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A REVIEW OF THE SQUAW CREEK AQUATIC MONITORING PROGRAM, THE GEYSERS, CALIFORNIA

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ABSTRACT

The Squaw Creek Aquatic Monitoring Program has been in operation since the summer of 1984, during initial development of the geothermal resource in the extreme northeast portion of Sonoma County, California. Several water quality parameters have exceeded various accepted standards and may stress biological components of the streams. Substantial variations in fish populations appear to be associated with extremes in stream flows. Benthic macroinvertebrate populations exhibit high variation but are indicative of productive stream conditions. A general increase in fine sediments has not been detected, inferring a positive effect from the engineering practices employed. Natural phenomena strongly influence the Squaw Creek drainage and tend to swamp many possible effects of development.

INTRODUCTION

The Squaw Creek Aquatic Monitoring Program (SCAMP), which was commissioned by GEO Operator Corporation and the Central California Power Agency No. 1, has been in operation since the summer of 1984. Since then the Squaw Creek watershed area, (located in the extreme northeast portion of Sonoma County, California), has under gone development for the production of geothermal power. During the first years of SCAMP (Jordan *et al*, 1986, 1987, 1988) water quality at eleven strategically placed sampling stations (fig. 1) has been monitored. Fish and benthic macroinvertebrate populations and stream sediments have also been evaluated at selected sampling stations.

WATER QUALITY

Using techniques patterned after those of the KGRA-ARM study (Karfiol and McMillan, 1983; McMillan, 1985) and standard methods (Standard Methods, 1981) various water quality parameters (table 1) were measured in August 1984 and every other month thereafter at all eleven stations. The salient features of the monitoring program are discussed below:

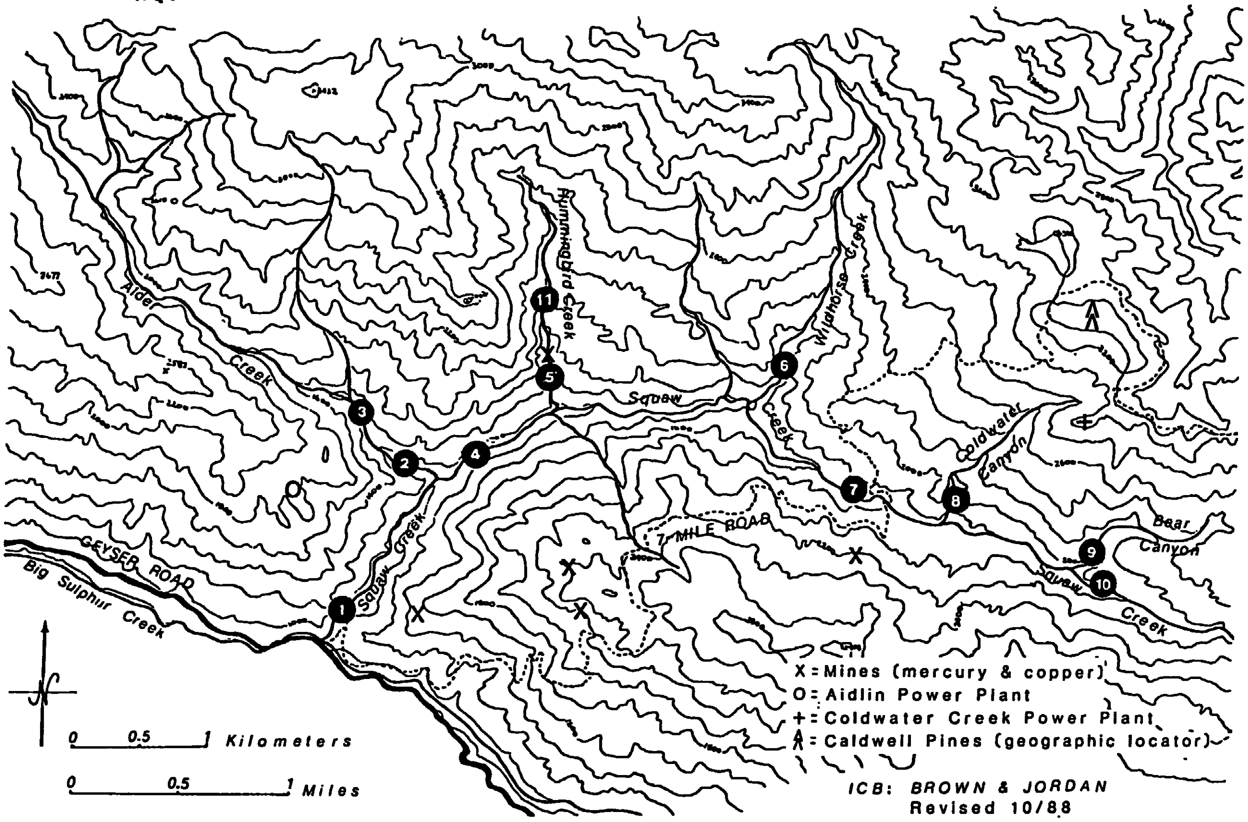
Water Temperatures were naturally high during the summers; particularly at downstream locations on Squaw Creek, temperatures were measured that could adversely affect trout. Specific Conductance was highest during months of low flow or years of drought. The California State Water Resources Control Board (CSWRCB, 1975) standard of 320 umhos/cm for the Russian River drainage was commonly exceed during the dry season. Dissolved Oxygen levels only rarely dropped so low (less than 7.0 mg/l) as to adversely affect aquatic life during the low flows of summer.

Water flows during normal rainy seasons are ample and serve to flush sediments and debris from the streams. However, drought conditions existed during 1987 and 1988. The low flows of summer marginally maintain aquatic life in many sections of the watercourses. Total suspended solids and turbidity were relatively low,strongly correlated with rainfall. Contamination of surface waters by oil and grease was not detected. Alkalinity and hardness, in general, were moderate and were lowest during the rainy season.

Ammonia (unionized) levels vary considerably between sample periods and were unusually high during 1986/1987. At individual stations and at various times throughout Scamp monitoring ammonia levels have exceeded criteria for the protection of aquatic life. Since the beginning of SCAMP, Nitrates have increased slightly (perhaps because of revegetation projects) but were well within acceptable standards (BLM, 1987).

FIGURE I

SONOMA COUNTY
AQUATIC MONITORING PROGRAM -- SQUAW CREEK WATERSHED



In general, sulfate levels were moderate, but have increased since the beginning of SCAMP. During the scheduled October 1986 sampling, a spill of geothermal fluids upstream of the project area raised sulfate levels above 100 mg/l in Squaw Creek. Orthophosphate values were sporadically higher at various stations and times of the year. The pH values of the stream waters are basic and may exceed the 8.5 recommended upper pH limit (CSWRCB, 1975) for the protection of aquatic life.

Calcium concentrations were moderate and not particularly noteworthy. Aluminum levels were high and frequently exceeded the 0.07 mg/l established (McKee and Wolf, 1963) for the protection of fish and their ova. Iron and magnesium concentrations were moderate.

Titanium levels were consistently low. Manganese concentrations were noticeable lower during the two most recent sampling years; this situation may be related to rainfall and runoff patterns. Although barium concentrations were somewhat lower in the 1986/1987 sample period, levels of this element were not of concern. Zinc levels were erratically high and routinely exceeded the recommended 24-hour criterion (USEPA, 1980) for the protection of aquatic life.

Strontium levels were, consistently, high; particularly on Alder Creek strontium concentrations have ranged widely over the first years of SCAMP. Vanadium levels, as reported, usually exceeded the United States Environmental Protection Agency (USEPA, 1976) estimated permissible ambient goal (based on human health) and, in general, were high compared to other surface water.

Lead concentrations remained high throughout SCAMP sampling periods, and they commonly exceeded the 0.050 mg/l criterion

Table 2. SCAMP water quality, yearly averages and minimum/maximum values for all stations and all parameters except elements, for which only the yearly average and maximum values are given. All values in mg/l unless otherwise indicated (* = a high value associated with a spill of geothermal materials upstream of the project area).

Parameters	84/85	85/86	86/87	87/88
Water Temp. (C)	13.5	13.5	13.5	14.0
	5.0/27.0	9.0/24.0	7.0/26.5	8.4/22.5
Conduct. (umhos/cm)	230	220	260	260
	150/360	140/350	110/890*	120/345
Dissolves Oxygen	10.0	9.9	9.9	10.0
	5.9/11.9	5.4/12.2	6.5/11.6	6.3/11.8
Flow (cfs)	-	-	1.8	3.3
	<0.1/32,9	0.0/45.9	0.0/23.3	0.0/32.2
Total Suspen. Solids	7.5	5.6	2.6	2.9
	<2/144	<1/76.6	<1/62.0	<1/39.9
Turbidity (NTU)	9.9	10.5	2.8	4.0
	0.3/216	0.1/162	0.1/84.0	0.1/79.0
Oil & Grease (visual)	none	none	none	none
Alkalinity	151	121	156	156
	112/208	78/172	103/215	91/204
Hardness	170	166	170	172
	117/266	89/279	112/596*	99/279
Ammonia	<0.02	<0.02	<0.10	<0.03
	<0.02/0.14	<0.02/0.13	<0.02/0.66	<0.02/0.13
Nitrate (mg N/l)	0.11	0.16	0.17	0.16
	0.02/0.38	0.02/0.55	0.08/0.60	<0.01/0.85
Sulfate	12	15	23	18
	4/30	0.8/35	12/>100*	7/45
Orthophosphate	<0.033	0.031	0.033	0.036
	<0.01/0.05	0.01/0.145	0.01/0.062	0.01/0.127
pH	8.5	8.2	7.8	8.3
	7.7/9.0	7.0/8.8	6.9-8.6	7.9/8.9
Ca	44.4	42.6	42.1	42.6
	74.9	76.0	170*	68.7
Al	0.228	0.371	0.439	0.395
	1.16	0.890	1.03	1.09
Fe	0.091	0.206	0.063	0.058
	0.811	0.595	0.233	0.152
Mg	13.9	13.8	14.8	15.2
	23.8	30.2	40.2*	27.0
Ti	0.006	0.004	0.002	0.003
	0.016	0.010	0.007	0.017
Mn	0.025	0.022	0.009	0.008
	0.378	0.286	0.066	0.062
Ba	0.128	0.126	0.104	0.131
	0.173	0.218	0.295*	0.242
Zn	0.050	0.193	0.298	0.129
	1.01	1.85	3.20	1.2

Table 2. continued.

Parameters	84/85	85/86	86/87/	87/88
Sr	0.416	0.389	0.416	0.440
	0.738	0.725	1.47*	0.846
V	0.014	0.016	0.007	0.014
	0.027	0.44	0.21	0.5
Pb	0.141	0.082	0.038	0.127
	0.469	0.291	0.142*	0.382
Mo	0.118	0.174	0.069	0.126
	0.493	0.510	0.224	0.385
Cr	0.011	0.008	0.002	0.008
	0.029	0.030	0.013	0.39
Cu	0.010	0.008	0.008	0.009
	0.29	0.22	0.116	0.44
Ni	0.018	0.008	0.005	0.017
	0.085	0.035	0.022	0.062
B	0.308	0.424	1.07	0.346
	0.625	1.35	36.0	0.753
Co	0.040	0.039	0.022	0.036
	0.104	0.133	0.161*	0.157
Cd	0.016	0.024	0.084	0.066
	0.092	0.251	0.428	0.481
Na	10.3	10.4	10.5	11.8
	17.8	23.4	20.4	30.8
Si	8.67	8.58	8.33	9.12
	12.2	11.3	12.3	14.3
As	<0.01	<0.01	<0.01	<0.01
	-	-	0.01	0.01
Hg	<0.001	<0.001	<0.001	<0.001

for domestic use. The yearly averages for molybdenum have varied widely, and the 0.070 my/l estimated permissible ambient goal (USEPA, 1976) was commonly exceeded.

Chromium, was present in the waters of the Squaw Creek drainage usually in amounts less than 0.008 mg/l. Levels of this element can be much higher; in August 1987, for example, the monthly station average was 0.034 mg/l, which exceeded criteria for the protection of aquatic life. Copper levels tend to be highest in late summer, when the 24-hour criterion (USEPA, 1980) for the protection of aquatic life was commonly exceeded.

Nickel levels tended to be lowest during the dry season. The highest concentrations of this element were recorded in December of 1984 when all stations averaged 0.043 mg/l.

Boron is commonly associated with natural geothermal waters and the geothermal industry. Concentrations less than 0.5 mg/l can harm sensitive vegetation. Due to a spill of geothermal materials upstream of the project area in October of 1986, water samples from Squaw Creek contained in excess of 36 mg/l of boron.

Cobalt concentrations vary widely with the seasons, but were unusually high in October of 1985, when the monthly mean for all sampled stations was 0.118 mg/l. Cadmium levels usually measured below analytical limits; however, it is apparent that cadmium levels at various stations and at differing times exceed water quality standards. Sodium and silicon levels were moderate and varied little throughout SCAMP monitoring.

Arsenic levels were always equal to or less than 0.01 mg/l; thus, water quality standards were never exceeded for this element. Mercury concentrations were never greater than 0.001 mg/l; thus water quality standards were never exceeded.

FISH POPULATIONS

Monitoring of sensitive fish populations is a particularly valuable component of SCAMP because they are continually exposed to variations in water quality and other factors. Thus, fish are good indicators of long-term "health" of the streams.

At each station fish populations were sampled by electrofishing a 30-meter stretch of stream, and population estimates were made using the methods described by Karfiol and McMillan (1983). With the exception of Station 8, all sample stations have populations of *Salmo gairdneri*, rainbow trout and/or steelhead. In addition, non-game fish such as California roach and Sacramento sucker are typically found at Station 1. However, for purposes of this discussion only trout at stations 1, 4, 7 and 10 on Squaw creek will be considered (table 2).

Table 2. Estimated trout populations at SCAMP stations 1, 4, 7 and 10 on Squaw Creek 1984 to 1988.

Date	Stn. 1	Stn. 4	Stn. 7	Stn. 10
7/84	79	138	75	97
9/84	52	137	50	36
5/85	36	76	18	25
9/85	26	24	24	33
5/86	2	17	21	55
8/86	115	186	32	80
5/87	38	51	33	34
8/87	59	63	35	32
5/88	3	26	6	19
8/88	0	66	16	25

At Station 1 trout populations declined during 1984 through the first part of 1986 but then rose substantially for a period, only to suffer a decline in 1987. In 1988 no trout were present. At Station 4 trout were relatively abundant in 1984. Thereafter, the population declined, but increased sharply in August of 1986. Since then the numbers of trout have been rather constant but fewer in number.

Since 1984 trout populations at Station 7 steadily declined but then partially recovered, until 1988 when the population dropped to the lowest point recorded at this station during SCAMP monitoring. The numbers of trout at Station 10 have remained relatively constant compared to those at other monitoring stations on Squaw Creek; the lowest number of trout was found during the Spring 1988 sampling.

During the course of a year many factors may influence the trout populations in the streams of the Squaw Creek drainage such as yearly water flows, changes in water quality, the ability of steelhead to pass natural barriers, spawning success of resident rainbow trout, sedimentation and spills of geothermal materials. Direct cause and effect relationships are difficult to establish since fish populations, even in an undisturbed area, can fluctuate due to natural variation in biotic or abiotic factors.

Higher rainfall in late 1985 through early 1986 correlate with an increase in trout numbers at many SCAMP stations. Drought conditions which began in 1986 and continued through 1988 created low flows which are positively correlated with population declines in trout populations in the Squaw Creek drainage.

MACROINVERTEBRATES

Benthic macroinvertebrates were evaluated by sampling 0.25 square meter areas of riffled stream bottom using kick-screens at stations 1, 4, 7 and 10 on Squaw Creek. Although sampling was done in both the spring and the fall, fall samples provided the most consistent and useful data. Captured organisms were identified, and the data quantified using the methods of Karfiol and McMillan (1983).

For purposes of this presentation, discussion is limited to samples taken in the fall and a single quantitative measure, community abundance (table 3). Community abundance is expressed as the number of individuals found within a square meter of substrate. According to McMillan (1985) streams containing more than 2,152 organisms per square meter are classified as rich; a designation of moderate indicates between 1,076 and 2,152 organisms per square meter; and low indicates a community abundance of less that 1,076 organisms per square meter. Community abundance, thus, infers a similar relative level of productivity.

At Station 1 the total community abundance followed an erratic downward trend from Fall 1984 to Fall 1986 but showed a marked increase in Fall 1987. The corresponding productivity returned from a moderate to a rich level. The continual decline in fine sediments at this station does not correlate positively with the observed population levels, since the noted increases occurred in taxa of varying sensitivities and ecological requirements. However, it is possible that rainfall and runoff patterns had a significant influence.

At Station 4 community abundance showed a large increase in Fall 1986 and Fall 1987 sampling compared to that in the fall of 1984 and 1985, increasing productivity from low or moderate to the rich level. *Gumaga* species, which react positively to silt, comprised 68 percent of the total community abundance for Fall 1986 and only 4 percent in Fall 1987. This shift in populations corresponds to the recorded increase in fines during 1986 followed by a decrease of fine sediments in 1987.

Although at Station 7 community abundance has shown variable tendencies, abundance rose to its highest level in Fall 1987. Productivity, which averaged at the upper moderate level, increased to rich. Fine sediments, that had remained fairly constant during the SCAMP sampling periods, rose to a high in Spring 1987. All sensitive, as well as tolerant taxa, either maintained population levels or increased in Fall 1987. Because of the differences in sensitivity and ecological requirements of the existing taxa, these population levels appear to be attributable to natural population fluctuations or some unidentified change in water quality.

Community abundance at Station 10 has remained fairly constant from Fall 1984 to Fall 1986 but increased considerably in Fall 1987. Productivity rose from moderate to rich. Fine sediment levels were stable from 1986 to 1987 which suggest the population fluctuations were due to other factors.

Table 3. Community abundance of benthic macroinvertebrates at SCAMP stations 1, 4, 7 and 10 on Squaw Creek in the Fall, 1984 through 1987; values are the numbers of individuals per square meter.

Stn.	1984	1985	1986	1987
1	4577	2985	1652	7112
4	1568	968	11096	5712
7	1210	2862	1244	8016
10	1981	1893	1364	4116

STREAM SEDIMENTS

During SCAMP, stream sediments were sampled at stations 1, 4, 7 and 10 on Squaw Creek following the end of seasonal rains. Methods of sampling and analysis were those set forth by Karfiol and McMillan (1983). At each station five replicate sediment samples were obtained using a modified McNeil-type sampler. The sediment samples (consisting of a bulk-sediment and water-sediment fraction) were air-dried and run through a graded series of sieves. The weight of the sediments trapped on each sieve was recorded, and the percentage of the total weight calculated.

As discussed by McMillan (1985) sedimentation, particularly fines (particles passing through a 0.841 mm mesh sieve), are of paramount importance because of their potential to adversely affect certain components of the aquatic environment. Sediments may negatively affect fish growth and reproduction by decreasing habitat quality, reducing available food and limiting available oxygen.

Most critically, sediments can negatively affect reproductive success of spawning fish such as the salmonids (in this case steelhead and rainbow trout). According to Iwamoto *et al.* (1978), 10 to 20 percent fines are acceptable for spawning and egg development. However, there are no universally accepted standards, and acceptable percentages may vary with the stream and segment of stream in question.

SCAMP data (table 4) indicate that only rarely were fines in excess of 10 percent encountered, and there does not appear to be a trend toward increased retention of fines in Squaw Creek.

Given the land surface disturbance associated with the construction of well pads, roads, stream crossings and power plants there was a great potential for increased erosion and sedimentation. The lack of evidence for increased sedimentation of the streams in the Squaw Creek drainage reflects favorably on the engineering practices employed.

Table 4. Percent fines present in the sediments at SCAMP stations 1, 4, 7 and 10 (on Squaw Creek), 1984 through 1987.

Stn.	1984	1985	1986	1987
1	11.2	7.5	5.9	5.1
4	11.3	7.8	10.8	7.4
7	4.9	5.0	5.2	9.0
10	8.7	5.3	8.1	8.0

CONCLUDING REMARKS

The first years of SCAMP indicate that:

(a) Several water quality parameters have exceeded various accepted standards and may stress biological components of the streams or interfere with some beneficial uses of the water.

(b) The fish populations, primarily rainbow trout and steelhead have shown increases during years with average or greater than average rainfall and declines during drought years.

(c) Although the benthic macroinvertebrate fauna of Squaw Creek exhibits a high degree of variation from station to station, the data are indicative of a stream in productive condition.

(d) The data indicate that there was not a general buildup of fine sediments in Squaw Creek.

Based on the experience gained during SCAMP it appears that natural phenomena (*i. e.*, precipitation patterns) and their inherent fluctuations strongly influence the Squaw Creek drainage and tend to swamp many possible effects of geothermal development. At present, the production of geothermal power has caused no identifiable major adverse alterations of the streams in the Squaw Creek drainage.

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REFERENCES

Bureau of Land Management. 1987. A Water Quality Trend Analysis of Big Sulphur Creek and Squaw Creek Drainage (draft). Bureau of Land Management, US Department of the Interior, Ukiah.

California State Water Resources Control Board. 1975. Water quality control plan report, North Coast Basin (1B).

Iwamoto, R. N., E. O. Salo, M. A. Mades and R. L. McComa. 1978. Sediment and water quality: a review of the literature including a suggested approach for water quality criteria. US Environmental Protection Agency, 910/9-78-048.

Jordan, W. P., R. J. Brown and G. L. Stevens. 1986. Squaw Creek Aquatic Monitoring Program (SCAMP) Annual Report 1985-1986. Published by the Institute of Chemical Biology (USF) for GEOOC, Santa Rosa.

Jordan, W. P., R. J. Brown, G. L. Stevens and K. D. Ward. 1987. Squaw Creek Aquatic Monitoring Program (SCAMP) Annual Report 1985-1986. Published by the Institute of Chemical Biology (USF) for GEOOC, Santa Rosa, and CCPA, Sacramento.

Jordan, W. P., R. J. Brown and K. D. Ward Jennings. 1988. Squaw Creek Aquatic

Monitoring Program (SCAMP) Annual Report 1986-1987. Published by the Institute of Chemical Biology (USF) for GEOOC, Santa Rosa, and CCPA, Sacramento.

Karfiol, R. C. and L. E. McMillan (Eds.). 1983. Geysers-Calistoga KGRA-ARM Program 1981-1982 annual report, 2 vols.

McKee, J. E. and H. W. Wolf (Eds.). 1963. Water Quality Criteria (3-a). California State Water Resources Control Board, Sacramento.

McMillan, L. E. (Ed.). 1985. Geysers-Calistoga KGRA-ARM Program 1982-1983 annual report, 2 vols.

Standard Methods. 1981. Standard Methods for the Examination of Water and Wastewater. 15th Edition, American Public Health Association, Washington.

United States Environmental Protection Agency. 1976. Quality Criteria for Water. 440/9-76-023.

United States Environmental Protection Agency. 1980. Ambient Water Quality Criteria for Zinc (440/5-80-079) and Copper (440/5-80-036).