Occurrence of Arsenic in the Dry Creek Basin, Sonoma County, California

U.S. GEOLOGICAL SURVEY
Water Resources Investigations 76-30

Prepared in cooperation with the
U.S. Army Engineer District,
San Francisco, Corps of Engineers

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle OCCURRENCE OF ARSENIC IN THE DRY CREEK BASIN, SONOMA COUNTY, CALIFORNIA			5. Report Date May 1976
			6.
7. Author(s) R. F. Middelburg			8. Performing Organization Rept. No. USGS/WRI 76-30
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division California District 345 Middlefield Road Menlo Park, California 94025			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division California District 345 Middlefield Road Menlo Park, California 94025			13. Type of Report & Period Covered Final
			14.

15. Supplementary Notes

Prepared in cooperation with the U.S. Army Engineer District San Francisco, Corps of Engineers

16. Abstracts

An arsenic reconnaissance study was made from August through November 1974 in the Dry Creek basin in northern California where the U.S. Army Corps of Engineers proposes to construct Warm Springs Dam. The purpose was to determine the extent of any potential arsenic problems that may affect Lake Sonoma which would form behind the dam. Samples of sediment, water, and biota were collected and analyzed for arsenic content. Results indicate that arsenic presents a potential problem only in the Little Warm Springs Creek area where samples of geothermal water contained 140 micrograms of arsenic per litre of water. However, the contribution of arsenic to the lake will be minimal because discharge of the geothermal water in the area is estimated to be only about 0.01 cubic foot per second (0.0003 cubic metre per second). Analyses of limited numbers of biota samples indicated that there is no biomagnification of arsenic through the food chain. Concentrations of arsenic in biota were similar both in samples collected from water containing high levels of arsenic and those collected from water with low arsenic content.

17. Key Words and Document Analysis. 17a. Descriptors

*Arsenic, *Water Quality, California, Springs, Hot Springs

17b. Identifiers/Open-Ended Terms

Lake Sonoma, Sonoma County

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 22
No restriction on distribution	20. Security Class (This Page UNCLASSIFIED	22. Price

OCCURRENCE OF ARSENIC IN THE DRY CREEK BASIN, SONOMA COUNTY, CALIFORNIA

By R. F. Middelburg

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 76-30

Prepared in cooperation with the
U.S. Army Engineer District,
San Francisco, Corps of Engineers

May 1976

UNITED STATES DEPARTMENT OF THE INTERIOR

Thomas S. Kleppe, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

For additional information write to:

District Chief
Water Resources Division
U.S. Geological Survey
345 Middlefield Rd.
Menlo Park, Calif. 94025

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric*
acre-ft (acre-feet)	1.233×10^{-3}	hm^3 (cubic hectometres)
ft (feet)	3.048×10^{-1}	m (metres)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic metres per second)
gal/min (gallons per minute)	6.308×10^{-2}	l/s (litres per second)
in (inches)	2.540×10^{1}	mm (millimetres)
mi (miles)	1.609	km (kilometres)
mi^2 (square miles)	2.590	km^2 (square kilometres)

OCCURRENCE OF ARSENIC IN THE DRY CREEK BASIN,

SONOMA COUNTY, CALIFORNIA

By R. F. Middelburg

ABSTRACT

A reconnaissance study was made of occurrence of arsenic in the Dry Creek basin in northern California where the U.S. Army Corps of Engineers proposes to construct Warm Springs Dam. The purpose of the study, made from August through November 1974, was to determine the extent of any potential arsenic problems that may affect Lake Sonoma which would form behind the dam. Samples of sediment, water, and biota were collected and analyzed for arsenic content.

Results of the study indicate that arsenic presents a potential problem only in the Little Warm Springs Creek area. Samples of the geothermal water from that area contained 140 micrograms of arsenic per litre of water--almost two and one-half times the maximum allowable concentration for drinking water. However, the contribution of arsenic to the proposed lake would be minimal because discharge of the geothermal water in the area is estimated to be only about 0.01 cubic foot per second (0.0003 cubic metre per second).

Analyses of limited numbers of biota samples indicated that there is no biomagnification of arsenic through the food chain. Concentrations of arsenic in fish and benthic invertebrates collected from water containing high levels of arsenic were similar to concentrations in samples collected from water with low arsenic content. Concentrations of arsenic on sediment were low throughout the project area.

INTRODUCTION

The U.S. Army Engineer District, San Francisco, Corps of Engineers, proposes to construct Warm Springs Dam on Dry Creek in Sonoma County, California. The reservoir formed by the dam (Lake Sonoma), would inundate a geothermal springs area called Skaggs Springs. Natural deposits of arsenic are found in and near the springs, and several organizations concerned about environmental effects have opposed the project, citing possible hazards from the arsenic.

The Corps of Engineers asked the U.S. Geological Survey to determine if potentially hazardous concentrations of arsenic exist in water, sediment, and biota in the area. A reconnaissance survey was made from August through November 1974 to evaluate the presence of arsenic in the proposed Lake Sonoma area. This report summarizes the results of that reconnaissance.

Purpose and Scope

The purpose of this reconnaissance study was to determine the concentration of arsenic in water, sediment, and biota of the study area and to make recommendations for further studies if potentially hazardous concentrations were found.

The study was confined to the proposed Lake Sonoma drainage basin (fig. 1) and one site on Dry Creek downstream from the Warm Springs damsite. More intensive sampling was done in the vicinity of Skaggs Springs, where natural deposits of arsenic occur.

Arsenic in the Environment

Arsenic can be found in measurable amounts in rock, soil, sediment, and water. The natural concentration of arsenic in rocks is low--about 2 mg/kg[1] (milligrams per kilogram) in igneous rocks, 10 mg/kg in shales, and 1.5 mg/kg in sandstone and limestone (Ferguson and Gavis, 1972). Shacklette and others (1974) found an average arsenic concentration of 7.4 µg/g in soils and surficial materials in the conterminous United States. World-wide data suggest that river water generally contains arsenic (in solution or as part of the sediment load) in concentrations ranging from 0 to 10 µg/l, with an average of 1 µg/l (Ferguson and Gavis, 1972).

[1]One mg/kg equals 1 µg/g (microgram per gram). One µg/g equals 1 ppm (part per million).

Arsenic toxicity is related to its valence state. For example, the trivalent state (As^{+3}) is considerably more toxic than the pentavalent state (As^{+5}). Conditions that favor chemical and biological oxidation, common in natural water, promote the shift to the pentavalent state. Reducing conditions, common in anaerobic sections of lakes, will shift the equilibrium to the trivalent state (Environmental Protection Agency, 1972). The excretion rate from the body seems to play an important role in the toxicity of arsenic. The pentavalent, inorganic state is rapidly excreted and is also the least toxic. The more toxic trivalent state is excreted less rapidly than the pentavalent state.

In water containing arsenic, aquatic organisms tend to accumulate arsenic in their bodies. However, the concentration of arsenic in tissue tends to be about the same at all trophic levels, indicating arsenic is not concentrated upward (biomagnified) through the food chain (Ferguson and Gavis, 1972).

Arsenic has been suspected of being carcinogenic. However, recent studies indicate that arsenic is not carcinogenic at levels found in most aquatic environments (Environmental Protection Agency, 1972). Frost (1967) thoroughly reviewed this matter and has concluded that arsenicals are remarkably free of carcinogenic properties.

The Environmental Protection Agency (1972) has proposed a public water-supply criterion for arsenic of 0.1 mg/l (milligrams per litre); the new "Interim Primary Drinking Water Standards" proposed by the Environmental Protection Agency (1975) and the allowable limit recommended by the Public Health Service for drinking water is 0.05 mg/l (U.S. Public Health Service, 1962). The Environmental Protection Agency (1972) has suggested an arsenic limit of 0.2 mg/l for drinking water for livestock. It also proposed an arsenic criterion for marine aquatic life but gave none for freshwater aquatic life. It suggested the following arsenic criteria for marine aquatic life, based on freshwater and marine toxicity data: 0.05 mg/l of arsenic constitutes a hazard; levels less than 0.01 mg/l present minimal risks.

DESCRIPTION OF STUDY AREA

The Dry Creek basin is in northern Sonoma and southern Mendocino Counties. Drainage from the 130 mi^2 (340 km^2) basin (measured at the proposed damsite) is southeastward into the Russian River (fig. 1). The proposed Warm Springs Dam would be an earthfill structure 319 ft (97 m) high, at the confluence of Warm Springs Creek and Dry Creek (fig. 2), 14.4 mi (23.2 km) upstream from the confluence of Dry Creek and the Russian River (fig. 1). Skaggs Springs, Skaggs Springs mercury mine, and an abandoned mercury test adit, all located along Little Warm Springs Creek (fig. 3), are within the area that would be flooded by Lake Sonoma.

Hydrology

Numerous springs and seeps occur throughout the area. Many of them have been used as domestic or livestock water supplies. Two geothermal-springs areas are within the project area. The Skaggs Springs area (23 and unnumbered)[2] is on Little Warm Springs Creek (fig. 3), and Cooley Ranch Hot Springs area (1)[3] is near Dry Creek just upstream of its confluence with Galloway Creek (fig. 2). Skaggs Springs would be inundated by Lake Sonoma; Cooley Ranch Hot Springs would not.

The Skaggs Springs area was developed into a hot springs resort in 1857; the resort was subsequently abandoned during the 1930's. At the Cooley Ranch Hot Springs a concrete cistern has been built about the spring, and some water has been diverted to a bath house. Adjacent to the springs are numerous seeps which are alined in north-south direction.

An abandoned, exploratory oil well, Skaggs well (26), is near the mouth of Little Warm Springs Creek (fig. 3). The well is a flowing geothermal well. Methane gas is bubbling up the well and at one time was piped to an adjacent cabin and used for cooking and heating.

As a part of a cooperative program with the Corps of Engineers, the Geological Survey is currently operating four surface-water gaging stations within the study area (figs. 1 and 2).

1. Dry Creek near Geyserville (11465200, drainage area 162 mi^2 or 420 km^2) is 2 mi (3 km) downstream from the proposed damsite. The station was established in October 1959 and has recorded a 14-year average discharge of 322 ft^3/s (9.1 m^3/s) or 233,300 acre-ft (287.7 hm^3) per year. Periodic water-quality samples are collected at this station.

2. Dry Creek near Cloverdale (11464500, drainage area 87.8 mi^2 or 227 km^2) is about 6 mi (10 km) downstream from the station Dry Creek near Yorkville and was established in October 1941. It has recorded a 32-year average discharge of 161 ft^3/s (4.6 m^3/s) or 116,600 acre-ft (143.8 hm^3) per year.

---

[2]Numbers in parentheses correspond to sampling sites shown in figures 2 and 3 and listed in table 1.

[3]Also known as Hoods Hot Springs and Fairmount Hot Springs (Waring, 1915).

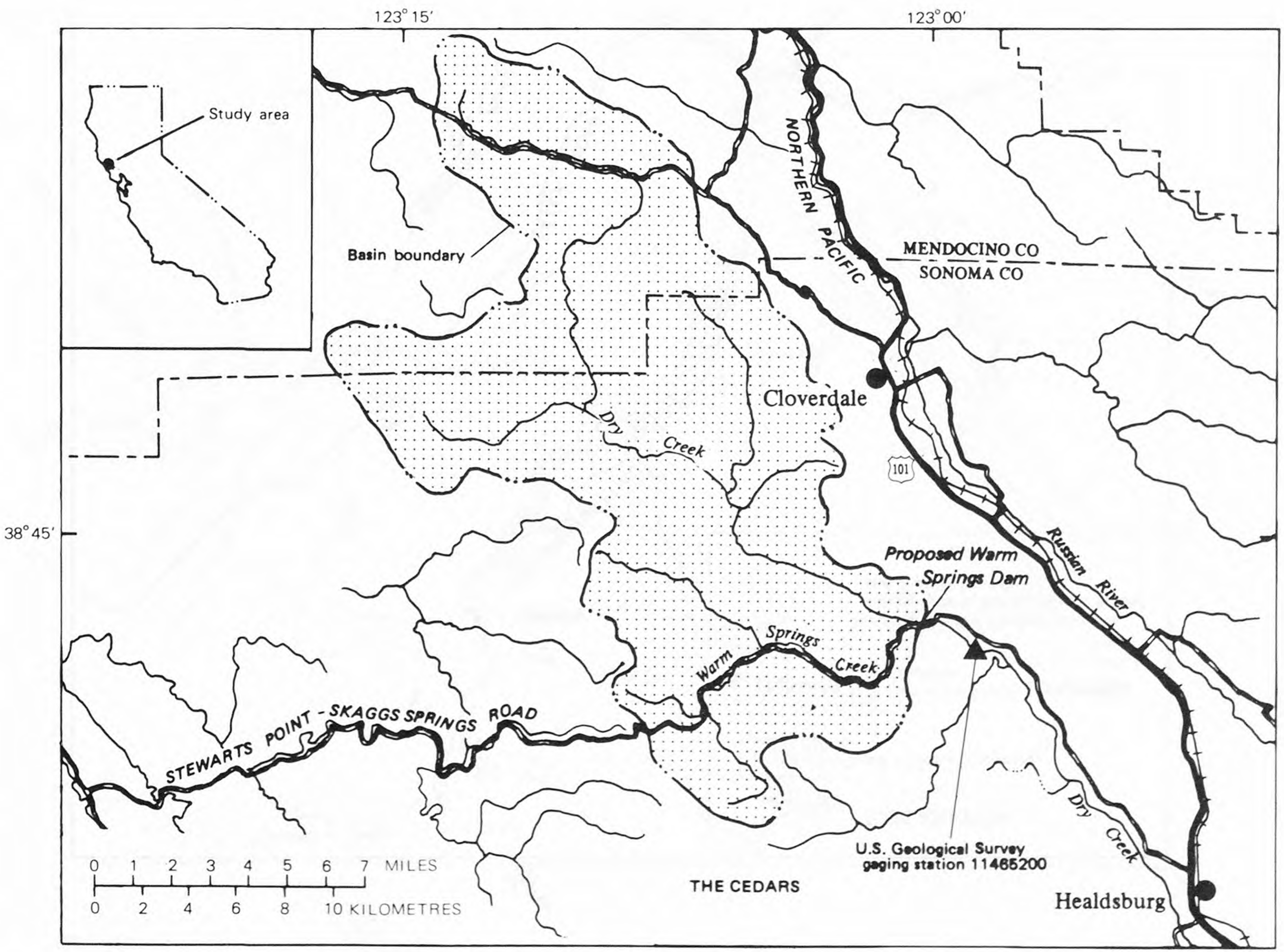
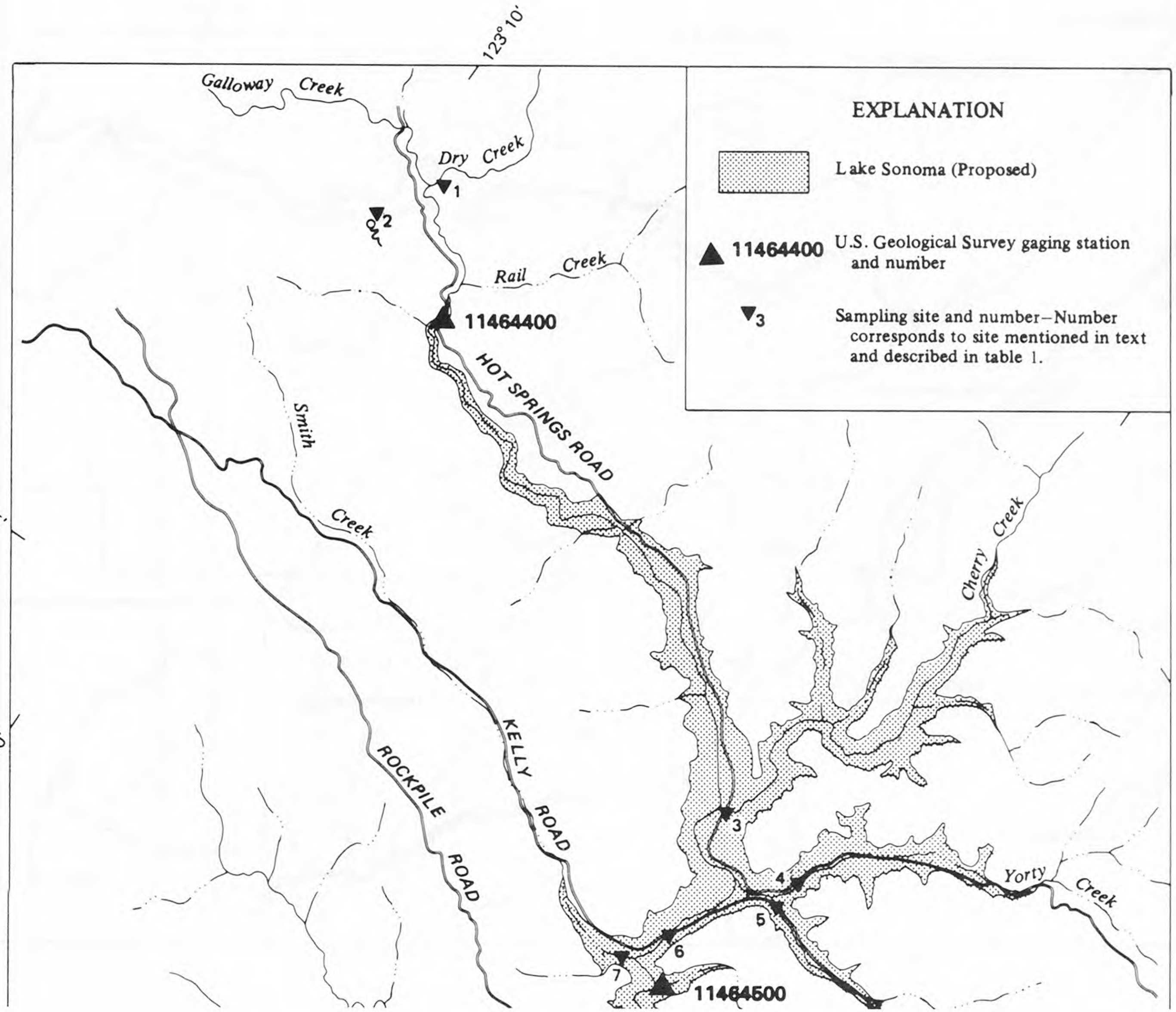


FIGURE 1.--Lake Sonoma drainage basin.


EXPLANATION
Lake Sonoma (Proposed)
11464400 U.S. Geological Survey gaging station and number
3 Sampling site and number–Number corresponds to site mentioned in text and described in table 1.
123°10′
38°45′
Galloway Creek
Dry Creek
Rail Creek
Smith Creek
Cherry Creek
Yorty Creek
HOT SPRINGS ROAD
KELLY ROAD
ROCKPILE ROAD
11464400
11464500
1
2
3
4
5
6
7

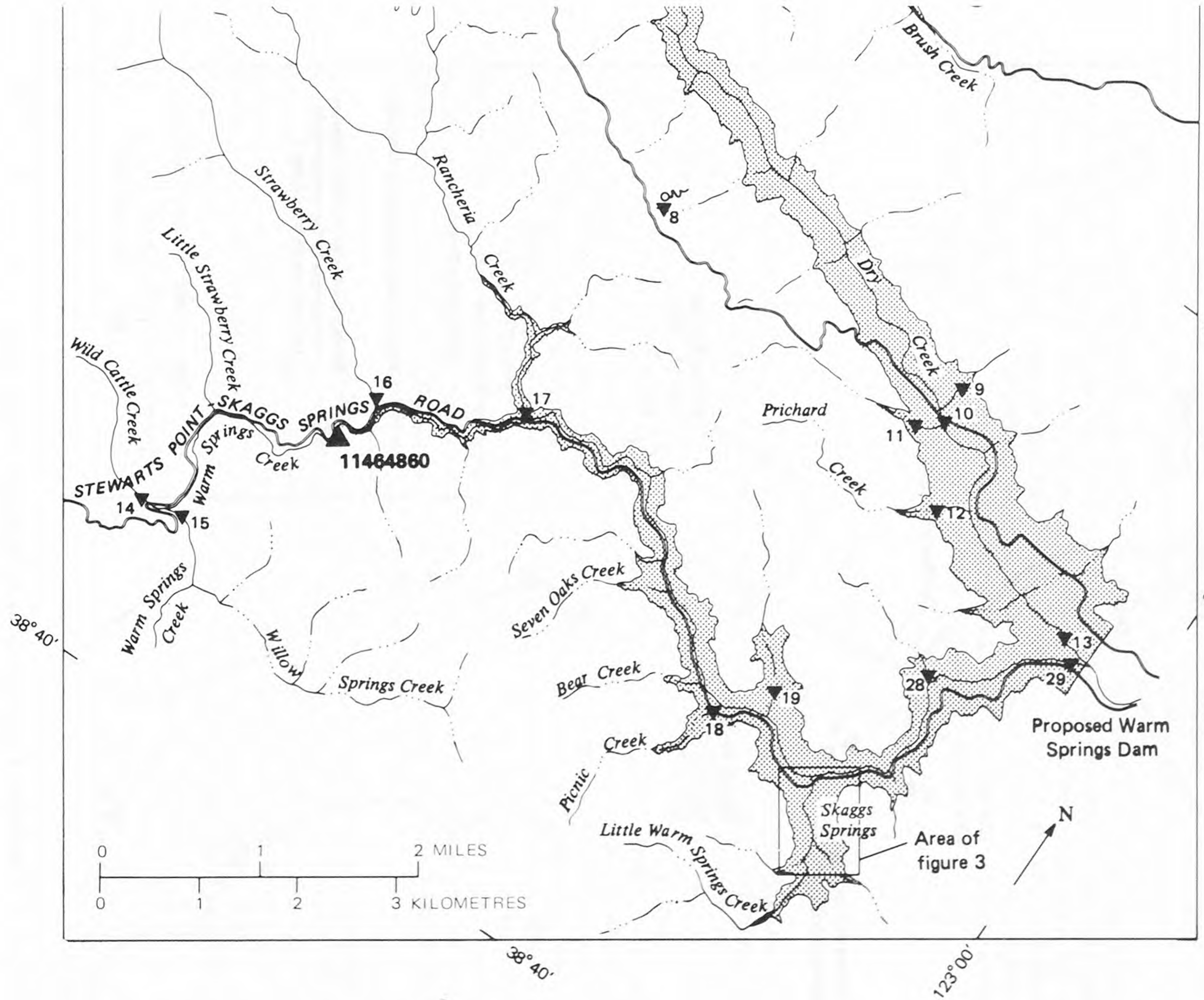


FIGURE 2.--Lake Sonoma study area, location of major tributaries, gaging stations, and sampling sites.

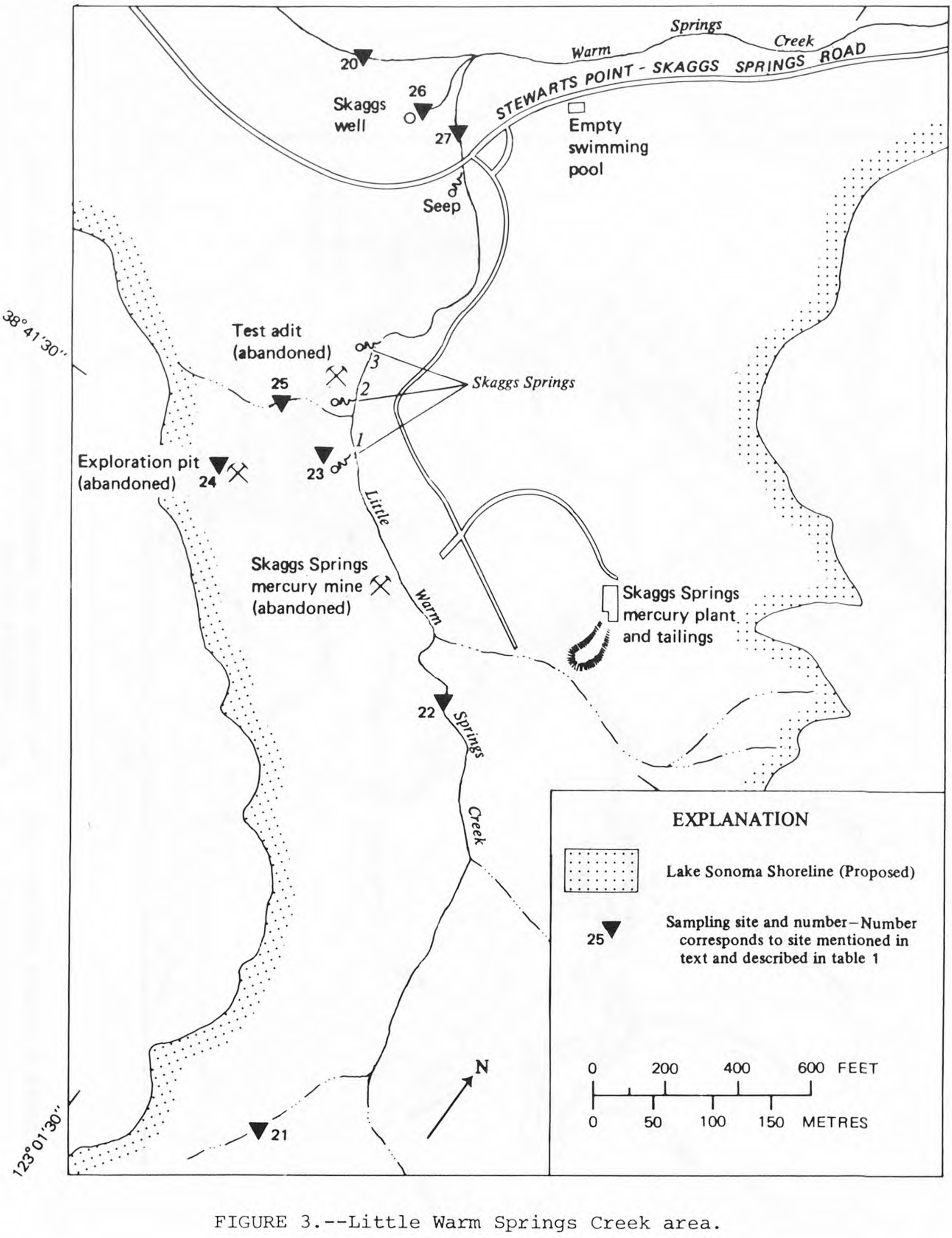


FIGURE 3.--Little Warm Springs Creek area.

3. Warm Springs Creek near Asti (11464860, drainage area 12.2 mi^2 or 31.6 km^2) is a new station established in August 1973. It is located above the maximum proposed reservoir level.

4. Dry Creek near Yorkville (11464400, drainage area 56.0 mi^2 or 145 km^2) is also a new station, established in September 1973 and also above the maximum proposed reservoir level.

The station Dry Creek near Cloverdale (11464500) would be inundated by Lake Sonoma so it would be discontinued before the reservoir was filled. The two new stations gage runoff from 52 percent of the area tributary to the reservoir. Periodic water-quality samples are collected at three temporary sites in the area: Dry Creek at Rockpile Road, Warm Springs Creek above Little Warm Springs Creek, and Little Warm Springs Creek at mouth. These sampling sites (10, 20, 27,) are shown in figures 2 and 3.

Geology

The rocks of the area are generally geosynclinal marine deposits called the Franciscan assemblage and Great Valley sequence (Bailey and others, 1964). Structural trends in the area are southeast. It is underlain by Franciscan graywacke, shale, chert, and conglomerate. Laced through the Franciscan sedimentary rocks of Cretaceous(?) age are Franciscan volcanic and metavolcanic rocks, predominantly greenstone basalt and diabase. Mesozoic ultrabasic intrusive rocks of serpentine, peridotite, and other altered serpentine rocks are also present (Koenig, 1963). There are few ore-bearing rocks. The only ore deposits that were mined commercially are in the southern part of the Warm Springs Creek basin. Mercury was mined at the Skaggs Springs mine from a large block of sandstone and shale of Cretaceous(?) age (Everhart, 1950). The chief mineral mined was metacinnabar (HgS), which is finely disseminated throughout the sandstone. Also associated with it are cinnabar (HgS) and curtisite ($C_{24}H_{18}$). Curtisite is a yellow, crystalline hydrocarbon that was originally discovered in the Skaggs Springs area.

Arsenic has been found in the deeper layers of the Skaggs Springs mine mostly as reddish crystals of realgar (AsS) (fig. 4). To a lesser extent, orpiment (As_2S_3), a common alteration of realgar, is found. Realgar normally occurs as a minor constituent in hydrothermal sulfide veins which are present along the lower stretch of Little Warm Springs Creek. Realgar and metacinnabar can be found in many of the outcrops exposed in the hydrothermal zones along the creek (fig. 5).

FIGURE 4.--Realgar crystal (AsS) in Cretaceous(?) sandstone. Sample was collected from an outcrop on the west slope of Little Warm Springs Creek at Skaggs Springs. The crystal is approximately 0.012 inch (0.3 mm) by 0.146 inch (3.7 mm).

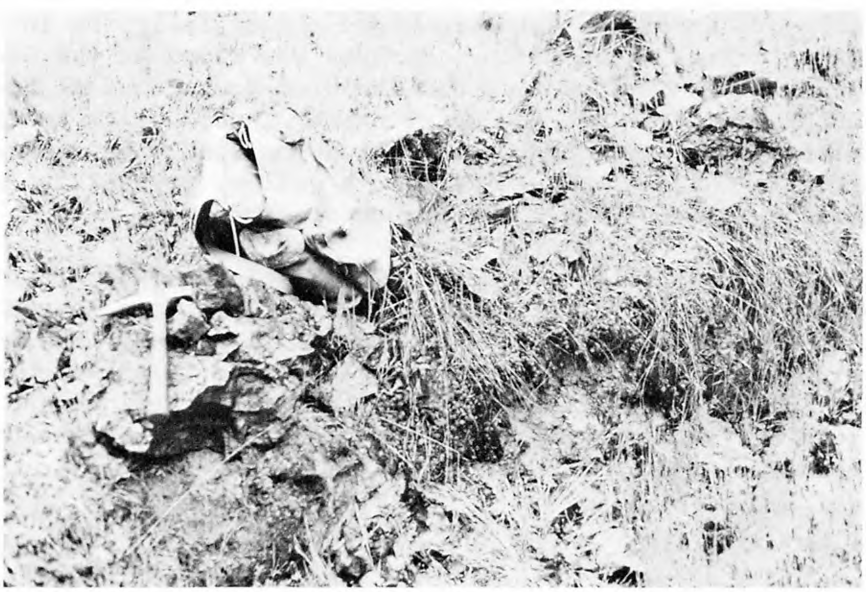


FIGURE 5.--Cretaceous(?) sandstone outcrop where orangish-red crystals of realgar (AsS) were found.

METHODS

From August through November 1974 field reconnaissances were made to sample for arsenic concentrations in the water, sediment, and biota throughout the Dry Creek basin. A total of 78 samples was collected at 31 sites. The sampling locations were mostly at the mouths of major streams for better definition of possible arsenic sources. Locations of the sampling sites are shown in figures 2 and 3. The results of the analyses are given in tables 1 and 2. The samples were analyzed at the U.S. Geological Survey Central Laboratory, Salt Lake City, Utah, and the U.S. Geological Survey Biological Laboratory, Doraville, Ga.[4] Water samples were analyzed for total arsenic, and therefore the samples were not filtered to remove suspended materials. However, very little suspended material was present at the time of sampling, and care was taken not to agitate the bed material during sampling. To determine the concentration of arsenic in water, all arsenic compounds were digested and reduced to arsine (AsH_3). The arsine was then injected into a hydrogen flame, and the arsenic concentration was determined by atomic absorption.

Bed material was sampled at several points across the stream channel and analyzed to determine concentrations of arsenic adsorbed on sediments. Efforts were made to collect fine-grained material rather than larger material such as gravel because the amount of adsorption of trace elements on sediments depends to a large degree on the surface area available. Fine-grained sediments have more surface area per unit volume than larger, coarse-grained material. Therefore, if arsenic is present it is more likely to be detected on the fine-grained material than on the coarse. To determine concentrations of arsenic on the sediment, the arsenic compounds were leached from the sediments by an acid digestion, then the liquid was analyzed using the same method as for the water samples.

Samples of algae were collected from Skaggs Springs (23) and Cooley Ranch Hot Springs (1). At Dry Creek near Geyserville (11465200) a periphyton (attached microorganisms) sample was collected on a strip of plastic and analyzed. After identifiying the dominant species a composite biomass sample was digested and analyzed by the methods previously described.

---

[4]The precision of measuring arsenic concentrations in water and on sediment is about 20 percent for values less than 10 μg (micrograms) and about 10 percent for values greater than 10 μg. Detection limits for arsenic in the biota are less than 0.01 μg/g. In converting from wet weight to dry weight, final values are reported to only 0.1 μg/g.

Samples of fish and benthic invertebrates were collected at four sites (11465200, 10, 20, and 27). The fish were collected by electroshocking. They were then packed in ice until they could be identified, weighed, and measured. For larger fish a sample of the flesh was collected from above the lateral line. A whole fillet was used as the sample from the smaller fish. The benthic invertebrates were collected qualitatively with a plastic screen held in the water while agitating the bed material upstream. No attempt was made to sample the benthic invertebrates quantitatively. After collection the benthic invertebrates were placed in water tanks for later sorting and identification. The samples of fish flesh and benthic invertebrates were then frozen and sent to the Salt Lake Central Laboratory for analysis. Analytical procedures were similar to those previously described.

RESULTS

Tables 1 and 2 contain the analytical results of all arsenic sampling done during this study. Results are for samples collected from August through November 1974.

Water and Sediment

The highest levels of arsenic were found in the vicinity of Skaggs Springs (23) and Skaggs well (26). The concentration of arsenic in water from Skaggs well was 140 μg/l; nearby sediments yielded 19 μg/g of arsenic. Water from Skaggs Springs contained 75 μg/l of arsenic; nearby sediments yielded 12 μg/g. During the period of investigation the combined discharge from the three Skaggs Springs and Skaggs well was estimated to be about 0.01 ft^3/s (0.0003 m^3/s). Hines (1971) measured the discharge of the three springs to be 9.4 gal/min (0.59 l/s) or 0.02 ft^3/s (0.0006 m^3/s). In 1909 the flows were reported to total 15 gal/min (0.95 l/s) or 0.03 ft^3/s (0.0008 m^3/s) (Waring, 1915). Indications are that the amount of geothermal water discharging in the area is slowly decreasing.

Geothermal water from Skaggs Springs and Skaggs well seems to be the only major source of arsenic in the Little Warm Springs Creek area (fig. 3). In Little Warm Springs Creek upstream from the spring (22) no arsenic was detected; downstream (27), after the geothermal water was diluted by the creek water, a concentration of 42 μg/l was measured. At this sampling site (27) the arsenic concentration was less than the maximum allowable concentration for drinking water of 50 μg/l (U.S. Public Health Service, 1962; Environmental Protection Agency, 1975).

TABLE 1.--*Concentrations of arsenic at selected sampling sites, August 1974*

[Location of sampling sites shown in figures 1, 2, and 3]

Sampling site number	Location	Arsenic, in water (μg/l)	Arsenic, on sediment, dry weight (μg/g)	Arsenic, in algae, dry weight (μg/g)
1	Cooley Ranch Hot Springs	1	3	3
2	Cooley Ranch domestic spring	2	5	-
11464400	Dry Creek near Yorkville	0	3	-
3	Cherry Creek	0	7	-
4	Yorty Creek	2	9	-
5	Brush Creek	0	15	-
6	Dry Creek at Kelly Road	0	8	-
7	Smith Creek	0	1	-
8	Rockpile Road spring	0	8	-
9	Dry Creek tributary	1	10	-
10	Dry Creek at Rockpile Road	1	3	-
11	Dry Creek tributary	0	6	-
12	Prichard Creek	0	7	-
13	Dry Creek above Warm Springs Creek	1	5	-
14	Wild Cattle Creek	0	7	-
15	Warm Springs Creek	1	4	-
16	Strawberry Creek	1	4	-
17	Rancheria Creek	0	2	-
18	Picnic Creek	1	7	-
19	Warm Springs Creek tributary	1	7	-
20	Warm Springs Creek above Little Warm Springs Creek	0	5	-
21	Little Warm Springs Creek tributary	-	9	-
22	Little Warm Springs Creek	0	5	-
23	Skaggs Springs No. 1	75	12	15
24	Soil sample collected near Skaggs Springs	-	13	-
25	Little Warm Springs Creek tributary	-	7	-
26	Skaggs well	140	19	-
27	Little Warm Springs Creek at mouth	42	6	-
28	Warm Springs Creek tributary	1	9	-
29	Warm Springs Creek	1	4	-
11465200	Dry Creek near Geyserville	1	-	2

TABLE 2.--*Arsenic content of fish and benthic invertebrates in the Dry Creek basin, August-November 1974*

Organism	Length (mm)	Weight (g)	Arsenic, dry weight (μg/g)
Dry Creek near Geyserville (11465200) (1 μg/l arsenic in water)			
Fish			
Western sucker (*Catostomus occidentalis*)	330	367	0.7
Sacramento squawfish (*Ptychocheilus grandis*)	172	43	1.4
Rainbow trout (*Salmo gairdneri*)	123	17	.2
Benthic invertebrates			
Cranefly (*Hexatoma sp.*)	-	-	.2
Mayfly (*Isonychia sp.*)	-	-	1.7
Stonefly (*Acroneuria sp.*)	-	-	1.3
Dry Creek at Rockpile Road (10) (1 μg/l arsenic in water)			
Fish			
Western sucker (*Catostomus occidentalis*)	185	64	.3
Western sucker (*Catostomus occidentalis*)	129	19	.8
Sacramento squawfish (*Ptychocheilus grandis*)	103	10	.7
Benthic invertebrates			
Cranefly (*Hexatoma sp.*)	-	-	1.0
Warm Springs Creek above Little Warm Springs Creek (20) (0 μg/l arsenic in water)			
Fish			
Sacramento squawfish (*Ptychocheilus grandis*)	242	144	.2
Sacramento squawfish (*Ptychocheilus grandis*)	195	79	.2
Benthic invertebrates			
Stonefly (*Acroneuria pacifica*)	-	-	1.4
Little Warm Springs Creek at mouth (27) (42 μg/l arsenic in water)			
Fish			
Venus roach (*Hesperoleucus venustus*)	88	10	.3
Western sucker (*Catostomus occidentalis*)	81	6	.1
Benthic invertebrates			
Caddisfly (*Hydropsyche sp.*)	-	-	.3
Creeping water bug (*Ambrysus californicus*)	-	-	1.1

Several other springs that are shown on local maps of the area were visited. Most of them were found to be either seeps or dry. One small spring on the southwest ridge of Dry Creek along Rockpile Road was sampled (8), but no arsenic was found in the water and only 8 μg/g was detected on the sediment. Another spring (2), adjacent to Cooley Ranch Hot Springs (1) and being used for domestic water supply, had 2 μg/l arsenic in the water and 5 μg/g on the sediment. Very little arsenic was present in water at Cooley Ranch Hot Springs (1): 1 μg/l in the water and 3 μg/g on the sediment.

For the 28 locations where water samples were collected arsenic levels ranged from 0 to 140 μg/l. Only three samples (23, 26, 27) had concentrations greater than 2 μg/l. Durum and others (1971) reported that of 727 water samples collected throughout the United States, 79 percent had arsenic concentrations less than 10 μg/l. Thus, the only significant levels of arsenic in water found in the study area were those associated with geothermal water at Skaggs Springs and Skaggs well.

No location showed any high level of arsenic on the sediments. The average concentration in the 30 samples collected was 7 μg/g. All five samples that contained at least 10 μg/g arsenic were of very fine-grained material. The soil sample (24) collected from the outcrop containing realgar (fig. 4) was less than twice the United States soil average of 7.4 μg/g (Shacklette and others, 1974). The lack of high concentration of arsenic on the sediment suggests that either there are no major sources of arsenic in the areas studied or, where arsenic is present, it is rapidly transported out of the area. This is evidenced by the noticeably low concentrations on the sediment collected at sites where concentrations in the water were high.

Biota

Concentrations of arsenic were determined for algae samples collected at three sites and fish and benthic invertebrate samples collected at four sites (tables 1 and 2). The highest arsenic concentration (15 μg/g) was measured in algae collected at the Skaggs Springs site (23) where the concentration in the water is also high (75 μg/l). At Skaggs Springs the filamentous blue-green alga *Phormidium* was the predominant form. *Phormidium* was also the dominant form in the area around the Skaggs well discharge.

At the Cooley Ranch Hot Springs (1) where little arsenic was found in the water (1 μg/l) and on sediment (3 μg/g), only 3 μg/g of arsenic was detected in the algae. Two co-dominant algae were identified: a coccoid blue-green (*Anacystis sp.*) and a filamentous green (*Spirogyra sp.*).

Downstream from the damsite at the Dry Creek near Geyserville station (11465200) the algae that grew on a periphyton strip left in the stream for 5 weeks showed an arsenic concentration of 2 μg/g. The dominant organisms were both filamentous green algae--*Oedogonium sp.* and *Stigeoclonium sp.* The arsenic content of the water at this location was low (1 μg/l).

Table 2 presents results of arsenic analyses made of fish and benthic invertebrates. The 10 fish-flesh samples analyzed for arsenic concentration averaged 0.5 μg/g, with a range of 0.1-1.4 μg/g. The arsenic concentration was generally less than 0.8 μg/g. There does not seem to be any correlation between the weight or size of a fish and its arsenic concentration.

Benthic invertebrates tended to have higher concentrations of arsenic than the fish. The mean arsenic concentration in the benthic invertebrates was 1.4 μg/g (range 0.2-3.1 μg/g), almost three times the concentration determined for the fish.

Concentration factors[5] for arsenic in the biota were as follows: algae, 200 to 3,000; benthos, 7.4 to 1,700; and fish, 1.4 to 1,400. These figures support the statement of Ferguson and Gavis (1972) that arsenic is not magnified through the food chains.

SUMMARY AND CONCLUSIONS

The results of this reconnaissance survey of the proposed Lake Sonoma area indicate that the only potential arsenic problem is in the Skaggs Springs and Skaggs well area. The water from Skaggs Springs and Skaggs well contains 75 and 140 μg/l of arsenic. Arsenic is also present in rocks in this area. Arsenic has been found in the lower levels of the abandoned Skaggs Springs mercury mine, and realgar crystals are present in some surface outcrops in the immediate area. However, high arsenic concentrations were found only in this area. The other geothermal water in the study area (Cooley Ranch Hot Springs) is low in arsenic (1 μg/l), and concentrations of arsenic on sediment are quite low and uniform throughout the project area.

Arsenic in the biota does not seem to be a potential hazard. Some accumulation of arsenic in the aquatic organisms occurs as indicated by the concentration factors. The biota associated with water containing high levels of arsenic did not show any increased arsenic levels over the biota of low arsenic areas. There was no evidence that arsenic is concentrated through the food chain (biomagnification).

---

[5]Concentration factors were computed by dividing the dry weight arsenic concentration of the biota, expressed in parts per million (ppm), by the arsenic concentration of the water, also expressed in parts per million.

Because there was no evidence of biomagnification and because arsenic is rarely accumulated to toxic levels by organisms (Wagner, 1973), arsenic should not be a potential problem in the proposed Lake Sonoma. No further studies of potential arsenic contamination in the area seem necessary at this time. Including arsenic determinations in the regular water-sampling program being conducted in this area should be adequate for long-term monitoring of arsenic concentrations in the study area.

SELECTED REFERENCES

Bailey, E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks and their significance in the geology of western California: California Div. Mines Bull. 183, 177 p., 2 pls.

Durum, W. H., Hem, J. D., and Heidel, S. G., 1971, Reconnaissance of selected minor elements in surface waters of the United States, October 1970: U.S. Geol. Survey Circ. 643, 49 p.

Environmental Protection Agency, Environmental Studies Board, 1972, Water quality criteria 1972-a report of the Committee on Water Quality Criteria: Washington, U.S. Govt. Printing Office, 594 p.

Environmental Protection Agency, 1975, Interim primary drinking water standards: Washington, Federal Register, v. 40, no. 51, pt. 2 (March 14), p. 11990-11998.

Everhart, D. L., 1950, Skaggs Springs quicksilver mine, Sonoma County, California: California Jour. Mines and Geology, v. 46, no. 3, p. 385-394, 4 pls.

Ferguson, J. F., and Gavis, Jerome, 1972, A review of the arsenic cycle in natural waters: Water Research, v. 6, p. 1259-1274.

Frost, D. V., 1967, Arsenicals in biology--retrospect and prospect: Federation Am. Societies for Experimental Biology, 50th, Atlantic City, N.J., April 14, 1966, Proc., v. 26, no. 1, p. 194-208.

Hines, W. G., 1971, Preliminary investigation of mercury-hazard potential, Warm Springs Dam and Lake Sonoma Project, Dry Creek basin, Sonoma County, California: U.S. Geol. Survey open-file rept., 19 p.

Koenig, J. B., 1963, Geologic map of California, Olaf P. Jenkins, ed., Santa Rosa sheet: California Div. Mines and Geology, scale 1:250,000.

Shacklette, H. T., Boerngen, J. G., and Keith, J. R., 1974, Selenium, fluorine, and arsenic in surficial materials of the conterminous United States: U.S. Geol. Survey Circ. 692, 14 p.

U.S. Public Health Service, 1962, Drinking water standards, 1962: U.S. Public Health Service Pub. 956, 61 p.

Wagner, S. N., 1973, Arsenic and cadmium in the environment *in* Heavy metals in the environment--a seminar: Corvallis, Ore. Water Resources Research Inst., 203 p.

Waring, G. A., 1915, Springs of California: U.S. Geol. Survey Water-Supply Paper 338, 410 p., 3 pls.