (both in the study area and in the Sacramento River downstream) of implementing the control strategy. Specifically:

- What is the estimated percentage of mercury loads removed (or controlled) by source control(s)?
- Would implementation of the controls result in significant increases in beneficial uses?

Potential Impacts of Source Controls: Are there potentially significant environmental or economic impacts associated with control strategy implementation? How severe are the expected impacts?

Costs: What is the expected relative cost of the mercury control strategy? Is the expected cost per kilogram of mercury controlled higher or lower than for other strategies?

Table C-2. Summary of control strategy evaluations.

evaluation criteria	Control Strategies: Hg recycl ing	tailings reclama-tion	tailings removal	stream channel dredging	reservoir dredging	reservoir operation changes	H_2O treatment facilities	mining regula-tion
% of in-place Hg sources removed or controlled	2	3	2	3	3	3	3	3
Is Hg source data sufficient to implement strategy?	1	2	2	3	2	1	1	1
impacts of implementation in study area	1	1	3	3	3	3	2	3
decrease in study area Hg loads and concentrations	2	2	2	3	3	3	3	3
increase in study area beneficial uses	3	2	3	3	3	3	3	3
decrease in Sacramento River Hg loads	2	2	2	3	3	2	2	3
increase in Sacramento River beneficial uses	3	3	3	3	3	3	3	3
relative cost per unit of mercury controlled	1	2	3	3	3	3	3	3
value as pilot or demonstration project	2	2	3	3	3	3	3	3
unweighted average:	**1.9**	**2.1**	**2.6**	**3**	**2.9**	**2.7**	**2.6**	**2.8**

Costs • $/kg compared to other controls *Rank: 2*	Primary expected costs of this alternative include: • locating and prioritizing hydraulic mining tailings suitable for reclamation • stabilization of tailings in lower riparian zone • vegetative reclamation of tailings Summary: It is expected that this option would result in a moderate cost per kg of mercury controlled.
Relevance • pilot project value outside of study area *Rank: 2*	If successful, this alternative could also be implemented effectively in other regions with substantial mercury-enriched mining tailings subject to erosion, particularly in regions with inactive historic mercury mines. However, while implementation would provide data specific to the effectiveness of mercury control, information is already available on controlling metal pollution from mine tailings drainage by similar methods. Summary: Moderate pilot project value outside of study area

Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • locating hydraulic mining tailings suitable for recovery • recovery and transport of tailings • storage/disposal of recovered tailings • mitigation of local environmental impacts Summary: It is expected that this option would result in the relatively high cost per kg of mercury removal.
Relevance • pilot project value outside of study area *Rank: 3*	If successful, this alternative could also be implemented effectively in other regions with substantial mercury-enriched mining tailings subject to erosion, particularly in regions with inactive historic mercury mines. Summary: Low pilot project value outside of study area

Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • developing access to hundreds of miles of stream bed • dredging of up to hundreds of miles of streams • disposal of dredgings (as hazardous waste?) • Environmental Impact Assessment Summary: It is expected that this option would result in very high cost per kg of mercury removed from the study area.
Relevance • pilot project value outside of study area *Rank: 3*	Although this control strategy could be implemented in other regions with substantial mercury-enriched instream sediments, there is already adequate information available to evaluate this alternative. Benefits, impacts and costs would probably be similar in other regions. Implementation in the study area would not develop any additional information useful in evaluating this alternative. Summary: Low pilot project value outside of study area.

Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • regular/annual dredging operations • disposal of dredged materials Summary: It is expected that this option would result in a relatively high cost per kg of mercury removed from the study area.
Relevance • pilot project value outside of study area *Rank: 3*	Although this alternative could be implemented effectively in other regions with substantial mercury-enriched reservoir sediments, there is already adequate information available to evaluate this alternative. Benefits, impacts, and costs would be similar in other regions. Implementation in the study area would probably not develop any additional information useful in evaluating this alternative. Summary: low pilot project value

Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • developing new reservoir operational models • increased frequency of reservoir maintenance • loss of revenues from water and power supply operations Summary: It is expected that this option would result in a high cost per kg of mercury controlled or removed from the study area.
Relevance • pilot project value outside of study area *Rank: 3*	This alternative could be implemented effectively in other regions with substantial mercury-enriched suspended sediments in surface waters upstream from major reservoirs. However, there is probably already adequate information available to evaluate this alternative for other regions. Benefits, impacts, and costs would likely be similar in other regions. Implementation in the study area would not develop additional information useful in evaluating this alternative. Summary: low pilot project value outside of study area

Relevance • pilot project value outside of study area *Rank: 3*	Although this alternative could be implemented in other regions with substantial mercury-enriched surface water, there is already adequate information available to evaluate this alternative. Benefits, impacts, and costs would likely be similar in other regions. Implementation in the study area would not develop any additional information useful in evaluating this alternative. Summary: low pilot project value

Downstream Benefits • loading and instream concentrations • beneficial uses *Rank (loading): 3* *Rank (uses): 3*	No decrease in average annual loads or mercury concentrations in the Sacramento River. Would not result in a significant increase in the ability to support beneficial uses.
Costs • $/kg compared to other controls *Rank: 3*	Primary expected costs of this alternative include: • development of new regulations • implementation and enforcement • mitigation of economic impacts (?) Summary: Because of the negligible reduction in mercury loads, it is expected that this option would result in a relatively high cost per kg of mercury controlled.
Relevance • pilot project value outside of study area *Rank: 3*	Few (if any) other mercury-rich regions support small-scale mining activity at the levels occurring in the study area. For this reason, the relevance of this alternative to other regions is extremely limited. Economic impacts would probably be lower in other regions, while the relative costs of mercury control would likely be higher. Summary: low pilot project value outside of study area

Costs • $/kg compared to other controls *Rank: 1*	Primary expected costs of this program include: • development of public education and promotional materials for program • cost of equipment for storage and transport of recovered mercury Summary: It is expected that this option would result in a relatively low cost per kg of mercury removed from the study area.
Relevance • pilot project value outside of study area *Rank: 2*	This alternative could be implemented successfully in other regions where elemental mercury was used in historical gold mining activity (although there are few other historical gold or mercury mining regions that currently support small-scale mining activity at the levels occurring in the study area.) However, this strategy could serve as a model for agency and special interest group cooperation for resolving other watershed related issues. Although the control strategy described is specific to mercury, he program could probably not be successfully transferred outside of the study area, due primarily to the lack of high concentrations of easily accessible elemental mercury outside of the historical gold mining region. Summary: Moderate pilot project value outside of study area

APPENDIX D:

PROJECT QAPPs