✓

MASTER

UCRL-15054

GEYSERS-CALISTOGA KGRA GEOTHERMAL ENVIRONMENTAL OVERVIEW: WATER QUALITY

Stephen F. Moore, Kenneth D. Pimentel, and Ray B. Krone

February 1978

P.O. 8482703

This report is a revised version of subcontractor's report
RMA 7100, January 1978.

RESOURCE MANAGEMENT ASSOCIATES
LAFAYETTE, CALIFORNIA

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

FOREWORD

The original version of this water quality report was submitted in January 1978 to Lawrence Livermore Laboratory in fulfillment of subcontracts then held by Resource Management Associates and the University of California at Davis. After we made minor revisions and additions to that subcontractors' report (dated February 1978), we released it for review in March 1978; the reviewers are listed on the following two pages.

Comments were so divergent--some reviewers vehemently disagreed with the contents of the subcontractors' report--that we completely re-researched and rewrote it. The revised, final version appeared as K. D. Pimentel, An Environmental Overview of Geothermal Development: The Geysers-Calistoga KGRA: Volume 6, Water Quality, Lawrence Livermore Laboratory, Livermore, CA UCRL-52496-6, 1978.

The present document, the subcontractors' report, is published at this late date primarily for the information of those involved in the Water Quality Workshop at Davis, November 1977. Note carefully that the views expressed in this subcontractors' report are preliminary and reflect only what was produced at the workshop itself, in addition to some early syntheses of the workshop's results by our subcontractors and ourselves.

The contents, opinions, and conclusions found in the final version cited above represent several months' more effort on my part and considerable post-workshop involvement by industry, regulatory agencies, and academia. The final version, Volume 6, is responsive to the comments made by our reviewers. All of these added efforts are missing from this, the February 1978 subcontractors' report.

Kenneth D. Pimentel
Environmental Sciences Division
Lawrence Livermore Laboratory
June 1979

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

LIST OF REVIEWERS

GEYSERS-CALISTOGA KGRA GEOTHERMAL ENVIRONMENTAL OVERVIEW: WATER QUALITY

February 1978 Draft

- Private Industry and Individuals

Lucille Enriques
Pacific Gas & Electric Co.
3400 Crow Canyon Road
San Ramon, CA 94583
(415) 820-2000

Stephen F. Moore
Resource Management Assoc.
3706 Mt. Diablo Blvd., Suite 200
Lafayette, CA 94549
(415) 284-9071

Warren A. Smith
Union Oil Co. of California
P.O. Box 6854
2099 Range Avenue
Santa Rosa, CA 95406
(707) 542-9543

- County Agencies

Mark Walters
Lake County Planning Dept.
255 N. Forbes Street
Lakeport, CA 95453
(707) 263-2221

Larry Vollintine
Lake County Planning Dept.
255 N. Forbes Street
Lakeport, CA 95453
(707) 263-2221

- State Agencies

John Emig
California Dept. of
Fish & Game
P.O. Box 47
Yountville, CA 94599
(707) 944-2443

Robert V. Giacocie
Chris Oliviera
Calif. Energy Resources Conservation
& Development Commission
MS-27 1111 Howe Avenue
Sacramento, CA 95825
(916) 322-3677

David Snetsinger
Water Quality Control Board
North Coast, Region 1
1000 Coddington Center
Santa Rosa, CA 95401
(707) 545-2620

- University

Richard G. Burau
Dept. of Land, Air & Water Res.
University of California
Davis, CA 95616
(916) 752-0194

Ray B. Krone
Dept. of Civil Engineering
University of California
Davis, CA 95616
(916) 752-1435

Wayne Wurtsbaugh
University of California
Dept. of Wildlife, Fisheries
and Biology
Davis, CA 94516
(916) 752-1011

GEYSERS-CALISTOGA KGRA GEOTHERMAL
ENVIRONMENTAL OVERVIEW: WATER QUALITY

by

Stephen F. Moore
Resource Management Associates
Lafayette, California

Kenneth D. Pimentel
Lawrence Livermore Laboratory
Livermore, California

Ray B. Krone
University of California, Davis
Davis, California

prepared for

LAWRENCE LIVERMORE LABORATORY

February 1978
RMA 7100 (revised)

"Work performed under the auspices of the
U.S. Department of Energy by the Lawrence
Livermore Laboratory under contract number
W-7405-ENG-48."

GEYSERS-CALISTOGA KGRA GEOTHERMAL
ENVIRONMENTAL OVERVIEW: WATER QUALITY

1.0 INTRODUCTION

Decisions regarding geothermal resource development in the Geysers-Calistoga area must be based on knowledge of impacts of the development on water resources of the region, as well as benefits and other costs. Detailed studies of particular impacts in a known geothermal resource area (KGRA) require preliminary assessment of available knowledge and planning. A first step is to identify important water-related issues of concern and to assess the available information regarding potential impacts on the quantity and quality of water in an area. This report presents the results of a study and a two-day workshop (see Appendix A) that included representatives of developers and of concerned local, state, and federal agencies.

The principal objects of the study presented in this report are:

1. Identification and description of important water-related issues in the Geysers-Calistoga KGRA;
2. Inventory of existing water resource data in the Geysers-Calistoga KGRA;
3. Identification of gaps and inadequacies in the existing water quality data base relative to the issues identified in #1;
4. Recommendations for future water quality studies in the Geysers-Calistoga KGRA.

Compiling this information for the water environment in the Geysers-Calistoga KGRA is one object of the Geothermal Environmental Overview

Project at Lawrence Livermore Laboratory. The scope of the Overview Project as a whole encompasses preliminary investigation of impacts on the environment for some 37 KGRAs. Because of the magnitude of the Overview Project, Lawrence Livermore Laboratory has subcontracted various parts of the study to other investigators. This report, which focuses on water-related issues and data in The Geysers-Calistoga KGRA, is the result of a cooperative effort of persons at Resources Management Associates, Lafayette, California, the Lawrence Livermore Laboratory, and the University of California, Davis.

2.0 APPROACH AND ASSUMPTIONS

Development of energy, land, and water resources are intimately interrelated. Use or modification of one of these resources invariably affects another. Therefore, management ultimately involves persons with different management roles and responsibilities from private enterprise, numerous public agencies, and from special interest groups. Any person involved in the management of resources in the Geysers-Calistoga KGRA is responsible for certain actions and decisions according to their management role.

An underlying basis for our assessment of water quality data needs in the Geysers-Calistoga KGRA is the effectiveness of management actions depends on the quality of available data and information. No matter how much data exists at any given time, it is always possible to suggest additional measurements, studies and experiments to provide further information. The questions which must be addressed are: What is the purpose for collecting this information? How and by whom will it be used? What management decisions require this information? These questions provide a management-oriented context for assessing the existing data base.

This report focuses specifically on the relationship between water quality and geothermal energy resource development in the KGRA. A useful

working definition of water quality is the suitability of the water for an intended use. The quality of water is not an inherent property of a given water. For example, suspended solids eroded from soils from a drainage basin contribute to sediment loads in creeks. Such suspended solids are not really harmful for irrigated agriculture, in fact in some parts of the world the silt carried by irrigation waters is depended upon for the fertility of the soil. Suspended solids are, however, harmful for municipal and industrial uses. The suitability of a water for an intended use, therefore, depends on the constituents of the water. The dissolved salts, organic materials, suspended solids, temperature, and the biological constituents are all important as far as water use is concerned.

Before considering constituents further we need to enumerate the water uses that might be affected by the development of the KGRA. Consider the streams in the area shown in Figure 1. Notice that the drainage in the area of the present Geysers development drains both to the east through Cache Creek, Putah Creek, and Napa River and also to the west to the Russian River. Many of these creeks are ephemeral, but the drainage concentrates in the major creeks. Although these are not heavily populated areas, agriculture exists along the stream valleys and consists of orchards, grapes, hops, alfalfa, clover and other crops. Each of these crops depends for its productivity on irrigation. Other uses of the waters in the area include municipal water supplies and recreation and aesthetic uses, some of which involve wildlife. There is quite a divergence, therefore, of the water uses in the area and water quality for all of these uses is protected by law. Management is challenged to maintain the highest water quality for beneficial uses. However, equity requires that developers not be made to improve existing stream water quality for other beneficial uses. Naturally occurring quantities of undesirable constituents, such as boron, in ground and surface waters will not be reduced by geothermal energy development activities. The existence of high concentrations of boron in a stream flowing through a developed area, for example, is not necessarily an indication that there is contamination by resource development. This

Fig. 1. Water systems in The Geysers-Calistoga KGRA.

point emphasizes the importance of knowing the existing water quality conditions before geothermal energy development begins.

These considerations lead directly to the conclusion that, except for possibly benign geothermal waters, water quality management actions affecting geothermal energy development will consist of measures to prevent geothermal waters from entering surface or ground waters. Indeed, if it were possible or feasible to completely eliminate contamination of surface and ground waters there would be no further concern for potential impacts of geothermal developments on water quality.

There is no absolute control, however. For example, an unplanned shutdown of a power plant at the Geysers can result in flooding of the cooling tower sump, and consequent release of highly mineralized water into the natural drainage. Wells can blow out, heavy rain during construction of landings and roads can carry large amounts of soil to streams and pipes can break. These might be called catastrophes. There are other modes for contamination of surface and ground waters in a developed area. The plume of droplets that emerges from cooling towers is evidence of the transport of waters to the environment. The brown edges on the leaves of vegetation near a power unit suggest that the constituents of plume droplets are undesirable to plants. What is the magnitude of this problem? What portion of this effluent will find its way into streams? When? How soon? Construction activities can increase soil erosion and can greatly increase the sediment loads in streams. These are not catastrophes; they will occur with some certainty. Our basic concern is to identify information available and needed for managing geothermal energy development which minimizes such adverse impacts on water resources.

In order to identify information needs it is necessary to identify possible water quality impacts due to geothermal energy development activities. Given specific impacts of concern, we can assess existing and needed water quality data relative to these concerns. Our analysis may show that a particular concern is adequately managed or insignificant; or, we may conclude that certain additional studies are needed.

The first step in our analysis is to define the scope of the potential impact. Is it a water quality problem? Relative to what uses? Surface or groundwater? Is it an existing problem or anticipated for the future? What is the geographical extent? What operational or development activities cause the problem? What mitigating measures and regulations are applicable?

Given that an issue of concern is defined as a potential water quality problem, management actions must be taken to minimize or eliminate the problem. Impact prediction, design and implementation of control and mitigation measures, and regulation each have certain information and data requirements. Existing data may or may not be adequate to meet these requirements. For example, the kinds of questions which must be addressed include: Are baseline data missing? Are governing physical/chemical/biological mechanisms sufficiently well understood? Are the sources of contaminants known or even measureable? Is the magnitude of the problem in time and space known or measureable? There are many ways in which existing data may be inadequate. The need is to determine in specific terms the shortcomings of existing information relative to a specific issue and proposed action.

Given the assessment of existing data, we can then define and recommend particular studies to be undertaken to provide the information needed to alleviate these inadequacies. Over what temporal and geographical extent are data needed? For what variables? Who is capable and responsible for conducting these studies? What are the consequences of not having this information?

By way of the first step described above, we describe specific water quality problem areas in the KGRA in the next section of the report. It is important to note that these problem areas emerged as the principal water quality issues of concern to workshop participants, who included many persons involved in water quality management in the KGRA on a day-to-day basis.

3.0 WATER QUALITY ISSUES

Figure 2 depicts a conceptual model for the water environment in The Geysers-Calistoga KGRA. Relationships are shown among various components or compartments which go to make up water quality and the sources where potential geothermal affects could originate. This figure serves as a basis for building our discussions of water quality issues associated with geothermal energy development.

The five key issues which emerged in the workshop are as follows:

1. Erosion and sedimentation;
2. Accidental spills;
3. Cooling tower drift deposition;
4. Groundwater use and contamination;
5. Hot water resource development.

Originally, the first four key issues were identified in the working groups as areas of greatest concern; these are consistent with the issues identified in related studies (e.g., Freeman et. al. (1977)). However, later discussions revealed that historically these issues have been areas of major concern in the steam-dominated areas unique to the current development at The Geysers. Reports (e.g., Donnelly, et. al. (1976), Goff, et. al. (1977)) suggest that there may be an extensive hot-water dominated resource in other areas of the KGRA. Issues associated with hot water resource development were felt to be so important that a fifth working group was formed to focus upon those problems.

In the following paragraphs we examine the scope and extent of each of these five water quality problem areas as they exist in The Geysers-Calistoga KGRA. Throughout the discussion, reference is made to various reports dealing with these issues. A more complete inventory of existing

Fig. 2. A conceptual model for water quality in The Geysers-Calistoga KGRA.

water quality data for the Geysers-Calistoga KGRA is presented in Appendix B.

3.1 Erosion & Sedimentation

As described in Freeman, et. al. (1977), erosion and siltation are potential problems associated with every phase of geothermal energy resource development. In fact, at one point during the water quality workshop, it was suggested that erosion-produced sedimentation and turbidity is the only major water quality problem associated with geothermal development in the Geysers-Calistoga KGRA. Although this point of view was rejected by many workshop participants, its suggestion reflects the importance of erosion and sedimentation related water quality problems in the KGRA.

Considerable background information on the soils of the KGRA are summarized in Freeman, et. al. (1977). In particular, Figure 3 shows the distribution of soils in the KGRA with a high erosion potential. The Mayacmas Mountains region, which consists almost entirely of these erodible soils, is the primary location of existing geothermal resource developments. The large geographic extent of erodible soils and the disturbance of soils caused during all phases of development indicate the scope of potential erosion problems and therefore its prominence in being identified as a problem.

Erosion and transport of soil materials into streams can have consequences for a variety of downstream users. Most notably, siltation may affect fish and other aquatic animals, especially if sedimentation alters spawning substrates. LeGore, Bowen and Norman (1976) report a field study conducted in August and September of 1975 on Big Sulphur Creek to determine if fine sediments have accumulated as a result of development activities and thereby affected the suitability of streambeds for trout spawning and egg survival. In addition, increased turbidity may be

Fig. 3. Map of soils with high erosion potential in The Geysers-Calistoga KGRA.
(from Freeman, et al. (1977)).

detrimental to municipal, agricultural or industrial users downstream. Where persistent siltation occurs flooding problems may be aggravated.

Short-term studies such as cited above have not demonstrated measureable impacts on downstream water users. Long-term comprehensive studies on sedimentation and erosion have not been conducted. Therefore, cumulative effects cannot be evaluated or predicted at the present time. However, Pacific Gas & Electric Co. has undertaken intensive, long-term studies at leaseholds which supply steam to Geysers Units 13, 14, 16 and 17. Because these studies include one year of pre-construction measurements, they are expected to allow more definitive assessments of sedimentation problems to be made in the future. Final results from these studies are not expected for 3-5 years. Interim results for sedimentation studies during construction of Geysers Unit 17 are reported by Price, Subicek and Enriquez (1976). Results of their studies to date show that the gravels of Squaw Creek are suitable for good salmonid reproduction and good production of aquatic insects. They point out, however, that subsequent additions of fine sediments to the streambed can have deleterious effects on trout populations.

3.2 Accidental Spills

Discharge to water-ways of any waterborne wastes or steam condensate is prohibited in the Geysers-Calistoga KGRA. However, pollution incidents do occur because of equipment failures or malfunctions, natural catastrophes, human errors and other such causes. Four well blowouts have occurred at The Geysers. The last one cost \$3-million to contain (see, for example, Bacon (1977)). Sump failures, pipeline leaks, and vehicle accidents can also occur.

The North Coastal Regional Water Quality Control Board reports 21 accidental spills in The Geysers area during the last four years (communicated by David Snetsinger at the workshop). Nineteen of these spills were condensate discharges and sixteen occurred in the vicinity of power plants. Table 1, taken from Freeman, et. al. (1977), is a list prepared by the U. S. Bureau of

Land Management of 37 pollutant incidents at the Geysers Geothermal Field from 1965 to 1976. Perusal of this list indicates that accidental spills occur from a variety of failures and result in the release of many different kinds of contaminants.

Experience with control of spill events is leading to improved mitigating measures (e.g., see PG&E, 1977). For example, construction of an impermeable retention barrier surrounding a power plant is now standard practice. These barriers are designed to contain any accidental condensate spills from a cooling system. In addition, regulatory procedures of the Regional Water Quality Control Boards for well drilling and sump operation are effective in reducing spill incidents. Waste discharge permits are issued by Regional Water Quality Control Boards specifying sump construction and operation procedures, as well as waste handling methods. These boards prohibit discharge of any wastes to surface waters.

In spite of generally adequate regulation and monitoring of installations and operations, failures can and do occur which result in accidental discharges of wastes to surface waters as evidenced in Table 1. Although the major constituents of drilling fluids are not generally toxic, additives such as detergents can be injurious to fish and other animals. Condensates contain high levels of ammonia, hydrogen sulfide, boron, mercury, and other constituents which can be toxic and detrimentally affect downstream water users. Toxicity bioassay studies have been conducted by Parametrix, Inc. and California State Department of Fish and Game. Results of these studies, which demonstrate a wide variation in toxicity among condensates, are on file with the respective investigators, but formal reports have not been published. Cal Fish and Game has also investigated reported fish kills in Big Sulphur and Squaw Creeks in 1974 and 1977. Reports are on file with Cal Fish and Game.

Accidental spills have led to occasional fish kills (see Table 1) and steam condensates can be toxic to fish species. However, no permanent damage by accidental spills to aquatic species or water quality has been

TABLE 1
LISTING OF POLLUTION INCIDENTS
AT THE
GEYSERS GEOTHERMAL FIELD

November 18, 1975

11/3/65	Discharge of power generation wastewater into Big Sulphur Creek.
11/28/67	Siltation into Big Sulphur Creek from road building activities.
1/4/68	Unusual milky/soapy substance causing turbidity in Big Sulphur Creek from confluence with Squaw Creek to within 1/4 mile of Russian River.
1/5-6/68	Drilling muds from Geothermal Resources Rorabaugh #2 found spilling into Big Sulphur Creek. Samples of "Magcogel" and "Magcobar Foam #44" obtained. Bioassays indicated Magcobar 44 toxic to trout at concentration of 10 ppm.
1/11/68	Sumps for GRI wells Rorabaugh #2 and #3 filled, earthen dams soft. Investigators felt they presented a threat to Big Sulphur if rains continued.
10/2/68	Reduction of fish food organisms and spawning gravels in area of Union Oil road construction (PG&E Units 3 & 4) (possible violation of Fish and Game Code Section 5650).
10/31/68	Silt and rock introduced to Big Sulphur as a result of road building.
11/13/68	Steelhead trout population downstream from Union Oil Company road reduced to 1/4 that of July 16, 1968 levels.
9/10/71	20,000 gallons of coolin tower wastewater and debris discharged to Big Sulphur Creek after pipeline failure in Union Oil wastewater disposal system. Low-flow condition present in Big Sulphur Creek.
7/6/72	Drilling muds and waste materials discharged to Big Sulphur Creek when an earthen sump at a Union Oil drill site (Hoover Rig E2) broke. Test conducted with drilling mud samples (bantonite clay, tannithin and lignite) indicated these materials can be toxic to fishlife.

Prepared by Bureau of Land Management, cited in Freeman, et. al. (1977).

4/19/73 Drilling muds and waste materials discharged to Squaw Creek as a result of a leaking sump at Union Oil drill site (Ottoboni #10). Seeps of drilling waste materials continued until 23 of April.

7/17/73 Discharge of cooling tower condensate reported and verified by DFG wildlife protection personnel.

10/73 RWQCB cleanup of Abatement Order No. 73-101 for Geothermal Kinetics, Inc. Rorabaugh #1 Well. Discharge of sump wastes in tributary to Big Sulphur Creek.

10/73 RWQCB and Abatement Order No. 73-102 for Pacific Energy Corp. Well No. 47. Discharge of drilling wastes to surface of dirt roads will probably result in discharge to Big Sulphur Creek.

12/11/73 Letter from RWQCB informing PG&E power plant supervisor of (1) sandblasting materials being discharged at power plants #1 and #2. These materials could pass into the waters of Big Sulphur Creek. (2) Trash and garbage dump located at power plants #9 and #10 which had not been approved by the RWQCB. (ref: 12,11,1973 letter to W. Pearce, PG&E plant superintendent from D. Snetsinger RWQCB. RWQCB files).

12/21/73 Recommendations from State WRCB regarding soil erosion and waste disposal at the Geysers state that: "The commonly expedient methods used in pit or sump construction disallows for proper design considerations against potential slope failure and/or the prevention of fluid infiltration into subsurface materials. Percolation of fluids through bed-rock fractures could affect the quality of local waters and promote instability of natural or man-made slopes." (ref: 12,21, 1973 Memorandum to Bob Tancreto, California Regional WQCB, Santa Rosa from State WRCB Geologist Gil Torres. RWQCB files).

2/5/74 Division of Oil and Gas notice of violation regarding unstable and overflowing sump for Union Oil Co. Well No. GDC 20-29.

2/5/74 Division of Oil and Gas notice of violation regarding unstable, washed out and eroded sump, natural springs draining at base for Union Oil Co. Well No. LF State 4597.

5/74 Approximately 2,000 gallons of water from the cooling tower basin and 50,000 to 70,000 gallons from the sediment basin emergency overflow drainage system of power plant Unit #5 & #6 discharged to the ground. Inspection of the plants also found oily discharges from stand pipes as a result of numerous spills from a waste oil and oil storage area. (ref: memorandum 5/28/74 to Tancreto, PG&E from D. Salisbury; 6/3/74 letter to BenKor CRWQCB, Santa Rosa from W. Pearce, PG&E. RWQCB files).

- 5/15/74 Condensate line from Unit #7 & #8 pond to Unit #11 broke at the drill rig water tie-in point. The tie-in weld broke, releasing condensate at the rate of 465 gpm. The total discharge was estimated at 28,000 gallons. There was a noticeable increase in turbidity in Squaw Creek noted. Parametrix personnel reported electroshocking data show fish to be healthy and active (?) (ref: Union 76 letter 5/22/74 to CRWQCB, Santa Rosa, attn: John Hannum).
- 6/3/74 50,000 to 75,000 gallons of steam condensate spilled from a ruptured pipe at PG&E plant #7. Water from this spill reached Squaw Creek. The spill was reported approximately two months after it happened. (ref: Letter 6/3/74 to CRWQCB from W. Pearce. CRWQCB files).
- 7/8/74 Spill of detergents into Squaw Creek from Union Oil Co. drilling rig wash water. Tests indicated that the material was toxic to fish.
- 8/20/74 A discharge of condensate water occurred at cooling tower #2. The water contained approximately 14 mg/l of iron in addition to the normal constituents found in the condensate. The high iron concentration was the result of an experiment by PG&E. The discharge reached Big Sulphur Creek and resulted in a red discoloration that persisted for approximately one hour (~10 ppm). (ref: memo (interoffice) to Bob Tancreto and Beu Kor from D. Snetsinger 8/21/74. (CRWQCB files).
- 9/9/74 Mechanical failure of the fiberglass disposal line from Unit #5 & #6 settling pond discharged ~4,500 gallons of condensate into Big Sulphur Creek. A fish kill and excessive siltation was noted. (ref: Union 76 letter 9/19/74 to CRWQCB. CRWQCB files).
- 9/16/74 A Unit #5 & #6 settling pond overflow on 9/15/74 discharged ~45,000 gallons of condensate to Big Sulphur Creek. Improper procedures in water transfer blamed. No fish kill noted, however, parametrix noted a higher than average ammonia and sulfate level present in Big Sulphur Creek. (ref: same as above).
- 1/6/75 Approximately 50 gallons of No. 2 diesel oil was spilled during routine fueling operations at the Ottoboni state well no. 20. The diesel was contained within a berm built for that purpose. Heavy rains overflowed the berm and released the diesel to Squaw Creek. (ref: Union 76 letter explaining the delay in reporting the spill to CRWQCB 1/15/75. CRWQCB files).
- 2/25/75 A water spill @ Horner state well #1 in Lake Co. released approximately 8,000 gallons condensed steam which had been used for drilling water was pumped onto the ground by accident. The water percolated into the ground and there was no visible

signs of contamination noted immediately after the accident. Mr. Pardini noted suds in High Valley Creek. (ref: Union 76 letter 3/17/75 to CRWQCB, attn: J. Robertson, RWQCB files).

- 3/31/75 Blow-out of Union Oil Co. Well No. GDC 65-28. Hillsides near well covered with greenish dust which washed into stream tributary to Big Sulphur Creek.
- 4/9/75 Construction efforts to control blow-out of Union Oil Co. Well No. GDC 65-28 result in high turbidity and sedimentation of Big Sulphur Creek and tributary (reportedly a continuing problem).
- 5/9/75 Discharge of cooling tower water from PG&E Unit #11 into Squaw Creek.
- 6/4/75 A flange broke at Unit #11 spilling an estimated 20,000 gallons of condensate to the ground. Of the amount spilled, most was contained in a basin but 10% was reported to have reached Squaw Creek. The flange is of the same type as installed at other units. (ref: PG&E letter 6/4/75 to CRWQCB, attn: Mr. Snetsinger; Interoffice memo 6/5/75 to B. Tancreto, B. Kor, & D. Snetsinger from D. Salisbury. CRWQCB files).
- 6/6/75 A spill of ~10,000 gallons from Unit #3 consisted of steam condensate and water from a tributary of Big Sulphur Creek. A vitrified clay pipe broke, and drained the water 1/2 mile down the hill carrying mud into the creek. Duration of the spill was approximately 4 hours. The clay pipe is being replaced with glass lined carbon steel pipe. (ref: PG&E letter 6/10/75 to CRWQCB, attn: Mr. Snetsinger. CRWQCB files).
- 9/5/75 Water was discharged from a Unit 10 cooling tower header pipe flange to the ground. The flange broke during a Unit 10 shutdown releasing 148,500 gallons of steam condensate in 4 minutes. The spill ran down 1/4 mile of hillside to Cobb Creek and eventually to Big Sulphur Creek. There was no visible damage to fishlife or excess siltation in Big Sulphur Creek noted. (Ref. PG&E letter 9/10/75 to CRWQCB, Attn: Mr. Snetsinger. CRWQCB files).
- 8/6/75 Discharge of material from Shell Oil Company Well U.S. Geothermal One-1 on Federal lease, Lake County, Sec. 1, T10N, R8W, MDB&M. Grey material discharged from well covered approximately 3-4 acres, coating ground surface, shrubs, and trees. Portion entered intermittent tributary to Dry Creek.
- 12/75 Spill of drilling mud from PEC well near Eagle Rock Mine. Mud return line broke and discharged to tributary to Big Sulphur Creek.

- 3/16/76 Condensate pipeline failure at Unit 2 power plant, resulting in discharge of 4,260 gallons. The pipeline was of rebar reinforced concrete and had been badly corroded by the condensate. No extensive fish kill was observed in the stream below the discharge site.
- 5/26/76 Spill of 4,000 gallons of steam condensate at Unit 11, with a discharge to Squaw Creek. Spill caused by failure of a check valve in the condensate return line to an injection well. A total of 54 dead steelhead trout were found in a stream section of 200 yards below the discharge.

documented. Price (1977) analyzes monthly water quality data from the Big Sulphur Creek watershed for the period 1968 to 1976 to determine if long-term effects of geothermal development can be detected. He concludes that there is no discernible trend in water quality characteristics related to power generation output in the Geysers area. However, the analysis does not investigate any direct connection between accidental spills and water quality.

3.3 Cooling Tower Drift Deposition

Water droplet emissions from cooling towers contain many of the constituents found in the original condensate. Water droplets which settle-out of the plume leave deposits of materials such as boron, ammonia, and heavy metals on soil and vegetation surfaces. These materials can be transported by runoff into surface and groundwaters (see Figure 2) leading to contamination of these waters. The constituents of primary concern are boron, ammonia, and heavy metals.

Pacific Gas and Electric Company has initiated studies designed to more clearly define the extent and nature of plume drift (reported by Mr. Carl Weinberg, PG&E, during the workshop). Studies at Geysers Unit 11 on droplet size distribution and deposition indicate that the radius of deposition is on the order of 1500 feet. Preliminary analysis of cooling tower drift at Geysers Units 5 and 6 demonstrates that drift composition and quantity are highly variable among units. Principal chemical constituents are boric acid and ammonium sulfate. Analysis of monthly water quality data collected since 1968 in Big Sulphur Creek has not demonstrated a significant correlation between megawatts of power produced and boron concentration in the stream water (Price, 1977). A study is now underway by PG&E to measure the production and fate of boron and ammonia in the Big Sulphur Creek drainage.

The principal constituents of interest in plume drift are boron, ammonia, mercury, arsenic, and other heavy metals. As these materials

move through a power plant system from incoming condensate to various effluent streams they partition between water and gas phases. Boron and ammonia apparently follow the water phase (Weinberg, communicated at the workshop), whereas mercury tends to follow the gaseous phase (Robertson, et al., 1976). Crecelius, et al., (1976) report that arsenic remains in the water phase. These measurements suggest that water droplets of plume drift may contain significant concentrations of certain constituents, especially boron, ammonia, and arsenic. Sampling cooling tower emissions directly is difficult. Systematic measurements of droplet composition have not been reported (see following page).

Mitigation of plume drift must occur in the cooling tower facility itself. Recent developments in drift control have significantly reduced the fraction of total cooling tower flow which is emitted as drift to the atmosphere. PG&E reports that the cooling towers are being designed to produce drift of no more than .008% of the total cooling tower flow and measurements suggest that .004% has actually been achieved in the field. However, these apparently low values do not guarantee prevention of water quality problems. The total emissions may still be significant and little is known about the actual magnitude and chemical form of the contaminants actually emitted from a tower. Distribution, chemistry, and fate of droplets and their constituents needs to be better understood to assess the need for and effectiveness of mitigating measures. Such information is likely to be highly site specific and dependent on local atmospheric precipitation, and soil conditions for a particular cooling tower and its particular condensate.

The following "back-of-the-envelope" calculation provides some indication of the magnitude of the problem. Assume for a 110 MW power plant a cooling tower flow of 4000 gallons per minute, drift flow of .008% of cooling tower flow, 100 mg/l boron in drift droplets, and drift deposition in an area of radius 1500 feet. Therefore we have, with appropriate conversion factors,

$$4000 \times .00008 \times 100 \times \frac{1}{\pi(1500)^2} \times 237 \times 10^6 = 1078 \frac{\text{mg}}{\text{Ac-day}}$$

The significance of this number for water quality impacts is unknown as it stands. It is not a prediction of what is or will be occurring because it represents too many simplifying assumptions and approximations. However, the magnitude of the number is sufficiently large to suggest that further study of mass emission and deposition rate from cooling tower drift warrant further study as a water quality issue.

3.4 Groundwater

Problems related to groundwater are addressed extensively in the Geological Effects Element of the Overview Project, particularly for potential problems in aquifers in the undeveloped hot-water resource area north and east of the current Geysers production field. However, because groundwater was one of the key issues addressed at the water quality workshop, we include some of the discussion here, with emphasis on groundwater in the steam-dominated area at The Geysers.

Existing regulations governing reinjection are apparently effective in preventing communication between geothermal fluids and groundwater basins under normal operating conditions. Accidental spills, leaks, well blowouts, and cooling tower drift deposition are all possible sources of effluents which could eventually affect groundwater through percolation. However, in the area developed to date at The Geysers, no known cases of groundwater contamination from geothermal activities have been reported.

Accidental spills of geothermal fluids or other substances incidental to geothermal activities (e.g., fuel oil, sanitary wastes, etc.) are monitored and reported through established procedures. Subsurface leaks in underground pipes and well-casings are more difficult to detect. There are no standard technologies or procedures for detecting leaks. The potential for the occurrence of leaks is not well defined and control and monitoring technologies are not well-developed.

A less significant potential groundwater problem arises due to the eventual conversion of geothermal temperature gradient test holes to shallow groundwater wells after they have been abandoned for geothermal purposes. County agencies do not receive notice of location or drilling of temperature gradient holes. Thus, they are not aware when a property owner may convert a hole for use as a water well. Conversely, the State Division of Oil and Gas (DOG) does not receive notice when wells are drilled for water. If hot water is encountered, DOG may not be made aware of it and no regulation enforcement may occur. Thus, there is a jurisdictional problem that may allow potential situations to arise which could affect groundwater quality and not be regulated. Questions here include: Who checks quality of water in converted wells? If water is of poor quality, who alerts regulatory agency? Who puts discharge requirements on such converted wells? Is there a need for a clear concise policy governing the disposition of temperature gradient wells after they are abandoned?

Overdraft of groundwater reservoirs for geothermal development is of concern. Certain developers have contracted with local ranchers and property owners for groundwater from wells for mixing of drilling muds and road construction. Small perched groundwater bodies and small aquifers in small alluviated basins have been depleted of their groundwater supplies by such pumpage and not recharged due to the drought in California. This could also affect the water quality in those aquifers. In particular, the question arises as to whether or not overdraft can induce recharge from geothermal sources.

In general, groundwater problems are a matter of concern because of the potential for contamination in the ways described above. No known problems of groundwater contamination have occurred to date in the development of the steam-dominated resource at The Geysers. However, in the hot-water dominated resource, where many more aquifers exist that are used both for domestic and agricultural water supplies, greater sensitivity to the potential for contamination of shallow groundwater

resources by geothermal development will be required. Awareness and recognition of these concerns is part of effective water quality management in the KGRA.

3.5 Hot Water-Dominated Systems

Most known geothermal resources are of the so-called hot water dominated type rather than steam dominated, of the sort currently being developed at The Geysers. Although only steam-producing reservoirs have been developed to date at The Geysers, data collected by the USGS (Goff, et al., (1977)) and others suggest extensive hot-water dominated reservoirs exist in the KGRA (Figure 4). Therefore, future water quality management in the KGRA may be concerned with several problems unique to hot water dominated systems. The following problems were identified in the workshop as of particular concern in the development of hot water resources:

- Large quantities of geothermal fluids must be disposed of in development of hot water resources. This could pose more problems in handling fluids from an accidental spill point of view, among others.
- Discharge quality of effluents are important in hot water conversion plants, where chemical properties of fluids are typically much more concentrated than for steam systems. This is a concern in assessing risks of accidental spills.
- Development of the hot water resource will probably result in higher use of existing freshwater supplies by geothermal industry. The reasons for this include: external cooling water supply requirements of binary conversion cycles if they are employed, nonelectrical uses would demand cooling water in many cases, etc. Drilling would require water for lubrication as distinguished from air drilling in steam fields.

Fig. 4. Approximate inferred limits of vapor-dominated and hot-water-dominated areas; heavy lines are major fault traces (from Goff, et al. (1977)).

- Alteration of natural hydrothermal phenomena which may be of historic or economic value could occur in the development of the hot water resources. Since the geothermal formations are not saturated with steam, release of hot water may reduce pressures far faster as the reservoir is developed than is occurring in steam production which could stop flows from some natural springs and seeps.
- Development of the hot water resource could affect existing groundwater reservoirs in the area. A great deal of uncertainty exists in the knowledge of the communication between geothermal and shallow groundwater aquifers.

In addition to the above problems that are unique to the hot water resource, the following problems are shared in common with development of steam resources:

- Accidental spills may occur where the potential for contamination is more severe in the hot water case because of the larger quantities of fluids being handled per megawatt, and the generally higher toxicity of the fluids themselves.
- Erosion and sedimentation are problems in development of hot water systems and are potentially more severe than in the steam case since more wells must be drilled to reach a comparable level of power production which means more construction activity.

Little information exists in print regarding the size and extent of the hot water resource that is suspected to stretch from the steam field at The Geysers northward and eastward to Clear Lake and beyond. Also, little is known quantitatively about the surface water and groundwater in this region. Little baseline data exists for trace metals which may be important if high salinity brines are encountered in drilling geothermal wells. For these reasons, regional studies were

suggested to document the surface water and shallow groundwater hydrology of this area, and to characterize the energy, nature, and extent of the hot water resource itself. Before even cursory knowledge of the magnitude and extent of the resource is known, little can be done in planning for rational water quality management as development of the hot water resource proceeds.

4.0 ASSESSMENT OF INFORMATION NEEDS

In preceding sections of the report we have described important water quality issues in The Geysers-Calistoga KGRA. As we have pointed out, management of water quality problems give rise to information needs, which lead to data collection programs. The inventory of existing data (Appendix B) illustrates the wide-ranging water data base available for the KGRA. Two questions now arise: 1) In what areas is information needed? and 2) What specific studies need to be undertaken? We address the first question in this section of the report, which leads to specific recommendations presented in Section 5. Several considerations described in the following paragraphs, guide our delineation of areas in which more information is needed.

The areas described below are broad in that they cut across many of the issues defined above. This is apparent from the common nature of many of the data gaps encountered. For example, many of the data needs are found to address questions about cooling tower drift deposition. But, much of the same data is needed to assess impacts of erosion and sedimentation.

A difficulty that arises in identifying information needs is that we never have complete, perfect knowledge about a particular problem. So, it is always possible to identify studies that could be undertaken to reduce uncertainty, to fill in data gaps. The question we much address is: Is this information useful to water quality managers? Management decisions much always be made in the face of uncertainty.

What additional information is likely to enhance the effectiveness of management actions? The data needs we describe below are suggested in response to this question. There are innumerable other programs of data collection and analysis programs which we could suggest. However, they are not presently perceived as contributing substantively to water quality management in The Geysers-Calistoga KGRA. We have relied heavily on the input from workshop participants to identify information needs.

Certain information needs are clearly the responsibility of particular agencies or parties involved in the KGRA. In such cases, studies are on-going which are intended to meet specified information needs. Typically, these situations arise in the context of particular impacts in which specific management actions have led to certain design requirements or mitigating measures. For example, PG&E has undertaken erosion and sedimentation studies to measure impacts of construction and operation at several Geysers Units. These studies include pre-operational and operational sampling to facilitate comparisons and estimate effects. We have not considered studies of this type in detail.

Another delimitation on the information needs we have identified are cases in which data apparently exist or are being collected, but not fully used to satisfy perceived management needs. A case in point is the chemical characterization of condensates from well fields. Such information is important for assessing effects of various geothermal activities and quantifying source terms in mass balance calculations. PG&E and/or steam producers have collected such data since 1968 as a permit requirement of the North Coastal Regional Water Quality Control Board. We do not discuss information needs in cases where existing data have apparently not been fully utilized.

A final restriction on the kinds of information we discuss below is the omission of ecosystem impact studies. This somewhat arbitrary restriction follows the general organization of the entire Overview Project which deals separately with water quality and ecosystem quality. As a

consequence of this delimitation, we do not give consideration one way or another to such data as fish toxicity bioassays and agricultural crop sensitivities to particular substances, e.g., ammonia, boron.

The foregoing restrictions on the kinds of information we have included in our analysis significantly reduces the list of candidates for future studies recommended in Section 5. However, we believe these restrictions allow us to focus on a small set of needed studies, which can yield useful results for management and which may not otherwise be undertaken.

Our basic strategy for assessing information needs is to adopt a mass (materials) balance point of view. Any material--water, soil, boron, mercury--moves through an environmental system defined to be of interest--the entire KGRA, a watershed, a defined site location, a particular power plant. We account for movement of a material through this system by conceptualizing a mass balance, consisting of source terms (inputs), storages in various locations and forms, transport among storages, transformations from one chemical form to another, and outputs to the surroundings (defined by system boundaries). Such a conceptualization is a model, a working hypothesis, about how the system works. Given such a model for, say, boron, we can devise sampling programs and experiments to test the model structure and generate estimates of storage levels and rates of transfer through the system. An iterative process of data collection, data analysis, model development, experimental design, and data collection leads to improved understanding of the system. Of course, at any stage in this iterative process, the model is based on existing information and reflects the quality of existing data.

4.1 Soil & Sediment Information Needs

Knowledge about physical and chemical relationships among water, soil, and sediment particles and chemicals such as boron, ammoniac, mercury, and arsenic is necessary in order to effectively regulate impacts on water quality of geothermal energy development. As can be seen in Figure 2, erosion and sedimentation, accidental spills, cooling tower drift deposition, and groundwater contamination are all water quality issues which depend in part on physical/chemical processes occurring in soil and sediments. However, little or no data are available on these processes nor on levels of contaminants stored in soils and sediments in the KGRA.

This lack of information points directly to the need to determine levels of chemicals in various soil and sediment storage reservoirs. A coordinated program of soil and sediment studies is needed which is aimed at the following overall purpose: to determine the inputs, dispersal, transport, and fate of boron, ammonia, mercury, arsenic, and other substances in the soil and sediment environments of The Geysers-Calistoga KGRA.

Specific objectives at a selected site within such a program include:

- 1) to measure the mass emission rates of substances from various sources, e.g., plume drift;
- 2) to estimate fluxes of materials to soil surfaces (i.e., inputs) from natural geothermal sources and development related sources;
- 3) to estimate existing levels and distribution of chemicals in soil and sediment reservoirs;
- 4) to estimate rates and routes of transfer of chemicals among soil, sediment, overland flow, and streams;

5) to determine the relative contribution of geothermal energy development activities to ambient levels of materials in soils and sediments; and

6) to determine whether or not materials are accumulating in soil and sediment reservoirs.

A program of studies to accomplish these objectives is likely to require many years of effort. Not all of the objectives can be accomplished at once. Many different investigators are likely to be involved. It will be important to coordinate with other on-going investigations, particularly cooling tower emission measurements, stream water quality monitoring and erosion/sedimentation studies. All of these factors will complicate the design and management of soil and sediment studies. A prudent approach to these difficulties is to undertake these studies incrementally, beginning with the relatively simple objective of measuring ambient levels at chosen sites. As information and experience expand, the scope and level of effort can be increased to address more difficult objectives such as rates and routes of transfer, which require information about physical/chemical processes occurring in the soil/sediment environment.

The issues that would be addressed by such a study are many as stated before. Understanding mobility of certain chemical species in stream beds, how they move with the sediments, what the speciation of a certain element is (toxic or benign form), which elements precipitate and are lost from the water column; all these depend intimately on soil particle/chemical/water interactions. Accidental spills and drift deposition are thought to be problems. Study of soils and sediments would allow assessing just how important spills and drift are to degradation of water quality. In the case of drift deposition, accumulation of boron in soils may occur in such a way that it is unavailable to important components in the ecosystem, or just the opposite may be true. Understanding which elements and which of their forms can leach through soils will shed light on suspected problems associated with groundwater contamination. All of these are particularly important in the development

of the hot water resource, where levels of dissolved material in circulating geothermal fluids may be orders of magnitude higher than that experienced in the steam resource. Results of studies of existing effects, for example, around cooling towers in the steam-dominated resource, may be extendable to future cooling towers in the hot water resource.

Such a study of soil/sediment chemistry would serve as a means for accumulating badly needed baseline data in the area of the suspected hot water resource. Effects studies aimed at understanding soil/water interactions would necessarily generate baseline levels of chemicals in soils, sediments, and water as the first phases of those studies. These would be valuable in documenting existing levels and to identify ongoing effects of natural geothermal emanations (e.g., springs, fumaroles), and effects from previous man-caused activities (e.g., mining, industry). Differences are expected to be found between results of soil/sediment chemistry studies done in the steam-dominated and hot-water resource areas. The soils are quite different in the two areas, stemming from basic differences in the geology. This manifests itself in less significance for erosion and siltation problems in the hot water area; see Figure 3.

4.2 Hydrologic Studies

Hydrologic processes are a principal driving force in the transport of materials to streams and lakes in the KGRA. Overland flow carrying dissolved and suspended materials is the principal source of contaminants to streams (see Figure 2). Although substances such as boron, ammonia, arsenic, and mercury may originally arise from plume drift, accidental spills or natural geothermal activity, overland flow during rainy periods transports these materials into surface water systems. Regulations prohibit releases of geothermal fluids to waterways (see CRWQCB Waste Discharge Requirements for the Big Sulfur Creek watershed, Appendix M in Freeman, et. al. (1977)). Accidental spills do occur, however, and some have reached waterways. In any event, understanding the hydrology and hydrologic processes in the KGRA is essential for effective water quality management.

Of primary interest is the hydrology of storms, because these events produce the overland flow and activate the numerous ephemeral streams in the area. In addition, the first storm event of a year is suspected of carrying particularly high pollutant loads, which have been accumulating on soil and vegetative surfaces. Storm events also create critical periods for sumps, holding ponds and other containment devices. For example, design of these control structures should be based on realistic estimates of 1 hour and 24 hour rainfall intensities to avoid potential failure and resulting accidental spills during storm conditions.

Furthermore, in order to assess sediment fluxes for existing sites, data are needed on soil loss, sediment loads during storms and sediment chemistry. Of particular importance is the need for storm runoff information. High rain runoff and fluctuating streamflows cause dramatic changes in bottom deposits. These must be measured during storm events themselves. The data needs for prediction of sedimentation include topography (slope, slope length, etc.), rainfall intensity distributions, vegetation, and soil erodibility.

The complex topography of the KGRA causes highly variable hydrologic characteristics. Therefore, detailed hydrologic studies of storms are needed on a localized, site-specific basis. For any given site the following kinds of information may be needed:

- 1) 1 hour and 24 hour rainfall precipitation;
- 2) meteorological data such as air temperature, wind, radiation and dew-point;
- 3) soil characteristics, especially permeability and erodibility;
- 4) overland flow volumes and velocities;

- 5) soil storage volumes (which are likely to vary with depth);
- 6) relative contributions of precipitation to evapotranspiration, stream-flow, and groundwater.

In general, not all of this information is available for each specific site. Guidance for design of studies to obtain the necessary information can be provided by appropriate hydrologic models. Several surface runoff models exist which are potentially applicable to the Geysers situation. Of particular interest are the EPA supported models for nonpoint source pollution (NPS) described by Donigian and Crawford (1976a and b). This model was originally developed by Hydrocomp, Inc., Palo Alto, California, and has been applied to urban and agricultural systems.

A practical problem which arises in the study of storm hydrology is the difficulties associated with taking measurements during storm events. Although automatic sampling equipment exists for some variables, e.g., flow, there is a need for further development and refinement of automatic sampling equipment of suspended and dissolved substances. This is particularly true in ephemeral streams.

It is interesting to note that the State Water Resources Control Board requires that a storm drainage and erosion control plan be submitted to the appropriate Regional Board prior to any geothermal energy development. Such plans are required to include expected volumes, peak rates, characteristics and other pertinent information concerning stormwater runoff.

In addition to the need for certain surface hydrologic information, workshop participants also expressed a need for certain hydrogeologic information. In particular, there is concern by groundwater users, e.g., agriculture, about potential contamination of shallow groundwaters with geothermal fluids. The particular question which arises is: Is there hydraulic continuity between shallow groundwater basins and geothermal

reservoirs? Until this concern is resolved, growers are likely to resist geothermal development in areas near agricultural irrigation water sources. Although the effects of geothermal development on groundwater quality was of importance to many participants in the water quality workshop, this was dealt with adequately and in detail in the Geologic Effects Element of the Overview Project.

The issues addressed by such a comprehensive hydrologic study are many. Study of Figure 2 shows that hydrology is in fact the driving force behind contaminant transport. Understanding the hydrology in the hot water resource area is of particular importance because large volumes of geothermal fluids with potentially high levels of toxic elements will be involved. The flushing potential of streams, the abundance of groundwater in storages, runoff rates during storms, all of these will be needed to make assessments in the hot water area. Relatively high requirements for cooling tower water consumption is expected in the implementation of hot water energy conversion cycles; for this reason, it will be required to know what water supplies exist that could be used for cooling.

4.3 Characterization of Hot Water Resources

As we have previously pointed out, characteristics of hot water resources must be evaluated before potential impacts of hot water development can be fully assessed. Figure 4 suggests that extensive hot water resources exist in the KGRA. To avoid piece-meal resource development and to facilitate an orderly development of these resources in an environmentally acceptable manner, an area-wide study is needed to determine:

- resource boundaries
- heat sources
- recharge

- communication among geothermal reservoirs and with shallow groundwaters
- quality and quantity of water in reservoirs.

In addition to area-wide studies, site-specific investigations will also be required in conjunction with proposed developments. An example of a site-specific study is described by Forsythe (1977) for the Republic Geothermal's Howard Springs Leasehold at Seigler Springs. This type of site-specific study should be undertaken by the developers themselves. Forsythe's program provides a model for assisting developers and regulators in designing studies for other developments.

4.4 Generic Needs for Water Quality Management

It is important to point out another set of issues which emerged during the workshop proceedings. These concerns do not deal with specific water quality impacts, but rather are generic management needs which often arise in water quality management. These needs differ from the kinds of data needs we have discussed to this point. During the workshop, particular attention was pointed to the need for:

1. Design and evaluation of monitoring programs;
2. Analysis of existing water quality data for use by decision makers;
3. A method for differentiating natural and development-related contributions to water quality;
4. An integrated and well-defined water quality regulatory and enforcement process.

These needs arise in the course of carrying out water quality management activities in any context. They form part of the technical analysis and process from which management decisions are made. Improvements in these processes and methods represent improvements in the management process itself. Water quality management in the Geysers area has access to the state-of-the-art in these areas of analysis. In fact, a forthcoming EPA report titled "Report on Strategy and Design for Monitoring and Monitoring Methodology, Four Geothermal Areas" deals with some of the needs listed above. Studies undertaken to address these needs can lead to generic improvements in the management process. However, water quality management in the Geysers is not any more restricted by these needs than water quality management in any other context. For example, Moore and McLaughlin (1977) develop criteria for the design of field studies to investigate the impacts of oil spills in marine intertidal environments. The results include information relevant to experimental design in any environmental situation and could be applied to problems in the Geysers area.

One of the recurrent, dominant issues raised during the workshop was the need for an improved regulatory structure and process. There are many local, state and federal agencies concerned with regulation of water quality in the Geysers-Calistoga KGRA. In general, there is relatively little coordination and communication among these agencies. We described one case of a jurisdictional problem between county agencies and the State Division of Oil and Gas concerning conversion of abandoned temperature gradient holes to water wells. During the workshop, the need for regulatory coordination, clarification and communication was repeatedly expressed. The lack of coordination and integration of regulatory activities has several consequences:

- a) Water quality data are collected as required by, for example, discharge permits, stored in files but not systematically analyzed for regulatory purposes;

- b) Monitoring programs are rarely, if ever, evaluated and modified because the data are not analyzed;
- c) Some problems and issues fall between regulatory "cracks." For example, plume drift deposition leads to potential water quality problems but who regulates plume drift from a water quality perspective?
- d) Developers are faced with a confusing maze of permits, requirements, demonstrations, reports, etc. which create an inefficient and costly decision process.

It is apparent from these concerns that there is a need for reorganizing and streamlining the existing regulatory structure to provide a process of water quality management which integrates:

- data collection
- data analysis and evaluation
- data storage and retrieval (library)
- modeling
- monitoring program evaluation
- permit requirements and approval
- other decisions guiding development.

The need for modifications and improvements in the regulatory structure emerged on numerous occasions during the workshop.

Management of water quality in The Geysers KGRA can substantively benefit from improvements in the existing regulatory process and structure.

5.0 RECOMMENDATIONS

The foregoing section has delineated a wide range of areas in which further information would contribute to water quality management in the Geysers-Calistoga KGRA. However, we must go beyond this assessment to identify and recommend specific studies to be undertaken. It is neither appropriate nor feasible to attempt to undertake a study in response to every area of information need discussed. Our selection of specific studies is based on the apparent magnitude and importance of related water quality problems, the degree of concern expressed during the workshop, and the extent to which existing studies are attempting to address the need for information.

5.1 Hot-Water Dominated Resources

A great deal of uncertainty and concern exists regarding hot water resource development in The Geysers-Calistoga KGRA. Water use and disposal and effects on existing water uses (hot springs, surface water, and groundwater) are virtually unknown. Until the extent and development potential of the hot water resource is known, little can be said to reduce uncertainties and alleviate concerns about potential development. Therefore, we make four recommendations involving development of the hot water resource.

1. Sufficient data should be collected and analyzed in order to estimate the extent and nature of the hot water resource.
2. Sufficient data concerning the hot water resource and the energy conversion technologies that are likely to be used in its development should be obtained in order to predict future cooling water requirements, effluent volumes, and effluent chemical characteristics.

Until the full extent of hot water geothermal resources in the KGRA is known, concerns about water quality impacts caused by development of these resources are speculative. Characterization of the resource on an area-wide scale on even a cursory basis is a necessary step towards effective management of its development. A cooperative arrangement should be established among DOE, USGS, and the Division of Oil and Gas, to permit geothermal fluid chemistry data held by developers to be released for use in environmental studies and planning, even if on a confidential basis. Such source term data is necessary to distinguish potential significant impacts from those that are inconsequential.

3. Sufficient data should be collected and analyzed in order to establish baseline conditions in the water environment of the hot water resource area.
4. Studies should be carried out to determine transport and fate of chemicals in soil, sediment, and water storage compartments of the environment before development proceeds, including effects caused by naturally occurring geothermal activity.

By beginning studies like the soils and sediments and hydrology studies identified in Sections 4.1 and 4.2 above, basic information on transformation and transport rates will be obtained that will be important in making future management decisions. Emphasis should be placed on collecting results from studies in other areas of the world where various levels of experience in hydrothermal development already exist. This information, together with information from studies to characterize the resource, can guide the direction and extent of future water quality studies in the hot water resource areas.

5.2 Steam-Dominated Resources

With respect to steam-dominated resources, successful mitigating measures do exist and the existing management process, in spite of certain

difficulties, has been successful in reducing water quality problems during the past ten years. Water quality problems do not presently appear to be critical decision points for continuing development of the steam dominated resources. Therefore, recommendations for studies in this area are not a first priority. However, the studies we suggest below can help resolve existing controversies and help quantify the extent and magnitude of certain potential impacts. We therefore recommend the following studies be undertaken:

5. Measurement and analysis of plume drift contributions of boron, ammonia, mercury, and arsenic to soil and vegetative surfaces; measurement of accumulation of these chemicals in soils near cooling towers and comparisons with areas nearby not affected by cooling tower drift.

In particular, these studies should quantify the mass emission and deposition rates for these substances, the present levels of accumulation in soils adjacent to operating cooling towers, and background levels in control areas away from existing development. Decisions regarding implementation of subsequent studies to control and regulate plume drift should be based on the results of these initial studies. A decision to undertake a comprehensive program of model development as outlined in Section 4.1 can be made after results of these initial cooling tower studies are available.

6. Make measurements or collect existing data to estimate chemistry of geothermal fluids involved in accidental spills that have occurred in the past at The Geysers. Measure present levels of boron, ammonia, mercury, and arsenic in soils affected by those spills in order to assess long term effects. Conduct laboratory soil transport studies with representative fluids and soils to calculate transport coefficients.

Data from these studies should allow assessment of levels of effects of typical spills which have been documented at The Geysers. Understanding of the effects of past spills should provide data to make predictions

of cumulative effects which may occur due to accidental spills over the future development of the steam resource.

7. Development of guidelines and criteria for the design of field studies to differentiate natural and development-related contributions to water quality.

Two questions arise in the study of any water quality impact: 1) What sampling or monitoring program design provides information which accomplishes given field study objectives; and 2) What methods of data analysis allow impacts of interest to be differentiated from natural phenomena and background variability? As we have pointed out, these are generic questions associated with water quality management in any context. However, they are specifically relevant to improving water quality management in The Geysers-Calistoga KGRA.

6.0 REFERENCES

- C. F. Bacon, "Blowout of a Geothermal Well," California Geology, January (1976).
- E. A. Crecelius, D. E. Robertson, J. S. Fruchter and J. D. Ludwick, "Chemical Forms of Mercury and Arsenic Emitted by a Geothermal Power Plant," presented at 10th Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, Missouri (1976).
- A. S. Donigian, Jr. and N. H. Crawford, Modeling Pesticides and Nutrients on Agricultural Lands (Hydrocomp, Inc., Palo Alto, California 94304), U. S. Environmental Protection Agency Report EPA-600/2-76-043 (1976a).
- A. S. Donigian, Jr. and N. H. Crawford, Modeling Nonpoint Pollution from the Land Surface (Hydrocomp, Inc., Palo Alto, California 94304), U. S. Environmental Protection Agency Report EPA-600/3-76-083 (1976b).
- J. M. Donnelly, F. E. Goff, J. M. Thompson and B. C. Hearn, "Implications of Thermal Water Chemistry in The Geysers-Clear Lake Area," Proceedings of the Geothermal Environmental Seminar - 76, Lake County, California (1976).
- D. Forsythe, "Hot Springs and Geothermal Development, Monitoring Programs for Hot Springs Preservation," (D. Forsythe, Environmental Consultant, Kelseyville, California 95451, unpublished manuscript (1977)).
- R. E. Freeman, R. K. White, L. A. Cavanaugh, K. M. Clark, D. T. Dick, M. Duffey-Armstrong, B. R. Holt, M. E. Ivory, C. A. Kroll, S. J. Mara, D. R. Myers, S. R. Pierce, R. E. Ruff, J. M. Steinberg, B. L. Walton, and D. R. Zoellner, Environmental Analysis for Geothermal Energy Development in The Geysers Region, Volume II: Master Environmental Assessment, (Stanford Research Institute, Menlo Park, California 94025) State of California Energy Resources Conservation and Development Commission (1977).

F. E. Goff, J. M. Donnelly, and J. M. Thompson, "Geothermal Prospecting in The Geysers-Clear Lake Area, Northern California," Geology 5, 509 (1977).

R. S. LeGore, The Effects of Geothermal Energy Utilization on Stream Biota and Water Quality at The Geysers, California, report to Union Oil Co., Parametrix, Inc., Seattle, Washington, Parametrix Doc. #75-0731-040FR (1975).

S. F. Moore and D. B. McLaughlin, Design of Field Experiments to Determine the Ecological Effects of Petroleum in Intertidal Ecosystems, a report to the National Oceanic and Atmospheric Administration and the Environmental Protection Agency, Resource Management Assoc., Lafayette, California (1977).

Pacific Gas and Electric Co., Environmental Data Statement Geysers Unit 16, Pacific Gas and Electric Co., San Francisco, California (1977).

D. G. Price, An Investigation of Unique Water Quality Conditions in the Big Sulphur Creek Watershed Related to Natural Geothermal Activity, Streamflow, and Geothermal Development, PG&E Report 420-77.1 (1977).

D. G. Price, P. F. Kubicek, and L. A. Enriquez, Geysers Unit 17 Site Specific Studies: Fishery Resources, Water Quality Characteristics and Stream Sedimentation, PG&E Report 7784.13-76 (1976).

D. E. Robertson, E. A. Crecelius, J. S. Fruchter and J. D. Ludwick, "Mercury Emissions from Geothermal Power Plants," Science 196, 1094 (1977).

APPENDIX A

LLL/GRIPS GEYSERS-CALISTOGA KGRA WATER QUALITY WORKSHOP

Program and List of Participants

Location: Conference Mini-Center, University of California, Davis

Monday, November 14, 1977

8:00 - 8:45 Registration

GENERAL SESSION I - OVERVIEW

8:45 - 9:00 Welcome and Introductory Remarks
 ● Steve Moore, Resource Management Associates

9:00 - 9:30 The Environment and Resources of The Geysers-
Calistoga KGRA
 ● Dave Hill, Calif. Energy Resources
 Conservation and Development Commission

9:30 - 10:00 Water Quality Management in The Geysers-
Calistoga KGRA
 ● Ray Krone, University of California at Davis

10:00 - 10:30 Geothermal Resource Development Activities in The
Geysers-Calistoga KGRA
 ● Carl Weinberg, PG&E

10:30 - 11:00 Perspectives on Regulatory Processes and Needs in The
Geysers-Calistoga KGRA
 ● Dowell Martz, Chairman, Napa County Board of
 Supervisors
 ● David Joseph, Executive Officer, North Coast
 Regional Water Quality Control Board

CONCURRENT WORKING GROUPS - SESSION I

11:00 - 12:00

Workgroup task: Generate List of Water Quality Issues of Concern in Geysers-Calistoga KGRA

Participants Join Working Groups According to "Roles":

- Regulators
- Developers
- Data Collectors/Evaluators
- Modelers

12:00 - 1:00

Lunch

1:00 - 2:30

- Working Groups Report Results of Issue Identification
- Compile Summary List of Issue Areas

CONCURRENT WORKING GROUPS - SESSION II

2:30 – 4:30

Regulators and Developers Working Groups Task:

- Clarify Management Actions and Identify Information and Data Needs for Management of Water Quality in the KGRA

Data Collectors Working Group Task:

- Identify and Summarize all Existing Water Quality Data for The Geysers-Calistoga KGRA

Modelers Working Group Task:

- Identify Existing Models Potentially Applicable to Water Quality Management in The Geysers-Calistoga KGRA

Tuesday, November 15, 1977

GENERAL SESSION III

8:00 - 9:30

- Recapitulation and Restart
- Working Group Reports

CONCURRENT WORKING GROUPS - SESSION III

(Form New Working Groups According to Water Quality Issue Areas Summarized in General Session II)

9:30 - 12:00

Working Group Task: Identify Inadequacies and Gaps
in Existing Water Quality Data Relative to
Selected Issue Area

12:00 - 1:00

Lunch

CONCURRENT WORKING GROUPS - SESSION IV

1:00 - 3:00

Working Group Task: Prioritization and Recommendations
for Future Studies on Water Quality in Geysers-
Calistoga KGRA

GENERAL SESSION IV

3:00 - 5:00

- Final Working Group Reports
 - Summary and Closure of Workshop
-

LIST OF PARTICIPANTS
LLL/GRIPS GEYSERS-CALISTOGA KGRA
WATER QUALITY WORKSHOP

November 14 & 15, 1977 University of California, Davis

Private Industry and Individuals

Fred Biagini
Pacific Gas & Electric Co.
77 Beale Street
San Francisco, Ca. 94106
(415) 781-4211

John Boughey
Brown & Caldwell
1501 North Broadway
Walnut Creek, Ca. 94596
(415) 937-9010

Linda Branscomb
Environmental Systems & Service
4895 Gaddy Lane
Kelseyville, Ca. 95451
(707) 279-4223

Catalino B. Cecilio
Pacific Gas & Electric Co.
77 Beale Street
San Francisco, Ca. 94106
(415) 781-4211 Ext. 1483

W. G. Christian
Sunedco
12700 Park Central Place
Dallas, Tx. 75225
(214) 233-2600

Scott Cressey
Western Ecological Services Co.
4340 Redwood Highway, Suite 145
San Raphael, Ca. 94903
(415) 479-9392

James Davidson
Pacific Gas & Electric Co.
77 Beale Street
San Francisco, Ca. 94106
(415) 781-4211 Ext. 3684

Lucille Enriquez
Pacific Gas & Electric Co.
3400 Crow Canyon Road
San Ramon, Ca. 95483
(415) 820-2000

David Forsyth
Environmental Consultant
9180 Konocti Bay Rd.
Kelseyville, Ca. 95451
(707) 994-9497

George Frye
Aminoil U.S.A., Inc.
P.O. Box 11279
Santa Rosa, Ca. 95406
(707) 527-5332

Ivan F. Gennis
Gennis & Assoc., Engineers
1812 14th Street
Sacramento, Ca. 95814
(916) 446-1421

Robert S. Harris
Multi-Tech Laboratories
860 Waugh Lane # H-1
Ukiah, Ca. 95482
(707) 462-5570

William J. Hauser
Nalco Environmental Sciences
875 Cowan Road
P.O. Box 4006
Burlingame, Ca.
(415) 692-6141

Dennis McLaughlin
Resource Management Assoc.
3706 Mt. Diablo Blvd., Suite 200
Lafayette, Ca. 94549
(415) 284-9071

Stephen F. Moor
Resource Management Associates
3706 Mt. Diablo Blvd., Suite 200
Lafayette, Ca. 94549
(415) 284-9071

James Nielson
Ecoview
2540 Trower Avenue
Napa, Ca. 94558
(707) 224-0750

Gerald T. Orlob
Resource Management Associates
3706 Mt. Diablo Blvd., Suite 200
Lafayette, Ca. 94549
(415) 284-9071

Mark Passarini
VTN
2301 Campus Drive
Irvine, Ca. 92713
(714) 833-2450

Robert Schultz
Ecoview
2540 Trower Avenue
Napa, Ca. 94558
(707) 224-0750

Warren A. Smith
Union Oil Co. of California
P.O. Box 6854
2099 Range Avenue
Santa Rosa, Ca. 95406
(707) 542-9543

Lane R. Tanner
Spectrum
P.O. Box 188
Kelseyville, Ca. 95451
(707) 279-4223

Carl J. Weinberg
Pacific Gas & Electric Co.
3400 Crow Canyon Road
San Ramon, Ca. 95483
(415) 820-2000

James Womack
Environmental Systems Corporation
P.O. Box 2525
Knoxville, Tn. 37901
(615) 637-4741

COUNTY AGENCIES

William J. Arnoni
Lake County Health Department
201 Smith Street
Lakeport, Ca. 95453
(707) 263-2241

Gerald F. Davis
Mendocino County Department
of Env. Health
890 N. Bush Street
Ukiah, Ca. 95482
(707) 468-4466

Willard Hansen
Lake County
P.O. Box 206
Upper Lake, Ca. 95485
(707) 275-2440

Robert Keith Jones
Napa County Flood
Control District
1127 First Street
Napa, Ca. 94558
(707) 253-4351

Yoram J. Litwin
Association of Bay
Area Governments
Hotel Claremont
Berkeley, Ca. 94705
(415) 841-9730

Dowell E. Martz
Napa County Board of Supervisors
1115 First Street
Napa, Ca. 94558
(707) 253-4386

Nat J. Passaglia
Napa County Health Department
1123 First Street
Napa, Ca. 94558
(707) 253-4471

William Stillman
Sonoma County Water Agency
2555 Mendocino Avenue
Santa Rosa, Ca. 95401
(707) 527-2211

Larry Vollintine
Lake County Planning Dept.
255 N. Forbes Street
Lakeport, Ca. 95453
(707) 263-2221

Mark Walters
Lake County Planning Dept.
255 N. Forbes Street
Lakeport, Ca. 95453
(707) 263-2221

STATE AGENCIES

B. J. Archer
State of California
Department of Water Resources
32nd & "S" Street
Sacramento, Ca. 95816
(916) 445-9434

Lloyd Batham
State of California
Department of Public Health
714 "P" Street
Sacramento, Ca. 95814
(916) 445-4171

John Emig
California Dept. of
Fish & Game
P.O. Box 47
Yountville, Ca. 94599
(707) 944-2443

Alvin L. Franks
Division of Planning Research
State of Calif. Water
Resources Control Board
P.O. Box 100
Sacramento, Ca. 95801
(916) 322-4548

Joseph Halterman
Calif. Energy Resources Conservation
& Development Commission
MS-32 1111 Howe Avenue
Sacramento, Ca. 95825
(916) 322-3811

Joseph J. Henao
Water Quality Control Board
3201 "S" Street
Sacramento, Ca. 95816
(916) 445-0270

David M. Hill
Alternatives Division
Calif. Energy Resources Conservation
& Development Commission
MS-15 1111 Howe Avenue,
Sacramento, Ca. 95825
(916) 322-6476

Martin Homec
Calif. Energy Resources Conservation
& Development Commission
MS-32 1111 Howe Avenue
Sacramento, Ca. 95825
(916) 322-3811

Sandra Houck
Water Quality Control Board
Central Valley Region 5
3201 "S" Street
Sacramento, Ca. 95816
(916) 445-0270

Louise C. Huen
Calif. Public Utilities
Commission
State Bldg., Civic Center
San Francisco, Ca. 94102
(415) 557-2525

Richard Lallatin
State of California
Department of Water Resources
2440 Main Street
Red Bluff, Ca. 96080
(916) 527-6530 EXT. 376

Thomas MacDonald
Calif. Energy Resources Conservation
& Development Commission
MS-19 1111 Howe Avenue
Sacramento, Ca. 95825
(916) 322-3763

Chris Oliviera
Calif. Energy Resources Conservation
& Development Commission
MS-27 1111 Howe Avenue
Sacramento, Ca. 95825
(916) 322-3677

Dennis Olmstead
State of California
Div. of Oil & Gas
1416 9th Street
Sacramento, Ca. 95825
(916) 445-9686

Lawrence Perry
State of California
Dept. of Public Health
2151 Berkeley Way
Berkeley, Ca. 94704
(415) 843-7900 EXT. 505

Bruce Wormald
State of California
Department of Public Health
714 "P" Street
Sacramento, Ca. 95814
(916) 445-4171

Charles Priddy
State of California
Lands Commission
100 Oceangate, Suite 300
Long Beach, Ca. 90802
(213) 590-5201

Tony Rygg
State of California
Energy Resources Conservation
& Development Commission
MS-27 1111 Howe Avenue
Sacramento, Ca. 95825
(916) 322-3811

Gene Serr
State of California
Department of Water Resources
2440 Main Street
Red Bluff, Ca. 96080
(916) 527-6530

David Snetsinger
Water Quality Control Board
North Coast, Region 1
1000 Coddington Center
Santa Rosa, CA. 95401
(707) 545-2620

James Steele
California Dept. of
Fish & Game
P.O. Box 47
Yountville, Ca. 94599
(707) 944-2443

David H. Weiss
Calif. Public Util. Comm
State Bldg., Civic Center
San Francisco, Ca. 94102
(415) 557-3938

DEPARTMENT OF ENERGY
OTHER FEDERAL AGENCIES

Robert Adams
U.S. Bureau of Land Management
P.O. Box 940
Ukiah, CA. 95482
(916) 484-4636

David Fach
U.S. Geological Survey
Area Geothermal Supervisor's Office
2465 E. Bayshore Road Suite 400
Palo Alto, Ca. 94303
(415) 323-8111, Ext. 2848
Lloyd Fritz
U.S. Bureau of Land Management
555 Leslie Street
Ukiah, Ca. 95482
(916) 484-4636

Robert Fujimoto
U.S. Geological Survey
Area Geothermal Supervisor's Office
345 Middlefield Road
Menlo Park, Ca. 94025
(415) 323-8111

Donald B. Gilmore
U.S. Environmental Protection Agency
Environmental Monitoring & Support Laboratory
P.O. Box 15027
Las Vegas, NV 89114
(702) 736-2969

John R. Haugh
U.S. Department of Energy
Div. of Biomedical and
Environmental Research
MSE-201
Washington, D.C. 20545
(301) 353-4155

George Kalkanis
U.S. Department of Agriculture
Soil Conservation Service
2828 Chiles Road
Davis, Ca. 95616
(916) 758-2200 EXT. 264

Lowell A. Miller
U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, Ca. 94612
(415) 273-7963

Susan G. Spencer
Idaho Natl. Engineering Lab.
Box 1625
Idaho Falls, Id. 83401
(208) 526-0111

Hilary Sullivan
U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, Ca. 94612
(415) 273-7933

Jacquelyn F. Sullivan
Idaho Natl. Engineering Lab.
Box 1625
Idaho Falls, Id. 83401
(208) 526-0111

Marc A. Sylvester
U.S. Geological Survey
Water Resources Div.
855 Oak Grove Avenue
Menlo Park, Ca. 94025
(415) 323-8111 Ext. 2463

Michael J. Thompson
U.S. Geologic Survey
Geologic Division
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111 Ext. 2162

UNIVERSITY

Richard G. Burau
Dept. of Land, Air & Water Res.
University of California
Davis, CA. 95616
(916) 752-0194

Joseph J. Cech, Jr.
Dept. of Wildlife, Fisheries
University of California
Davis, Ca. 95616
(916) 752-3103

Charles Hall
University of California
Lawrence Livermore Laboratory
Livermore, Ca. 94550
(415) 422-1100 Ext. 5501

Jan Hamrin
University of California
Energy Extension Service
Davis, Ca. 95616
(916) 752-1011

Robert R. Ireland L-613
University of California
Lawrence Livermore Laboratory
Livermore, Ca. 94550
(415) 422-1100 EXT. 4630

Ray Krone
Dept. of Civil Engineering
University of California
Davis, CA. 95616
(916) 752-1435

Paul L. Phelps L-453
University of California
Lawrence Livermore Laboratory
Livermore, CA 94550
(415) 422-1100 Ext. 5501

Kenneth D. Pimentel L-453
University of California
Lawrence Livermore Laboratory
Livermore, CA 94550
(415) 422-1100 Ext. 5501

Evan M. Romney
University of California
Lab. of Nuclear Medicine
and Radiationcology
Los Angeles, Ca. 90024
(213) 825-8776

Carl L. Strojan
University of California
Lab. of Nuclear Medicine
and Radiationcology
Los Angeles, Ca. 90024
(213) 825-8776

David F. Snoeberger
University of California
Lawrence Livermore Laboratory
Livermore, Ca. 94550
(415) 422-1100 Ext. 23880

Wayne Wurtsbaugh
University of California
Dept. of Wildlife, Fisheries
and Biology
Davis, Ca. 94516
(916) 752-1011

APPENDIX B

Inventory of Existing Water Quality Data

The following table provides a listing and summary of data on water resources and water quality in The Geysers-Calistoga KGRA. Although the table is incomplete, it represents a substantial effort* towards compiling an inventory of existing water data.

No attempt is made herein to evaluate the quality of the data and related analysis in the reports cited in the table. Different data users have different purposes and any evaluation of the data must reflect these purposes. Therefore, the process of evaluation must be left up to persons making specific use of the information found here.

<u>Legend</u>	<u>Type of Study</u>
B	Baseline or Existing Water Quality Conditions
I	Impact
M	Monitoring
R	Resource Description
S	Source of Pollution

*Special thanks to Ms. Lucille Enriques, PG&E, for her contribution to this table.

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
Sedimentation	M, I	PG&E	Geysers Area Prelim. W. Q. Investigation- Nov. 1974	Big Sulphur 37 stations	Single Event	November 1974	NH ₃ , B, S	PG&E #7485.21-75 August 1975	C	
	I	PG&E	Water Temp. Effects on Juvenile Steelhead	Big Sulphur 10 stations	Continuous	Summer 1975	Temp	PG&E Report #7784.4-75. January 1976	C	
	B	PG&E	Geysers Unit 17 Site Specific Studies	Squaw Creek 2 stations	Quarterly	October 1976 - October 1977		PG&E Rep. #7784.13-76. December 1976	C	Final report in progress
	B	PG&E	Geysers Unit 16 Site Specific Studies	Bear Canyon, Anderson, Putah 6 stations	w.q. single sediments Quarterly	October 1976 - Present		PG&E Rep. #411-77.9 & 10. April 1977	preliminary w.q. report complete	
	I, M	PG&E	Production & Fate of Boron, Ammonia	Big Sulphur, Squaw Creek 5 stations			B, NH ₃		In progress	
	M	PG&E & Aminoil	Upper Putah Creek Monitoring	Upper Putah Creek 15 stations W.Q.	Quarterly to cont.	January 1978 - January 1979	"complete" including Hq in sediments, particle size analysis & fishery inventory		Initial phase	

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
	B	Union Oil (Parametrix)	Water Quality Studies on Kelsey, High Valley Alder & Lee Creeks	11 stations	Quarterly	September 1974 - June 1975	T. Coliform, Tur., color pH, Alk, SS, TDS, B,...	Doc. #76-0817-081 FR	complete	
	M, I, R	"	Geothermal Utilization Effects on W.Q. at Geysers	Big Sulphur & Squaw, 12 stations	Monthly	13 months May 1974-May 1975	"complete"	Parametrix Doc. #75-0731-040 FR	complete	
		"	Sedimentation Study	Big Sulphur Drainage						
	I		Toxicity Studies	Geysers						
		Union Oil (VTN)								
	M	Aminoil	Use Permit req.	Anderson Creek 5 stations	February & August	1975 - Present	general			To be superseded by PG&E Upper Putah Creek studies
	M	Chevron	Well drilling	Dry Creek	Monthly		general			Filed with Lake Co?

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
	M	Other Steam Producers	Well drilling							Filed with Lake Co?
	M	No. Calif. Reg. W.Q.C.B.	Permit Req.	Big Sulphur & Squaw 5 stations	Monthly	1968 - Present	T, pH, color, turb., EC, DO, SS, NH ₃ , SO ₃ , B, NO ₃	PG&E Rep. #7784.2-75 November 1975 #420-77.1, August 1977		Collected & analyzed by PG&E and/or steam producers
	M	N.C.R.W.Q.C.B. #1	Condensate	Geysers	Monthly	1968 - Present	"	On file at PG&E		Collected & analyzed by PG&E and/or steam producers
		Central Valley Reg. W.Q.C.B.	Drilling Disch. Permits							Collected & analyzed by PG&E and/or steam producers
		?	Condensate	Geysers			B, F1, S, Na, Ca & Metals, K	Reported by L. Schieler in Konociti Seminar, 1975		
	B, R	C.V.R.W.Q.C.B. #5	Pollution Study	Cache & Putah Creeks, Sacramento R. Watershed		1954 (?)	Table of Discharges			

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
Condensate Spills ?	R,B	Calif. Fish & Game	Fish & Wildlife assessment	Kelsey, Putah, Big Sulphur, Squaw			W.O. & sediment			
	B	Cal. Dept. of Fish & Game	Water Temp. Observations, Eel River			1957 - 1967		Data Report, 1972		
	I	"	Bioassay toxicity studies			1974		On File		
	M	Cal. Dept. of Fish & Game	Turbidity Investigation, Big Sulphur, Squaw			October 1975				
	I	"	Fish kills	Big Sulphur, Squaw	Single	1974 & 1977 res.		On File		
	B	USGS (Geo. Div.)	Thermal Water Chemistry	100 Springs in KGRA	Single		Complete			
		USGS (W.R. Div.)	Water Quality Springs							
	B	Cal. Dept. of Fish & Game		Clear Lake		1976 to present	large mouth bass		In progress	

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
	B	USGS	Ground water of the Lower Lake, Middle-town Area					Water Supply Paper 1297		
	B	"	Prel. Invest. of Suspended Sand Discharge, Russian River			1971		Open-file Report		
	B,M	"	Data for Wells & Streams, Russian & Upper Eel River Val., Sonoma & Mendocino Ctys			1958		Open-file Report		
		"	Geology & Ground Water, Santa Rosa Val.					Water Supply Paper 1427		
		"	Geology & Ground Water, Russian River Valley Areas					Water Supply Paper 1548		
	R	"	Water Storage on Cache Cr.					W-S paper 45 pp. 11-48		

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
	B	USGS	Data for Springs in North Coast Ranges, Klamath Mtns., Calif.	Sonoma Co., Lake Co. Napa	Single	1968		Open-file Report		Berkstresser
	B	"	Sediment Transport, Cache Ck. Drainage Basin			1967		Professional Paper 562-A		
	B	"	Sedimentation of Lake Pillsbury, Lake Cty			1964		Water Supply Paper 1619-EE		
		"	Turbidity & Suspended Sediment Trans. Russian River Basin			1971		Open-file Report		
	B	"	Ammoniated Thermal Waters Lake & Colusa Counties					Water Supply Paper 1535-A		
	B	"	Springs of California					Prof. paper 492 pp. 383		Waring

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		USGS	Geology & Ground Water, Napa & Sonoma Valleys					Water Supply Paper 1495		
		"	Surface Water hydrology of Cal. Coastal Basins between San Francisco Bay & Eel Riv.					Water Supply Paper 1851		
		"	Relation of Turbidity to Suspended Sediment, NW Calif.			1966				
		"	Nitrogen & Phosphorus Sources of Sediment Dist., Clear Lake			1968 - 1969				
		USGS	Chemical Composition of Subsurface Waters					Prof. Paper 440-F 67 pp.		

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		USGS	Great South Coastal ... & North Coastal Basins			October 1959 - September 1960	Chem. Anal. Surface Waters			
		"		Anderson Springs Area			Water Quality			At 2 sites East of Burmah Oil Lease CA-1862
		Lake Co. Mos. Abot. Dist.		Clear Lake &	1 month	1960 - present	Benthics Temp. Turb.	None		
Baseline		U. of Calif. Davis (Hiram Li)	Impact of Fish Introduction	Clear Lake	Bi-weekly - monthly	1975 - present	Fish pop., Zooplankton Population, Light, Turbidity, Temp.	N.S.F. reports Publications in prep.	In progress	
B		DWR	Clear Lake Monitoring	Clear Lake 6 Stations	Semi-monthly - monthly	1968 - present	Complete	Office report	In progress or cont.	
		USGS	A preliminary bibliography for the Clear Lake Geysers area			1977		Open file report 77-489		Good Bibliography

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		BLM	Big Sulphur		Bi-annual	September 1975	"complete"	BLM Open File Rep. #77-220		
		(Ecoview)	Envir. Monitoring-List of Existing Studies	Entire KGRA				#YA-512-CT6-71		Good collection of refs. on Water Quality Reports done by many agencies
	B	Cal. Dept of Transp.	Pieta Creek	1 station	Monthly	February 1974	pH, DO, T, EC, Alk, Hard, Cl, SO ₃ , Turb, SS			
		Cal. Dept. of Water Resources	Clear Lake Water Quality Investigation, 1966	41 stations		Throughtout 1964		WR Bull 143-2, 202 pol		
		"	Russian River Watershed Water Quality Investigation, 1968			1965-1966	Anal. Surface Waters	Bulletin No. 143-4		
		"	Upper Putah Ck. Basin Investigation, Dry Ck.			1905-1962	Dry Creek Discharge Data	Bulletin #99-1		

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		Cal. Dept. of Water Resources	Clear Lake - Cache Creek Basin Investigation, 1961					Bulletin No. 90		
		"	Reconnaissance Report on Upper Putah Creek Basin Investigation, 1962					Bulletin No. 99		
		"	N.E. Counties Investigation, 1960					Bulletin No. 58		
	R	"	Land & Water Use in Eel River Hydro-graphic Unit, 1965					Bulletin No. 94-8		
	R	"	Land & Water Use in Russian River Hydro-graphic Unit,					Bulletin No. 94-11		

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		Cal. Dept. of Water Resources	Surface Water Hydrology of Putah-Cache Creek Hydrographic Unit					The Resources Agency office report, 1964		
		"	Eel River Basin Environmental Studies					1974 Progress Report		
		"	Upper Eel River Development Report--Water Quality					Office Report 1966		
		"	Lake County Investigation, 1957					Bulletin No. 14		
		"	Well Levels & Ground Water Quality in significant ground water basins					DWR Bulletin Series #130		

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		Cal. Dept. of Water Resources	N.E. Counties Ground Water Investigation, 1963					Bulletin 98		
		"	Alternative Eel River Projects & Conveyance Routes, Appendices A,B,C,D, & E, 1972							
	R	"	Land & Water Use in Putah-Cache Creek Hydrographic Unit, 1965	Putah & Cache Creeks			Table of Water Diversions	Bulletin No. 94-13	Comp.	
		"	Ten Counties Investigation, 1971					Bulletin No. 184		
		"	Memorandum Report-North. District, Revised Clear Lake Hydrology, 1969							

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		Cal. Dept. of Water Resources	Ground Water Resources, Sonoma County, 1975					Bulletin 118-4		
		Cal. State Div. of Water Resources	Flow & Quality Characteristics of the Russian River							
		"	Quality of Water: Russian River & Mendocino Coast Hydrographic Units							
	S. B	ERDA (Battelle)	Condensate	At Various Geysers Units	One Time	1976	Heavy metals & trace elements, mass balances	Science, 196, 1094 (1977)	C	Robertson, Crecelius, et. al.
		CERCDC (SRI)	Many technical		(Existing data collected for making assessments)			Env. Anal. for Energy Devel. in Geysers region (1977)	C	Extensive resource of environmental information
		G. Tchobanoglous (U.C. Davis)	Condensate							
		Sonoma State College								

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		US Army Corps of Engineers	Flood Plain Information, Big Valley Streams, Kelseyville, Cal., 1974							
		"	Design Memo. No. 3, Lakeport Lake, Scotts Creek, Cal.					General Design, 1973		
		"	Investigation of Mercury Hazard Potential, Warm Springs Dam & Dry Creek Basin 1971							
		"	Water Resources Development, Eel River, 1964							
		"	Conservation Treatment of the Dry Creek Watershed, 1966							

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		U.S. Army Corps of Engineers	Flood Control & Allied Purposes, Russian River, 1964							
		Dept. of Health, Education & Welfare, Public Health Service Region IX, S.F.	Eel River Basin. Rept. on Water Uses & Future Water Quality Control Flow, 1962							
		U.S. Forest Service	Dos Rios Reservoir -- Impact Survey Report, 1969							
		Fed. Water Pollution Control Admin.	English Ridge Project, Water Quality Control Study, 1969							
		U.S. Dept. of Agric., River Basin Survey Staff	Conservation Treatment of the Dry Creek Watershed in the Russian River Basin, Sonoma & Mendocino Counties					Reconnaissance Survey Report		

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
		Lake Co. Flood Control of Water Conservation District	Big Valley Ground Water Recharge Investigation, 1967					Unpublished		
		"	Kelsey Creek Dam Project						Unpublished	
		"	Scotts Valley Recharge & Ground Water Distribution Investigation, 1970						Unpublished	
		Napa County Flood Control & Water Conservation District	Napa Co. Water Resources Development Study							
		Sonoma Valley Soil Conservation District	An Inventory of Watershed Resources, 1965							

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
	R	Other Studies Burgg, R.H. 1972	Eval. of Water Yield Potential in the East Putah Creek Watershed under Multiple Use Mgmt.							
		Wallis, J.R. 1965	A Factor Analysis of Soil Erosion & Stream Sedimentation in No. Cal., U. of Cal., Berkeley Unpublished PhD dissertation							
		Kaiser Engineers, 1968	Task Force Rept. on Upper Eel River Routing Studies							
		U.S. Bureau of Reclamation	"English Ridge Unit," Eel River Division North Coast Project, 1972							
	M	State Public Health	Monitoring Drinking Waters		Weekly-coliform monthly- annually-trace	metals				

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
	M,I	PG&E	Evaluation of W.Q. Monitoring Data	Big Sulphur Creek Drainage 5 Stations	Monthly	May 1968 - Present	Q,T, pH, d.o., color, Turb., SC, NH ₃ , NO ₃ , SO ₄ , B	7784.2-75 420-77.1	Continuing	
	B,R	PG&E	Baseline Fishery Inventory	Upper Putah, Kelsey, Cole, Big Sulphur, Putah, Big Canyon, Sausal, Siegler	Single event	1975 1976	Fish, d.o., pH, Turb., NH ₃ , Sp. Cond., Flow	7784.3-75 7784.5-76 7784.6-76 In Progress	Complete	
	B	Alex Horne	Defines Clear Lake Eco System				Algae Limnology Nutrients			
	B	Hiram Li (UCD)	Clear Lake Aquatic							
	B	Dr. Meule	Clear Lake Aquatic							

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
Drift, sanitary wastes, condensate spills, etc.		USEPA		Roosevelt Hot Springs						
	B	UC Berkeley		Big Canyon Creek 15 Stations	Weekly	April 1975 - May 1975	pH, Sc and Temp.	Report June 1975	Comp.	
	I	Bacon C.F.	Blow out of a Geysers geo- thermal well					Calif. Geology Vol. 29, no1 pp. 13-17		
	S,R,B	PG&E	EDS Unit 16 & 17	Bear Canyon Creek Anderson Creek Squaw Creek					Complete	

ISSUES	TYPE OF STUDY	PARTY RESPONSIBLE	DESCRIPTOR-PURPOSE	LOCATION, WATERSHED & NO. OF STATIONS	FREQUENCY	PERIOD OF RECORD	PARAMETERS MEASURED	REPORTS	STATUS	COMMENTS, EVALUATIONS
	B	DWR	Monitoring w.q. in Clear Lake	3 stream 3 on Clear Lake	Bi-monthly monthly	1968 to Present	Complete Chemical, Nutrients, Algae, Zooplankton	1968 - 1973	Complete	Office Reports
	B	Lake Co. Mosquito Abatement District	Investigate Gnats	Clear Lake Borax Lake			B Salinity pH			
	B	Republic Geothermal	Assemble Data on w.q. in Seigler Springs Area	Sieglar Springs			Temp, Flow, Mineral, Gas Deuterium, Oxygen, Isotope & Carbon Tritium	Pub. by David Forsythe	In Progress Continuing	
		John McCall	Big Canyon Creek Study							
	B	McCullough (Gennis & Assoc.)	EIR Sieglar Canyon Creek	Seigler Canyon Creek 5 Stations						

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."

NOTICE

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.