EMISSIONS CHARACTERISTICS OF COOLING TOWERS USING RECLAIMED WASTEWATER IN CALIFORNIA

11 AUGUST 1981

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Prepared For

State of California
Air Resources Board
Sacramento, California 95812

Contract No. A8-126-31

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ACKNOWLEDGEMENTS

The following Science Applications, Inc. (SAI) staff participated in this project:

FIELD SAMPLING: Linda Fargo, Michael Guttman, Paul Mankiewicz, Alan Miller, Bill Paplawsky, Michael Rogozen, Robert Sims, and Gary Smith.

LABORATORY ANALYSIS: Norman Flynn, Michael Guttman, Paul Mankiewicz, Bill Paplawsky, Robert Sims.

SAMPLER DESIGN AND CONSTRUCTION: Walter Clyne, Linda Fargo, Bruce Kirstein, Paul Mankiewicz, John Nemmers, Michael Rogozen, Gunter Schrecker.

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TECHNICAL TYPING: Rhona Lubaroff, Melanie Nelson

We would especially like to thank Robert Reynolds, who initiated this project while at the Air Resources Board, and Dane Westerdahl, who took over and provided unflagging support during the past two years. We thank the Lake County and Northern Sonoma County Air Pollution Control Districts for loan of equipment. Daniel Chang of the University of Califonria at Davis provided valuable advice in sampler design and air pollution modelling.

Finally, we wish to acknowledge the extremely important support of the agencies and companies whose cooling towers we tested. Special thanks go to John MacDougall of the Burbank Public Service Department for his help in all aspects of our tests at the Olive and Magnolia cooling towers.

This report was submitted in fulfillment of ARB Contract No. A8-126-31, "Emission Characteristics of Cooling Towers Using Reclaimed Wastewater in California," by Science Applications, Inc. under the sponsorship of the California Air Resources Board. Work was completed as of 31 July 1981.

ABSTRACT

Present and planned use of reclaimed municipal wastewater, industrial process water, and geothermal condensate as makeup to cooling towers have raised questions about the potential for atmospheric emissions of pathogenic microorganisms, organic compounds, heavy metals, and other wastewater constituents. In this study, the makeup and circulating water of six towers were sampled and analyzed for indicator bacteria and virus, volatile and nonvolatile organic compounds, metals, and other components of potential concern. Further water sampling and exhaust air emissions tests were then conducted on four of the towers; for the microbiological emissions tests, a special isokinetic sampling device was developed.

Toxic trace metal emissions resulting from wastewater use were insignificant. A simple modelling exercise showed that ambient metal concentrations around a typical plant would at most be two to three orders of magnitude below levels of human health concern. However, there is a potential for significant chromium emissions if that metal is added to a tower's circulating water as a corrosion inhibitor.

Both water sampling and stack emission data are consistent with the premise that all volatile organic compounds present in the makeup water are emitted to the atmosphere, perhaps before thorough mixing with circulating water. Towers also act as conduits, emitting organic components of the inlet air. Some evidence for generation of halogenated methane compounds in the tower was found. Total net emissions of both volatile and nonvolatile organic compounds are very small compared to those of other stationary sources.

Cooling towers using municipal wastewater provide good environments for bacterial growth. Indicator and bacterial virus particles were found in the exhaust from one tower. Emissions of hydrogen sulfide and mercury from the geothermal tower tested were consistent with previous researchers' findings, while measured ammonia emissions were higher than expected.

A survey of California cooling tower users identified 407 towers associated with manufacturing plants, and 56 towers used by electric utilties. The number of towers in the state is probably between 900 and 1900. Almost half of the towers are used by wineries, fruit and vegetables canneries, and

industrial organic chemical plants. The largest towers are those associated with power plants and the industrial gas, petroleum refining and organic fiber and synthetic rubber industries. Most cooling towers in California are in Southern California. The use of asbestos in construction and chromium in water treatment chemicals is declining.

Technology for controlling drift emissions from cooling towers is well advanced. Considerable research in means to abate hydrogen sulfide emissions from geothermal cooling towers is underway. Finally, while techniques for removing volatile organics from wastewater are available, it is questionable whether the very low concentrations of these compounds in makeup water can--or need to--be removed.

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1.0

FINDINGS AND CONCLUSIONS

1.1 CALIFORNIA COOLING TOWER INVENTORY (TASK 1)

1.1.1 Number and Distribution of Cooling Towers in California

(1) In this first inventory of cooling towers in a state, we identified 407 industrial cooling towers used by 142 manufacturing plants, and 56 towers associated with 14 electrical generating stations.

(2) Cooling towers are used by industries falling under 39 four-digit Standard Industrial Classification (SIC) codes. Almost half the identified towers are associated with plants which manufacture wine (SIC 2084), canned fruits and vegetables (SIC 2033), and industrial organic chemicals (SIC 2819). These industries typically have four to six cooling towers per facility.

(3) The largest towers (over 2500 gallons per minute circulating water flow) are used by the electrical utilities and the industrial gases (SIC 2813), petroleum refining (SIC 2911) and organic fiber and synthetic rubber (SIC 2824) industries.

(4) Our survey results were used with U.S. Census data on the distribution of industries by county to estimate the total number of industrial cooling towers in the State. The 95-percent confidence interval for the number of towers is 900 to 1900.

(5) Most cooling towers in the State are in Southern California; Los Angeles, Orange and San Bernardino Counties account for 42 percent of the identified towers and about one third of the estimated total for the State.

1.1.2 Cooling Tower Operating Practices

(1) Because heat exchanger leaks can introduce potential air pollutants into circulating waters, survey respondents were asked to identify the fluid being cooled. The most common fluid was clean water (60 percent). Others, none of which

accounted for more than 8 percent of the number of towers, were chemical process water, petroleum fractions, ammonia, inorganic gases, food processing water, organic gases, and solvents.

(2) The use of chromium as a corrosion inhibitor is declining. It was used in only 19 percent of the towers surveyed.

(3) The use of asbestos for cooling tower fill and louvers is also decreasing. About one third of the towers surveyed had asbestos components.

1.1.3 Trends in Cooling Tower Design and Use

(1) All industrial-size cooling towers in California except the two serving the Rancho Seco power plant are the mechanical draft type. The trend in mechanical draft towers is towards counterflow, and away from crossflow design; the former are believed to have lower drift emissions and better service records.

(2) The growth in use of natural draft towers in the U.S. has been slow. Although they use less energy than mechanical-draft towers, they have much higher initial capital costs.

(3) Considerable research is being conducted on wet-dry cooling towers. They use less water and emit less fog than do conventional towers, and they have higher operating costs.

(4) Reinforced concrete is replacing wood as the major structural component of cooling towers. Fiberglass-reinforced plastic is now the major material for fanstacks.

(5) Design of cooling tower fill now emphasizes creation of a surface film, rather than formation of droplets, to facilitate evaporation. Polyvinyl chloride, fiberglass and other materials are replacing asbestos concrete for fill.

1.2 USE OF RECLAIMED WASTEWATER FOR COOLING IN CALIFORNIA

1.2.1 Present Use of Wastewater

(1) About 0.30 cubic meters per second (m^3/s), or 4700 gallons per minute (gpm) of treated municipal wastewater are used for

cooling tower makeup in California. Because industrial proces water is generated and recycled on-site where it used as makeup, its consumption rate could not be determined for all facilities.

(2) Since 1967, the City of Burbank has been using about 0.2 m^3/s (3100 gpm) of secondary-treated municipal wastewater in four cooling towers at its oil- and gas-fired power plants. The water receives no additional treatment before use as makeup, and no major operating problems have been experienced.

(3) The City of Glendale has been using about 0.1 m^3/s (1600 gpm) of secondary-treated municipal wastewater in five power plant cooling towers since January 1979. The water is treated with alum flocculation and polymer addition to remove phosphorus before reuse. Problems with the phosphorus plant have limited wastewater use during much of 1981.

(4) A refinery in Southern California uses from 0.01 to 0.03 m^3/s (150 to 500 gpm) of reclaimed process water as makeup to eight cooling towers. Before re-use, the water is pretreated by gravity separation and gas flotation and blended with fresh water.

(5) A large industrial facility has a complex system for recycling wastewater. Six water circuits, each having from one to five cooling towers, are used.

(6) A large chemical plant recycles chemical process water in a cooling tower having a circulating water rate of 0.10 to 0.11 m^3/s (1600 to 1800 gpm). Other wastewater users include a tire factory and two food processing plants.

(7) Geothermal steam condensate is used for makeup to 13 cooling towers at power plants operated by Pacific Gas and Electric Company at The Geysers, in Sonoma and Lake Counties.

(8) Brackish water from Suisun Bay is used for makeup to two cooling towers at Pacific Gas and Electric Company's Pittsburg 7 power plant.

1.2.2 Near-Term Planned Use of Wastewater for Cooling

(1) Our survey identified 13 companies, having 66 towers, who plan to use wastewater for cooling within the next five to ten years. Most of the towers in this category are associated with wineries (SIC 2084) and one industrial organic chemicals plant (SIC 2819).

(2) Chevron U.S.A. is testing the feasibility of using secondary-treated municipal wastewater effluent from the Los Angeles/Hyperion Treatment Plant in a cooling tower at its El Segundo oil refinery. If the tests are successful, the refinery could use up to 0.28 m^3/s (4400 gpm) in 11 cooling towers.

(3) The Contra Costa County Water District and the Central Contra Costa Sanitary District have signed a contract to provide for the re-use of tertiary-treated municipal wastewater for cooling tower makeup in two oil refineries, two chemical plants and two electric power plants. Technical problems and disputes over contract terms have delayed the project.

(4) McClellan Air Force Base, near Sacramento, has just begun to use up to 0.025 m^3/s (400 gpm) of treated domestic and industrial wastewater in 40 small cooling towers.

(5) Future cooling towers in the Geysers-Calistoga Known Geothermal Resource Area will use geothermal steam condensate as makeup. Planned geothermal power plants in the Imperial Valley may use flashed steam condensate and/or unflashed geothermal fluid.

(6) The areas where agricultural wastewater is most likely to be used as cooling tower makeup are the San Joaquin, Imperial and Palo Verde Valleys. Since power plant projects which would have considered this water source have been delayed or abandoned, there is presently no plan to use agricultural wastewater for cooling. Furthermore, any such plan would encounter serious technical difficulties and political problems.

1.3 CHARACTERISTICS OF WASTEWATER USED FOR COOLING IN CALIFORNIA (TASK 2)

1.3.1 Municipal Wastewater

(1) Of the types of reclaimed water under consideration in this study, municipal wastewater is unique in that it contains pathogenic microorganisms which, if released in significant amounts through cooling tower drift, could pose a public health risk.

(2) Municipal wastewater may also contain industrial chemicals, including solvents and heavy metals.

(3) Unidentified substances which produce positive responses in *in vitro* bacterial mutagenicity tests have been found in treated municipal wastewater.

(4) The cooling tower environment may promote the growth of pathogenic organisms, including Legionnaires' Disease Bacterium (*Legionella pneumophila*), amoebae and fungi.

1.3.2 Industrial Wastewater

(1) The constituents of air pollution concern in industrial process water vary from industry to industry. Major types of pollutants of concern include solvents, hydrogen sulfide, and other substances which volatilize readily.

(2) In certain cases, the presence of highly corrosive substances in industrial wastewater necessitates use of higher levels of water treatment chemicals in cooling systems, with the consequent introduction of potential air pollutants such as chromium into the circulating water.

1.3.3 Geothermal Fluid

(1) In the Geysers-Calistoga KGRA, the goethermal fluid is in the form of steam. Constituents of the greatest air pollution concern include hydrogen sulfide, mercury vapor and particulate boron. H_2S is of concern chiefly as a nuisance, due to its low odor threshold, while boron may produce adverse effects in certain plants.

(2) In the Imperial Valley KGRA's, the geothermal fluid is in the form of brine. The extent to which salts and noncondensible gases in the brine would be released to the environment in flashed steam processes is unknown. The brine generally contains much lower H_2S and boron levels than does the steam in the Geysers-Calistoga KGRA, but may contain significant levels of reactive hydrocarbons. Salt from cooling tower drift could pose a problem for agriculture in the Imperial Valley.

1.3.4 Agricultural Wastewater and Brackish Water

The principal potential air pollution problem resulting from use of these types of wastewater would be saline drift.

1.3.5 Other Constituents of Concern in Cooling Waters

(1) A review of the literature on chlorination chemistry showed a potential for formation of volatile trihalomethanes (e.g. chloroform) in cooling towers.

(2) Environmental conditions within cooling towers are moderately favorable toward leaching of asbestos from fill material and louvers. One field study identified asbestos materials as the source of asbestos emissions from a cooling tower. Due to the declining use of asbestos in California towers, however, this problem is probaby not of major concern.

1.4 RESULTS OF WATER SAMPLING PROGRAM (TASK 3)

In order to identify potential constituents of concern in cooling towers presently using wastewater, SAI collected samples of makeup and circulating water from three towers using reclaimed municipal wastewater, two using recycled industrial process water, and one using geothermal steam condensate. Water samples were analyzed for trace metals (all towers), volatile and nonvolatile organics (municipal and industrial towers), indicator bacteria and virus (municipal towers), Legionnaires' Disease Bacterium (two municipal towers and the two industrial towers); and hydrogen sulfide and ammonia (geothermal tower).

1.4.1 Organic Constituents

(1) Several volatile organic compounds of potential air pollution concern, including benzene, toluene and various halocarbons, were found at concentrations ranging from 5 to 500 parts per billion (ppb) in both the makeup and circulating water of two of the municipal towers and one of the industrial towers.

(2) In general, circulating water concentrations of volatile components of the makeup were either relatively low or undetectable.

(3) Non-volatile organic compounds concentrations were very low in four of the five towers in which these components were sought.

1.4.2 Toxic Trace Metals

(1) With three exceptions, toxic trace metal concentrations were low in all the towers. Chromium and zinc levels were high in towers to which treatment chemicals containing these compounds were added. High copper concentrations in two towers' circulating water systems were probably due to condenser tube corrosion.

(2) Most of the arsenic and mercury detected in the circulating water of the geothermal tower were in particulate form.

1.4.3 Bacteria and Virus

(1) Two of the three municipal towers had appreciable concentrations of total coliforms, fecal coliforms, fecal streptococci, and E. coliphage (an indicator virus) in their hot and cold water basins.

(2) In general, bacterial concentrations in the circulating water were higher than they were in the makeup, while the reverse was observed for the E. coliphage.

(3) Legionnaires' Disease Bacterium was detected in one of the industrial towers.

1.5 EMISSIONS ESTIMATES (TASK 3 AND 4)

Emissions tests were conducted at two of the municipal towers, one of the industrial towers, and the geothermal tower. In each case, makeup and circulating water sampling was repeated.

1.5.1 Emissions of Organic Compounds

(1) Nonvolatile organic compound emissions from the towers we tested were negligible.

(2) The following scenario is consistent with our field data (although others are possible):

- Most or all of the volatile organic compounds present in the makeup are emitted to the atmosphere.
- Most or all chemical species, other than halomethanes, present in the exhaust originate in the ambient air and should not be considered to be cooling tower emissions.
- Most or all of the halomethane emissions detected in the cooling tower exhaust originate in the tower itself.

(3) Although data are insufficient to make accurate estimates, net volatile organic emissions are on the order of one or two hundred kg/yr from the municipal towers and 500 to 1000 kg/yr from the one industrial tower measured.

1.5.2 Emissions of Indicator Bacteria and Virus

(1) Viable indicator bacteria and bacterial virus particles were collected only from the stack of one of the two municipal towers tested.

(2) Emission rate estimates based on the stack tests were at least 1800 total coliform particles per second, less than 18 fecal coliform or fecal streptococcus particles per second, and about 80 E. coliphage particles per second.

(3) Emission rate estimates based upon indicator microorganism concentrations in the circulating water and assumed drift rates of 0.001 and 0.01 percent were 1.5 to 1500 total coliforms/second, 0.84 to 320 fecal coliforms/second, 0.84 to

320 fecal streptococci/second, and 0 to 1520 E. coliphage/second.

(4) For the municipal tower where viable indicator microorganisms were successfully sampled, measured stack exhaust concentration estimates fall within ranges of estimates based upon circulating water concentrations and drift rates.

1.5.3 Emissions of Toxic Trace Metals

(1) Toxic trace metal emissions resulting from the use of treated wastewater for makeup do not appear to be significant.

(2) High total dissolved solids emissions, and those of sulfate, could be of concern if cooling towers are used in agricultural areas.

(3) Emissions of chromate salts added to tower basins for corrosion inhibition (whatever the makeup water source) could be significant.

1.5.4 Emissions of Geothermal Pollutants

(1) Hydrogen sulfide emission from the tower we measured were estimated to be 0.27 kg/s (2.1 lb/hr). We believe that this value is consistent with hydrogen sulfide input and abatement data provided by the plant operator.

(2) Ammonia emissions were estimated to be 27.4 kg/hr (60 lb/hr). After considering ammonia input data provided by the plant operator, we believe this result to be high by a factor of two.

(3) The estimated mercury emission rate was 2.7×10^{-3} g/s (0.3 lb/hr). This value is consistent with findings of previous researchers.

1.5.5 Modelling Exercise

At the request of the California Energy Resources Conservation and Development Commission, a simple Gaussian diffusion model was run to estimate trace metal emissions around a typical tower using municipal wastewater as makeup. Our results, which probably overestimated actual values, were as follows.

(1) Concentrations within 1 Km of the tower range from 0.0017 ng/m^3 for mercury to 40 ng/m^3 for zinc.

(2) Metals concentrations would be from two to five orders of magnitude below suggested standards for minimum exposure to protect against toxic and/or carcinogenic effects.

1.6 REVIEW OF CONTROL TECHNOLOGY

(1) Existing drift eliminator technology can reduce drift emission rates to below 0.001 percent of the circulating water rate; the most likely range for towers in use today is 0.001 to 0.01 percent.

(2) Biocidal treatment of cooling tower water is directed at controlling biofouling, rather than reducing specific pathogens.

(3) Given the complexity of the cooling tower ecosytem, any treatment program should consider that elimination of one species may stimulate growth of another.

(4) At present, only downstream methods--an iron catalyst system and the Stretford Process--are used to control hydrogen sulfide emissions from geothermal cooling towers. Research on upstream abatement methods is underway.

(5) A variety of adsorption, oxidation, and membrane retention methods for reducing organics from wastewater are available. However, it is unknown whether these processes would be effective for the low concentrations of organics found in the makeup water of the cooling towers we studied.

2.0

RECOMMENDATIONS

Given the findings and conclusions presented in Chapter 1, we make the following recommendations.

(1) As significant emissions of pollutants of potential air pollution concern do not appear to result from the use of reclaimed municipal wastewater, we recommend its continued use.

(2) Although at least one cooling tower using wastewater as makeup has been shown by this study to emit indicator bacteria and viruses, and other studies have detected emissions of human pathogens from similar cooling towers, surveys of health effects in the surrounding population are not likely to be sensitive enough to detect significant increases of disease, and are therefore not recommended. However, if an outbreak of a disease whose etiologic agent is an airborne microorganism which can thrive in cooling towers occurs in the general population, then nearby cooling towers should be investigated as potential sources.

(3) Extrapolations from our results show that total organic emissions (volatile and nonvolatile) from the industrial cooling towers we measured would not exceed one metric tonne per year. This emission rate is very small compared with other stationary source emissions in the same counties. Further tests would be warranted only if (a) the use of industrial process water for makeup were greatly increased, or (b) the ARB were interested in emissions of specific chemical compounds.

(4) If volatile organic emissions were indeeed of concern, then long-term monitoring of makeup water composition is recommended.

(5) We recommend against the addition of hexavalent chromium compounds to cooling tower waters where the cooling tower is surrounded by populated or agricultural areas.

(6) As the issue of boron emissions from geothermal cooling towers was not addressed by our field studies, we recommend a combination of isokinetic stack emission sampling and deposition measurements of this element.

(7) Emissions from the use of flashed or unflashed geothermal fluid in Imperial Valley KGRA's have not been thoroughly assessed. We recommend a program similar to the present study, once the new towers are in operation.

3.0

INTRODUCTION

3.1 PURPOSE AND OBJECTIVES OF THE STUDY

Three electric utilities and a handful of manufacturing plants presently use treated wastewater as makeup supply for cooling towers, while new uses of wastewater for cooling are being planned and implemented. The State of California has adopted policies encouraging this practice, especially in the case of power plant cooling. The prospect of increased reclaimed water use in cooling towers has raised questions about the potential for air pollution problems, including emissions of pathogenic microorganisms, toxic metals, asbestos, pesticides, volatile organic compounds, and other substances which may be present in the makeup water supply or in the circulating water.

While numerous studies of the emissions, dispersion and environmental effects of salt emissions from cooling towers have been conducted, relatively little research has been directed to characterizing other potential emissions, including those which could, in sufficient quantities, affect the health of the general public. The California Air Resources Board (ARB), recognizing the potential for public health concern and the lack of sufficient information for decision-making, contracted with Science Applications, Inc. (SAI) to conduct a comprehensive study of potential and actual emissions from cooling towers using wastewater. The objectives of this study were:

- To ascertain the extent of cooling tower uses in California;
- To determine the sources, composition, and extent of use of reclaimed wastewater, brackish water, geothermal fluid and other low quality waters in cooling towers in California;
- To develop emission factors for pollutants of concern from cooling towers (emphasizing emissions of toxic substances);
- To identify technologies for control of such emissions; and
- To identify future trends in cooling tower design and use of reclaimed water for cooling.

3.2 SCOPE OF THE STUDY

This was, in essence, a problem definition study. It began with the educated, but as yet untested, guess that cooling towers using reclaimed wastewater could be important sources of various air pollutant emissions. At the end of the study we were able to say that certain emissions do indeed

occur as a result of wastewater use, and can be roughly quantified. In order to get from beginning to end, it was necessary to limit somewhat the scope of our research. First, in order to gain as much information as possible about potential pollutants of concern, we chose to perform exploratory tests on several cooling towers, rather than make in-depth studies of one or two. The main advantage was being able to identify a large number of pollutants and to gain some insight into emission mechanisms. The main disadvantage of this approach was the resulting uncertainty over the accuracy of our emission estimates.

As implied by the title of this project, we confined our attention to cooling tower emissions, excluding questions of downwind exposure, deposition and effects. One exception was a special exercise, done at the request of the California Energy Resources Conservation and Development Commission, in which a simple Gaussian diffusion model was used to estimate ambient trace metals concentrations around one of the towers we measured.

Another limitation on the study was that only California towers were to be considered. This led to lengthy delays in our testing program, since many of the towers to be tested were not operating or were using fresh water for a large portion of the study period. Finally, of the potential pollutants of concern, the most attention was to be paid to wastewater constituents which could affect the health of the general public. Pollutants which damage plants and materials, and/or which may be added to a cooling tower system (regardless of whether wastewater is used for makeup), were examined, but not as closely.

3.3 OUTLINE OF THE RESEARCH

Research under this contract was conducted between June 1979 and July 1981. The major elements of the study were as follows.

3.3.1 Cooling Tower Survey

Before this study, no information about the extent and nature of cooling tower use in California was publicly available. We therefore conducted a survey, by written questionnaire and telephone, of firms in those types of industries most likely to use cooling towers. In addition, all electrical utilities using circulating water systems for cooling were interviewed. We were thus able to enumerate towers by geographical area and

industry type, and to summarize information on tower size and operating practices. Our survey is described in Chapter 4, which covers all of our activities under Task 1. The same chapter contains the results of a review of present and developing cooling tower design practices.

3.3.2 Survey of Reclaimed Wastewater Use for Cooling

In order to gauge the extent of use of reclaimed water for cooling tower makeup in California, we contacted all known users, as well as those planning water reuse projects, and obtained detailed information about their present and future operations. In addition, as part of the cooling tower survey mentioned above, we asked all cooling tower owners about their intentions to use wastewater in the near future. The results of our research are presented in Chapter 4.

3.3.3 Characterization of Wastewater Used For Cooling

The objective of Task 2 of the research, which is presented in Chapter 5, was to identify constituents of reclaimed wastewater which could pose a threat to human health or general environmental quality if released to the air. Actual sources of water presently used for cooling, as well as proposed sources for future projects, were evaluated. Special attention was paid to the following issues in wastewater reuse:

- Pathogenic microorganisms in municipal wastewater;
- Presence and growth of Legionnaires' Disease Bacterium in cooling towers;
- Potential for formation of halomethanes in makeup and circulating water; and
- Use and emission potential of asbestos.

Provisions for coping with upsets in wastewater treatment processes were also reviewed.

3.3.4 Field Measurements

Field work under this project was conducted in two phases. The purpose of the first phase, Task 3, was to determine whether potential air pollutants of concern were actually present in cooling towers now using wastewater. To this end, we collected samples of makeup and circulating water from three towers using secondary-treated municipal effluent, two using reclaimed industrial process water and one using condensed geothermal steam

for makeup. We were accompanied in the field by a team from the University of California at Davis, who were investigating the possible presence of pathoenic bacteria in the three municipal wastewater-using towers. Our samples were analyzed for indicator bacteria and virus, volatile and nonvolatile organic compounds, toxic trace metals, Legionnaires' Disease Bacterium; and noncondensible gases associated with geothermal fluid.

The results of our sampling and analysis program, which is described in Chapter 6, were used to plan the second phase of field sampling, which included direct measurement of emissions from cooling tower fanstacks. As part of the stack sampling effort, Task 4, SAI designed, built, tested and used a device for isokinetic collection and preservation of aerosolized microorganisms. Emissions tests were conducted at two of the same municipal wastewater-using towers as in Task 3, one of the industrial towers and the geothermal tower. Exhaust air was sampled, as appropriate, for indicator bacteria and virus, volatile organic compounds, ammonia, hydrogen sulfide and mercury emissions. The second phase of testing is described in Chapter 7.

3.3.5 Emissions Estimates and Emission Factors

Before using our field test data to estimate emissions from the cooling towers we examined, we reviewed the literature on cooling tower emissions testing, paying special attention to the relatively few previous attempts to measure the pollutants of concern to our study. We then formulated emission mechanisms which were at least consistent with our findings. Our emissions estimates and corresponding emissions factors are presented in Chapter 8. Included are the results of the diffusion modelling exercise mentioned in Section 3.2.

3.3.6 Review of Control Technology

Chapter 9 contains our review of present and developing technology to reduce emissions of pollutants of concern from cooling towers using wastewater. Topics covered under Task 5 included devices to eliminate drift emissions, treatment of circulating water to remove pathogens, abatement of geothermal pollutants, and techniques to remove volatile organics from wastewater.

3.3.7 Recommendations for Future Field Sampling

Finally, under Task 6, we used our field measurement experience to suggest elements of future sampling programs, should the ARB determine them to be desirable. Our recommendations are presented in Chapter 10.

4.0

CALIFORNIA COOLING TOWER INVENTORY (TASK 1)

4.1 TRENDS IN COOLING TOWER DESIGN AND USE

Cooling systems contain three basic elements: an intake water supply, a condenser where the working fluid is cooled by heat exchange with water, and a process for transferring the heat gained by the cooling water to the atmosphere. The three basic methods for heat transfer to the atmosphere are (Christianson et al., 1973):

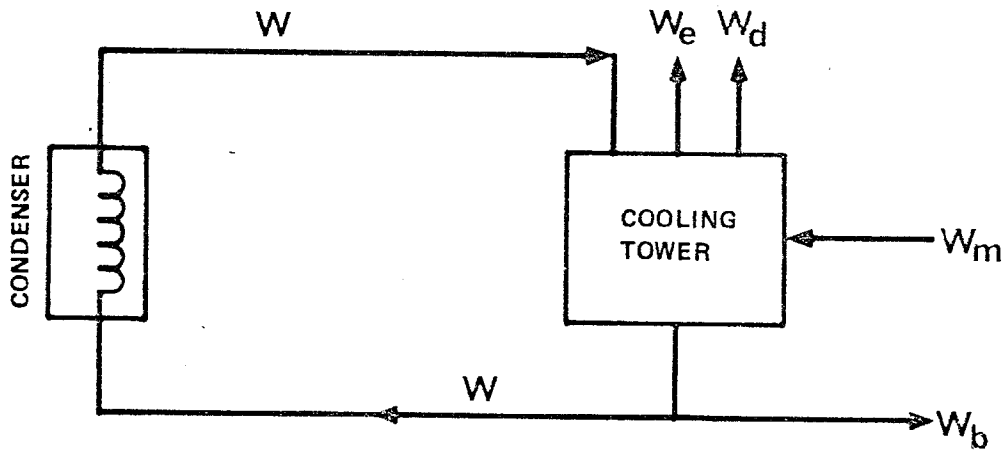
- Once-through cooling, in which the cooling water is discharged to a receiving water body (e.g., river, lake, ocean) after one pass through the condenser.
- Closed-cycle cooling, in which cooling water is recycled through a tower, pond, or spray system after each pass through the condenser.
- Combination cooling. This is a combination of closed-cycle and once-through cooling.

This study is concerned only with closed-cycle cooling using towers. Closed cycle cooling is gaining in popularity, especially in the West, where water conservation has a high priority. The three major types of closed-cycle cooling towers are:

- Evaporative cooling towers, in which the primary means of cooling is by transfer of latent heat to the atmosphere. (Latent heat is energy gained or lost by a substance without a change in system temperature during a change in state, e.g. from liquid to gas.)
- Dry cooling towers, completely closed systems, in which circulating water is cooled by sensible heat transfer (by conduction, convection and radiation) to the atmosphere.
- Wet-dry cooling towers, hybrid systems which dissipate heat in either of the two abovementioned modes, or by a combination thereof.

4.1.1 Evaporative Cooling Tower Types

The following discussion applies to all evaporative cooling tower types, be they atmospheric, mechanical draft or natural draft. The vast majority of cooling towers used in industry are wet, or evaporative, cooling towers. A flow diagram of a closed-cycle cooling system using wet cooling towers is shown in Figure 4.1-1. Water is lost as evaporation, blowdown, and



W = Recirculating water
W_m = Makeup
W_e = Evaporation
W_b = Blowdown
W_c = Drift

Figure 4.1-1. Schematic of Wet Cooling Tower System.

drift. "Blowdown" is a portion of the recirculating flow which is continually or intermittently bled from the system to prevent the buildup of undesirably high concentrations of dissolved and suspended materials. Water lost as droplets in the cooling tower exhaust is termed "drift" or "windage" and is typically limited to 0.01 to 0.05 percent of the recirculating rate by drift eliminators. More efficient drift eliminators, which can limit drift to a typical value of 0.004 percent of the circulation rate, are available but are not yet in extensive use. To maintain a nearly constant circulation rate and assure a minimum level of water quality, blowdown, evaporative loss and drift must be balanced by relatively higher quality water, termed "makeup."

The quantity of recirculating water (W) required depends on the quantity of heat to be dissipated in the cooling tower ("heat load") and on the number of degrees the water is cooled in the tower ("cooling range"). The flow rate of makeup water (W_m) depends upon the evaporation (W_e), blowdown (W_B) and drift (W_c) rates. Associated with these water flows are latent evaporative and sensible (advective) heat losses. Approximately 75 percent of the waste heat in the cooling tower is dissipated as latent heat and the remainder as sensible heat (Christianson et al., 1973).

Some cooling towers consist of an empty shell through which the hot water is sprayed; these are called "spray-filled towers." The interiors of most large industrial towers, however, are equipped with some sort of material, called "packing" or "fill," to break up water droplets and/or provide a surface for film formation and thus increase the evaporation rate.

In "counterflow" towers, inlet water flows downward over the packing or fill, while air flows in the opposite direction. As seen in Figure 4.1-2, counterflow tower interiors are completely occupied by fill; there is no plenum chamber. Either splash packing or film packing may be used, with film packing being more common in new towers. Splash packing is designed to break the falling water into droplets, while film packing causes the falling water to form a thin film on the packing, thus increasing the wetted surface area. Splash packing is usually constructed of redwood (Carey et al., 1969) but it can also be made of plastic, asbestos-cement bars, steel, aluminum, or ceramic tile (Lewis, 1977). Film packing consists most often of asbestos sheets (Carey et al., 1969) but may also be constructed of polyvinyl or polypropylene plastics, cellulose, aluminum, and steel (Lewis, 1977).

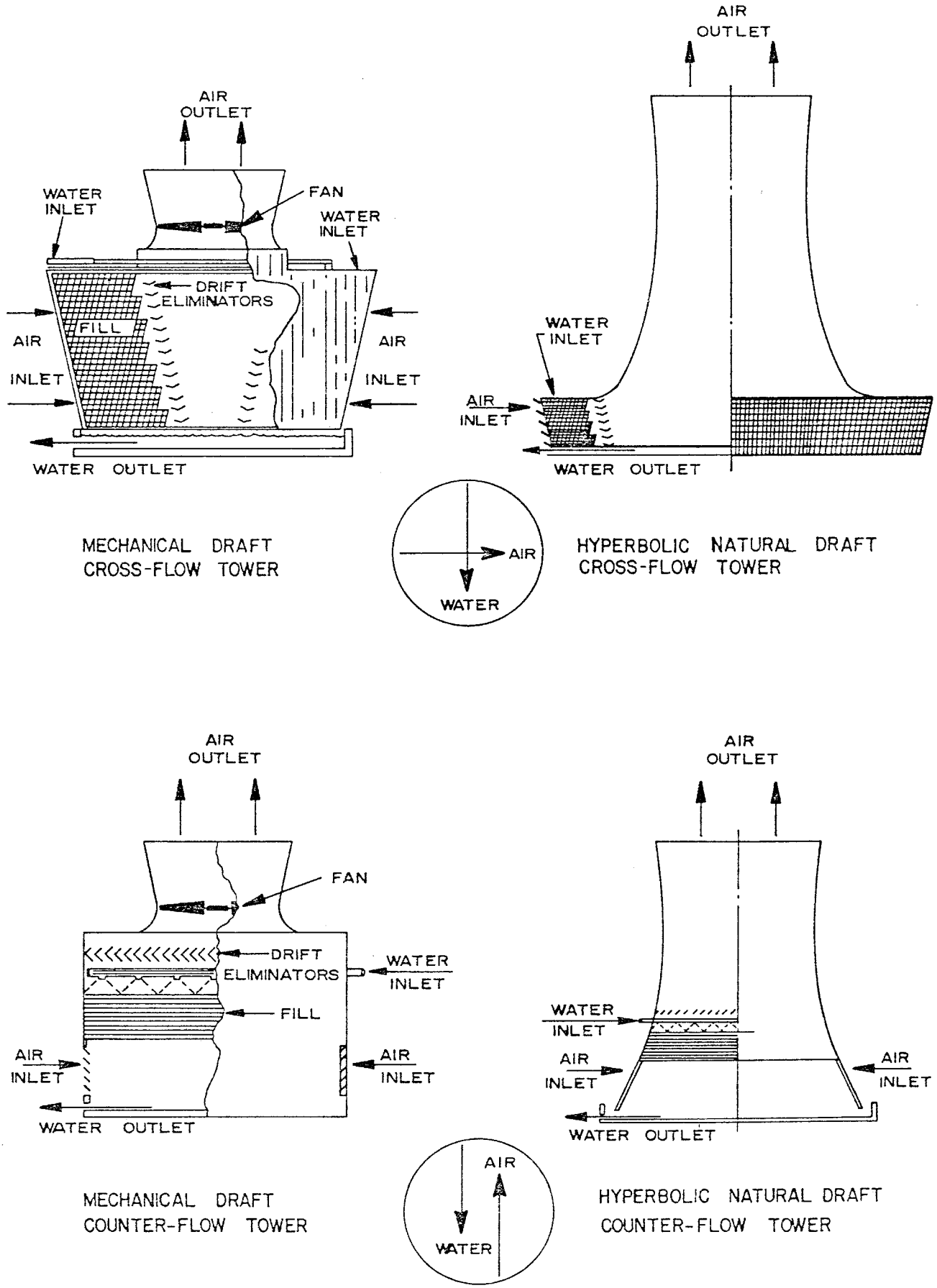


Figure 4.1-2. Basic Cooling Tower Types (Holmberg and Kinney, 1973).

In "crossflow" towers, the packing is arranged around the periphery of the tower so that incoming air flows perpendicularly to the falling water. Timber splash packing is usually employed (Carey et al., 1969). Crossflow towers contain a plenum chamber in the center. Since heat transfer is maximized when the coldest air comes into contact with the hottest water, designers try to maximize fill height and minimize fill depth.

The three major categories of wet cooling towers are: atmospheric, mechanical draft, and natural draft.

Atmospheric Cooling Towers

Air flow through atmospheric towers depends solely on naturally occurring winds. Water is sprayed downward either through an empty enclosure or over fill. Louvered walls permit breezes to pass through the tower. Atmospheric towers are best suited to comparatively small-scale applications such as small refrigeration units (McKelvey and Brooke, 1959).

Mechanical Draft Cooling Towers

Air flow through a mechanical draft tower is created by a fan, eliminating the great height necessary for natural draft towers (see below). The fan may be located at the air exit ("induced draft") or at the air inlet ("forced draft"). Mechanical draft towers tend to have greater drift rates than do natural draft towers (Roffman, 1974).

Figure 4.1-2 depicts two types of mechanical draft cooling towers, induced draft counterflow and induced draft crossflow. In forced draft towers, which are not very common in California, crossflow occurs in some parts of the tower, usually near the fan, while counterflow tends to occur near the top of the packing. The packing usually used in forced draft towers is splash type (Carey et al., 1969).

Natural Draft Cooling Towers

Air flows upward through a natural draft cooling tower without mechanical assistance. As the air entering the tower at the bottom comes into contact with the hot water it picks up moisture and therefore becomes less dense than the surrounding atmosphere. The density difference results in an updraft. Natural draft towers used for cooling large electric power plants are usually 300 to 500 feet tall and 400 feet in diameter. Their hyperbolic

profiles and circular cross-sections promote efficient air movement. Because of their lack of moving parts and use of concrete instead of wood for construction, these towers use less energy and are less expensive to maintain than are mechanical draft towers. Drift rates also tend to be lower (Roffman, 1975).

4.1.2 Dry and Wet-Dry Cooling Towers

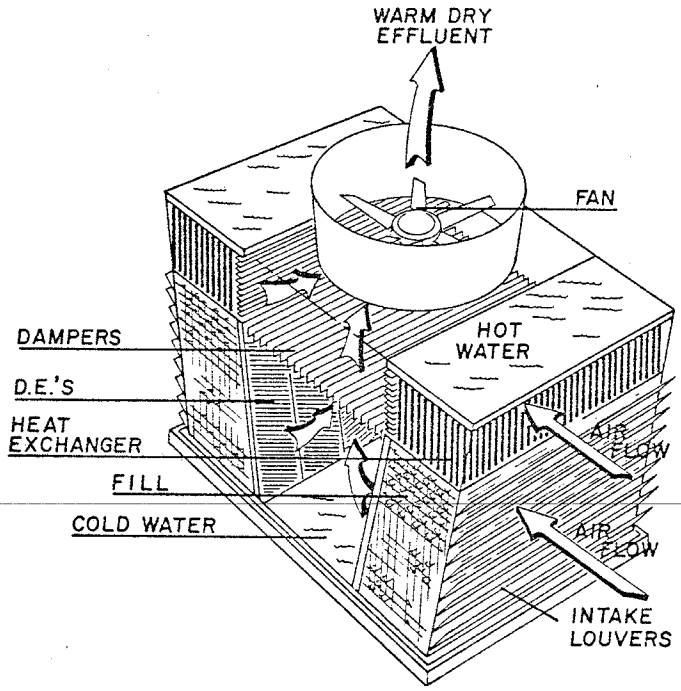
Dry cooling towers use finned tubes to transfer heat from the water to the atmosphere, in much the same way as an automobile radiator. Because water in this type of tower never comes into direct contact with air, dry cooling towers will not be considered further in this study.

As the name implies, wet-dry towers use a combination of evaporative and dry cooling. The main purpose for incorporating a dry section in tower design heretofore has been to reduce fog droplet production due to exhaust vapor condensation in cold, humid weather. Nevertheless, a wet-dry tower can use as little as one percent of the makeup water required by a conventional wet tower (Hu, 1976).

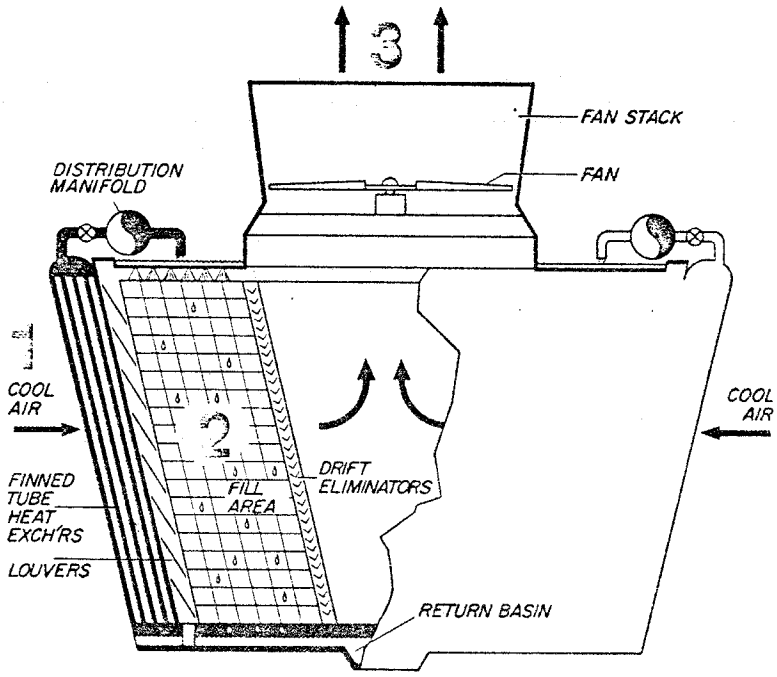
As seen in Figure 4.1-3, the dry section can be in series or in parallel with the wet section. Dampers direct the flow of air in various proportions to the two sections, depending upon weather conditions. For example, in summer only the wet section would be used, while in very cold weather most of the air flow would be directed to the dry section (Hansen and Cates, 1972). Because few wet-dry towers are in use today, performance data are lacking. However, computer simulation models of thermal performance and costs under a variety of loads and meteorological conditions have shown parallel path towers to be more flexible and effective than comparable series path configurations (Cheng et al., 1976).

4.1.3 Future Trends in Cooling Tower Design and Use

Twelve major cooling tower manufacturers were interviewed to ascertain trends in cooling tower design and use, fill material composition, and new research and development. Table 4.1-1 lists the organizations contacted. Before discussing our findings, it should be noted that the potential for changes in design and use is greater in California than in regions where water is more abundant. Although it is presently cheaper to use relatively larger amounts of fresh or wastewater than to build and operate



Parallel Path Configuration (Reisman and Dolan, 1974)



Series Path Configuration (Rubin and Klanian, 1975)

Figure 4.1-3. Two Types of Wet-Dry Cooling Towers

Table 4.1-1

COOLING TOWER MANUFACTURERS CONTACTED FOR INFORMATION ON TRENDS IN DESIGN AND USE

Manufacturer	Location
Andco Environmental Processes	Buffalo, NY
Baltimore Aircoil	Los Angeles, CA
Ceramic Cooling Tower Co.	Fort Worth, TX
Ecodyne Cooling Products Division	Santa Rosa, CA
Heil Process Equipment	Avon, OH
Jones and Hunt	Orwigsburg, PA
Lilie-Hoffman Cooling Towers, Inc.	St. Louis, MO
MacDermid of Bristol	Bristol, CT
The Marley Cooling Tower Company	Mission, KS
Munters Corporation	Fort Meyers, FL
Research-Cottrell, Inc.	Somerville, NJ
Zurn Industries	Tampa, FL

advanced concept towers which conserve water, water conservation in and of itself is the overriding concern in many cases.

Trends in Design and Use

The trend in cooling tower design and use is toward change in mechanical draft towers, the status quo for natural draft towers, and increased attention to wet-dry towers.

Mechanical-Draft Towers. The trend in mechanical draft cooling towers is away from cross-flow and toward counter-flow configurations. Although cross-flow cooling towers have lower initial capital costs, counter-flow cooling towers are more economical to operate. The lower power usage from the lower pumping head in the counter-flow design is the deciding economic factor. The counter-flow inherently has less drift than the cross-flow cooling tower and therefore has less need for drift reduction (Collins, 1979). Finally, the cross-flow cooling tower has a poor service record as compared to the counterflow cooling tower (Krause, 1979).

Natural Draft Towers. Although natural draft cooling towers are used for industrial cooling in Europe, they are used in the U.S. only for power plant cooling (Collins, 1979). Use of these towers in the U.S. is growing very slowly. Because they use less energy to operate and are more capital-intensive than mechanical draft towers, natural draft towers are less affected by rises in energy costs and by inflation in general (Haggerty and LeFevre, 1976). Energy considerations may thus lead to increased use of natural draft towers in the future.

Wet-Dry Towers. Use of wet-dry cooling towers is expected to grow slowly at first but eventually become widespread (Donovan, Hamester and Rattien, 1977). There is a trend toward increased research and projected use of the wet-dry cooling towers. The wet-dry cooling tower's main advantages are visible plume abatement and water conservation (Campbell, 1979; Collins, 1979). Of the two advantages, water conservation is the more important for the West. However, the high initial cost of the wet-dry cooling towers and their high operating costs currently limit their use in anticipated California power plants, except for a one-cell experimental unit tested by Southern California Edison in San Bernardino, California (Reeves, 1979). The higher operating costs are due in part to the higher energy costs for the fan and

tube heat exchangers in the dry section (Campbell, 1979). New design concepts under study include "deluge water augmentation" (wetting the outer surfaces of the finned tubes to increase heat transfer rates) and use of an intermediate ammonia evaporation-condensation step (Zaloudek et al., 1976; Johnson and Maulbetsch, 1977, Tokarz et al., 1978).

Trends in Fill Material

Changes in cooling tower fill design and materials are underway. The general trend is toward designs which promote formation of evaporative film, and away from the traditional splash design (Collins, 1979). Due to restrictions on asbestos emissions in cooling tower blowdown, asbestos-concrete fill material is not being ordered for new cooling towers, especially those associated with electrical power plants (Collins, 1979; Drown, 1979). While polyvinyl chloride (PVC) is an excellent substitute for asbestos-concrete, its cost has been increasing and its future is uncertain (Swindt, 1977).

Several fill materials are being newly introduced or becoming economical given the price of existing materials. Reinforced fiberglass fill is a new product (Santee, 1979) and ceramic fill material is now economically competitive (Bardo, 1979). However, ceramic fill material may only be competitive when it is manufactured as a byproduct by the cooling tower manufacturer and may not generally be available on a competitive basis and thus see increased use. Also, ceramic fill design and configurations are limited by structural considerations (Collins, 1979) and this may limit expanded future use.

Trends in Structural Materials

Reinforced concrete has replaced wood as the primary structural material for cooling towers in the U.S. (Swindt, 1977). For wooden towers, redwood is being replaced by Douglas fir, due to the lower cost of the latter. While steel currently has limited use in wet towers, improved coatings could increase its prospects. Fiberglass is expected to remain the dominant material for fanstacks in new towers.

Trends in Drift Eliminators and Fans

Much effort is being spent on new and more efficient drift eliminators (Abrahams, 1979; Campbell, 1979; Gavin, 1979), while new materials

of construction for drift eliminators are being developed (Bardo, 1979; Krause, 1979). (The state of the art of drift control is discussed in Chapter 9.) Fan designers are developing induced-draft fans with larger diameters (Leonard, 1979), and using fan motors with lower horsepower. However, these changes are limited by optimum air velocities for given cooling tower configurations, as too high or too low air velocities are less efficient (Campbell, 1979). Damper controls are being improved in conjunction with new fan designs (Marcella, 1979).

Other Research

Several efforts are underway to develop equipment upstream of the cooling tower to improve performance. One system is for geothermal cooling towers anticipated for use in areas with liquid geothermal fluids. A turbine separator is being developed to remove any carry-over of liquid after the geothermal brines are flashed (Collins, 1979). Removal of the carry-over will reduce cooling tower corrosion and air pollutants in the drift. Finally, several special designs of the cooling towers for industrial applications using wastewaters have been developed. Some of these cooling towers have no fill and use only spray chambers due to the high solids loading in the process waters (Leonard, 1979).

4.2 SURVEY OF CALIFORNIA COOLING TOWERS

4.2.1 Towers Associated With Electric Power Plants

At the time of our survey (late 1979), the majority of California's Electric power plants used once-through cooling. Those which used cooling towers are listed in Table 4.2-1. Information for this table was obtained from the California Energy Commission and from the power plant operators. A total of 56 towers were associated with these facilities. The breakdown of towers per county was as follows:

County	Towers
Contra Costa	6
Kern	5
Los Angeles	22
Sacramento	2
San Bernardino	8
Sonoma	13

A variety of water sources were used for cooling tower makeup. The most common sources were local ground water and imported surface water. As

Table 4.2-1

COOLING TOWERS ASSOCIATED WITH ELECTRIC GENERATING PLANTS IN CALIFORNIA

Utility	Plant	County	Installed Capacity MWe	No. of Towers	Circulating Water Rate m^3/min (gpm)	Makeup Water Source[a]
Los Angeles Dept. of Water & Power	Valley[b]	Los Angeles	546	9	1,075 (284,000)	S,W
Pacific Gas and Electric Co.	Avon[c]	Contra Costa	40	2	148 (39,000)	S,W
	Kern[c]	Kern	166	5	674 (178,000)	W
	Martinez[c]	Contra Costa	40	2	148 (39,000)	S,W
	Pittsburg 7[c]	Contra Costa	2,029	2	1,363 (360,000)	B
	The Geysers[d]	Sonoma	510	13		G
Southern California Edison Co.	Cool Water[e]	San Bernardino	149	3	958 (253,000)	W
	Etiwanda[e]	San Bernardino	931	3	780 (206,000)	S
	San Bernardino[e]	San Bernardino	131	2	293 (77,400)	W
City of Burbank	Magnolia[f]	Los Angeles	70	2	174 (46,000)	M
	Olive[f]	Los Angeles	99	2	257 (68,000)	M
City of Glendale	Grayson[f]	Los Angeles	159	5	464 (122,700)	M,S,W

Table 4.2-1 (Ctd)

COOLING TOWERS ASSOCIATED WITH ELECTRIC GENERATING PLANTS IN CALIFORNIA

Utility	Plant	County	Installed Capacity MWe	No. of Towers	Circulating Water Rate m^3/min (gpm)	Makeup Water Source[a]
City of Pasadena	Glenarm[g]	Los Angeles	59	1	136 (36,000)	W
	Broadway[g]	Los Angeles	161	3	409 (108,000)	W
Sacramento Municipal Utility District	Rancho Seco[h]	Sacramento	913	2	1,688 (446,000)	S

a B = Brackish Water, G = Geothermal Steam Condensate, M = Municipal Wastewater, S = Surface Water, W = Well Water

b Westerson, 1979

c Unverferth, 1979

d McCluer, 1979

e Tam, 1979

f Information obtained during site visits

g Duby, 1979

h Anderson, 1979

will be discussed in detail later in this report, five of the facilities listed used some form of low-quality water. The 13 operating units at The Geysers, a geothermal facility in Sonoma County, used condensed geothermal steam, to which non-condensible hydrogen sulfide is added. Pacific Gas and Electric Company's Pittsburg 7 plant used water from Suisun Bay, which is brackish for most of the year. Finally, the Cities of Burbank and Glendale operated power plants whose cooling tower makeup was reclaimed municipal wastewater.

4.2.2 Towers Associated With Other Industries

Survey Procedure

One of the objectives of this study was to establish an inventory of cooling tower uses, users, and their location in California by county; the inventory was to include a description of the characteristics of these towers and to identify present and potential use of wastewater or other low-quality water for makeup. A review of the literature and discussions with cooling tower manufacturers, trade organizations, and pollution control officials revealed a near total absence of information on the extent of cooling tower use in California--or any other state for that matter. It was therefore necessary to conduct a survey of potential users and to base our estimates on results thereof.

The first step in SAI's survey was to identify those industry groups which would be most likely to use cooling towers. We initially relied upon the results of a 1970 study by the California Department of Water Resources (CDWR, 1977c), which found that about 83 percent of the cooling water used in the State could be attributed to the sugar, paperboard mill, industrial chemicals and petroleum refining industries. Discussions with cooling tower users and manufacturers led us to include several other industrial categories in the survey. Industry groups surveyed are listed by three-digit Standard Industrial Classification (SIC) code in Table 4.2-2.

Establishments falling under these categories were identified in the 1979 California Manufacturers Register (CMA, 1979). Firms were chosen for the survey according to the more detailed four-digit SIC code, in order to avoid those industries which would not be likely to have cooling towers. It should be noted that all establishments within a given classification were not

Table 4.2-2

INDUSTRIES SURVEYED FOR CALIFORNIA COOLING TOWER INVENTORY

SIC Code	Type of Industry
202	Dairy Products
203	Canning and Preserving Fruits and Vegetables
206	Sugar and Confectionery Products
207	Fats and Oils
208	Beverages
209	Food and Kinndred Products, Miscellaneous
249	Wood Products, Miscellaneous
261	Pulp Mills
262	Paper Mills
263	Paperboard mills
264	Paper Products, Miscellaneous
265	Containers adn Boxes, Paperboard
281	Chemicals, Industrial Inorganic
282	Plastics Materials and Synthetics
283	Drugs
285	Paints and Allied Products
286	Chemicals, Industrial Organic
287	Chemicals, Agricultural
289	Chemical Products, Miscellaneous
291	Petroleum Refining
299	Petroleum and Coal Products, Miscellaneous
301	Tires and Inner Tubes
306	Rubber Products, Fabricated
330	Primary Metal Industries
331	Blast Furnaces, Steel Works and Rolling and Finishing Mills
332	Iron and Steel Foundries
333	Primary Smelting and Refining of Nonferrous Metals
334	Secondary Smelting andn Reffining of Nonferrous Metals
336	Nonferrous Foundries (castings)
346	Iron and Steel Forging (castings)

surveyed. Also, it turned out that many of the establishments listed in the 1979 California Manufacturers Register were sales offices or warehouses, rather than manufacturing plants. On the other hand, several responding firms sent us information on plants which were not listed in the Register. Our survey covered 633 manufacturing plants.

Samples of the cover letter and questionnaire sent to the putative cooling tower users are included in Appendix A. Each firm was given a unique identification number so that confidentiality could be preserved. Approximately 100 firms were contacted by telephone from four to six weeks after they were sent the questionnaires. Responses may be classified as follows:

Facilities Surveyed	633
Facilities Responding	354
Facilities Unavailable	13
Facilities Definitely Having Towers	142
Facilities Definitely Not Having Towers	200

"Facilities unavailable" includes those which declined to furnish information, were out of business, or could not be located.

Survey Results

The following discussion is based upon the survey responses received as of April 1981. The number of towers and the water use per tower for each of the SIC Codes known to use cooling towers are shown in Table 4.2-3. No cooling tower use was reported for the three-digit SIC Codes 249, 261, 265, 299, 330, 331, and 346. It is apparent from the data reported in Table 4.2-3 that there is considerable variability both within and among the different user industries. The three largest tower-using industries, accounting for almost half of the 407 towers identified, are wineries (SIC 2084), canned fruits and vegetables (SIC 2033), and industrial organic chemicals (SIC 2819). These industries use an average of 4 to 6 towers per facility.

Water use, which is an indirect indicator of the size of the cooling towers, also varies considerably among industries. The largest towers, with an average 43.65 m^3/min (11,532 gpm) per tower circulating water rate, are those used by the industrial gases industry (SIC 2813). As the large standard deviation implies, the high mean is due largely to one 4-tower installation which uses a total of 757 m^3/min (200,050 gpm). Other large tower users (over 2,500 gpm per tower), are the petroleum refining (SIC 2911), beet sugar (SIC

Table 4.2-3

CALIFORNIA COOLING TOWER INVENTORY: SUMMARY OF CHARACTERISTICS BY SIC CODE

S.I.C. Code	Total Towers Reported	Towers Per Facility		Circulating Water Rate Per Tower m^3/min (gpm)	
		Mean	Std. Dev.	Mean	Std. Dev.
2020	2	2.00	NA[a]	ND[b]	ND
2033	69	5.75	5.864	4.26 (1125)	4.54 (1200)
2062	8	2.00	0.817	7.45 (1969)	3.54 (934)
2063	9	1.80	0.837	17.67 (4667)	5.87 (1550)
2066	1	1.00	NA	0.11 (30)	NA
2074	1	1.00	NA	3.79 (1000)	NA
2076	1	1.00	NA	ND	
2079	5	5.00	NA	8.14 (2150)	NA
2082	7	7.00	NA	4.33 (1143)	NA
2083	3	3.00	NA	ND	
2084	84	4.67	3.581	2.20 (581)	0.88 (233)
2085	2	2.00	NA	0.87 (230)	NA
2086	22	2.20	1.398	0.80 (211)	0.51 (134)
2095	1	1.00	NA	1.19 (315)	NA
2810	2	2.00	NA	0.31 (83)	NA
2813	21	3.50	1.378	43.65 (11532)	72.57 (19172)
2815	3	3.00	NA	ND	
2818	1	1.00	NA	0.35 (93)	NA
2819	34	3.78	5.495	6.37 (1683)	4.30 (1136)
2820	4	1.00	0	2.23 (588)	1.36 (360)
2821	24	1.60	0.828	1.02 (269)	1.03 (271)
2822	5	1.67	0.577	9.78 (2583)	14.48 (3825)
2824	3	3.00	NA	11.00 (2907)	NA
2830	4	4.00	NA	ND	
2851	1	1.00	NA	0.04 (10)	NA
2865	1	1.00	NA	2.08 (550)	NA
2879	1	1.00	NA	0.68 (180)	NA
2899	7	1.40	0.548	2.70 (714)	4.21 (1111)
2911	24	4.00	3.521	34.16 (9025)	26.54 (7012)
3011	16	2.29	1.113	2.75 (727)	1.34 (354)
3069	2	2.00	NA	0.52 (138)	NA
3320	1	1.00	NA	0.28 (75)	NA
3321	15	3.00	1.581	0.94 (250)	1.52 (401)
3339	4	4.00	NA	0.19 (50)	0
3341	3	3.00	NA	0.19 (50)	0
3360	6	3.00	2.828	0.73 (193)	0.31 (82)
3361	2	1.00	0	2.74 (725)	2.54 (672)
3370	1	1.00	NA	0.28 (75)	NA
3463	5	1.67	0.577	0.90 (238)	0.26 (68)

[a] Only one data point.

[b] Insufficient data on water use rate.

2063), organic fiber (SIC 2824) and synthetic rubber industries (SIC 2822).

The distribution of towers per county was estimated by the following procedure. From the survey data the 95-percent confidence interval for the mean number of towers per facility was calculated for each SIC Code. For example, the interval for the wine industry (SIC 2084) is 4.67 $\pm$ 1.77 or 2.90 to 6.44 towers per facility. The numbers of establishments under each SIC Code for each county were found in the U.S. Bureau of Census' County Business Patterns, 1977, California (USDOC, 1979). Estimates of numbers of towers were then made by multiplying, for each combination of SIC Code and county, the mean number of towers per facility and the number of establishments.

The results of our calculations are shown in Table 4.2-4, along with the actual number of towers identified by the survey. It is evident that Southern California, specifically Los Angeles, Orange and San Bernardino Counties, has the greatest concentration of cooling towers in the state. These three counties account for about 42 percent of the known towers and 30 to 32 percent of the estimated towers.

Our survey also addressed questions of present use of chromate and asbestos, type of condenser fluid, and plans for future use of wastewater for cooling tower makeup. The results to date are shown in Table 4.2-5.

Only about 19 percent of the identified towers, according to our survey, use chromate for corrosion inhibition. Strict discharge requirements are probably the reason why the use of chromate is declining. The industries which appear to use chromate most often are industrial inorganic chemicals (SIC 281) and plastics materials and synthetics (SIC 282).

As noted in Section 4.1.2, the use of asbestos in cooling towers is also declining. About one-third of the towers identified have asbestos components.

The most common condenser fluid by far was clean water, which accounts for over half of the cooling towers identified. About 35 percent of the towers are not connected with condensers. Other uses are fairly evenly distributed. Ammonia seems to be used most often in wineries (SIC 2084).

Table 4.2-4

ACTUAL AND ESTIMATED NUMBERS OF INDUSTRIAL COOLING TOWERS BY CALIFORNIA COUNTY

County	Towers Reported	Estimate of Total Towers
Alameda	31	47-131
Alpine	0	0
Amador	0	0
Butte	0	0
Calaveras	0	0
Colusa	0	0
Contra Costa	11	12-49
Del Norte	0	0
El Dorado	0	0
Fresno	16	48-109
Glenn	1	1-2
Humboldt	0	0
Imperial	3	3
Inyo	0	0
Kern	10	14-30
Kings	2	2
Lake	0	0
Lassen	0	0
Los Angeles	104	185-454
Madera	1	9-17
Marin	0	0
Mariposa	0	0
Mendocino	1	2
Merced	12	12
Modoc	0	0
Mono	0	0
Monterey	10	10-21
Napa	11	57-127
Nevada	0	0
Orange	37	39-105
Placer	0	0
Plumas	0	0
Riverside	9	9-13
Sacramento	3	6-22
San Benito	15	15
San Bernardino	31	31-51
San Diego	5	8-20
San Francisco	5	41-69
San Joaquin	17	42-126
San Luis Obispo	0	0
San Mateo	15	18-39

Table 4.2-4 (Continued)

ACTUAL AND ESTIMATED NUMBERS OF INDUSTRIAL COOLING TOWERS BY CALIFORNIA COUNTY

County	Towers Reported	Estimate of Total Towers
Santa Barbara	1	4-15
Santa Clara	29	123-162
Santa Cruz	0	4-19
Shasta	0	2-5
Sierra	0	0
Siskiyou	0	0
Solano	8	9-12
Sonoma	1	45-112
Stanislaus	8	52-61
Sutter	1	2-9
Tehama	0	3-14
Trinity	0	0
Tulare	3	9-31
Tuolumne	0	0
Ventura	3	5-11
Yolo	3	5-17
Yuba	0	0
TOTAL	407	874-1,887

Table 4.2-5

RESPONSE TO SURVEY OF COOLING TOWER PRACTICES

	Number	Percent
Use of Chromate		
Towers Using Chromate	78	19.1
Towers Not Using Chromate	293	71.6
Towers For Which Data Unavailable	38	9.3
	409	100.0
Use of Asbestos		
Towers Having Asbestos Components	126	30.8
Towers Without Asbestos Components	272	66.5
Towers For Which Data Unavailable	11	2.7
	409	100.0
Condenser Fluid		
Clean Water	243	59.5
Chemical Process Water	32	7.8
Petroleum Fractions	25	6.1
Ammonia	21	5.1
Inorganic Gases	18	4.4
None	20	4.9
Food Processing Water	9	2.2
Organic Gases	9	2.2
Solvents	1	0.2
Unknown	31	7.6
	409	100.0
Wastewater Reuse Plans		
Yes	66	16.1
No	286	70.0
Don't Know or Decline to State	57	13.9
	409	100.0

4.3 PRESENT USE OF WASTEWATER FOR COOLING IN CALIFORNIA

4.3.1 Municipal Wastewater

As of this writing the only facilities using treated municipal wastewater in California are the electric power plants owned and operated by the City of Burbank and the City of Glendale. The following discussion is based upon the site visits and information provided by the plant operators.

City of Burbank

In 1967 the City of Burbank began using reclaimed municipal wastewater for cooling tower makeup at its oil- and gas-fired Magnolia and Olive steam-electric generating plants. The plants are located on the same site. The Magnolia plant's two generators are rated at 22,000 and 33,000 kW, while those of the Olive Plant are rated at 44,000 and 55,000 kW. Characteristics of the facilities' four cooling towers are summarized in Table 4.3-1. All towers were designed with a 9 ^{o}C (16 ^{o}F) temperature differential with 36 ^{o}C (96 ^{o}F) inlet water and 21 ^{o}C (70 ^{o}F) wet-bulb temperature.

Wastewater for cooling tower makeup receives primary and activated sludge treatment at the Burbank Water Reclamation Plant, which is about 1.4 km (0.9 mi) away and uphill from the power plants. About 0.07 m^3/sec (1.6 million gallons per day) of the waste treatment plant's output is used for the makeup; the rest is used to dilute cooling tower blowdown prior to discharge to a flood control channel (Adams et al., 1978; Woodbury, 1978). City water drawn from local wells is used when the treatment plant is shut down by upsets or for maintenance; this alternate water source accounts for about five percent of the total need (Woodburn, 1978).

The Burbank operation is unusual in that the wastewater receives no additional treatment before reuse in the cooling towers. Since an excess of water is available at no pumping cost, it is economical to operate the towers at only 2.5 cycles of concentration. Blowdown is released intermittently, in response to high electroconductivity levels in the circulating water. Although phosphonates already in the wastewater treatment plant effluent inhibit corrosion to some extent, a zinc-based corrosion inhibitor (Olin 2100) was used in all the towers until early 1980; since then Olin 2100 has still been used in the Magnolia towers, but a copper-based inhibitor (Betz 562C) has been used in the Olive towers. Foaming is controlled by slug-feeding Dow DB

TABLE 4.3-1

CHARACTERISTICS OF COOLING TOWERS AT BURBANK, CALIFORNIA PUBLIC SERVICE DEPARTMENT POWER PLANT

Tower	Manufacturer	No. of Cells	Air Flow[a]	Circulating Water Rate
Olive 1	Marley	5	Crossflow	129 m^3/min (34,000 gpm)
Olive 2	Marley	5	Crossflow	129 m^3/min (34,000 gpm)
Magnolia 3	Fluor	5	Counterflow	76 m^3/min (20,000 gpm)
Magnolia 4	Fluor	6	Counterflow	98 m^3/min (26,000 gpm)

Source: MacDougall (1979).

[a] All are mechanical, induced-draft towers with wooden drift eliminators

110 when detergent concentrations up to 0.5 ppm are encountered; when detergent concentrations exceed 0.5 ppm, city water is used instead of wastewater (Adams et al., 1978; MacDougall, 1979). Circulating water pH is maintained between 6.5 and 6.7 by addition of sulfuric acid, since corrosion inhibition by the polyphosphates in the wastewater is optimum at 6.6 (Woodburn, 1978). At various times, a phosphonate (Olin 2101) and polyacrylates (Olin 2602 and Betz 2020) have been used to prevent calcium phosphate deposition and to disperse suspended solids (MacDougall, 1980).

Although the wastewater treatment plant effluent contains a 2.0-ppm chlorine residual, the water is further chlorinated to provide biological control. From 1976 to 1978, Burbank used chlorine dioxide, which was added at 0.27 kg/hr (0.6 lb/hr) to the cooling tower basins between 6 a.m. and 6 p.m., in the Olive towers. By the time of our field tests, however, all towers were treated only with hypochlorite solution (MacDougall, 1980).

City of Glendale

In January 1979 the City of Glendale began using treated wastewater from the Los Angeles/Glendale Water Reclamation Plant as makeup to its Public Service Department's 148-MW oil- and gas-fired power plant's cooling towers. Since mid-1979, the plant has reverted at least twice to well water use. The first time, personnel were unavailable to run the phosphorus removal plant. The second time, the electrical support system for the phosphorus plant was accidentally destroyed.

Table 4.3-2 lists the characteristics of the power plant's five cooling towers. Two pairs of cooling towers, Units 1 and 2 and Units 3 and 4, operate as combined systems; each pair shares circulating water and makeup. Unit 5 is a one-tower system. In order to achieve the goal of 6 to 9 cycles of concentration, the phosphate concentration must be maintained below 8 ppm (Kendall, 1979). When the plant is on wastewater, a 10.2 m^3/min (2700 gpm) capacity facility uses alum flocculation and cationic polymer addition to reduce phosphate to below 1 ppm. Sulfuric acid is used to maintain pH between 8.0 and 8.2. Chlorine gas is slug fed to the cold water basin 3 times per day for 60 minutes at a time, to achieve a free chlorine residual of 0.5 to 1.5 ppm. Blowdown is discharged to the Los Angeles/Glendale Water Reclamation Plant's collection system.

Table 4.3-2

CHARACTERISTICS OF COOLING TOWERS AT GLENDALE, CALIFORNIA
PUBLIC SERVICE DEPARTMENT POWER PLANT

Tower Number	Manufacturer (year)	No. of Cells	Air Flow	Circulating Water Rate[a]	Makeup Water Rate[a]
1	Ecodyne (1977)	4	Counterflow	75.7 m^3min (20,000 gpm)	0.76 m^3/min (200 gpm)
2	Marley (1947)	6	Crossflow	60.6 m^3/min (16,000 gpm)	0.76 m^3/min (200 gpm)
3	Foster-Wheeler (1953)	6	Counterflow	75.3 m^3/min (19,900 gpm)	1.14-1.51 m^3/min (300-400 gpm)
4	Foster-Wheeler (1959)	8	Counterflow	126.4 m^3/min (33,400 gpm)	1.14-1.51 m^3/min (300-400 gpm)
5	Foster-Wheeler (1965)	5	Crossflow	126.4 m^3/min (33,400 gpm)	1.89 m^3/min (500 gpm)

Source: Boothe, 1979

[a]Units 1 and 2 and Units 3 and 4 share circulating water and makeup supplies.

During the 16 months of wastewater use, no major operational problems were encountered (Kendall, 1979). Plant operators expressed some concern over potential corrosion due to ammonia, since makeup water is added to the condensers, rather than directly to the cooling tower. However, no problems were observed. Handling of waste treatment plant upsets is discussed in Section 5.1.4.

4.3.2 Industrial Process Water

Our survey identified three plants which definitely use industrial process water for cooling tower makeup. All wished to remain anonymous. Towers at "Industrial Plant No. 1" and "Industrial Plant No. 2" were later sampled.

Industrial Plant No. 1

This refinery uses about 0.57 to 1.82 m^3/min (150 to 500 gpm) of process wastewater as makeup to eight cooling towers. Before re-use, the water is treated by two stages of gravity separation and two stages of nitrogen gas flotation and blended with well water. The refinery originally used 2.65 m^3/min (700 gpm) but the South Coast Air Qaulity Management District (SCAQMD) maintained that odors were appreciable at that use rate (Chatfield, 1979); use was then restricted to 1.89 m^3/min. The refiniery operators, who deny that there was an odor problem, are currently considering requesting permission to increase wastewater re-use to 3.41 m^3/min (900 gpm).

Industrial Plant No. 2

This large industrial facility in Southern California uses six water circuits, each having from one to five cooling towers, for cooling. In some cases the blowdown from the cooling towers of one is routed directly to another circuit, while in other cases wastewater is sent to an on-site treatment facility, disposed of on site, or discharged to the Los Angeles County Sanitation District's treatment system.

Table 4.3-3 summarizes the salient features of each of the six circuits. "Levels" are listed in descending order of water quality and use. Water for Level I is obtained from a local water company and from on-site wells. Treatment before use consists of cold lime softening and sodium aluminate coagulation, chlorination, carbonation (to decrease pH to 8.8), and sand filtration. The high-quality effluent is used for domestic purposes and

Table 4.3-3

WATER RE-USE SYSTEM AT INDUSTRIAL PLANT NO. 2

Water Re-use Circuit	No. of Towers	Total Circ. m^3/min (gpm)	Uses of Circ. Water	Problem Constituents	Disposal
Level I	3	219 (57,800)	Motor room and furnace cooling	Algae Slime	Level II
Level II	2	197 (52,000)	Bearing cooling, Scale flushing	Oil Grease Scale	On-site treatment
Level III	5	223 (59,000)	Cooling of high temperature process	Suspended organic and inorganic solids	Level IV
Level IV	4	53 (14,000)	Gas Scrubbers	Suspended Solids, TDS	Land disposal
Steam Plant	1	168 (44,340)	Condensers	Salts	Level III
Major Process	3	70 (18,500)	Ammonia Condensers	TDS	Product Cooling

Source: Plant operators.

for condenser fluid in the on-site power plant. Water for boiler makeup and for process use is pretreated by sodium zeolite ion exchange and by reverse osmosis, respectively.

For Levels I, II and III, sidestream treatment of circulating water enables continued re-use. Biocides are added in Level I, while water in Levels II and III is clarified to remove suspended solids, scale, and floating oil and grease. Water discharged from the Level IV circuit is evidently too degraded for any recirculating type of re-use and is therefore used in spray cooling and then disposed of.

The "problem constituents" listed in Table 4.3-3 are problems from the standpoint of industrial re-use. Constituents which could potentially cause air pollution problems are discussed in Section 5.2.

Other

Our survey found one other certain user of industrial process water for cooling, and three possible users. A large chemical plant in the San Francisco Bay area recycles chemical processs water in an Ecodyne mechanical draft tower having a circulating water rate of about 6.1 to 6.8 m^3/min (1600 to 1800 gpm). The possible users include a tire factory and two food process ing plants. We were unable to obtain more information about these facilities.

4.3.3 Geothermal Fluid

Geothermal fluid is now being used for electrical generation in California only in the four-county Geysers-Calistoga Known Geothermal Resource Area (KGRA), which is about 110 km (70 miles) north of San Francisco and is shown in Figure 4.3-1. For the power plant complex at The Geysers, Union Oil Company supplies the steam, while Pacific Gas and Electric (PG&E) operates 13 electrical generation units having a combined full-load capacity of 510 MW (McCluer, 1979).

All cooling towers associated with The Geysers are mechanical draft types about 15 m (50 ft) high, with up to 10 cells apiece (Rosen and Molenkamp, 1978). Units 1, 3 and 4 are counterflow, while the rest are crossflow. Marley and Fluor built the towers for Units 1 through 4, while Ecodyne built the towers for Units 5 through 12. Towers for the most recent units, 12 and 15, were built by Marley.

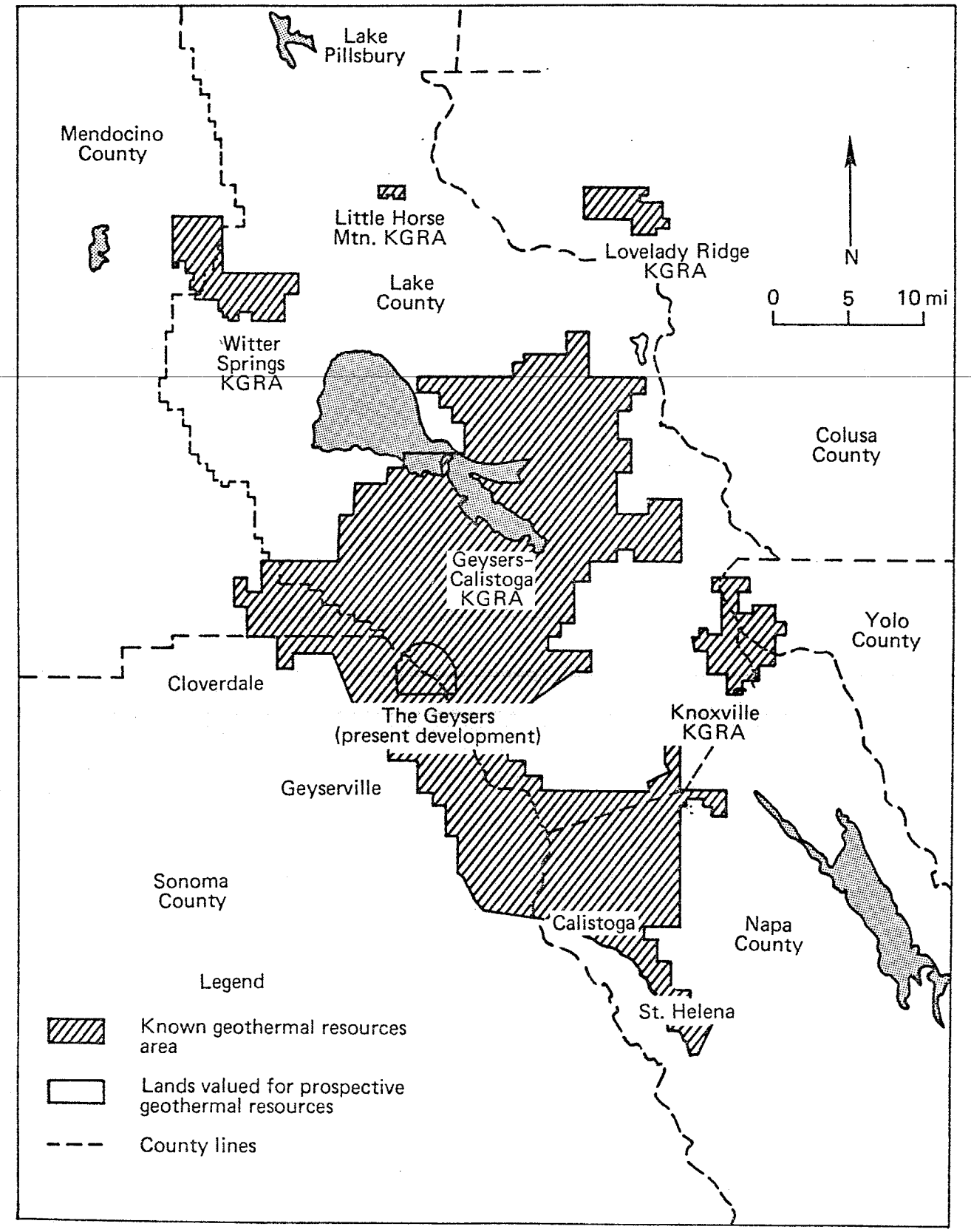


Figure 4.3-1. Geysers-Calistoga Known Geothermal Resource Area (Ermak and Phelps, 1978).

Under normal operating conditions, geothermal steam is directed through a turbine and then into a direct-contact condenser. The hot condensate is pumped to a cooling tower and the noncondensible gases are removed from the condenser and then (for Units 1 through 12) injected into the cooling tower. Water collected in the cooling tower's cold water basin is used in the condenser or reinjected into the geothermal reservoir through an injection well. About 80 percent of the original geothermal fluid ends up in the atmosphere (Rosen and Molenkamp, 1978).

On Unit 15, which went into commercial operation in 1979, and on all future units, noncondensible gases will be treated by the Stretford process for abatement of H_2S before being injected into the cooling tower. For Units 3 through 6, 11, and 12, ferrous and nickel sulfate are added to the circulating water to catalyze the oxidation of H_2S to elemental sulfur. (These treatment systems are discussed in detail in Section 9.3).

Experimental facilities in the East Mesa KGRA and the Salton Sea KGRA in the Imperial Valley use agricultural irrigation water for cooling. These operations are discussed in Section 4.4.3.

4.3.4 Brackish Water

The only facility using brackish water for cooling in California at present is the 2,029 MWe Pittsburg 7 gas- and oil-fired power plant, operated by Pacific Gas and Electric Company (PG&E) in Contra Costa County. The plant uses once-through cooling, a cooling pond and two Marley 600 mechanical draft crossflow cooling towers (Unverferth, 1979). Each tower has 13 cells and a circulating water flow rate of 681 m^3/m (180,000 gpm).

Makeup water is obtained from Suisun Bay, which is part of the Sacramento River-San Francisco Bay estuary system. Except for the two or three months when spring snowmelt increases the freshwater flow in the Bay, the water is brackish (Halterman, 1979). Only 1.5 to 3 cycles of concentration are normally achieved.

4.3.5 Agricultural Wastewater

At present agricultural wastewater is not used for cooling purposes anywhere in California. A three-year program for testing proocesses to treat agricultural wastewater for power plant cooling and a demonstration treatment project to simulate agricultural wastewater treatment and use in a proposed

nuclear power plant will be summarized, as they are the closest agricultural wastewater has come to being used for power plant cooling.

Firebaugh Test Facility

In 1976-1977, the California Department of Water Resources (CDWR) and the University of California Seawater Conversion Laboratory (UCSCL) tested several methods of treating agricultural wastewater for reuse in power plant cooling. The tests, which were sponsored by the CDWR and several public and private utilities, were conducted at a facility in Firebaugh, in Fresno County. Ion exchange was employed to remove magnesium and calcium hardness, while blowdown from the cooling tower was concentrated and used to regenerate the ion exchange resin. Problems with higher than anticipated levels of silica, and the resulting scale formation, forced the additional testing of a silica treatment process.

The study team concluded that the processes evaluated are technically feasible to treat agricultural wastewater for power plant cooling. At the pilot-plant scale, operating costs appear to be attractive. However, recommendations fall short of urging full-scale use and call for a demonstration plant to be constructed at 20 to 50 times the pilot plant scale to verify the processes and their economics (CDWR and UCSCL, 1978).

Palo Verde Demonstration Project

To demonstrate the feasibility of using agricultural wastewater from the Palo Verde Outfall Drain (PVOD), San Diego Gas and Electric Company (SDG&E) conducted a 10-month demonstration at a test facility near Palo Verde. This testing of a simulated water treatment and circulating water system was designed for satisfying cooling water requirements of the proposed SDG&E Sundesert Nuclear Power Plant in Riverside County. The treatment process consisted of lime-soda ash softening in a clarifying unit to remove precipitating flocculent. The test system was scaled at 0.1 percent (1:1000) and included a Marley cooling tower.

The results of the testing demonstrated the ability of the process to treat agricultural wastewater at the PVOD, and other high salinity wastewater, so that the circulating water achieved the required cycles of concentration without reduced heat transfer efficiency. The testing results were sufficient to allow full scale design and construction if the power plant project had been approved.

4.4 NEAR-TERM FUTURE USE OF WASTEWATER FOR COOLING IN CALIFORNIA

4.4.1 Municipal Wastewater

Chevron U.S.A., El Segundo

Negotiations were completed in 1980 to conduct a test of the use of secondary-treated municipal sewage effluent in a tower at the Chevron, U.S.A., oil refinery in El Segundo, California. Effluent will be provided by the City of Los Angeles' Hyperion Treatment Plant in Playa del Rey and conveyed by the West Basin Municipal Water District (Joham, 1978). The U.S. Environmental Protection Agency will provide partial funding (Smith, 1980).

The planned pilot program consists of four three-month phases, during each of which the percentage of wastewater in the makeup to Tower No. 19 will be increased in a 25-percent increment (Peel, 1979). Chevron will monitor heat transfer performance, deposit formation, microbiological fouling, and corrosion. At 100-percent wastewater Chevron will use 1.51 m^3/min (400 gpm) of Hyperion effluent in the tower. The recirculating water rate for the tower is about 87 m^3/min (23,000 gpm). If the pilot program is successful and costs are favorable, the refinery could use up to 16.7 m^3/min (4400 gpm) of wastewater for cooling in some or all of the 11 towers (Smith, 1980).

Characteristics of the secondary-treated municipal wastewater to be used are described in Section 5.1.4.

Contra Costa County

In April 1972 the Contra Costa County Water District (CCCWD) and the Central Contra Costa Sanitary District (CCCSD) signed a contract to provide for the re-use of treated municipal sewage effluent for various industrial purposes, including industrial cooling tower makeup. The following project description is summarized from a paper by DeVito and Gregg (1979), except where otherwise noted.

Contra Costa County has the largest concentration of heavy industry (chiefly oil, chemicals, steel and paper) in California. Under present arrangements, CCCWD obtains water from the Central Valley Project by a diversion from the Sacramento-San Joaquin Delta and delivers it to the most industrialized areas of the county through the Contra Costa Canal System. The water is generally of sufficient quality for existing industrial uses. The

CCCSD provides subregional wastewater treatment for the southwestern and southern portions of Contra Costa County, and presently discharges about 1.31 m^3/sec (30 mgd) of treated effluent into Suisun Bay. Because of projected increasing demands for CCCWD water and the need for upgrading and expanding CCCSD's treatment facilities, it became apparent in the late 1960's that a wastewater reclamation project could benefit both districts. Among the provisions of the most recent version of the Reclaimed Water Supply Contract are the following:

- The quantity of reclaimed water to be delivered is that which the Water District needs, not to exceed 1.31 m^3/sec (30 mgd) or that amount which can be produced by the Sanitary District, whichever is less.

- The Water District has first and prior rights to purchase the reclaimed water except that water in excess of Water District needs may be sold or disposed of outside of the territory of the Water District.

- The reclaimed water must meet the following water quality standards: TDS 375 mg/L; Hardness 300 mg/L; Alkalinity 255 mg/L; Cl_2 residual 0.5 mg/L; Coliforms 2.2 MPN/100 mL; pH 6.5 to 8.5; Turbidity 3 JTU; BOD_5 10 mg/L; TOC 20 mg/L; Total Phosphorus 1 mg/L.

- The Water District agrees to construct delivery facilities to its customers.

- The water quality measuring points, measuring frequency, constituents and analytical methods are specified.

- The Water District retains the right to review and comment on facility designs prior to approval of final design by the Sanitary District.

- A price of $4.00 per acre foot ($3.24 per 1000 m^3).

- If quality standards are not met, the price can be decreased to offset the increased costs incurred by the users.

- The contract runs through June 30, 2006.

The wastewater treatment facilities provided by the CCCSD include chemical primary treatment with lime, biological nitrification, sludge incineration, filtration and a pipeline to transmit treated effluent to the CCCWD. The CCCWD is to provide a 0.65 m^3/sec (15 mgd) ion exchange softening plant, storage tanks, and a distribution system. Potential water users include:

- Lion Oil Company - Avon Refinery, Avon
- Shell Oil Company - Martinez Refinery, Martinez
- Stauffer Chemical, Martinez
- Monsanto Chemical, Avon
- Pacific Gas and Electric Company
  - Avon Power Plant (40 MWe), Avon
  - Martinez Power Plant (40 MWe), Martinez

Certain water quality aspects of this project merit attention. Under the original version of the Reclaimed Water Supply Contract the reclaimed water was to have a maximum total nitrogen concentration of 5 mg/L. However, while the new treatment facilities were being designed, the U.S. Environmental Protection Agency (USEPA) and the San Francisco Bay Regional Water Quality Control Board decided that denitrification was not necessary for discharge to Suisun Bay. Since annual operating costs for the proposed nitrification/denitrification facilties would have been $800,000 per year, the CCCSD preferred to defer construction of that portion of the plant until such time as regulatory agencies should require denitrification. The contract between the CCCWD and CCCSD was amended to delete the total nitrogen water quality requirement.

Deletion of the denitrification step resulted in another process change. CCCWD's engineering consultants had recommended using a strong acid-sodium exchange ("SANAX") process for water softening. The SANAX process, however, is not optimum if the water to be treated is not denitrified first. A simpler sodium ion exchange softening process is to be used instead.

The re-use implications of the changes in water quality are uncertain. According to one potential reclaimed water user, the high nitrate concentrations in the effluent are not expected to cause operational problems; the main concern is with potentially high phosphate concentrations (Spahl, 1979). As of mid 1981, CCCSD was having problems with the chemical primary treatment system, and the tertiary treatment process was not yet on line. Both technical problems and disagreements between the districts will likely delay the project until 1982 (Micanek, 1980).

4.4.2 Industrial Process Water

McClellan Air Force Base

McClellan Air Force Base, which is in Sacramento County, has 58 cooling towers ranging in size from 20 to 600 tons (0.23 to 6.8 m^3/min recirculating water). All are used for workplace air conditioning. The towers presently use about 1.51 m^3/min (400 gpm) of ground water for makeup and are estimated to release about 0.003 m^3/min (0.83 gpm) as drift (SCS Engineers, 1979). The Air Force base presently treats its domestic and industrial wastes in two separate plants and discharges all treated effluent to Magpie Creek, a tributary of the Sacramento River. Faced with expiration of its discharge permit in 1979, the base management decided to implement a large-scale water-reuse system in which effluent from the treatment plants will be upgraded and then used for landscaping, engine test cells, acid fume scrubbers, cooling, and several other activities. About 40 towers will be connected to the water reclamation system. The new tertiary treatment facilities and nine-mile long distribution system was completed in the summer of 1981, and is scheduled for official startup in April, 1982. Characteristics of the new makeup water are discussed in Section 5.3.

SAI Survey Results

As reported in Section 4.2.2, users of about 17 percent of the cooling towers identified in California stated that they are considering using reclaimed wastewater as a makeup source. Over two-thirds stated that they were definitely not planning to use this new source. The positive responses were distributed as follows:

SIC	Type of Industry	No. of Firms	No. of Tower
2084	Wineries	5	32
2819	Industrial inorganic chemicals	1	18
2911	Petroleum refining	1	5
3011	Tires and inner tubes	2	3
2824	Organic fibers	1	3
2821	Plastics materials and resins	1	1
3341	Secondary smelting/nonferrous	1	3
3361	Aluminum casting	1	1
		13	66

4.4.3 Geothermal Fluid

Geysers-Calistoga KGRA

As of mid-1979, 11 geothermal energy facilities of over 50-MWe capacity were under review by the CEC or were expected to enter the permit approval process. These are listed in Table 4.4-1. Under all these plans, steam condensate will be used for cooling tower makeup (MacDonald, 1979).

Imperial Valley

Geothermal electric power plants in the Imperial Valley will use the region's hot water resource in one of two principal ways. Those operations based upon a binary fluid cycle will produce no geothermal condensate and must depend upon a non-geothermal source for cooling tower makeup. Operations based upon use of flashed geothermal steam to drive the turbine will have some geothermal condensate available for cooling, the amount depending upon system design and upon State and local reinjection requirement. Since the steam condensate is generally of higher quality than local surface and drainage water supplies, it is likely to be preferred for cooling tower makeup. If 100 percent of the geothermal volume must be reinjected, then supplementary water (most likely irrigation supply or wastewater) must be added to the unflashed geothermal brine to compensate for the flashed steam used in the cooling towers.

Table 4.4-2 lists geothermal power plants recently begun and/or planned for the Imperial Valley. Magma Power's East Mesa Plant will use a binary system while the other facilities will use flashed steam. Since all these plants will have capacities below 50 MWe, CEC approval is not necessary.

In the East Mesa KGRA, local groundwater could be used for either cooling water or reinjection makeup. In the Salton Sea KGRA, agricultural return flows drained by the New or Alamo Rivers or water from the Salton Sea could be used as reinjection makeup, if necessary, as the cooling water at the Imperial Magma Power Company's 49-MWe flash cycle power plant will use flashed geothermal steam condensate for cooling water.

Republic Geothermal plans to begin construction in 1982 on the first 10-MWe unit of an eventual 50-MWe binary cycle geothermal power plant at East Mesa in Imperial County (Carey, 1981). A 4-cell mechanical-draft cooling tower would use unflashed geothermal fluid for makeup. The fluid would be

Table 4.4-1

NEAR-TERM FUTURE GEOTHERMAL DEVELOPMENT
IN THE GEYSERS-CALISTOGA KGRA

Status[a]	Utility	Facility	Capacity MWe
AFC and NOI approved	Pacific Gas and Electric Company	Geysers Unit 17	110
NOI approved; AFC under review	Pacific Gas and Electric Company	Geysers Unit 18	110
	Northern California Power Agency	NCPA 2	110
	Calif. Dept. of Water Resources	Bottle Rock	55
NOI approved; AFC expected	Sacramento Municipal Utility District	Geothermal 1	55
	Pacific Gas and Electric Company	Geysers Unit 16	110
NOI under review	Northern California Power Agency	NCPA 1	66
NOI projected	Pacific Gas and Electric Company	Geysers Unit 19	55
		Geysers Unit 20	110
		Geysers Unit 21	110
	Calif. Dept. of Water Resources	South Geysers	55

Source: California Energy Commission (MacDonald, 1979).

[a]NOI = Notice of Intention, AFC = Application for Certification.

Table 4.4-2

HOT WATER-DOMINATED GEOTHERMAL POWER PLANTS
PLANNED FOR THE IMPERIAL VALLEY

Known Geothermal Resource Area	Facility
Salton Sea (Niland)	Four wells at Niland, Imperial Valley, to be drilled by Union Oil Company, Southern California Edison Company, and Southern Pacific Land Company. Edison will install a 10 MWe power plant, scheduled to begin producing in 1982.
Brawley	A 10-MWe power plant at Brawley, Imperial Valley was built by Union Oil Company and Southern California Edison Company, in 1980 and is operating intermittently.
Heber	A 49-MWe double flash power plant at Heber, in the Imperial Valley, to be built by Southern California Edison, Union Oil Company, and Chevron U.S.A., Inc.
East Mesa	A 12-MWe binary cycle power plant at East Mesa, constructed by Magma Power Company and the Imperial Irrigation District, is currently in operation.
East Mesa	A 50-MWe power plant for East Mesa, Imperial County, is planned by Republic Geothermal, Inc. and San Diego Gas and Electric Company. The project, scheduled for completion in the early 1980's, will cost $50 million.

taken from a tap on the heat exchanger at a point after it has transferred its heat to the working fluid, which will be isobutane. Negotiations with a utility customer are underway.

4.4.4 Brackish Water

Brackish water was proposed as a cooling tower makeup source for two Pacific Gas and Electric Company (PG&E) power plant projects. Both the 1550-MWe combined cycle Pittsburg 8 and 9 plant and the 1600-MWe coal-fired Fossil 1 and 2 project would use water from Suisun Bay, which is brackish for most of the year (MacDonald, 1979). These projects are currently dormant (Peter, 1982).

When the Fossil 1 and 2 project was at the NOI stage, the California Energy Commission sponsored a study of the potential for using brackish groundwater for an alternative site in Yuba County (Scott et al., 1978). Water having 2,800 to 3,500 mg/L total dissolved solids--considered acceptable for powerplant use and unacceptable for competing uses--may be found in the Domingene-Ione, Starkey, Winters and Kione Formations. Detailed technical and economic feasibility studies were not performed.

Scott et al. also made a general review of the availability to brackish ground water for power plant cooling. Of the 113 basins containing water of a specific quality and quantity, most are in the South Lahontan Hydrologic Study Area, which includes portions of Inyo, Kern, Los Angeles, Mono, and San Bernardino Counties.

Desert sites in this area were given at least preliminary consideration by the California Department of Water Resources in its planning for a coal-fired power plant to provide energy for the State Water Project (Anderson et al., 1977). (The power plant project has since been cancelled.)

4.4.5 Agricultural Wastewater

The areas of California where agricultural wastewater is most likely to be used as cooling tower makeup are the San Joaquin, Imperial and Palo Verde Valleys. Other agricultural areas of the State either do not produce sufficient wastewater or are not presently being considered for power plant siting or other major industrial growth.

San Joaquin Valley

The San Joaquin Valley, one of the world's richest agricultural areas, is faced with a severe wastewater disposal problem. About 162,000 hectares (400,000 acres) of the Valley are underlain by impervious clay strata which limit the percolation of agricultural drainage water to a relatively shallow subsurface layer (MacDonald and Wire, 1979). Figure 4.4-1 shows areas where saline perched water table conditions occur.

In 1975, in an attempt to coordinate a number of independent efforts to resolve the agricultural drainage problem, the California Department of Water Resources (CDWR), California Water Resources Control Board (CWRCB) and the U.S. Bureau of Reclamation (USBR) instituted the San Joaquin Valley Interagency Drainage Program (IDP). The IDP has evaluated several alternative plans for collecting and disposing agricultural wastewater, most of which would depend upon a "master drain" to convey the water to an ultimate disposal site. Disposal sites proposed include the Pacific Ocean, the San Joaquin River, the Delta (or Suisun Bay), and evaporation basins.

Pending a final plan by the IDP, local projects, which could one day form a part of the master drain system, have been started or planned. The USBR's San Luis Drain, which is to run from Kettleman City to the Delta near Antioch, is complete between Kettleman City and the 2.1×10^7 m^3 (17,000 AF) Kesterson Reservoir near Gustine. Since few on-farm drainage systems have been installed in the service area, relatively little wastewater actually flows through the system. By the year 2000 the San Luis Drain could supply 2.48×10^7 m^3 (20,100 AF) to 1.33×10^8 m^3 (107,400 AF) of wastewater per year, depending upon the extent of on-farm drainage installation.

Meanwhile, the Tulare Lake Drainage District (TLDD) in Kings County presently collects and disposes of 4.9×10^6 to 6.2×10^6 m^3/yr (4000 to 5000 AF/yr) of wastewater in evaporation basins. By the year 2000, up to 4.3×10^7 m^3/yr (35,000 AF/yr) could be collected, again depending upon the installation of on-farm drainage systems. The Kern County Water Agency (KCWA) at one time planned to construct a collection system and dispose of wastewater at least partially through consumptive use in cooling towers (see below). It is estimated that this system could collect 1.1×10^8 m^3/yr (88,000 AF/yr) by the year 2005.

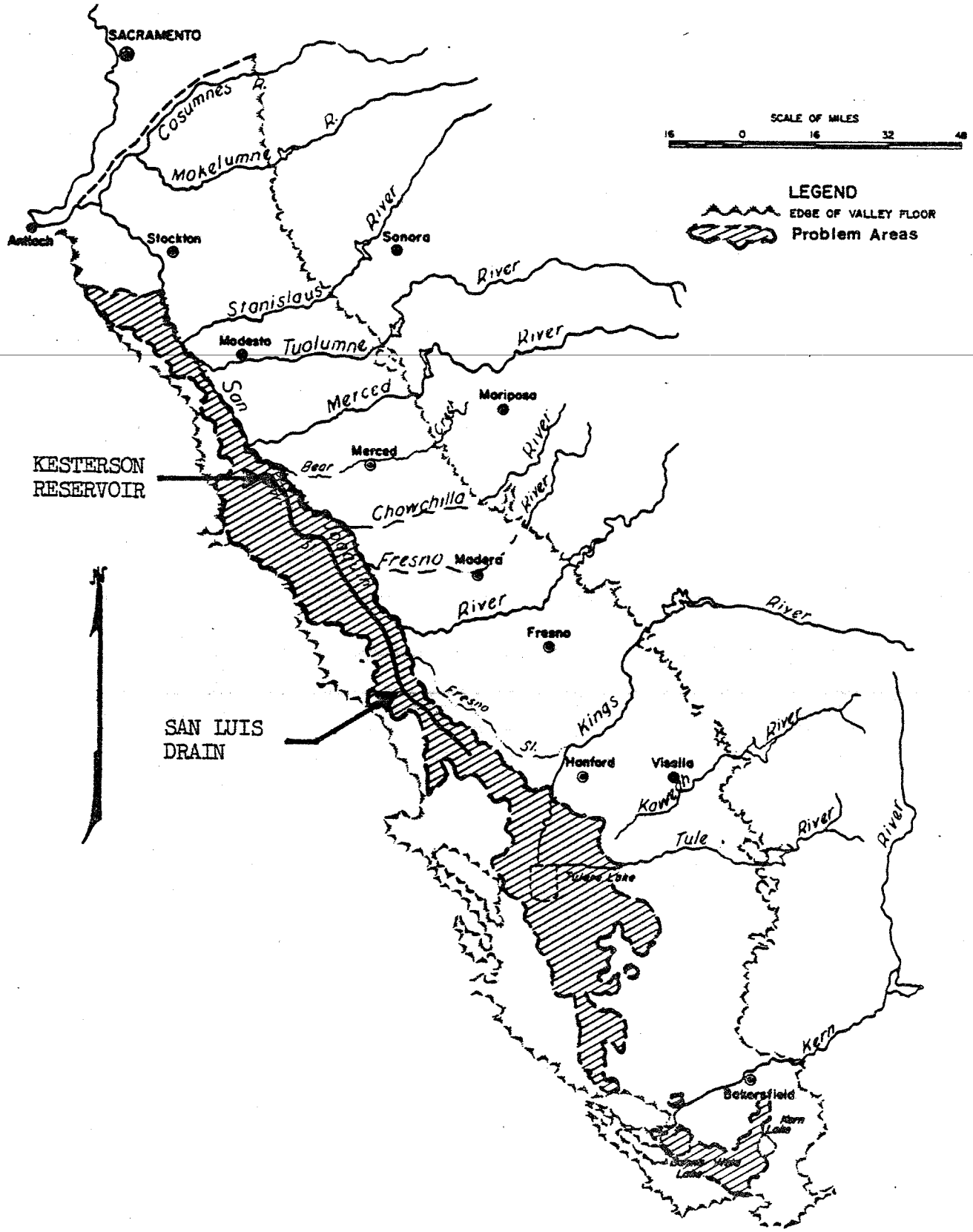


Figure 4.4-1. Present and Potential Drainage Problem Areas, San Joaquin Valley (California Department of Water Resources, in MacDonald and Wire, 1979).

The use of agricultural wastewater for power plant cooling has been widely discussed. A preliminary assessment by the CDWR (1972) estimated that from 3 to 9 nuclear or 4 to 10 fossil-fueled 1,000-MWe power plants could be served by wastewater available in the year 2000; the number of plants would depend upon water quality and the heat rises across the condensers.

Three specific projects using agricultural wastewater have been proposed (MacDonald and Wire, 1979). The now defunct San Joaquin Nuclear Project, which the Los Angeles Department of Water and Power wished to construct in Kern County, would have included a wastewater collection system and evaporation basins for disposal of excess wastewater and cooling tower and boiler blowdown. One of the arguments used in the ultimate defeat of the project in a Kern County referendum was that wastewater supplies would be insufficient at least during some years and that therefore fresh water would have to be diverted from present agricultural uses. LADWP signed a letter of intent with the TLDD to obtain wastewater as a backup supply for the San Joaquin Project. The possibility for an alternative site nearer to the TLDD service area remains open.

Another project under active consideration in 1979 was PG&E's Stanislaus Nuclear Project, alternative sites for which were identified in Merced and Madera Counties. (The site favored by PG&E is in Stanislaus County.) The USBR has indicated its willingness to supply the Merced or Madera sites with 6.2×10^7 m^3/yr (50,000 AF/yr) of wastewater from the San Luis Drain project, although an adequate supply would not be available until the late 1980's, and even then only if adequate on-farm collection systems are installed.

Finally, the CDWR considered using agricultural wastewater if the coal-fired power plant proposed to provide energy for the State Water Project (see Section 4.4.4) had been sited in the San Joaquin Valley (Struckmeyer, 1979).

MacDonald and Wire (1979) have identified some supply-related constraints upon the potential use of San Joaquin Valley wastewater for cooling. These include:

- Lack of long-term data on quantity and quality;
- Uncertainty about the installation of the thousands of

on-farm drainage systems upon which the master drain will ultimately depend;

- Need in many cases for storage reservoirs to compensate for unreliable supply; and

- Competing beneficial uses of wastewater, such as development of wetlands for wildlife habitat.

Imperial Valley

It is generally believed that geothermal energy will occupy center stage in any energy development scenario in the Imperial Valley. As noted in Section 4.4.3, flashed steam condensate will probably constitute a major source of cooling tower makeup. If local regulatory bodies insist upon 100-percent (or even 75-percent) reinjection of geothermally-derived fluids, then additional water sources will be necessary to compensate for the water lost to evaporation in the cooling towers. It will be the policy of the Imperial Irrigation District (IID) to allow the use of irrigation water for the first 75 MW of geothermal development, for a five-year demonstration period. Because the flashed steam condensate is of higher quality than the irrigation water, it is probably the latter which would be reinjected. Diversions of irrigation water from agriculture to energy production, however, may be expected to encounter considerable political opposition, as is discussed below in the case of the Palo Verde Valley. Thus agricultural wastewater, which has a value for further agriculture use, is being considered as a cooling water source. Indeed, the IID's policy is that wastewater should be used for the production phase (Macdonald and Wire, 1979).

The most likely sources of agricultural wastewater for cooling in the Imperial Valley are the tributaries to the Salton Sea. About 90 percent of the inflow to this sink is contributed by the Alamo, New and Whitewater Rivers. Figure 4.4-2 shows total surface water inflows during 1962-1975. Mean discharges for this period were 16.0 m^3/sec (408,000 acre-ft/year) and 24.7 m^3/sec (632,000 acre-ft/year), respectively for the New and Alamo Rivers. Flows vary relatively little from year to year, and, since irrigation is conducted year-round, there is little seasonal variation; thus these drains could provide a large, dependable supply of cooling water. The New River has been suggested as a source of cooling water for the proposed Heber Geothermal Project (MacDonald and Wire, 1979).

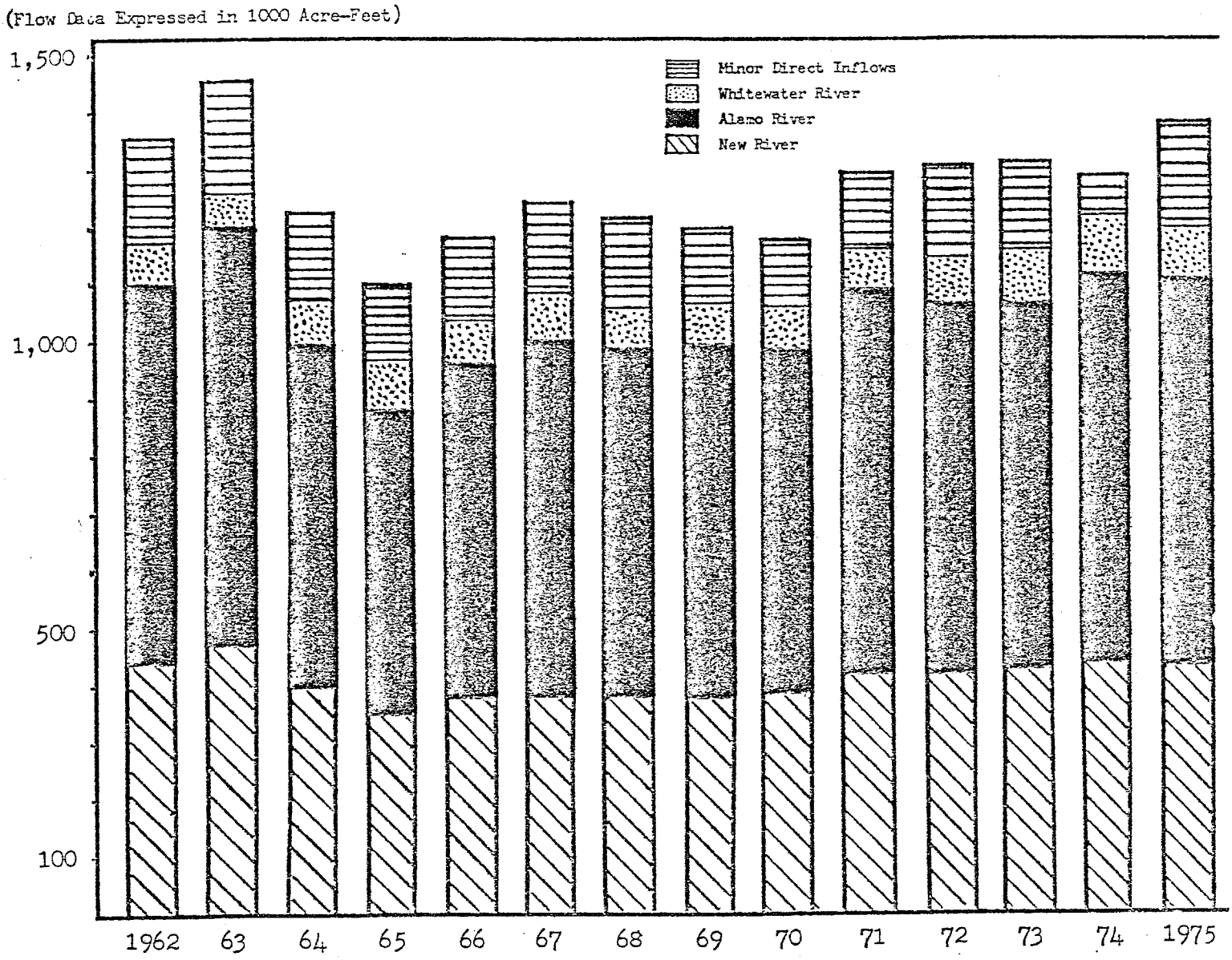


Figure 4.4-2. Salton Sea Surface Inflows, 1962-1975 (MacDonald and Wire, 1979).

Layton (1978) has identified some problems which could arise from the consumptive use of agricultural wastewater in the Imperial Valley:

- Effects upon salinity and elevation of the Salton Sea;
- Disposal of highly saline blowdown should subsurface injection not be possible;
- Change in wetland habitat at the mouths of the New and Alamo Rivers; and
- Salt drift from the cooling towers.

Diversion of wastewater for re-use in cooling should be seen as only one of several activities which could, individually or in combination, have an impact upon the Salton Sea. Inflows to the Sea may be reduced in any event by implementation of water conservation methods in the Imperial Valley and/or a reduction in California's use of Colorado River water. Thus any wastewater reuse in the Imperial Valley is likely to generate controversy.

Palo Verde Valley

A third potential source of agricultural wastewater is the return flow from the Palo Verde Valley to the Colorado River. The Palo Verde Irrigation District (PVID) diverts about 9.9×10^8 m^3/yr (800,000 AF/yr) from the Colorado River near Parker, Arizona to irrigate 37,000 Ha (91,400 acres) in Riverside and Imperial Counties (Anderson et al., 1977). Wastewaters are returned by the Palo Verde Outfall Drain (PVOD), which discharges to the Colorado near Palo Verde, California. The volume of return flows has decreased since the early 1960's from about 7.2×10^8 m^3/yr (580,000 AF/yr) to about 5.5×10^8 m^3/yr (450,000 AF/yr); the decline may be due to more efficient water use, increased evapotranspiration from greater crop coverage or a combination of factors. Return flows are markedly seasonal, with highs in August and lows in February, although minimum flows have traditionally greatly exceeded the cooling water requirements of even a large number of power plants.

A major constraint on the use of PVOD wastewater is the need to comply with various legal restrictions on consumptive use of Colorado River water. Cooling water consumptive use in excess of present net consumptive use would have to be compensated by either leaving an equivalent amount of water in the river or replacing it with fresh water. An arrangement of this sort

was proposed by San Diego Gas and Electric Company (SDG&E) to supply cooling water for the now defunct Sundesert Nuclear Project (SDGE, 1975).

Figure 4.4-3 shows the water budget proposed by SDG&E. The Metropolitan Water District (MWD) would, for financial recompense, have foregone diversion of 2.1×10^7 m^3/yr (17,000 AF/yr) at Parker Dam. For Unit 1, the PVID would have continued its normal diversion and water use, but SDG&E would have used 2.1×10^7 m^3/yr (17,000 AF/yr) of the drain water for cooling. Thus 2.1×10^7 m^3/yr less would be returned to the river, exactly compensating the 2.1×10^7 m^3/yr left in the river by the MWD. For Unit 2, SDG&E purchased 2,938 Ha (7,259 acres) of land and their attendant water rights in the PVID, and would have taken these lands out of production. This would have saved an additional 2.1×10^7 m^3/yr. By diverting 4.2×10^7 m^3/yr (34,000 AF/yr) less from the river at Parker Dam, the drain would have contained only 2.1×10^7 m^3/yr less than normal. SDG&E would have consumed 4.2×10^7 m^3/yr for Units 1 & 2, leaving the drain 6.3×10^7 m^3/yr (51,000 AF/yr) shy at the river outfall. This would have been exactly compensated by the water left in the river by the MWD (17,000 AF/yr) and the PVID (34,000 AF/yr).

MacDonald and Wire (1979) have described some of the political and institutional problems resulting from the Sundesert plan and other potential diversions of PVOD water for cooling. Since there is no legal distinction between "fresh" Colorado River water and its return flows, interests concerned with sustaining or increasing supplies of fresh water to Southern California look askance at replacement arrangements such as the one outlined above. In addition, agricultural interests were opposed to the retirement of the SDG&E-owned farmland from irrigated producton. MacDonald and Wire believe that "it is likely that any other proposal to devert Colorado River water for power plant cooling--fresh or return flow--would be met with similar opposition."

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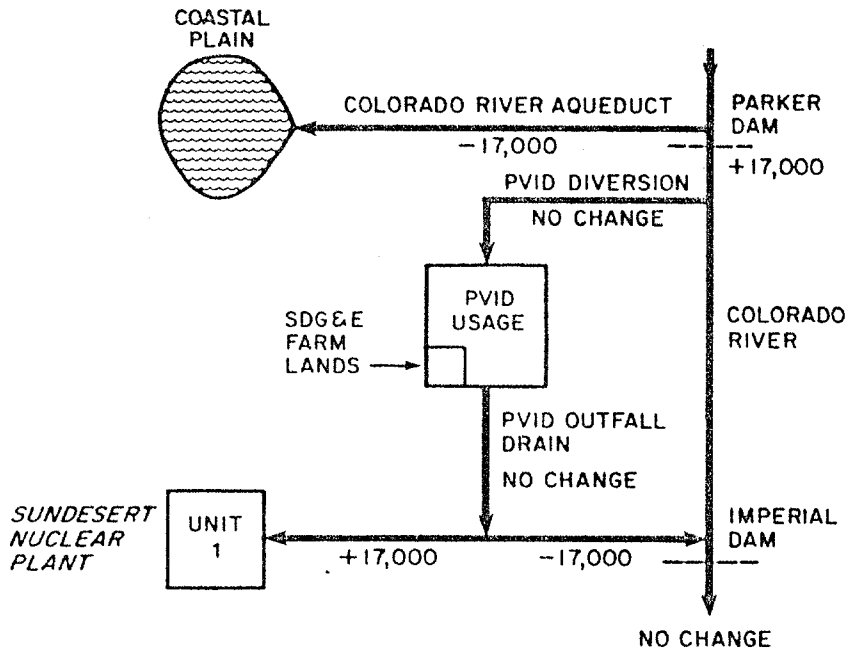
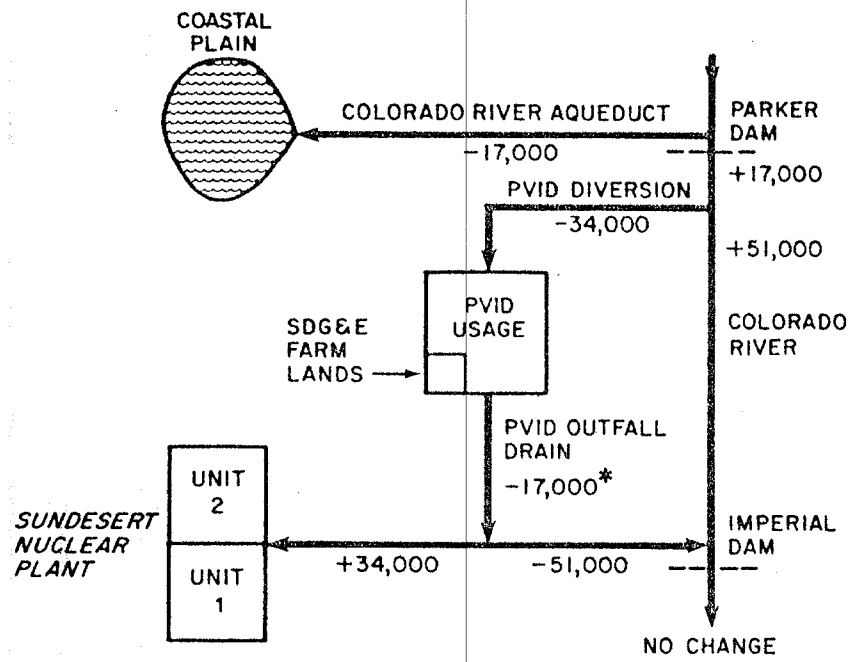


UNIT 1



UNITS 1 & 2

EXISTING FLOWS (ACRE-FT/YR, TYPICAL):

1. COLORADO RIVER AQUEDUCT · · · 1,200,000
2. COLORADO RIVER (PARKER DAM) · 6,800,000
3. PVID DIVERSION · · · · · · · 850,000
4. PVID OUTFALL · · · · · · · · 400,000
5. COLORADO RIVER (IMPERIAL DAM) · 6,000,000

NOTE:
ALL QUANTITIES REPRESENT CHANGES TO EXISTING FLOW IN ACRE-FT/YEAR

*NET EFFECT ON OUTFALL DRAIN FLOW FROM ASSUMED REDUCTIONS IN DIVERSIONS FROM RIVER AND DECREASED IRRIGATION OF COMPANY FARM LANDS

Figure. 4.4-3. Scheme for Using Palo Verde Irrigation District Return Flows for Power Plant Cooling (SDG&E, 1975).

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5.0

CHARACTERISTICS OF WASTEWATER-DERIVED MAKEUP (TASK 2)

The purpose of this task was to characterize the makeup water of cooling towers using "wastewater, low quality water, or other suspect water." In addition, the measures employed by cooling tower operators to handle upsets at wastewater pretreatment facilities were to be described. Although the wastewater presently used for cooling in California contains several types of constituents which may affect cooling tower operations or be of concern as water pollutants if discharged, we have focused our attention on those which may pose an air pollution problem. Since these constituents are rarely monitored, relatively little data on their prevalence were available before the present study. The findings of the previous research reviewed in this chapter were used to guide the design of our Task 3 and 4 field sampling programs.

5.1 MUNICIPAL WASTEWATER

In the following discussion it is necessary to distinguish among raw, primary-treated, secondary-treated and tertiary-treated municipal wastewater. In primary treatment, suspended solids and a small percentage of dissolved organic matter are removed from the wastewater, chiefly by mechanical means such as screening and settling. Secondary treatment generally uses biological processes (mainly activated sludge or trickling filters) to remove a high percentage of organic matter. Tertiary treatment consists of a wide variety of physical, chemical and biological processes to remove specific pollutants of concern, such as heavy metals, nutrients (nitrogen and phosphorus), or organics. Although the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) originally required secondary treatment of municipal wastewater by July 1977, many California municipalities failed to meet the deadline. As of May 1979, about 80 percent of the municipal wastewater considered to be available for power plant cooling in California, i.e., that water presently discharged to the Pacific Ocean, received only primary treatment (MacDonald, 1979). Furthermore, Section 301(h) of the Clean Water Act of 1977 (P.L. 95-217) allows a waiver of the secondary treatment required for ocean discharge if certain water quality and monitoring requirements are met (U.S. Senate, 1977). Primary-treated effluent, however, is generally of too low quality to be re-used in

recirculating cooling systems. This section, therefore, will focus upon the potential air pollutants present in raw wastewater (sewage), and the extent to which they are removed by secondary and tertiary treatment.

5.1.1 General Characteristics of Municipal Wastewater

The composition of sewage varies with locality and time (hour of the day, day of the week and month of the year). Sewage flow rates follow a somewhat diurnal pattern. The connection of storm drainage systems to sanitary sewer lines results in higher inorganic matter concentrations in the sewage and a greater influence of rainfall on flow patterns. Local conditions affecting the composition of sewage include the use of water softeners and garbage disposals and discharge of industrial wastes to the sanitary sewer.

Physical Characteristics

The physical characteristics of interest in this case include solids content, temperature, color and odor. Total solids in sewage include matter in solution, colloids, and floating and suspended particles. Medium strength sewage contains approximately 700 ppm of total solids, of which about 450 ppm are dissolved, 50 ppm are colloidal and 200 ppm are floating and suspended solids (Metcalf and Eddy, 1972). The color of sewage indicates its age; fresh sewage is grey, while septic or stale sewage darkens to black. Odors in sewage are generally due to decomposition of organic matter. The "rotten-eggs" odor of hydrogen sulfide is characteristic of septic or stale sewage. The temperature of wastewater is generally higher than that of the surrounding air and that of the local water supply. Depending upon the locality, the actual wastewater temperature will vary from 10 ^{o}C (50 ^{o}F) to 21 ^{o}C (70 ^{o}F).

Chemical Characteristics

The chemical constituents of municipal wastewater include organic matter, inorganic matter and gases. In medium-strength sewage, organic and inorganic contents are equal. About 36 percent of dissolved solids, 80 percent of colloidal matter, and 75 percent of suspended solids are organic in chemical composition.

Organic Constituents

The principal groups of organic chemicals in sewage are those found in foods, namely proteins, carbohydrates, fats, and oils. The relative

amounts of the principal groups are: proteins, 40 to 60 percent, carbohydrates, 25 to 50 percent, and fats and oils, 10 percent. In addition to these organic chemicals, sewage contains smaller quantities of synthetic organic substances such as surfactants, phenols, pesticides and other agricultural and industrial chemicals. Surfactants, primarily from synthetic detergents, can cause foaming problems in wastewater. Even very small amounts of phenols, primarily from industrial wastes, can cause a disagreeable taste in drinking water; their source in drinking water is from naturally or artificially recycled wastewater. Pesticides and other agricultural chemicals are not normal constituents of sewage but enter collection systems from surface runoff. Chlorinated hydrocarbons, which are of special concern in this study, are discussed in detail in Section 5.6.

The quantity of readily biodegradable organic matter (especially carbohydrates and proteins) in a wastewater sample is conventionally measured indirectly by the biochemical oxygen demand (BOD) test, in which the oxygen consumption of the sample over a five-day period is observed. Chemically oxidizable organic matter is measured by the chemical oxygen demand (COD) test. Organic matter, except for certain resistant organic compounds, is also detectable by the total organic carbon (TOC) test. For a medium-strength domestic sewage, BOD values are about 200 mg/L, COD about 500 mg/L and TOC about 200 mg/L.

Inorganic Constituents

Half of the matter in wastewater is inorganic in nature and yet wastewater is seldom treated for removal of inorganic constituents. Concentrations of minerals in surface waters are greatly increased by domestic and industrial use. Concentrations in subsequently generated wastewater are also increased by addition of highly mineralized ground water and natural evaporation. Inorganic constituents typically measured in wastewater include pH, chlorides, alkalinity, sulfur, heavy metals and other toxic elements such as arsenic and boron.

Of the inorganic constituents, toxic trace elements are of particular concern in this study. The presence and concentration of a given element will depend largely upon the extent to which industrial wastewater is combined with wastewater from domestic sources. Chromium is of special interest here, since it is often used as a corrosion inhibitor in cooling

tower systems, and has been shown to be emitted in measurable amounts from cooling towers (Taylor et al., 1979). A recent study of chromium in municipal sewage treatment plant effluent in Southern California showed that chromium concentrations were fairly consistent from plant to plant and that the less toxic Cr(III) species was two orders of magnitude higher in concentration than the more toxic Cr(VI) species (Jan and Young, 1978). Table 5.1-1 lists ranges of values measured, while Table 5.1-2 lists concentrations of other trace elements of concern in municipal wastewater in Southern California. Note that the two tables report results of grab samples and annual averages, respectively. Trace elements have also been monitored at Water Factory 21 (McCarty et al., 1978). Results from tests of systems operation are of interest, since they indicate the relative concentrations of certain substances in secondary- and tertiary-treated wastewater. Table 5.1-3 shows values measured during two different test periods. It is interesting to note that chromium concentrations in Water Factory 21's secondary effluent are an order of magnitude higher than those in the primary effluent of the plants listed in Table 5.1-1.

Gases associated with wastewater are primarily dissolved oxygen, hydrogen sulfide and methane. The amount of dissolved oxygen in wastewater is critical to biological treatment, which uses microbial respiration to degrade the organic matter in the sewage. Hydrogen sulfide, as previously noted, is a corrosive material in solution and also causes odors. Methane is the principal by-product of anaerobic digestion of sewage solids and has been used to sustain the endothermic digestion process itself. It is, however, highly combustible and can become contaminated with hydrogen sulfide.

Biological Characteristics

Because domestic wastewater is known to contain a variety of pathogenic microorganisms, the use of such water in cooling towers raises the possiblity of a public health impact through the emission and release of contaminated drift droplets. In this section we shall discuss the microbial content of raw and treated municipal wastewater, the viability of microorganisms entrained in drift, and the results of several previous aerosol measurement studies.

Domestic wastewater may be regarded as an ecosystem, the biotic components of which interact with each other and with the environment. Of special interest in water pollution control are those organisms which interact

Table 5.1-1

TYPICAL DISSOLVED CHROMIUM CONCENTRATIONS IN TREATED MUNICIPAL WASTEWATER IN SOUTHERN CALIFORNIA

(concentrations μg/ℓ)

Plant[a]	Level of Treatment	Cr(III)	Cr(VI)	Total[b]
Hyperion	Primary	45.1-52.3	0.21-0.38	53.0
Hyperion	Secondary	47.8-58.6	0.13-0.25	40.9-65.1
JWPCP	Primary	13.6-14.5	0.35-0.43	15.6-16.2
Orange County	Primary	15.3-16.4	0.10-0.12	13.9-14.2
San Diego	Primary	11.1-12.3	≤ 0.08	12.7
Oxnard	Primary	9.9-10.3	< 0.08	13.6

Source: Jan and Young, 1978

[a] Plant identified in Jan and Young, 1978

[b] Independently measured; not sum of Cr(III) and Cr(VI) values

Table 5.1-2

TRACE ELEMENT CONCENTRATIONS[a] IN MUNICIPAL WASTE DISCHARGES TO OCEAN OUTFALLS, SOUTHERN CALIFORNIA, 1977

(concentrations in μg/ℓ)

Element	Facility				
	Los Angeles County	L.A. Hyperion (5 Mile)	Orange County	San Diego	Ventura
Arsenic	9.1	10	ND[b]	13	5.8
Cadmium	2.5	20	44.1	17	9.0
Chromium	380	130	170	55	25
Copper	251	200	330	125	123
Lead	190	29.9	94.7	80	50
Mercury	0.99	2.1	1.5	1.0	1.3
Nickel	240	180	130	80	210
Silver	8.0	29.9	10	17	ND
Zinc	838	320	409	170	111

Source: Data from SCCWRP, 1978.

[a] Concentrations = Reported annual loading (mass)/Reported annual flow (volume)

[b] ND = No data

Table 5.1-3

TRACE ELEMENT CONCENTRATIONS IN SECONDARY- AND TERTIARY-TREATED MUNICIPAL WASTEWATER, WATER FACTORY 21, ORANGE COUNTY, CALIFORNIA

(concentrations in μg/ℓ)

	January-June 1976		October 1976-June 1977	
Element	Secondary Effluent	Final Effluent	Secondary Effluent	Final Effluent
Arsenic	2.5	1.1	3.3	2.4
Barium	81	33	81	31
Boron	NM[a]	0.63	1.0	NM
Cadmium	9	2.2	29	1.7
Chromium	192	48	154	26
Copper	285	27	266	32
Iron	179	45	325	66
Lead	40	26	19	5.3
Manganese	38	4.1	35	4.9
Mercury	1.2	4.9	9	6.7
Selenium	6.2	6.4	< 2.5	< 2.5
Silver	13	14	5.5	1.5
Zinc	300	124	380	162

Source: McCarty et al., 1978

[a] NM = Not Measured

with treatment processes. For example, heterotrophic bacteria aid in the decomposition and stabilization of organic matter during secondary wastewater treatment. The coliform group of bacteria are used as indicators of pollution in domestic wastewater. Algae in wastewater are primarily a nuisance to plant operators, especially in the event of an algal bloom, the rapid growth of a single species. Protozoa function in biological treatment to maintain a proper balance among the various groups of bacteria. The significant protozoan groups include amoebas, flagellates, free-swimming and stalked ciliates. The role of viruses in wastewater, aside from the spread of disease, is unknown. The presence of small animals such as rotifers and worms and aquatic plants can indicate progressive stabilization and lack of toxic substances in wastewater.

Most of the microbial species present in wastewater are not harmful to people coming into contact with either treated or untreated wastes. Several types of pathogens (disease-causing organisms) may be present, and it is to them that we turn our attention.

Pathogens in Domestic Wastewater. Table 5.1-4 lists the major pathogenic microorganisms found in raw domestic sewage and the disease conditions associated with these microbes. At present *Salmonella sp.*, which are responsible for acute gastroenteritis, and infectious hepatitis disease agents are of primary public health concern in relation to enteric disease spread via wastewater contaminants. Tuberculosis and leptospirosis agents are not major problems as wastewater pathogens (UCLA/ESE, 1979).

Approximately 100 human enteric viruses have been isolated from wastewater. Potentially pathogenic bacteria of significance in wastewater, in addition to those listed in Table 5.1-4, include genera of the Enterobacteriaceae, such as *Proteus* and *Klebsiella.* Other types of pathogens such as cestodes, nematodes, fungi and rickettsia may also be present (Westerdahl, 1977).

Because of the diversity of aquatic pathogens and the difficulties encountered in recovery and subsequent identification of these organisms, their presence is not normally detected and used to determine the biological quality of wastewater. Tests are usually done to detect, instead, the presence of non-pathogenic bactria that are normal inhabitants of the human intestine and are shed in feces and urine. This group of bacteria, the fecal

Table 5.1-4

MAJOR PATHOGENIC MICROORGANISMS IN DOMESTIC SEWAGE

Microorganism	Disease Condition
Bacteria	
Salmonella sp.	Typhoid fever, gastroenteritis
Shigella sp.	Bacillary dysentery
Vibrio cholerae	Cholera
Yersinia enterocolitica	Gastroenteritis
enteropathic *Escherichia coli*	Gastroenteritis
Pseudomonas aeruginosa	Infections associated with gastroenteritis
Viruses	
(Infections hepatitis particles)	Infectious hepatitis
Poliovirus	Poliomyelitis
Coxsackievirus	Aseptic meningitis
Echovirus	Aseptic meningitis
Adenovirus	Respiratory disease, eye infection
Reovirus	Respiratory disease, diarrhea
Protozoa	
Entamoeba histolytica	Amoebic dysentery
Giardia lamblia	Giardiasis

Sources: Acton et al., 1974 and UCLA/ESE, 1979.

coliforms and fecal streptococci, are fairly easy to recover and identify by standardized tests. Use of fecal bacteria as indicators of contamination by human pathogens is based upon three hypotheses, as stated by Pipes (1978):

"1. The more fecal material in the water the higher the densities of fecal indicator bacteria in the water.

2. There is a more or less stable ratio of the density of a particular fecal indicator to the density of a particular pathogen in sewage from a large population which is a function of the incidence of the disease in the user population.

3. The greater the density of the pathogens in the water being used the greater the incidence of the disease in the user population."

These hypotheses have never been verified; "at least, not in the sense of establishing the quantitative relationships they imply." One of the objectives of the cooling tower water testing program conducted under Task 4 was to shed light on this issue. (See Section 7.3.3)

It should be noted that the great majority of the sewage pathogens mentioned are enteric pathogens; i.e., they are harmful when ingested. Their potential health impact due to airborne dispersion is uncertain. Some wastewater pathogens, such as Klebsiella pneumonia and certain viruses, are associated with human respiratory disease. In addition, inhaled particulates greater than 5 m can be removed from the trachea by the ciliar escalator system and subsequently swallowed. Finally, it has been shown that aerosolized enteric bacteric can survive after deposition on the surfaces of edible plants (Cronholm, 1978).

The concentration of pathogens in raw wastewater is highly variable. The measured numbers of pathogens in a given wastewater can vary both with environmental conditions and with the measurement technique used. During epidemics, when a large portion of the population contributing to the sewage load have active cases of an enteric disease or act as carriers, pathogen concentrations can increase by two orders of magnitude. Concentrations of some viruses vary with the season of the year.

One reason for the wide variation in viral numbers reported in the literature is the lack of standardized procedures for quantifying viruses in wastewater. Quantification requires large sample size, some means of

concentrating virus particles and then analysis for identification (Westerdahl, 1977; Dryden et al., 1979). Techniques for rapid, efficient concentration of wastewater samples for viral analysis are not available for many types of viruses (Hetrick, 1979). Simple, rapid means of virus identification are also not always available. Particularly problematic is recovery of viruses from water containing appreciable suspended solids; prefiltration may remove virions adsorbed onto the particulate matter. Viruses in water are often in the form of clumps containing thousands of individual virus particles; certain analytical techniques identify these clumps as single infective units. Those viruses which cannot be cultured escape detection. The same problem can exist in bacterial quantification by membrane filter techniques.

Pathogens Surviving Wastewater Treatment Processes. The wastewater treatment sequence most likely to be used to provide cooling tower makeup, primary and secondary treatment followed by chlorination, normally removes about 99 percent of the fecal coliform indicator bacteria and up to 90 percent of the viruses in the original wastewater influent. Standard chlorination procedures (using chlorine gas or hypochlorous acid) are relatively ineffective against not only many viruses but also against certain bacterial pathogens, notably *Klebsiella* (Kinney et al., 1979). If organic material or ammonia is present, ineffective combined chlorine compounds such as chloroamines may form. Disinfection with chlorine dioxide (ClO_2), ozone, and ultraviolet radiation have proven more effective in many cases, especially against viruses, but these alternatives are not widely used in California. Also, the effectiveness of these agents decreases in the presence of suspended solids which may include virus particles, at concentrations typical of secondary effluent (Brigano et al., 1979).

Certain tertiary treatment processes can be effective in removing pathogens from secondary treatment effluent. As reported by Westerdahl (1977), flocculation methods can remove about 98 percent of the remaining virus, while lime treatment (which is commonly used for pretreatment of cooling tower makeup) has been shown to reduce poliovirus counts by up to 99.9 percent and reduce other viruses by at least 90 percent.

McCarty et al. (1978) provide information on the effects of tertiary treatment at Water Factory 21 upon viruses in the secondary-treated effluent

which is treated by that plant. Table 5.1-5 lists viruses identified in the input to the plant. Virus levels were lowest during the winter and highest during the summer. Lime treatment and clarification at pH above 11.3 resulted in 99.88- and 97.7-percent reduction, as measured by two different unconfirmed assay procedures.

Carcinogenicity/Mutagenicity of Municipal Wastewater

In vitro mutagenicity assays, such as the Ames test, have been performed recently upon raw and treated municipal wastewater. The Ames test (Ames et al., 1975) uses mutant strains of the bacterium *Salmonella typhimurium* that are unable to synthesize histidine, an essential amino acid. Ordinarily, these bacteria would be unable to grow in a histidine-free medium. However, if some substance added to the medium interacts in a certain way with the organisms' DNA, a significant percentage of the bacteria revert back to "normal" strains and are able to grow. The extent of growth (over and above spontaneous reversion) under these conditions is a measure of the mutagenicity of the added substance. In turn, it is hypothesized that a positive Ames test result indicates a good chance that the substance tested is carcinogenic. Because some substances must be chemically altered in the body before they are mutagenic, and because the test species lack the enzymes to catalyze this activation, enzymes (derived from liver cell homogenates) are sometimes added to the test medium.

Saxena et al. (1979) mention two caveats for interpreting results of *in vitro* mutagenicity tests on municipal wastewater. First, other substances in the water may inhibit or modify the mutagenic response, so that a linear dose-response curve may not always be seen. Also, due to its biological origin, municipal wastewater contains small quantities of histidine, which interferes with the Ames *Salmonella* assay by increasing the number of spontaneous revertants.

In Saxena et al.'s experiments, secondary and tertiary-treated wastewater samples and fractions thereof were given the Ames test. Both the influent to and effluent from the treatment plant showed significant mutagenesis of strains TA-100 and TA-1538 of *S. typhimurium*. The wastewater was toxic to other strains. Interestingly enough, the lime addition and recarbonation processes incorporated in the tertiary treatment appeared to promote synthesis of mutagenic compounds. These mutagens were substantially

Table 5.1-5
VIRUSES IDENTIFIED IN WATER FACTORY 21 INFLUENT

Virus	No. of Samples	Total No. of Plaques
Polio 2	16	27
Echo 1	8	17
Echo 7	7	16
Reo 2	5	12
Echo 14	7	8
Coxsackie B5	6	8
Polio 3	7	7
Echo 8	6	6
Reo	6	6
Unknown	5	5
Echo 12	3	5
Coxsackie B4	5	5
Coxsackie B2	3	4
Coxsackie B3	1	3
Echo 11	2	3
Reo 1	3	3
Coxsackie B6	2	2
Coxsackie A17	2	2
Coxsackie A13	1	1
Coxsackie A18	1	1
Coxsackie A20	1	1
Echo 3	1	1
Echo 9	1	1
Echo 19	1	1
Echo 25		
Polio 1	1	1
Total No. Samples With Virus	46	

Source: McCarty et al., 1978.

removed, however, by breakpoint chlorination and/or carbon filtration. Assays of different fractions of the wastewater gave mixed results, and Saxena et al. did not attempt to associate any compound or class of compounds in the water with mutagenesis.

Rappaport et al. (1979) tested water from five wastewater treatment plants in the San Francisco Bay area and one in the Los Angeles area for mutagenic activity. All plants but one incorporate primary and secondary treatment followed by some form of filtration and chlorination and/or ozonation. One secondary-treatment plant does not use post-secondary filtration, and one plant includes lime precipitation and recarbonation, which could be considered to be tertiary-treatment. All the plants receive municipal wastes, while four also process various forms of industrial waste. Primary-, secondary- and post-secondary treated samples were tested with *S. typhimurium* strains TA-98, TA-100, TA-1535 and TA-1537, with and without rat liver enzymes. Rappaport et al.'s findings may be summarized as follows:

- Three of the plants provided at least one sample that was definitely mutagenic.
- All but one of the positive responses required metabolic activation of the tested compounds.
- All but one of the positive responses (defined as at least twice the number of spontaneous reversions) were found in secondary- or post-secondary effluents.
- Parallel tests results imply that the organic loading of the effluent *per se* did not affect mutagenicity and that the possible presence of histidine had no influence.
- The activities of wastewater mutagens were low compared to those of known potent environmental mutagens, such as cigarette smoke, although certain basic extracts of the wastewater showed high mutagenicity.

Cumming et al. (1978) performed bacterial mutagenicity tests on samples from seven waste treatment plants in Colorado, New Jersey and Tennessee. All but one treated primarily residential wastes. In addition to *S. typhimurium* (strains TA-98, TA-100, TA-1535 and TA-1538), a strain of *Escherichia coli* which cannot synthesize the amino acid tryptophan was used. For five of the seven treatment plants no mutagenicity was observed in any

tester strain. The effluent from another plant proved to be weakly mutagenic to TA-1535, but nonmutagenic to the other tester organisms. However, in the remaining plant, a substantial, repeatable positive effect was observed when TA-1535 was exposed to primary-treated effluent. Furthermore, this positive response was observed only with chlorinated effluent. Attempts to isolate mutagenic substances in the effluent are underway (Cumming et al., 1978; Jolley et al., 1979).

Pathogens Associated With Cooling Water

Legionnaires' Disease Bacterium. In discussing pathogenic microorganisms which could be of significance in cooling tower drift, mention should be made of *Legionella pneumophila*, the "Legionnaires' Disease" bacterium (LDB), although it is not necessarily associated with municipal wastewater. LDB was first isolated from environmental samples in 1977, when it was recovered from the aerosols of water collected from a rooftop air conditioner cooling tower which was implicated in a Legionnaires' disease epidemic in Pontiac, Michigan. The organism is an aerobic gram-negative rod that grows at body temperature; at least four distinct serotypes are known to cause this disease (Sanford, 1979).

Legionnaires' Disease most commonly manifests itself as a lobar pneumonia. However, there are no physical symptoms specific to this disease to differentiate it from other types of pneumonia. The onset of symptoms occurs two to ten days after exposure to the organism. The attack rate of Legionnaires' Pneumonia is approximately two percent, depending on the susceptibility of the exposed population. Since 1976, about 3000 cases have been confirmed in the U.S.; however, the federal Centers for Disease Control (CDC) estimate that many times that number occur annually. Until recently the mortality rate was as high as 15 percent but improvements in early recognition and diagnosis have lowered this rate to approximately 4 percent.

Another manifestation of the disease which does not involve pneumonia is called Pontiac Fever. This is a self-limiting systemic disease characterized by a generalized malaise with few or no respiratory symptoms (Jones and Hebert, 1978).

Legionnaires' disease can occur in large common source outbreaks, in a series of cases, or in seemingly unrelated sporadic cases. Eickhoff (1979)

has noted a summer-fall seasonality in the occurrence of the disease, and a striking absence of person-to-person transmission. It is well established that the disease is spread primarily via the airborne route (Morris et al., 1979). More specifically, inhalation of aerosols generated from air treatment and air conditioning equipment has been implicated in several epidemics.

Evidence to date suggests that LDB is an opportunistic organism that is widespread in nature. It has been isolated in natural waters and soil samples unrelated to any disease outbreak (Fliermans et al., 1979). Tobin et al. (1981) have recovered specimens from a variety of water storage and distribution systems including cooling towers, storage tanks and shower taps. However, in 25 of the 42 samples there was no known association with disease. Circumstantial evidence for the presence of L. pneumophila in a steam turbine condenser has been reported (Fraser et al., 1979). Shands et al. (1981) identified potable water as a source of the disease in the 1980 outbreak at the Wadsworth Veterans Administration Hospital in Los Angeles, California.

The survivability of LDB in an aqueous environment may help to explain its presence in cooling towers. The organism has been shown in laboratory tests to survive in tap water for at least one year, although there was a marked decrease in the number of organisms. (Skaliy and McEachern 1979). Wang et al. (1979) have characterized its growth pattern as having a lag phase of less than 24 hours and a generation time of 3.8 hours. A plateau concentration of 2×10^7 organisms/ml persisted for 110 days.

Because LDB is ubiquitous in the environment, cooling towers may actually serve as a secondary amplification and delivery system of the bacillus. Sanford (1979) suggests that the temperature and humidity regimes of cooling towers may encourage persistence and growth of the organism. Fliermans (Anon., 1980) has shown that LDB can obtain all the nutrients they require from the blue green algae which are commonly found in cooling towers. In addition, the bacteria seem to derive special protection against dessication when airborne if they travel with algae. Lastly, it is possible for LDB in an aerosol to travel half a mile and remain infectious.

Amoebae. Other pathogenic organisms that have been isolated in natural and cooling waters are thermophilic pathogenic amoebae of the genera Naegleria and Acanthamoeba. These amoebae are recognized as the etiologic agents of primary meningoencephalitis (PAM), chronic meningoenciphalitis, and

conjunctivitis. Over 150 cases, most of which have been associated with swimming in heated waters, have occurred throughout the world (Tyndall, 1980). Naegleria, the more critical agent, enters the brain by invading the nasal mucosa. Although exposure to these amoebae may be widespread, clinical cases are few. However, many other cases of amoebic encephalitis may have gone undiagnosed because it is difficult to distinguish this disease from bacterial or viral encephalitis.

Pathogenic strains of Naegleria fowleri have been isolated from a natural lake and river in Florida, and from a man-made lake in Texas, all of which received wastewater from electric power plants. Tyndall et al. (1981) tested for the presence of pathogenic amoebae in cooling water from four northern and four southern and western power plants. A significantly higher proportion of the samples from these sites were positive for thermophilic amoebae, thermophilic Naegleria, and pathogenic Naegleria than were samples from unheated control sites. In the same study, 43 percent of the samples from heated waters at the Savannah River Nuclear Plant yielded Naegleria. Naegleria was also isolated in 30 of 39 samples of an electrical power plant which had received no biocidal treatment.

At present, little is actually known about the ecology and epidemiology of these pathogenic amoebae. The potential health risk from these organisms needs to be assessed to determine if specific control is warranted.

Fungi. In addition to LDB and pathogenic amoebae, several species of pathogenic fungi are also associated with heated waters. Both Mucorales and Aspergillus can cause massive pulmonary infections in susceptible individuals. Secondary infections of other organs such as the heart, eye, and brain can also occur. These fungi have been isolated from artificially-heated waters and associated effluents from the Savannnah River Nuclear Plant and from an electric power plant (Tyndall, 1980). However, in both cases the presence of the fungi appeared to remain within the confines of the plant.

Lastly, Buck (1980) has recovered isolates of the pathogenic yeast, Candida albicans from samples taken over a 12-month period from five wastewater treatment plants. This opportunistic organism is responsible for the condition Monilia, which is an infection of the skin and mucous membranes. This disease is most often observed in children and in persons whose resistance has been lowered through illness.

Buck found significant positive correlations between total and fecal coliforms, fecal streptococci and Pseudomonas aeruginosa and the presence of C. albicans in wastewater. The results of this study support the potential of C. albicans for possible application as an indicator of water quality.

5.1.2 Characteristics of Municipal Wastewater Presently Used For Cooling

City of Burbank

Burbank's Olive and Magnolia power plants receive their makeup water from the Burbank Water Reclamation Plant, which is owned and operated by the City of Burbank. The design capacity of the Burbank plant is 0.39 m^3/sec (9 mgd); the normal flow through the plant is approximately 0.26 to 0.31 m^3/sec (6 to 7 mgd). Effluent from the waste treatment plant is available to the power plants as it flows down the Burbank-Western channel to the Los Angeles River. The power plant accepts the wastewater from the treatment facility without special water quality requirements. In 1978-1979, about 0.085 m^3/sec (1.94 mgd) of the Water Reclamation Plant's treated effluent was used for cooling (Spencer, 1979).

Figure 5.1-1 is a schematic of the processes used at the Burbank Water Reclamation Plant. After primary clarification, the wastewater enters a complete-mix activated sludge system which uses diffused-air aeration. Following secondary clarification, the wastewater is pumped up to flow by gravity through a dual-media coal/sand filter. The filtered effluent is chlorinated and discharged to the Burbank-Western Channel. The Burbank plant does not have any facilities for solids treatment; solids collected are returned to the sewer line and handled at the Los Angeles Hyperion plant.

The Burbank treatment plant engineer reports regularly to the Regional Water Quality Control Board regarding certain chemical and biological characteristics of the plant's effluent in order to maintain the plant's discharge permit. Tests for various constituents such as heavy metals and total coliforms indicate the quality of the effluent being discharged. Figure 5.1-2 shows the cumulative frequency distributions for continuously monitored total residual chlorine and daily grab samples of total coliforms in the treatment plant effluent during June and September 1978. The median chlorine residual was about 5 and 7 ppm for the two months, respectively. Total coliform concentration distributions were similar. The Regional Board's

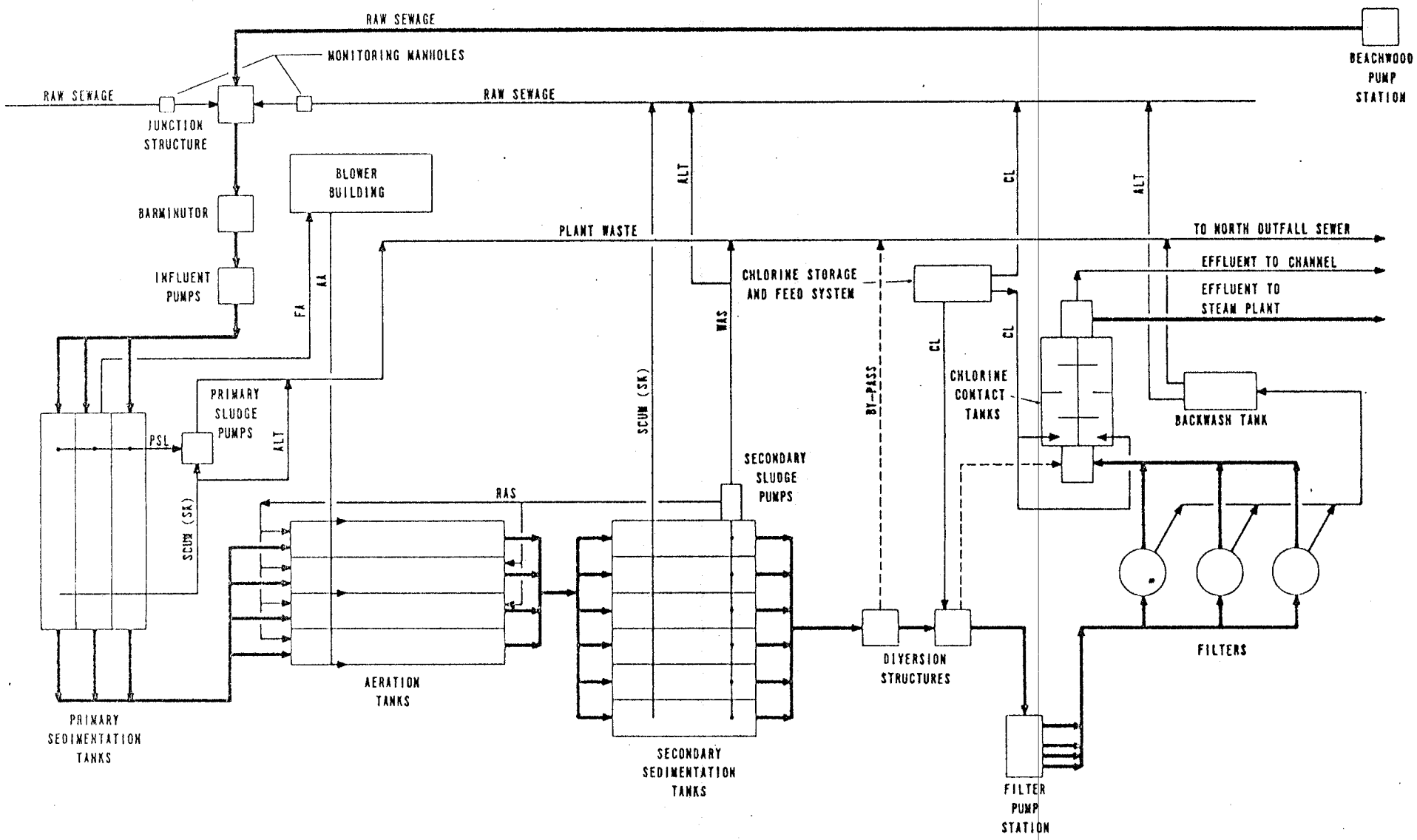
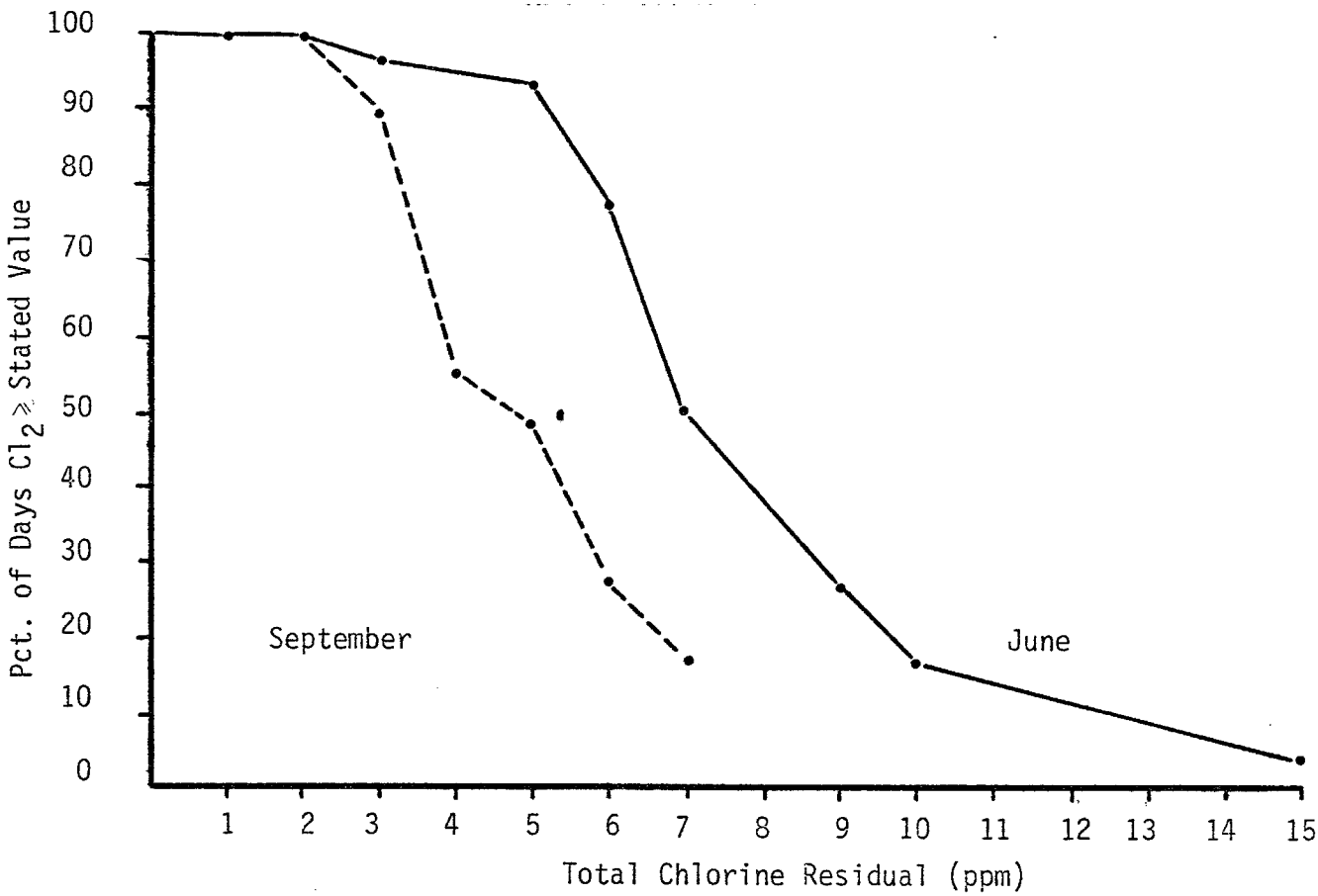


Figure 5.1-1. Process Flow Diagram, Burbank Water Reclamation Plant (Spencer, 1979).



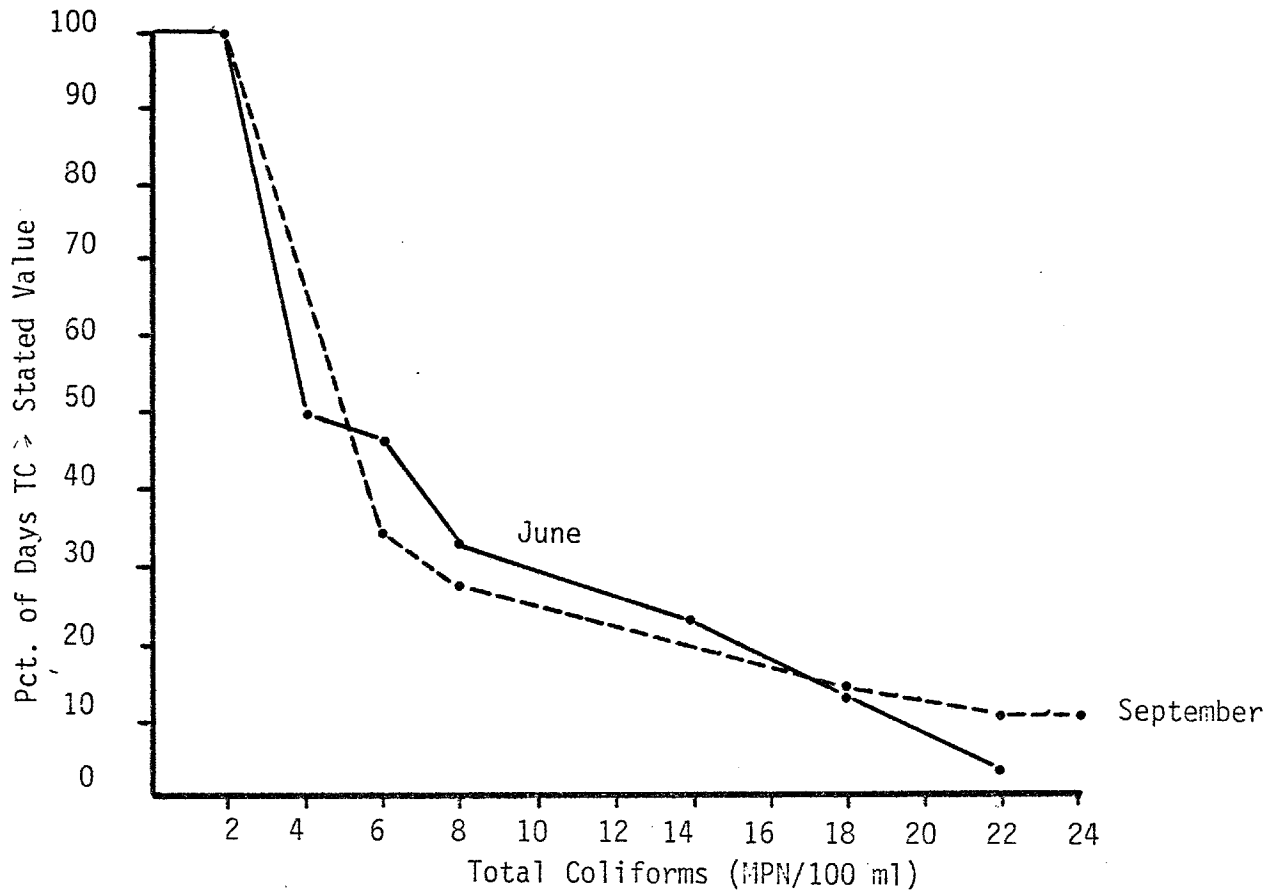


Figure 5.1-2. Cumulative Frequencies of Total Chlorine Residual and Total Coliform Values, Burbank Water Reclamation Plant Effluent, June and September 1978 (computed from data in James, 1978a and 1978b).

standard of 2.2 organisms/100 ml median value was met on most days, although in September, daily readings of 23, 33 and 49 most probable number (MPN)/100 ml were observed. (The MPN is a statistical estimate of the concentration of organisms in a water sample, based upon the results of an analysis of multiple portions drawn from that sample.) Table 5.1-6 shows concentrations of pollutants of interest in a 24-hour composite sample taken once in each month.

City of Glendale

The Glendale Public Service Department obtains cooling tower makeup water from the Los Angeles/Glendale Water Reclamation Plant, which is owned jointly by the Cities of Los Angeles and Glendale and operated by the City of Los Angeles Bureau of Sanitation. The treatment plant has a design capacity of 0.88 m^3/sec (20 mgd) but generally operates at a flow of about 0.44 m^3/sec (10 mgd). About 5 percent of the usual flow, or approximately 0.22 m^3/sec (0.5 mgd) was used by the Glendale Public Service Power Plant for cooling tower makeup water for the first six months of 1979.

The Los Angeles/Glendale plant is a secondary sewage treatment facility using a conventional activated sludge system. It is a part of and connects with the City of Los Angeles sewerage system, whose main plant is the Hyperion Treatment Plant in Playa del Rey. Figure 5.1-3 shows a process flow diagram for the Los Angeles/Glendale plant. After primary clarification, wastewater enters a plug-flow activated sludge unit with a diffused-air operation system. Following secondary clarification the wastewater is pumped 6.1 m (20 ft) up to flow by gravity through a dual media anthracite coal/sand filter. After chlorination, the filtered effluent enters an aerated supplemental chlorine contact pond. From the pond the effluent is discharged to the Los Angeles River. There are no facilities at Los Angeles/Glendale for solids removal. Solids collected are returned to the sewer line and treated at the Hyperion plant. The addition of a coagulation facility between the activated sludge unit and the dual media filter is planned. The new unit is designed to be able to use alum and liquid or dry polymer flocculants.

Laboratory tests are routinely run to determine certain chemical and biological characteristics of the Los Angeles/Glendale plant effluent in response to Los Angeles Regional Water Quality Control Board discharge permit requirements and to ensure proper plant operation. Total coliform tests are

Table 5.1-6

CITY OF BURBANK,CALIFORNIA MAKE-UP WATER COMPOSITION

(All concentrations in mg/l)

Constituent	24-hour Composite Sample June	24-hour Composite Sample September	Regional Water Quality Control Board Limit
Organics			
Chlorinated HC	< 0.05	< 0.05	0.006
Detergents (MBAS)	0.60	0.28	0.50
Phenols	0.007	< 0.001	0.20
Inorganic Ions			
Chloride	119	104	150
Cyanide	0.052	0.006	0.20
Nitrite & Nitrate	5.61	8.8	8
Sodium	5.0	4.6	--
Sulfate	150	126	300
Trace Elements			
Arsenic	0.005	0.005	0.10
Boron	1.08	1.02	1.5
Cadmium	0.004	0.006	0.01
Fluoride	0.52	0.50	1.20
Lead	0.05	0.017	0.05
Mercury	0.0004	0.0002	0.005
Nickel	0.013	0.047	0.20
Selenium	0.004	0.005	0.01
Silver	0.002	0.005	0.05
Zinc	0.054	0.067	5.0

Source: City of Burbank Public Works Department (James, 1978a and 1978b).

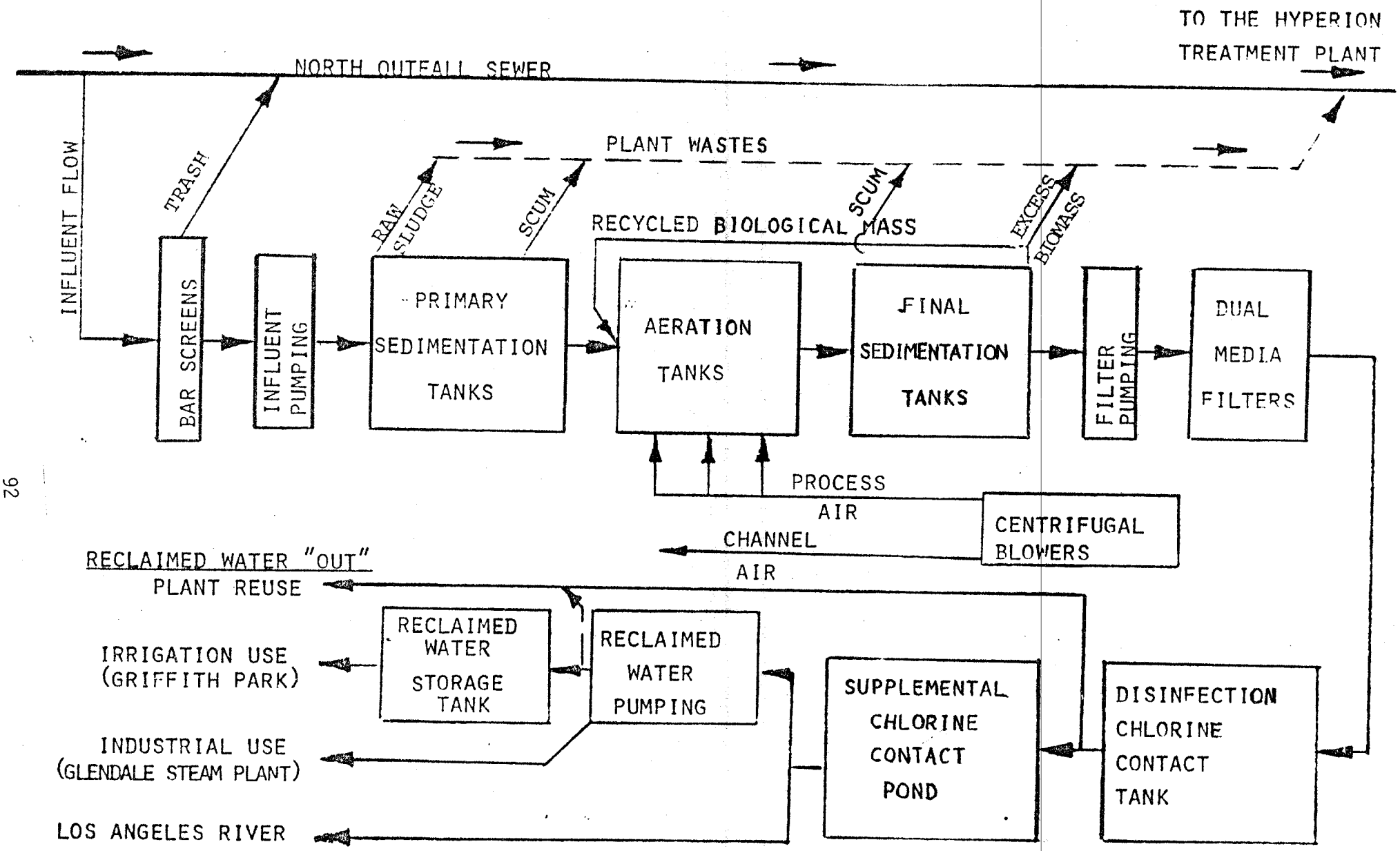


Figure 5.1-3. Process Flow Diagram, Los Angeles/Glendale Water Reclamation Plant (Betz, 1979).

run daily at the plant. The discharge limit is 2.2/100 ml. When the Los Angeles/Glendale plant was supplying reclaimed wastewater to the power plant, fecal coliform tests were done; in that case the limit was 23/100 ml. Physical and chemical analyses for consituents such as total dissolved solids (TDS), heavy metals and chlorinated hydrocarbons are done quarterly at the Hyperion
plant laboratory.

Table 5.1-7 shows chlorine levels and indicator bacteria levels measured in the Los Angeles/Glendale plant's effluent in 1978. During January through April and July and August there was no effluent discharge; hence no measurements were made (Langley, 1980). According to the Los Angeles City Department of Public Works, values reported here and in the next table are representative of effluent water quality in 1979 (Betz, 1979). Table 5.1-8 shows results of daily, monthly or weekly sampling for various wastewater parameters of interest.

In comparing data from Burbank and Glendale, it can be seen that trace effluent concentrations were quite similar during comparable reporting periods (June and September, 1978), although fluoride, nickel and zinc levels were higher in the Los Angeles/Glendale effluent. Concentrations of organics and major inorganics were also similar.

5.1.3 Measures For Handling Upset Conditions at Wastewater Treatment Plants

Use of untreated or primary-treated wastewater in the Burbank or Glendale power plant cooling systems would create numerous operational difficulties and could result in increased releases of pathogens into the air. Power plant and wastewater treatment plant operators were contacted to ascertain the methods used to avert these problems should a shutdown of the wastewater treatment plant be necessary.

Burbank

Upsets serious enough to interrupt delivery of reclaimed wastewater to the Olive and Magnolia plants occur at most three times per year. The most common cause for upsets is loading of industrial wastes which are toxic to the activated sludge bacteria. Power failures, such as the one following the 1971 Sylmar earthquake, can also result in water reclamation plant

Table 5.1-7

TOTAL CHLORINE RESIDUALS AND INDICATOR BACTERIA IN LOS ANGELES-GLENDALE WATER RECLAMATION PLANT EFFLUENT, 1978[a]

Month[b]	Total Chlorine Residual (mg/l)		Total Coliform (MPN/100 ml)		Fecal Coliform (MPN/100 ml)		
	Average	Maximum	Arithmetic Average	Maximum 7-Day Median	Arithmetic Average	Maximum	Minimum
May	ID[c]	1.6	< 2.2	< 2.2	ID	< 2.2	< 2.2
June	0.1	1.0	< 2.2	< 2.2	< 2.2	< 2.2	< 2.2
September	0.4	1.1	2.2	< 2.2	< 2.2	9.2	< 2.2
October	0.1	0.4	3.3	5.1	< 2.2	2.2	< 2.2
November	0.3	0.3	2.2	< 2.2	< 2.2	2.2	< 2.2
December	ID	ID	ID	< 2.2	ID	ID	ID

Source: City of Los Angeles, 1979.

[a] Samples taken daily

[b] No effluent January-April and July-August (Langley, 1980)

[c] ID = Insufficient data

Table 5.1-8

LOS ANGELES-GLENDALE WATER RECLAMATION PLANT EFFLUENT CHARACTERISTICS, 1978

Constituent	Sampling Freq.[a]	Units	One Time or Average Concentration					
			May	Jun	Sep	Oct	Nov	Dec
Organics								
Chlorinated HC	M	ng/ℓ	870	NM[b]	NM	50	140	150
Detergents (MBAS)	W	μg/ℓ	380	400	390	300	200	180
PCBs	M	ng/ℓ	480	NM	NM	ND[c]	ND	ND
Phenols	M	μg/ℓ	NM	0	10	10	10	0
Inorganic Ions								
Chloride	W	mg/ℓ	95	108	103	110	106	108
Cyanide	M	μg/ℓ	NM	0	30	60	30	40
Nitrite & Nitrate	D	μg/ℓ	1300	900	3400	6100	5300	3000
Sulfate	W	mg/ℓ	132	154	129	130	141	128

Table 5.1-8
(continued)

Constituent	Sampling Freq.[a]	Units	One Time or Average Concentration					
			May	Jun	Sep	Oct	Nov	Dec
Trace Elements								
Arsenic	M	µg/ℓ	10	10	10	10	10	20
Boron	M	µg/ℓ	NM	NM	230	920	1150	1070
Cadmium	M	µg/ℓ	10	10	10	40	20	30
Chromium	M	µg/ℓ	10	10	50	40	40	30
Copper	M	µg/ℓ	20	20	20	30	20	30
Fluoride	M	µg/ℓ	NM	1200	1000	1000	960	910
Lead	M	µg/ℓ	40	40	20	30	40	60
Mercury	M	ng/ℓ	NM	400	1000	100	100	1000
Nickel	M	µg/ℓ	390	400	220	380	300	440
Selenium	M	µg/ℓ	NM	10	0	0	20	0
Silver	M	µg/ℓ	60	0	10	0	10	10
Zinc	M	µg/ℓ	150	110	170	200	420	210

Source: City of Los Angeles, 1979.

[a] M = monthly, W = weekly, D = daily

[b] NM = not measured

[c] ND = none detected (<10 ng/ℓ

shutdown. If it is observed that harmful wastes are entering the treatment plant, flow is diverted to the Los Angeles/Glendale Water Reclamation Plant, and from the latter to the Los Angeles Hyperion plant. The Burbank Public Service Department is notified, and an auxiliary supply of well water is used for cooling tower makeup.

Glendale

The influent to the Los Angeles/Glendale Water Reclamation Plant is monitored every four hours for toxicants, specifically cyanide, copper and chromium. If any of these substances is found in concentrations high enough to be harmful to the operation of the activated sludge unit, the flow to the plant is shut off and diverted to the Los Angeles Hyperion plant, which is better equipped to handle such wastes. In addition the Los Angeles/Glendale plant has a 10,900-m^3 (2.7-acre) supplemental storage pond with a 21,000-m^3 (5.5 million gallons) capacity, which can provide a continuous source of water to small reclaimed wastewater users during periods of necessary diversion to the Hyperion plant.

According to its operators, the City of Glendale Public Service Department's power plant can switch within ten minutes from wastewater to well water use (Kendall, 1979). Having a 189-m^3 (50,000 gal) storage supply of well water, the plant has roughly an hour to react upon notification by the Los Angeles/Glendale Water Reclamation Plant that a problem exists. Upsets at the water treatment plant occurred four times during the six months in which the power station was on wastewater, and in all cases the switchover was made successfully.

5.1.4 Characteristics of Municipal Wastewater Proposed For Use As Cooling Tower Makeup

Two proposals to use reclaimed municipal wastewater for cooling tower makeup were described in Section 4.4.1. As of this writing neither the Chevron U.S.A. nor the Contra Costa County project had been initiated.

Chevron U.S.A., El Segundo

Makeup water for the test cooling tower at the Chevron U.S.A. Refinery would be obtained from the Los Angeles Hyperion treatment plant. Toxic metal concentrations in this water (secondary-treated effluent) were summarized in Tables 5.1-1 and 5.1-2. In addition, the secondary-treated

effluent contains an average of 2.4 ppb of total identifiable chlorinated hydrocarbons (SCCWRP, 1978).

Contra Costa County

Because the new water softening facility built by the Contra Costa County Water District (CCCWD) has not yet been put into operation, the characteristics of the makeup water to be provided to participating cooling tower users can only be inferred from predictions of delivered water quality (J. Montgomerey, 1974; Jones and Stokes, 1975). Unfortunately for the present study, data are available only for those constituents which could affect cooling tower operation. Of these, only biocides are likely to be of interest in an air pollution assessment.

5.1.5 Summary: Constituents of Concern as Potential Air Pollutants

Of the types of reclaimed water under consideration in this study, municipal wastewater is unique in that it contains pathogenic microorganisms which, if released in significant amounts through cooling tower drift, could pose a public health risk. Measurements made under Task 3 and 4 have helped to quantify these emissions and put them into proper perspective. In addition to known pathogens, municipal wastewater has been found to contain as yet unidentified substances which produce positive responses in *in vitro* bacterial mutagenicity assays. This type of wastewater may also contain a wide variety of toxic substances originating in industrial discharges to the sewer system. Finally, recirculating water in cooling towers using reclaimed municipal wastewater is apt to contain potentially important constituents which are common to cooling towers in general; these may include *Legionella pneumophila* and other soil microorganisms, chromium-based corrosion inhibitors, and halogenated organic compounds formed by the interaction of biocides and organic precursors in the makeup water.

5.2 INDUSTRIAL PROCESS WASTEWATER

The composition of industrial process water presently used or under consideration for uses as cooling tower makeup in California is as varied as the industrial processes themselves. As reported in Section 4.4.2, our industrial cooling tower survey showed that the present and near-term future users of process water for makeup include producers of:

- Wine
- Industrial inorganic chemicals
- Refined petroleum products
- Tires and inner tubes
- Organic fibers
- Plastics materials and resins, and
- Steel

Potential pollutants contained in the process water from these industries would enter the air through volatilization of hydrogen sulfide or low molecular-weight organics or through drift emissions. In addition there is a potential for contamination of recirculating water (whatever its origin) by leakage through the condensers of the fluids to be cooled. Our survey found that chemical process water, petroleum fractions, ammonia, inorganic and organic gases, and solvents were the condenser fluids in about 27 percent of the towers accounted for. Unfortunately extremely little is known about the chemical composition of the process waters presently used or under consideration for use in California.

5.2.1 Characteristics of Industrial Process Water Presently Used For Cooling in California

Industrial Plant No. 1

Several types of process water are used for cooling tower makeup at Industrial Plant No. 1. According to the refinery operators, the composition of the water varies according to its history of use, and to the types of chemicals added to it to permit continued re-use. Oil-contaminated water is treated by API separation, gas flotation, and dilution. Among the constituents of potential air pollution concern are hydrogen sulfide, various hydrocarbons and, in the case of a tower associated with a sulfur facility, diethanolamine (DEA). The plant operators monitor the water only for H_2S and conventional water pollutants.

Industrial Plant No. 2

As reported in Section 4.3.2, Industrial Plant No. 2 uses an extensive, complex system of water treatment, recycling, and cooling. A number of contaminants have been identified as "problem constituents," in the sense that they must be controlled to permit economical re-use or to avoid maintenance problems with the cooling towers. These include oil, grease, salts and a variety of particulate substances. No information on constituents of potential air pollution interest was available before we performed the tests under Tasks 3 and 4. Indeed, water quality at the facility is not regularly monitored for any parameters, according to the operators.

5.2.2 Characteristics of Industrial Process Water Being Considered For Cooling in California

McClellan Air Force Base, Sacramento County

Plans to re-use tertiary-treated domestic and industrial effluent for cooling and other on-site uses at McClellan AFB were discussed in Section 4.4.2. Tertiary-treatment will include dual mixed-media pressure filtration and alum and polyelectrolyte flocculation to remove phosphorus. From an operating standpoint, the major constituents of concern are phosphorus and silica. Lime treatment and flocculation is expected to reduce these to about 0.5 and 49 mg/L, respectively, although the Si concentration will still limit recirculation to about 3 cycles. Table 5.2-1 lists the expected concentrations of various constituents in the reclaimed water.

Zinc dichromate, maintained at about 25 mg/L, is expected to be used for corrosion control. The water will also be chlorinated for control of biological growths. Due to the presence of ammonia and organic compounds in the makeup water, chlorine demand will be somewhat higher than if fresh water were used. SCS analyzed the makeup for PCB and pesticides and found none; however, there is a possiblity that other organic compounds of interest may enter the system as the result of on-site industrial uses. The nature of these contaminants and their potential for survival through the industrial waste treatment plant is unknown (Schmidt, 1979).

Other Projects

We have at this writing no information on the characteristics of industrial process water considered for near-term future re-use at other

Table 5.2-1

EXPECTED CHARACTERISTICS OF MAKEUP WATER QUALITY
MC CLELLAN AIR FORCE BASE

Parameter	Treated Domestic Effluent	Treated Industrial Effluent	Blended Effluent For Re-Use
Trace Elements (ppb)			
Arsenic	4	2	3
Boron	590	200	460
Cadmium	2	10	5
Chromium	38	50	42
Copper	20	10	17
Fluorine	500	570	520
Lead	36	10	27
Mercury	1	1	1
Selenium	2	2	2
Zinc	53	10	39
Other Inorganics			
TDS (ppm)	359	1272	663
Nitrate (ppm)	5	4	4.67
Cyanide (ppb)	98	50	82
Phenol (ppb)	10	2	7
Total Coliforms (No./100 ml)	< 20	< 20	< 20

Source: Schmidt, 1979.

facilities in California. In most cases, when re-use as cooling tower makeup is contemplated, only those parameters which could affect cooling tower performance--hardness, nutrient concentrations, salt concentrations, and pH--are considered.

5.2.3 Summary: Constituents of Concern as Potential Air Pollutants

Given the wide variety of industrial process water types and the paucity of measurement data for actual cooling tower re-use, it is impossible to generalize about the composition of these potential makeup water sources. Our Task 3 and 4 measurements identified and quantified pollutants of concern at two industrial plants. As will be discussed in Chapters 6 and 7, we identified a variety of organic compounds in the makeup water of one cooling tower, and found negligible levels of pollutants of concern in the other.

5.3 GEOTHERMAL FLUID

5.3.1 Characteristics of Geothermal Fluid Presently Used for Cooling

As described in Section 4.3.3, the only present commercial-scale use of geothermal fluid for cooling is at The Geysers electrical power plant complex in Sonoma and Lake Counties, where condensed geothermal steam serves as makeup to 13 cooling towers. Components of the steam may be emitted to the atmosphere in two principal ways (Altshuler, 1978). First, in Units 1 through 12, noncondensible gases such as hydrogen sulfide (H_2S) are drawn off the condensers by off-gas ejectors and ducted to the cooling towers, where they are emitted (after dilution and some scrubbing) to the atmosphere. Second, steam constituents which remain in the condensate may be emitted in cooling tower drift droplets. It should be noted that some compounds which are not present in the original steam are formed as byproducts of H_2S abatement processes and thus become potential drift constituents. Our review of makeup water characteristics therefore focuses on the geothermal steam and the circulating water.

Characteristics of Steam

The geothermal reservoir at The Geysers contains steam at initial temperature and pressure of 250 ^{o}C and 32 bars (464 psi), respectively (Robertson et al., 1977). The steam travels to wells through fractures in Franciscan graywacke, a type of sandstone. Pressure and temperature at the turbine are 7.9 bars (115 psi) and 180 ^{o}C, respectively. Through contact with

the rock, the steam picks up a variety of particulate compounds. Of special interest in the present study are the noncondensible gases, such as H_2S and ammonia (NH_3), and potentially toxic trace elements such as arsenic (As), boron (B) and mercury (Hg). Table 5.3-1 shows concentrations of various constituents in steam from 61 producing wells measured in 1972-1974.

More recent data on NH_3 and B in steam from Units 1 through 11 are summarized in Table 5.3-2. Analysis of monthly data shows that the concentrations of these constituents vary significantly among well fields. Also, for most of the wells, boron concentrations in 1977 were considerably higher than those reported for 1972-1974.

Mercury in geothermal steam at The Geysers has been measured more recently by Robertson et al. (1977), whose results are reported in Table 5.3-3. These values are roughly three orders of magnitude higher than those reported by Pacific Gas and Electric Company (PG&E) in Table 5.3-1. The main reason for the discrepancy is that PG&E condensed the steam, filtered the condensate and measured the particulate mercury collected by the filters, while Robertson et al. collected mercury directly from the vapor on selective adsorbents (Robertson, 1980). Since almost all of the mercury is in the form of volatile Hg^0 or soluble Hg^{2+}, only a tiny fraction would have been collected by PG&E's method.

Table 5.3-4 summarizes composition data for steam from wells serving Units 11, 12 and 17, as measured by Union Oil Company (Enriquez, 1978). Copper, lead, silicon and zinc were not detected. Noncondensible gas concentrations are slightly higher than those in producing wells, while boron concentrations are lower. Finally, Table 5.3-5 shows elements analyzed for in geothermal steam but <u>not</u> detected.

<u>Constituents in Circulating Water</u>

After passing through the turbine, geothermal steam enters a direct contact condenser where it is mixed with a relatively large volume of cool circulating water and, as noted above, noncondensible gases are removed. The condensate, which contains dissolved and suspended mineral and some dissolved gases, is pumped to a cooling tower. A number of events which can significantly alter condensate commposition take place in the tower:

Table 5.3-1

NONCONDENSIBLE GASES AND SOLIDS IN STEAM FROM PRODUCING WELLS AT THE GEYSERS POWER PLANT, 1972-1974

	Concentrations (ppmw unless otherwise noted)		
Constituent	Low	High	Average
Carbon dioxide	290	30600	3260
Hydrogen sulfide	5	1600	222
Methane	13	1447	194
Ammonia	9.4	1060	194
Nitrogen	6	638	52
Hydrogen	11	218	56
Ethane	3	19	a
Arsenic	0.002	0.050	0.019
Boron	2.1	39.0	16.0
Mercury[b]	0.31	18	5.0
Radon - 222[c]	5.0	30.5	16.2

Source: Griffin and McCluer, 1974

[a]Negligible.

[b]Concentration in ppbw; values reported may be low by a factor of 1000; See text.

[c]Concentration in nCi/kg of steam.

Table 5.3-2

SUMMARY OF MONTHLY MEASUREMENTS OF AMMONIA AND BORON CONCENTRATIONS IN STEAM AT THE GEYSERS, 1977
(Concentrations in ppmw)

	Ammonia[a]			Boron[b]		
Unit	Low	High	Mean	Low	High	Mean
1	42	160	117	6	9.9	8.2
2	39	120	86	18	64	28.5
3	106	400	265	26	42	27.3
4	68.5	290	158	42	120	67.3
5	180	300	222	48	74	58.2
6	67	300	226	48	110	78.4
7	66	200	139	36	44	38.8
8	48	120	86	39	77	60.4
9	7	27	15	10	78	38.8
10	7	115	28	12	18	16.0
11	53	230	170	17	32	21.9

Source: Calculated from PGE data cited in Rosen and Molenkamp, 1977.

[a]January-July

[b]March-July

Table 5.3-3

MERCURY IN GEOTHERMAL STEAM AT THE GEYSERS

Unit	Incoming Steam Concentration ng/l (ppbw)[a]	Incoming Steam Pct. Hg^0 /Pct. Hg^{2+}	Ejector Off-gas Concentration ng/l (ppbw)[a]	Ejector Off-gas Pct. Hg^0 /Pct. Hg^{2+}
3	5800(1000)	72/23	<10(<2)	b
4	>4000(>690)	b	>400(70)	84/<16
7	2500(430)	79/21	65(11)	88/12
8	1800(310)	78/22	50(9)	b
11	1800(310)	b	83(14)	b

Source: Data from Robertson et al., 1977.

[a]ppbw = parks per billion by wt of steam, assuming steam MW of 26.74, 180°C, 7.9 bars.

[b]Not reported.

Table 5.3-4

NONCONDENSIBLE GASES AND SOLIDS IN EXPLORATORY WELLS AT THE GEYSERS

(Mean concentrations in ppmw)

Constituent	Unit 11	Unit 12	Unit 17	Other
Carbon dioxide	6,309	NR[c]	10,068	NR
Hydrogen sulfide	340	148	443	160
Ammonia	199	NR	420	NR
Arsenic	a	NR	NR	NR
Boron	1.5	NR	0.5	NR
Mercury	b	NR	NR	NR

Source: Calculated from data in Enriquez, 1978.

[a]Single value of <0.005 ppmw reported.

[b]Single value of 0.0012 ppmw reported

[c]NR = Not Reported

Table 5.3-5

ELEMENTS ANALYZED FOR IN GEOTHERMAL STEAM AND COOLING WATERS BUT NOT DETECTED

(Limit of detectionn was 0.1 ppm unless otherwise noted)

Actinium	Palladium
Antimony	Phosphorus
Barium	Platinum
Beryllium[a]	Polonium
Bismuth	Potassium
Bromine[b]	Protactinium
Cadmium	Radium
Cerium	Rhenium
Chlorine[b]	Rhodium
Cobalt	Ruthenium
Gadolinium	Scandium
Gallium	Selenium
Germanium	Silver
Gold	Tantalum
Hafnium	Thallium
Iodine[b]	Thorium[c]
Iridium	Thulium
Lanthanum	Tin
Lithium	Tungsten
Lutetium	Uranium
Molybdenum	Vanadium
Niobium	Yttrium
Osmium	Zirconium

Source: Altshuler, 1978.

[a]Limit of detection = 20 ppb
[b]Limit of detection = 1 ppm
[c]Limit of detection = 180 ppm

- Volatile compounds remaining in the condensate are transferred from water to air;

- Noncondensible gases removed from the condenser are injected into the cooling tower air supply; a portion of these may dissolve in the falling cooling water;

- Entering gases and constituents already in the water react to form compounds, such as sulfate, which do not occur in the original steam; and

- H_2S abatement systems introduce new chemicals and catalyze reactions among pre-existing constituents.

Hydrogen sulfide abatement systems merit special attention due to their potential for directly and indirectly altering air pollutant emissions. Units 3 through 6, 11 and 12 use an iron catalyst system, while future units will use the Stretford Process (McCluer, 1979). A new proces, which treats the steam before it reaches the turbine, is under study (Dagani, 1979). These systems are described in detail in Section 9.3. It should be noted here, however, that the iron catalyst system adds iron, nickel, elemental sulfur and sulfate to the circulating water, while use of the Stretford Process may introduce small amounts of 2,7-anthraquinone disulfonic acid (ADA) and vanadium into the cooling tower system.

Relatively few data on condensate, circulating water and overflow composition are available. Table 5.3-6 summarizes results from one-time and monthly sampling from various points in the system. Values for Unit 17 are estimates based upon knowledge of Unit 11 since the incoming steam composition is similar for the two units (Enriquez, 1978). A possible explanation for the comparatively low arsenic concentration in Unit 11's water is that, since only filtrates were analyzed, arsenic adsorbed onto particulate matter was not measured. Results of analyses of two grab samples taken on the same day from the circulating water in the Unit 12 tower are shown in Table 5.3-7. The fact that concentrations of many elements are higher than those shown in Table 5.3-6 is probably due to the concentrating effect of evaporation from the tower. Mercury concentrations measured in a special study by Robertson et al. (1977) are shown in Table 5.3-8. From their data, it appears that most of the aqueous mercury is in dissolved form, perhaps as a complex or colloid. Robertson et al. suggest HgS_2^{2-}, $Hg(HS)_2$ and ammonia complexes as thermodynamically stable species under the conditions observed. Finally, Table 5.3-9

Table 5.3-6

COOLING WATER COMPOSITION AT THE GEYSERS

Constituent	Units 1 & 2[a]	Unit 4[b]	Units 5 & 6[c]	Unit 10[b]	Unit 11[d]	Unit 17[e]
pH	7.7	6.66	7.50	5.16	NM[b]	NM
Major Constituents (ppm)						
Ammonia as N	74	224	115	13	175	200
Boron	197	NM	236	NM	85	100
Nitrite as N	0.3	NM	0.95	NM	NM	NM
Nitrite as N	NM	NM	0.012	NM	NM	NM
Silica	2.6	NM	NM	NM	NM	NM
Sulfate	216	7.0	120	6.0	450	10
Minor Constituents (ppb)						
Arsenic	NM	5.9	315	102	5[f]	200
Cadmium	NM	4.4	0.02	0.04	NM	NM
Chromium	NM	NM	1.9	NM	NM	NM
Copper	NM	0.2	5.9	0.2	NM	NM
Lead	NM	2.0	8.5	16.0	NM	NM
Mercury	NM	0.22	0.24	0.05	13[g]	15[g]
Selenium	NM	0.4	NM	0.6	NM	NM
Zinc	NM	0.01	NM	0.01	NM	NM

a Cooling tower overflow (Dodd et al., 1975; reported in Weres et al., 1977).

b Sample probably from condenser hotwell or pipeline between it and cooling tower (Le Gore et al., 1975; reported in Weres et al., 1977).

c Sample from settling pond (Le Gore et al., 1975; reported in Weres et al., 1977).

d Average of monthly analyses (Enriquez, 1978).

e Estimated by Enriquez, 1978.

f Filtered (Robertson, unpublished data reported in Enriquez, 1978); see text.

g See Table 5.3-7 and text.

Table 5.3-7

CIRCULATING WATER COMPOSITION, UNIT 12
COOLING TOWER AT THE GEYSERS

Constituent	Sample No.1	Sample No.2
Major Constitutents (ppm)		
Boron	77.4	82.3
Calcium	1.46	1.75
Chloride	10	6.8
Fluoride	0.55	ND[a]
Iron	29.6	25.9
Magnesium	0.28	0.42
Manganese	1.04	0.65
Sodium	4.45	7.91
Sulfate	1425	700
Minor Constituents (ppb)		
Arsenic	60	30
Lead	40	50
Zinc	80	40

Source: Koranda, 1980.
[a]ND = No data.

Table 5.3-8

MERCURY IN COOLING WATER AT THE GEYSERS

(Concentrations in μg/l)

Unit	Steam Condensate		Cooling Tower Water	
	Filtered	Unfiltered	Filtered	Unfiltered
3	10.1	12.0	3.90	6.1
4	3.8	NM[a]	3.0	8.55
7	3.45	3.99	0.99	0.99
8	3.30	NM	0.72	1.40
11	8.60	NM	2.10	12.8

Source: Robertson et. al., 1977

[a]NM = Not measured.

Table 5.3--9

CHEMICAL COMPOSITION OF COOLING TOWER SLUDGES AT THE GEYSERS, OCTOBER 1977

(concentrations in ppm by weight, except where otherwise noted)[a]

Element	Unit 4	Unit 8	Unit 11
Si[b]	1.58 ± 0.15	11.6 ± 0.6	1.00 ± 0.25
S[b]	62 ± 2	26 ± 1	72 ± 3
Fe[b]	4.84 ± 0.08	6.63 ± 0.15	16.8 ± 0.7
K[b]	0.65 ± 0.01	0.98 ± 0.02	0.18 ± 0.02
Ca[b]	0.36 ± 0.01	1.21 ± 0.61	0.39 ± 0.02
Ti	1850 ± 90	8600 ± 200	760 ± 60
Cr	616 ± 55	880 ± 25	400 ± 37
Mn	309 ± 17	560 ± 20	⩽ 48
Ni	106 ± 4	122 ± 7	⩽ 15
Cu	671 ± 23	966 ± 25	382 ± 15
Zn	2690 ± 80	3256 ± 85	655 ± 30
Hg	1995 ± 35	222 ± 2	425 ± 23
Se	80 ± 2	20 ± 1	52 ± 5
Pb	164 ± 3	176 ± 4	473 ± 38
As	184 ± 8	1120 ± 32	866 ± 31
Br	234 ± 5	⩽ 90	93 ± 5
Rb	⩽ 1.7	24 ± 2	⩽1.4
Sr	⩽ 13	62 ± 4	⩽11
Ag	14 ± 4	20 ± 3	20 ± 3
Cd	⩽4.3	30 ± 2	9 ± 1
Sn	16 ± 2	20 ± 3	23 ± 4
Sb	11 ± 2	12 ± 6	⩽3.5

Source: Unpublished study by D.E. Robertson, Battelle Pacific Northwest Laboratories; reported by Rosen and Molenkamp, 1978.

[a] Values are average ± standard deviation of four replicate samples.

[b] Weight percent

shows the chemical composition of sludges from three cooling tower basins at The Geysers.

5.3.2 Characteristics of Geothermal Fluid Planned for Use in Cooling

Geysers-Calistoga KGRA

As reported in Section 4.4.3, all of the 11 geothermal energy facilities proposed for the Geysers-Calistoga KGRA will use steam condensate for cooling tower makeup. As of this writing, data on the composition of the fluids in other than PG&E projects were unavailable; however these fluids should be qualitatively similar to those described for The Geysers, and should contain essentially the same pollutants of potential concern.

Imperial Valley

Our discussion will be limited to those proposed Imperial Valley geothermal operations which will use flashed steam to drive the turbine; binary cycle operations would of necessity depend upon a non-geothermal source for cooling water makeup. As noted in Section 4.4.3, flashed steam operations are proposed for the Salton Sea, Heber and East Mesa KGRA's.

Figure 5.3-1 is a schematic of the liquid and gaseous flows through a flashed steam system. A principal difference from the sytsem used at The Geysers is that noncondensible gases are in this case vented to the atmosphere after the condenser, rather than injected into the cooling tower. In general, hydrogen sulfide concentrations in the geothermal fluid are lower in the Imperial Valley KGRA's than in the Geyser-Calistoga KGRA's.

Table 5.3-10 summarizes data on concentrations of constituents of potential air pollution concern in the geothermal fluid typical of four KGRA's. It is evident that fluid composition varies considerably, even within a single KGRA. Concentrations of certain constituents are significantly higher than in other sources of makeup water. For example, chloride and TDS levels are on the order of 10^3 to 10^5 ppm. On the other hand, boron concentrations are lower than those observed at The Geysers. In general, fluids in the Salton Sea KGRA have the highest concentrations of salts.

As the geothermal fluid flashes, its constituents partition between the noncondensible gas, the steam condensate and the flashed brine. Concentrations in the noncondensible gas and steam condensate are important,

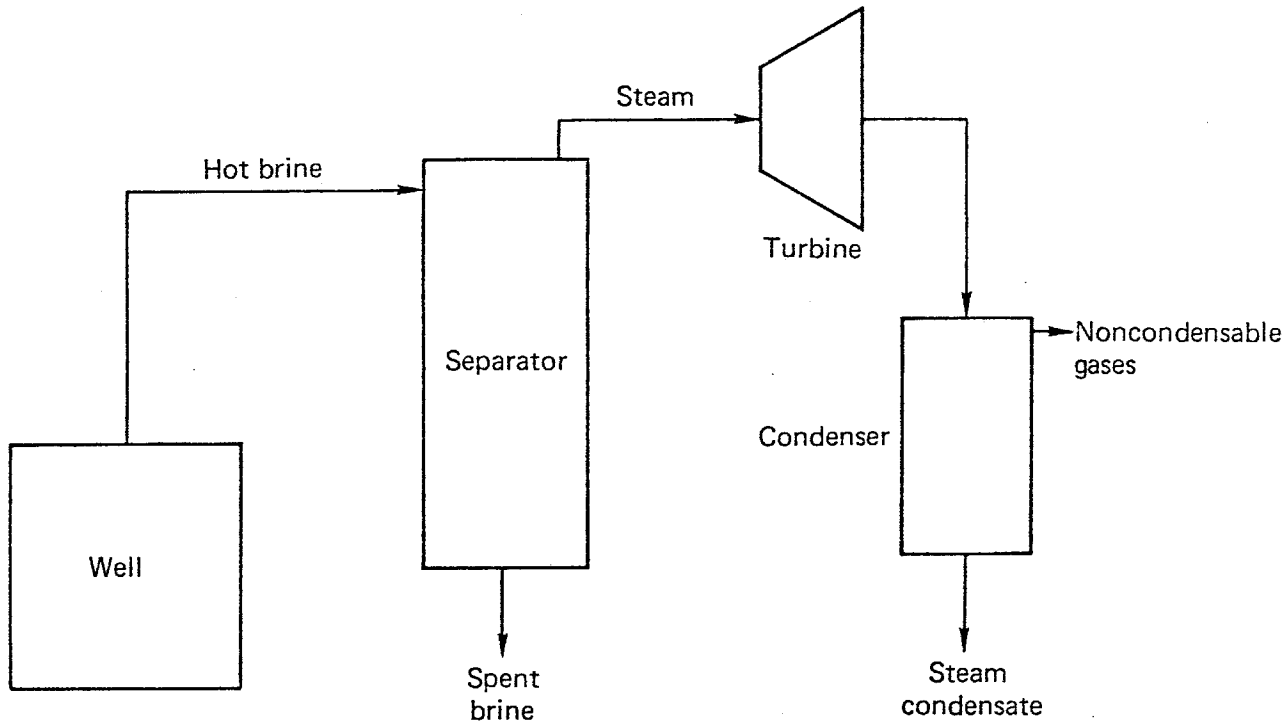


Figure 5.3-1. Schematic of Flashed Geothermal Steam Process (Snoeberger and Hill, 1978).

Table 5.3-10

CONSTITUENTS OF UNFLASHED GEOTHERMAL FLUID, IMPERIAL VALLEY

(Concentrations except pH are in mg/l, unless otherwise noted)

Constituent	Salton Sea[a]	East Mesa Well 6-1[b]	East Mesa USDI[b,c]	Brawley[e]	Heber[f]
pH	ND[g]	5.45	6.21	6.1	6.3
Major Minerals					
Ammonia	350[h]	40.75[h]	7.37	ND	ND
Boron	4	9.75	5.90	140	5.4
Chloride[i]	131	15.85	1.05	46	8.21
Nitrate	ND	<0.02	0.29	ND	ND
Silica	287	320	311	ND	222
Sulfate	ND	42.8	171	ND	130
TDS[i]	247	26.3	3.17	76	14.86
Trace Elements					
Arsenic	ND	0.26	0.10	2.6	ND
Cadmium	ND	< 0.01	0.01	ND	ND
Chromium	ND	< 0.01	< 0.10	ND	ND
Copper	4	< 0.10	< 0.10	0.11	0.4
Fluoride	22	0.99	1.42	ND	1.3
Lead	94	0.5	< 0.5	1.1	0.8
Mercury	ND	< 0.002	0.008	ND	ND
Selenium	ND	< 0.1	0.80	ND	ND
Zinc	361	0.07	< 0.01	14	0.40

Table 5.3-10
(continued)

---

[a] Austin et al., 1977, reported in Snoeberger and Hill, 1978.
Mean for 1 to 3 wells

[b] USDI data reported in Snoeberger and Hill, 1978

[c] USDI, 1978. Data for Wells Mesa 6-2, 8-1, and 31-1.

[d] Thomas, 1979. Data are median values for 8 to 22 measurements

[e]

[f] EPRI, 1976, reported in Snoeberger and Hill, 1978.
Mean for 5 wells

[g] ND = No data

[h] As NH_4^+

[i] In g/ℓ

as constituents of concern will be released from these two streams. It is very difficult to estimate the extent to which a given constituent will be partitioned between the liquid and vapor phases. Theoretical predictions and empirical data reported in the literature are based upon highly simplified systems, such as a pure gas mixed with distilled water, while in a real geothermal fluid numerous interactions occur among dissolved constituents. Also, the partitioning of soluble gases is highly pH- and temperature-dependent, and will thus vary with operating conditions.

Table 5.3-11 summarizes reported concentrations of various constituents in the steam condensate from geothermal fluids in the East Mesa, Salton Sea, Heber and Cerro Prieto (Mexico) KGRA's. Note that concentrations vary considerably. The composition of noncondensible gases also varies widely among and within KGRA's. Table 5.3-12 summarizes reported values for the Imperial Valley and Cerro Prieto.

Higher-molecular weight hydrocarbons such as benzene, toluene and xylene have also been reported to be found among the noncondensible gases (Nehring and Truesdall, 1978; Thomas, 1979). These compounds are probably steam-distilled from organic sediments by the hotter geothermal brines, for they are apparently absent in lower-temperature geothermal fluids. Reported concentrations for benzene and toluene are 0.065 and 0.004 percent by weight, respectively.

5.3.3 Summary: Constituents of Potential Concern as Air Pollutants

The air pollution potential associated with geothermal dvelopment in the Geysers-Calistoga KGRA is quite different from that associated with developments in the Imperial Valley. Not only do the fluids differ in nature and chemical composition, but also the potential for environmental and economic damage from exposure to pollutants of geothermal origin is different for the two regions.

The Geysers-Calistoga KGRA is sparsely populated, and existing geothermal power plants are isolated. The geothermal fluid is in the form of steam. Constituents of the greatest potential concern include hydrogen sulfide, mercury vapor, and particulate boron. Where the Stretford Process is used, there is a potential for vanadium emissions. H_2S is of concern as an nuisance, due to its low odor threshold, while boron may produce adverse

Table 5.3-11

COMPOSITION OF GEOTHERMAL STEAM CONDENSATE, IMPERIAL VALLEY

(Concentrations in mg/l, except where otherwise noted)

Constituent	Salton Sea[a]	KGRA Heber[a]	East Mesa[a,b]	Cerro Prieto[a,c]
Hydrogen sulfide	5.5 - 9.5	ND	0.09 - 2.8	4 - 85
Ammonia	331 - 360	ND	1.4 - 50	88 - 163
Mercury[d]	2.2 - 3.12	3.9	1.45 - 14.4	3.8 - 5.4
Arsenic[d]	ND[e]	ND	6 - 10	6
Boron	5.9[f]	< 0.1	1.0 - 1.3	< 0.1

a

b USDI, 1977

c Mercado, 1975

d Concentration in μg/ℓ

e ND = No data

f Single well

Table 5.3-12

COMPOSITION OF NONCONDENSIBLE GASES, IMPERIAL VALLEY AND CERRO PRIETO

Constituent	Salton Sea[a,b]	KGRA Heber	East Mesa	Cerro Prieto
Hydrogen sulfide (ppmv)	820 - 4670	ND	0 - 630	15000 - 20000
Ammonia (ppbw)	45	ND	56 - 108	17.8
Mercury (ppbw)	0.8 - 1.8	<0.03	2.3 - 3.6	0.3 - 0.4

effects in certain plants. The significance of mercury and vanadium emissions must be evaluted.

In the Imperial Valley KGRA's, the geothermal fluid is in the form of brine. While this brine contains varying amounts of salt and noncondensible gases, the extent to which these would be released to the environment in flashed steam operations is presently uncertain. The brine generally contains lower H_2S and boron concentrations than does the steam in the Geysers-Calistoga KGRA. On the other hand, the presence of toluene and xylene in the brine could contribute to photochemical smog formation. In addition, salt release through cooling tower drift may pose a problem for agriculture in the surrounding area.

5.4 AGRICULTURAL WASTEWATER

In Section 4.4.5, it was noted that the areas of California where agricultural wastewater is most likely to be used as cooling tower makeup are the San Joaquin, Imperial and Palo Verde Valleys. One of the major environmental concerns in the siting of power plants in these areas is the potential for crop damage due to airborne pollutant emissions. While cooling tower emissions are probably less important than sulfur oxides and other combustion emissions, deposition of salt drift could lead both to direct damage to crops and to a buildup of salts in the upper soil horizons.

Figure 5.4-1 shows mean and 95th-percentile concentrations of total dissolved solids (TDS), boron and sulfate in subsurface drainage waters in the northern (N), central (C) and southern (S) portions of the San Joaquin Valley. Values shown were calculated from data reported by the San Joaquin Valley Interagency Drainage Program (CDWR 1975, 1977, 1978, 1979). Since TDS levels are generally over 200 ppm (over 6000 ppm in the southern part of the Valley), only a few cycles of concentration may be achieved in cooling systems using this water. Sulfate concentrations are very high, especially in the south.

Irrigation return flows in the Palo Verde Irrigation District Outfall Drain near Blythe, California are of slightly higher quality than San Joaquin Valley subsurface flows. During 1964-1972, TDS and sulfate concentrations averaged 1,888 and 605 ppm, respectively (Rogozen, 1977).

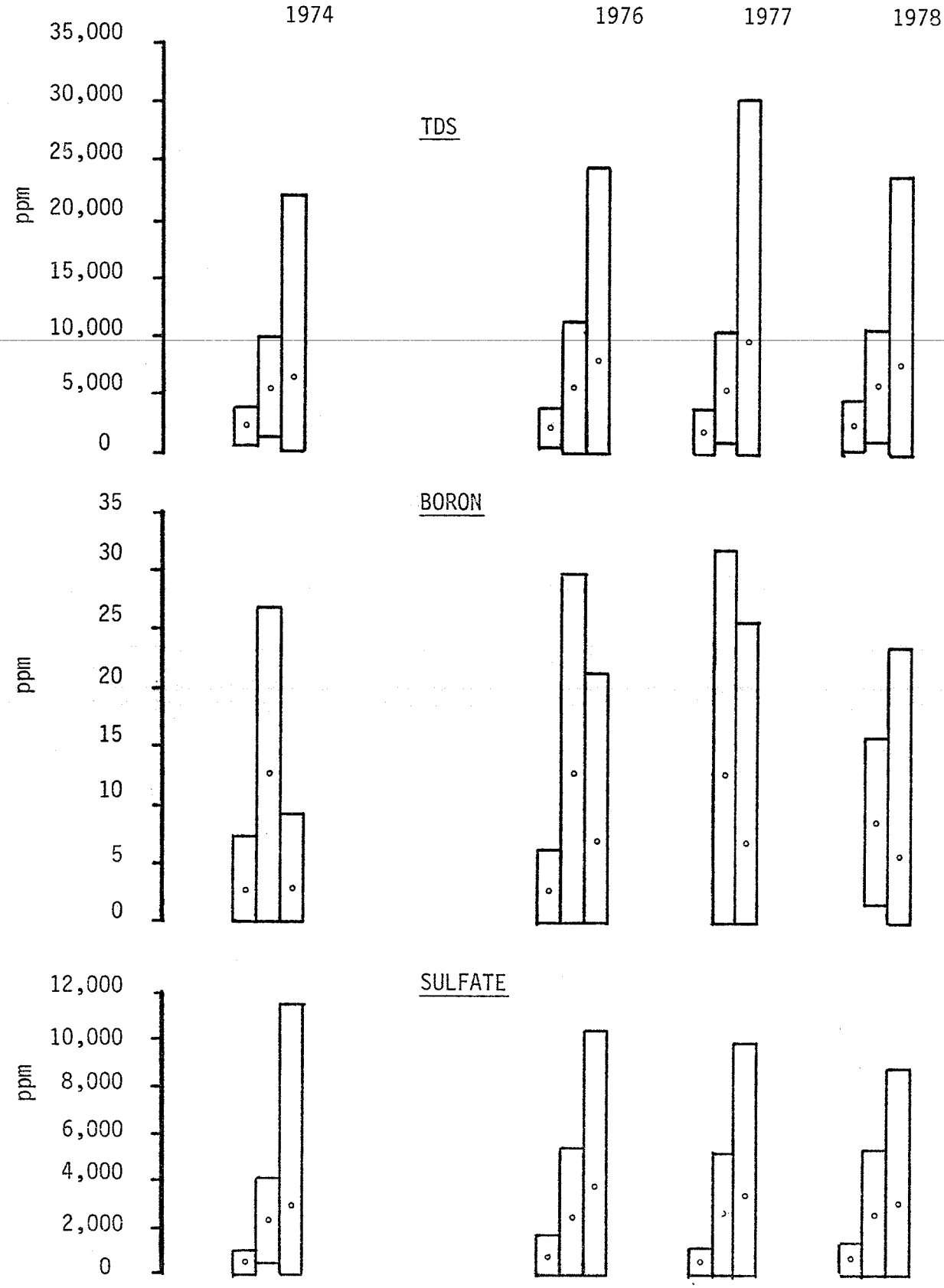


Figure 5.4-1. Means (o) and 95th Percentile Concentrations of Total Dissolved Solids, Boron and Sulfate in Subsurface Drains in Northern (N), Central (C) and Southern (S) Parts of the San Joaquin Valley, 1974-1978 (Calculated from data in CDWR 1974, 1978, 1979).

5.5 BRACKISH WATER

5.5.1 Characteristics of Brackish Water Presently Used For Cooling In California

The only cooling tower using brackish water in California is at Pacific Gas and Electric Company's oil- and gas-fired Pittsburg Power Plant. As seen in Table 5.5-1, makeup water quality varies with the tide and with the season. Salt, metal and suspended solids concentrations are lowest during February-May, when spring snowmelt increases the relative flow of freshwater to San Freancisco Bay. Because of the high dissolved solids concentrations, only 1.25 to 1.5 cycles of concentration are normally achieved (Barr, 1980).

5.5.2 Characteristics of Brackish Water Potentially Used for Cooling In California

As noted in Section 4.4.4, Scott et al. (1978) identified 113 California ground water basins yielding water having greater than 1,000 mg/L of total dissolved solids. While the upper limit exceeds 100,000 mg/L in several cases, the salinity of most of these basins (59 percent) is below 4,000 mg/L. (It should be noted that in a great number of reported cases, data are derived from one or two well tests.) Since the PG&E Pittsburg 7 power plant's cooling towers use water having TDS of up to 7,800 mg/L, many of these brackish ground water sources could be feasible makeup water sources. Data on chemimcal composition of these sources are insufficient to permit generalizations. However, the above-expressed concern about the potential adverse effect of salt drift on agriculture would apply.

5.6 HALOGENATED HYDROCARBONS IN COOLING WATER

Chlorine and chlorine-containing compounds are added to most cooling tower systems to suppress the growth of algae, slime, and other biota which would otherwise proliferate in the warm, nutrient-rich cooling tower environment. Because the chlorine additives and some of their reaction products are toxic to many aquatic organisms, the U.S. Environmental Protection Agency has set limits on the concentrations of chlorine in power plant aqueous effluent, most of which is comprised of cooling tower blowdown. The main concern of the present study, however, is the possibility that certain chlorine reaction products--in particular, low-molecular-weight volatile halocarbons--are released into the air from cooling towers. Some of

Table 5.5-1

MONTHLY VARIATION[a] IN MAKEUP WATER QUALITY
PITTSBURG NO. 7 UNIT COOLING TOWER

(All concentrations except pH are in ppm)

Month	Total Suspended Solids		Total Dissolved Solids		Iron	Copper	pH	
	High Tide	Low Tide	High Tide	Low Tide			High Tide	Low Tide
January	38	37	2560	1697	2.86	0.07	7.4	7.5
February	45	27	189	183	0.19	0.02	7.3	7.3
March	34	31	157	181	2.28	0.02	7.4	7.4
April	59	70	185	172	2.90	0.01	7.5	7.3
May	68	75	545	513	5.65	0.02	7.5	7.5
June	132	90	1640	1616	3.75	0.02	7.3	7.3
July	90	110	3264	3774	6.43	0.04	7.5	7.5
August	93	108	4152	4423	1.50	0.06	7.5	7.5
September	197	156	7781	6537	3.82	0.01	7.3	7.2
October	153	183	4962	4678	0.70	0.04	7.5	7.6
November	94	114	6459	2369	1.47	0.01	7.9	7.6
December	37	80	875	1299	0.90	0.02	7.5	7.4

Source: Pacific Gas and Electric Company (Barr, 1980).

[a] One sample per month.

these compounds pose a direct human health risk while others are presently believed to play a role in the depletion of stratospheric ozone.

5.6.1 Chlorination Chemistry

Chlorine is normally added to water in the form of chlorine gas (Cl_2), as a hypochlorite salt (such as NaOCl), or as an aqueous solution of chlorine dioxide (ClO_2). The aqueous species formed thereafter depend upon the temperature, pH and chemical composition of the receiving water.

Chlorine and Hypochlorite

At pH values typical of wastewater, molecular chlorine (Cl_2) does not exist in aqueous solution; rather it reacts with water to form hypochlorous acid:

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^- \qquad (5.6\text{-}1)$$

Likewise, salts of hypochlorous acid ionize as follows:

$$NaOCl + H_2O \rightleftharpoons HOCl + Na^+ + OH^- \qquad (5.6\text{-}2)$$

Hypochlorous acid dissociates weakly:

$$HOCl \rightleftharpoons H^+ + OCl^- \qquad (5.6\text{-}3)$$

The extent of dissociation depends upon the temperature and pH. For example, at pH 7.5 and 25 ^oC, the concentrations of HOCl and OCl^- are approximately equal (NRC, 1979). Using data from Snider and Alley (1979), we estimate that at 40 ^oC and pH 6.7, more typical of cooling tower conditions, about 85 percent of the chlorine is in the form of HOCl, which is the more active of the two species. Other forms of chlorine, such as Cl_2O and Cl_2OH^+, exist in aqueous solution and may take place in chlorination reactons (Snider and Alley, 1979).

Chlorine in the form of HOCl and/or OCl^- is defined as "free available" or "available" chlorine. The amount of available chlorine in a solution may be significantly diminished by competing side reactions with inorganic reducing agents (H_2S, SO_3^{2-}, NO_2^-, Fe^{2+}, Mn^{2+}), ammonia and amines, various unsaturated organic compounds, and bacteria. The reducing agents convert the chlorine to chloride ion, which has no bactericidal ability.

slightly acidic conditions typical of cooling towers, ClO_2 is stable. It decomposes readily when exposed to sunlight.

Chlorine dioxide's major role in water treatment is as an oxidant. Although its oxidation-reduction potential under normal operating conditions is lower than that for Cl_2, it is equivalent to 3.6 times its weight in chlorine if permitted to be reduced all the way to Cl^-. An example of these circumstances is the oxidation by ClO_2 of phenolic compounds. Unlike chlorine, ClO_2 is active over a fairly wide range of pH.

In general, reactions with organics are as follows:

$$\text{organic} + ClO_2 \rightleftharpoons \text{oxidized organic} + ClO_2^- \qquad (5.6\text{-}10)$$

in which ClO_2 functions as a one-electron acceptor. Reactions with phenol and chloro-substituted phenols result in formation of p-quinone and a variety of chlorinated benzoquinones. Some aliphatic alcohols are oxidized to the corresponding acids. ClO_2 reacts with 3,4-benzopyrene mainly to form benzopyrene quinones, e.g. 3,4-benzopyrene-1,5-quinone; only a small fraction of the reaction products consist of chlorinated benzopyrenes. Triethylamine is oxidized to acetaldehyde and diethylamine.

It is important to mention the types of reactions which do <u>not</u> occur with ClO_2. Primary aminnes are completely unreactive and secondary amines react only slightly, so that competing chloroamines do not form. Amino acids (except for those containing sulfur) do not react, nor do saturated carboxylic acids and carbonyl compounds. Perhaps most significantly for the present study, trihalomethanes are not formed in ClO_2 solutions (Roberts et al., 1981).

One complicating factor is that the chlorite formed in the reaction of ClO_2 with organics may also be a reactive agent under certain circumstances. It reacts wtih aldehydes, yielding ClO_2, and it has been proposed as a possible source of some of the chlorinated products resulting from reaction between ClO_2 and aromatic compounds.

5.6.2 Formation of Halogenated Organics

The Haloform Reaction

The process of formation of trihalomethanes ($CHCl_3$, $CHBr_3$, etc.) from the hypohalous acids (e.g. HOCl) and certain organic precursors is known as "the haloform reaction." Compounds which are likely to participate in the

Reactions with ammonia and amines produce chloramines, in the following sequence (Metcalf and Eddy, 1972):

$$NH_3 + HOCl \rightleftharpoons NH_2Cl + H_2O \quad (5.6\text{-}4)$$

$$NH_2Cl + HOCl \rightleftharpoons NHCl_2 + H_2O \quad (5.6\text{-}5)$$

$$NHCl_2 + HOCl \rightleftharpoons NCl_3 + H_2O \quad (5.6\text{-}6)$$

The chloramines serve as disinfectants but are extremely slowly acting. In addition, trichloramine (NCl_3) is a volatile gas with an unpleasant odor. At the pH typical of cooling tower operations, NH_2Cl and $NHCl_2$ are the dominant species. To assure that sufficient free available chlorine is present in solution, additional chlorine must be added. When this is done, most of the chloramine compounds are converted to nitrogen gas (which leaves the solution) and hydrochloride acid (which is neutralized by the alkalinity in the water).

Chlorine Dioxide

Chlorine dioxide, ClO_2, is an orange-yellow, highly volatile gas which is used in the pulp and paper industry for bleaching and in a relatively small number of water and wastewater treatment plants for taste and odor control and for disinfection. Since it was formerly used as a biocide in one of the cooling towers measured in Tasks 3 and 4 of the present study, its water chemistry will be reviewed briefly. The main sources of information for this section are thorough literature reviews performed for the USEPA by Miller et al. (1978) and the National Research Council (1979).

Because it is explosive in its gaseous or pure liquid state, ClO_2 is normally prepared on-site from reactants which are safer to handle and store. The most common method for preparing chlorine dioxide is to mix chlorine gas (Cl_2) with sodium chlorite ($NaClO_2$) in acidic aqueous solution:

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl \quad (5.6\text{-}7)$$

$$HOCl + HCl + 2NaClO_2 \rightleftharpoons 2ClO_2 + 2NaCl + H_2O \quad (5.6\text{-}8)$$

An excess of Cl_2 is usually added to assure conversion of all the chlorite to ClO_2. The excess is also necessary to compensate for the following side reaction, which depletes the amount of available chlorine:

$$HOCl + ClO_2 \rightleftharpoons ClO_3^- + HCl \quad (5.6\text{-}9)$$

As a result, water treated with ClO_2 usually has some excess aqueous chlorine and chlorate (ClO_3^-) along with the chlorine dioxide. Under the neutral pH or

haloform reaction under conditions relevant to this study have the general formulas CH_3CHOHR or $RCOCH_3$, where R indicates an organic constituent (NRC, 1979). Examples include ethanol, acetaldehyde and pentene. The site of attack by the halogen is the carbon adjacent to the one bearing oxygen. An example of the haloform reaction is the formation of bromoform and sodium benzoate from bromine and acetophenone (Menger et al., 1972):

$$CH_6H_5 - \underset{\underset{O}{\|}}{C} - CH_3 + Br_2 \xrightarrow{NaOH} C_6H_5 - \underset{\underset{O}{\|}}{C} - O^-Na^+ + CHBr_3$$

Olefinic substances which may be oxidized by HOCl, first to secondary alcohols and then to methyl ketones, may also participate in the haloform reaction. The rate-limiting step in the reaction is the production of a carbanion ($-CH_2^-$) to react with an electron-deficient halogen (e.g., Cl^+ or Br^+). Simple ketones, such as acetone, are ionized too slowly to particpate in the haloform reaction to a significant degree. Rather, it is believed that precursors in raw waters and wastewaters are highly complex humic acids. The structures of these compounds are poorly characterized, but they are known to have functional groups which would permit their participation in the haloform reaction. As noted above, chlorine dioxide does not form THM's from humic acids.

In laboratory studies Rook (1976) obtained chloroform from chlorination of diketones (e.g., 1,3-cyclohexanedione) at Cl_2 dosages considerably higher than those commonly used for disinfection.

Halogenated Organic Formation in Wastewater

Relatively few studies of the formation of halomethanes and other halo-organics from disinfection or biocidal treatment of wastewater have been made; the preponderance of research has been directed of haloforms in finished drinking water. Trihalomethanes (THM's) are less likely to form in wastewater than in treated drinking water becuase the high ammonia content of the former results in a competing reaction, the formation of chloramines (Brigano et al., 1979). The presence of ammonia may also inhibit production of other chlorinated organics, such as chlorophenols (Murphy et al., 1975). Nevertheless, chlorination reactions under wastewater treatment conditions have been observed. The following is a brief review of the literature.

Jolley (1975) chlorinated one sample of primary-treated and five samples of secondary-treated municipal wastewater with ^{36}Cl-tagged chlorine gas or hypochlorite solution to a 1- to 2-ppm chlorine residual. About one percent of the radioactively-tagged chlorine ended up in chlorinated organic compounds; the rest was presumed to be consumed in oxidation reactions. Table 5.6-1 lists 17 chloroorganics which were tentatively identified. The chlorination yield was approximately the same for both primary- and secondary-treated effluents.

Chlorination of aromatic compounds under waste treatment conditions has been studied by several researchers. Gaffney (1977) measured chlorobenzene and chlorobiphenyls in the influennt and effluent of a wastewater treatment plant serving a community where biphenyl is used extensively for industrial purposes. Laboratory-chlorinated samples of biphenyl-spiked influent and effluent were also examined. Table 5.6-2 summarizes the qualitative results. In general, chlorination resulted in an increase of chlorobenzene compounds and of dichlorobiphenyl. Work on biphenyl, which passes undegraded through biological waste treatment processes, was continued by Snider and Alley (1979), who focussed upon reaction kinetics under wastewater treatment conditions. In laboratory experiments at pH 6.2 to 9.0 and at a temperature of 40 ^{o}C, both ortho and para isomers of monochlorobiphenyl were formed. The reaction proceeds so slowly that extensive chlorination of biphenyl is not expected for short contact times and low chlorine doses. However, since the reaction rate is proportional to the square of the undissociated HOCl concentration, high doses (e.g., 2,000 ppm) such as are commonly applied to wastewater sludges prior to dewatering could be of concern.

Murphy et al. (1975) state that phenols are relatively easily chlorinated under wastewater treatment conditions. In their experiments 6-chlorophenol; 2,6-dichlorophenol; and 2,4,6-trichlorophenol were formed from Cl_2 and phenol. It should be noted that no ammonia was present and that reactant concentrations were higher than in normal wastewater, although their relative proportions were realistic. Laboratory chlorination of toluene in secondary-treated wastewater has also been reported (Sievers et al., 1978; cited in NRC, 1979).

Table 5.6-1

CHLORINE-CONTAINING CONSTITUENTS IDENTIFIED IN CHLORINATED PRIMARY- AND SECONDARY-TREATED MUNICIPAL WASTEWATER EFFLUENTS

Compound	Concentration (μg/ℓ)
5-Chlorouracil	4.3
5-Chlorouridine	1.7
8-Chlorocaffeine	1.7
6-Chloroguanine	0.9
8-Chloroxanthine	1.5
2-Chlorobenzoic acid	0.26
5-Chlorosalicyclic acid	0.24
4-Chloromandelic acid	1.1
2-Chlorophenol	1.7
4-Chlorophenylacetic acid	0.38
4-Chlorobenzoic acid	1.1
4-Chlorophenol	0.69
3-Chlorobenzoic acid	0.62
3-Chlorophenol	0.51
4-Chlororesorcinol	1.2
3-Chloro-4-hydroxybenzoic acid	1.3
4-Chloro-3-methylphenol	1.5

Source: Jolley, 1975.

Table 5.6-2

EFFECTS OF CHLORINATION OF AROMATICS IN WASTEWATER

Compound	Changes Due to Waste Treatment (No chlorination)	Changes Due to Chlorination of Biphenyl-spiked WTP Influent	Changes Due to Chlorination of Biphenyl-spiked WTP Effluent
Dichlorobenzene	Decrease	Increase	Increase
Trichlorobenzene	Decrease	Increase	Increase
Monochlorobiphenyl	Increase	Increase	Decrease
Dichlorobiphenyl	Increase	Increase	Increase
Trichlorobiphenyl	Increase	Increase	Decrease

Source: Summary of data reported by Gaffney (1977).

Chlorinated aliphatic compounds have been detectetd in lime-treated tertiary sewage effluent (Garrison et al., 1976; cited in NRC, 1979). Those identified included chlorocyclohexane and tetra-, penta- and hexachloroethane. These compounds may have been experimental artifacts (NRC, 1979). Chlorinated aliphatics were produced when secondary-treated sewage effluent was treated with 2,000 ppm of chlorine (Glaze and Henderson, 1975; cited in NRC, 1979).

Halogenated Organic Formation in Cooling Towers

At this writing the only assessment of halogenated organics in cooling tower waters of which we are aware is that performed by Jolley et al. (1977a, 1977b) of Oak Ridge National Laboratory. Grab samples were taken from towers serving the Oak Ridge Gaseous Diffusion Plant (ORGDP) and the High Flux Isotope Reactor (HFIR). Municipal drinking water, initially chlorinated to 2 ppm chloride residual, is the makeup source for the HFIR tower. The tower basin is chlorinated weekly to achieve a 2 ppm residual. The makeup water source for the ORGDP tower is softened Clinch River water chlorinated to a 1-ppm residual. Chlorine is added continuously to the tower basin to maintain a 0.5-ppm residual. Table 5.6-3 summarizes the results of analyses for THM's in the makeup water and the cold water basin. Jolley et al. (1977b) estimate emissions of 130 and 810 kg/year of chloroform from the ORGDP and HFIR towers, respectively.

5.7 ASBESTOS IN COOLING WATER

5.7.1 Use of Asbestos in Cooling Towers

As asbestos is a known airborne carcinogen, it is important to identify all sources of atmospheric emissions and to estimate the health significance of the resulting ambient concentrations. Cooling towers, many of which contain asbestos-derived components, have been investigated recently for their asbestos emission potential (Lewis, 1979). This section summarizes this recent research and outlines ways by which asbestos may contaminate cooling tower water.

The cooling tower components which most often contain asbestos materials are the fill (or "packing") and the siding (or "louvers"). Splash-type fill, which is employed to break up falling hot water droplets and thereby increase evaporation, may consist of either flat or corrugated asbestos-cement bars or boards. In film-type fill, upon which a thin film of

Table 5.6-3

TRIHALOMETHANES IN OAK RIDGE NATIONAL LABORATORY COOLING TOWER WATERS

(all concentrations in ppb)

Compound	Sampling Location			
	ORGDP		HFIR	
	Makeup	Basin	Makeup	Basin
Chloroform	86	12 - 31	120 - 137	1 - 38
Bromodichloromethane	7	0.5 - 0.7	15	ND
Dibromochloromethane	1	0.9	1	ND
Bromoform	0.2	0.7	0.4	ND

Source: Results reported by Jolley et al. (1977a).

hot water forms, asbestos paper or asbestos-cement sheets are often used. The asbestos paper consists of asbestos bound with rubber or neoprene and bonded together to form packs. Sheets of asbestos-cement are used for siding or louvers. As in all asbestos-cement products, the asbestos is used to reinforce the structure, increase tensile strength, and reduce fire hazard.

SAI's cooling tower inventory, presented in Section 4.2.2, found that 126 (30.8 percent) of the cooling towers identified contain asbestos-derived components. As noted in our review of cooling tower trends (Section 4.1.2), most new and replacement fill is made of non-asbestos materials such as PVC, ceramic tile, or wood.

5.7.2 Factors Affecting Leaching of Asbestos

Three main factors affect the release of asbestos bound in the cooling tower material to the cooling tower circulating water: chemical leaching, mechanical weathering, and microbial attack.

Chemical Leaching

Asbestos fibers can be released from asbestos-cement bars and sheets using portland cement when the hardened cement is dissolved by free carbon dioxide (CO_2) in the cooling tower circulating water. The CO_2 (as carbonic acid in the water) reacts with the calcium hydroxide formed during the cement hardening process. As a result the cement binder may dissolve.

There are two indices of the potential for chemical leaching of asbestos, neither of which is highly accurate for this purpose. The first is the Langelier Saturation Index, which is commonly used to indicate the potential for scale formation or corrosion in circulating water systems. This index is defined as (Clark et al., 1971):

$$S.I. = pH - pH_s$$

$$= pH - [(pK_2' - pK_s') + pCa^{++} + pAlk] \qquad (5.7\text{-}1)$$

where: pH = actual pH of the water,

pH_s = pH at saturation with calcium carbonate,

$(pK_2' - pK_s')$ = empirical constants based on water temperature and ionic strength,

pCa^{++} = the negative logarithm of the calcium ion concentration (moles/liter), and

$pAlk$ = the negative logarithm of the total alkalinity (equivalents/liter).

Lewis (1979) observed that although there are inconsistencies in using the Langelier Index to predict the detection of asbestos fibers in cooling tower waters, highly negative values (less than -2) will accelerate the erosion of asbestos-cement fill. Anderson and Stone (1981) recommend that the Index be maintained as high as possible without causing calcium carbonate scale.

Another measure of asbestos leaching potential is the "agressiveness index" (A.I.), which was developed for assessment of asbestos-cement pipe (Hallenbeck, 1977):

$$A.I. = pH + \log_{10}A + \log_{10}H_c \qquad (5.7\text{-}2)$$

where H_c is the calcium hardness (mg/L $CaCO_3$) and A is the total alkalinity (mg/L as $CaCO_3$) in the recirculating water. If the A.I. is 10 or below, the water is considered to be "aggressive;" if it is above 12, the water is considered to be "non-aggressive;" and water with intermediate values is "moderately aggressive." Using this formula and data from Woodburn (1978), it can be seen, for example, that the recirculating water in the City of Burbank's cooling towers has an A.I. of 10.6, which would imply that the potential for asbestos leaching is moderate. The usefulness of this index is subject to question, however. Lewis (1979) points out that the index does not take temperature into account. Hallenbeck (1977), who measured asbestos leaching from 15 asbestos-concrete pipes carrying public water supplies, found no statistically significant difference between pipes carrying nonaggressive and moderately aggressive water. There are some indications that the A.I. may be inapplicable to cooling tower asbestos-cement fill (Maurer and Skelonis, 1978; cited in Lewis, 1979).

Mechanical Weathering

Cycles of freezing and thawing can causes asbestos-cement fill to alternately shrink and expand. The resulting stress may be sufficient to eventually disintegrate the fill and release asbestos fibers. This type of weathering is most prevalent in areas with severe winters and may not occur to a significant extent in California. Also, if breakage occurs in large pieces which fall into the cooling tower basin, routine removal of the basin sediments will reduce the potential for airborne emissions.

Microbial Attack

There exists the potential for attack upon the cement binder of the asbestos-cement fill from acid excreted by microorganisms, or reactions mediated by them (Lewis, 1979). The dissolution of the cement would then release asbestos fibers to the circulating waters in the cooling tower.

5.7.3 Studies of Asbestos in Cooling Tower Waters

Argonne National Laboratory measured asbestos fibers in and around 18 cooling tower systems (Lewis, 1979). The study included a review of the human health effects literature on asbestos; collection of information from cooling-tower vendors and users; collection of water, sediment, and air samples at operating cooling towers and analysis for asbestos-fiber content using electron microscope techniques; and estimation of the quantities of fibers that could be released to the ambient air due to drift from cooling towers.

Chrysotile asbestos fibers were detected in cooling tower basin water, basin sediment, or blowdown at 10 of the sites. Table 5.7-1 summarizes the findings for the towers where asbestos was detected in circulating water or blowdown. (At the remaining four sites, asbestos was found in cooling tower makeup and/or in basin or blowdown sediments.)

One cooling tower was studied in detail to determine the origin of asbestos fibers found in the water. Fibers were not found in the makeup water or in the hot water basin. Concentrations in the basin water ranged from below 2×10^5 fibers/L to 1.1×10^8 fibers/L (0 to 1.306 g/L), while in the blowdown concentrations varied from below 2×10^5 fibers/L to 4.3×10^8 fibers/L (0 to 3.846 g/L). No asbestos fibers were found in the ambient air. Although the air sampling method was not sensitive enough to detect the 6×10^3 fibers/m^3 likely to be found in nonurban ambient air, it could have detected the 4.3×10^5 fibers/m^3 which Lewis estimated would have been necessary to result in the observed blowdown concentrations. Lewis concludes that the chrysotile asbestos fibers found in this cooling-tower basin and discharge originate in cooling-tower structural material, most likely from the asbestos fill, rather than from the makeup water or from the air drawn through the tower.

Table 5.7-1

ASBESTOS IN COOLING TOWER WATERS, ARGONNE NATIONAL LABORATORY SURVEY

Site Number	Tower Type	Medium	Fiber Count 10^6 fibers/ℓ	Mass Concentration μg/ℓ
3	Nat. Draft	Blowdown	0.92	0.005
		Blowdown	110	36.5
4	Nat. Draft	Basin	1.9	0.03
		Blowdown	1.3	0.009
		Blowdown	160	17.3
9	Nat. Draft	Blowdown	37	3.15
11	Nat. Draft	Basin	370	5.44
		Basin	330	31.5
		Basin	210	1.53
12	Nat. Draft	Basin	24	0.18
13	Mech. Draft	Basin	4.3	0.242
		Basin	2.5	0.059
		Riser	1.5	0.105

Source: Data from Lewis, 1979.

Riepenhoff and Boyd (1979) monitored asbestos fiber counts in cooling tower waters at the Goodyear Atomic Corporation plant in Piketon, Ohio. Fiber counts in 1976-1979 varied from below detectable limits (7×10^5 fibers/L) to 16.2×10^6 fibers/L. No air sampling was performed.

5.7.4 Implications of Using Wastewater in Cooling Towers

The use of certain wastewaters in cooling towers containing asbestos fill, drift eliminators, and/or asbestos pipes could accentuate the breakdown of the asbestos material and possibly result in entry of fibers into the cooling water. The wastewaters of concern are geothermal, brackish and agricultural. Geothermal condensate and the accompanying H_2S can corrode the fill supports, leading to collapse and physical disintegration. In addition H_2S can promote the corrosion of asbestos-cement components by certain species of microorganisms. High levels of dissolved CO_2 in the geothermal steam condensate from flashed geothermal brines can promote chemical deterioration of the cement by the reaction of the calcium hydroxide formed during the hardening process and the carbonic acid in the water.

If naturally brackish waters or highly saline agricultural wastewaters are used, one-sided wetting of the asbestos-cement board can cause delamination. Asbestos cement casings and louvers are particularly vulnerable, and it is recommended that these components be coated for salt water cooling towers, or manufactured with sulfate-resistant portland cement.

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6.0

COOLING TOWER WATER SAMPLING

In order to achieve the objectives of Tasks 3 and 4, it was necessary (1) to obtain accurate data on concentrations of cooling tower water constituents of potential concern as air pollutants and (2) to identify constituents to be measured in cooling tower stack emissions. Water samples were collected from six towers and analyzed at SAI's Trace Environmental Chemistry Laboratories in La Jolla, California; Morning Star Laboratories in Vernon, California; the U.S. Environmental Protection Agency's Municipal Environmental Research Laboratory in Cincinnati, Ohio; and the Centers for Disease Control in Atlanta, Georgia. This chapter outlines our methods of sample collection and analysis, and presents results for each tower. Emission estimates and emission factors derived from our water sampling results are presented in Chapter 8.

6.1 CHOICE OF TEST SITES

Under the research contract, SAI was to test towers using three different municipal wastewater sources, two which use recycled industrial process water, and one which uses condensed geothermal steam as makeup. During the study period, the Burbank and Glendale Municipal power plants were the only facilities in California which used municipal wastewater as cooling tower makeup. It was hoped that the Contra Costa County and Chevron U.S.A. wastewater reuse projects described in Section 4.4.1 would come on line in time for us to test one of their towers. Since these projects are still not underway, it was necessary to sample a second tower at Burbank or Glendale. We chose a tower at Burbank for reasons detailed below. Table 6.1-1 lists the facilities, towers, wastewater sources and Task 3 sampling dates. Water for a special study of Legionella pneumophila (Legionnaires Disease bacterium) was collected from Burbank/Olive 1, Glendale, and the two industrial towers.

6.2 METHODS FOR SAMPLE COLLECTION AND ANALYSIS

6.2.1 Collection, Handling and Transport

In general, grab samples were taken from the hot water trough or riser, the cold water basin, and the makeup supply pipe of each tower; exceptions are described in the individual tower descriptions which follow. Table 6.2-1 summarizes the sampling vessel, pre-sampling treatment, and

Table 6.1-1

COOLING TOWERS TESTED IN TASK 3

Tower	Facility	Specific Tower	Wastewater Source	Sampling Date
MT 1	Burbank Public Service Dept. Power Plant (Burbank)	Olive 1	Municipal	27 November 1979
MT 2	Burbank Public Service Dept. Power Plant (Burbank)	Magnolia 4	Municipal	21 January 1981
MT 3	Glendale Public Service Dept. Power Plant (Glendale)	No. 4	Municipal	22 April 1980
IT 1	Industrial Plant (Los Angeles County)	South Tower	Industrial	5 August 1980
IT 2	Industrial Plant (San Bernardino County)	No. 1	Industrial	6 December 1979
GT	Geothermal Power Plant		Geothermal	23 January 1980

Table 6.2-1

SUMMARY OF COOLING TOWER WATER SAMPLE COLLECTION

Constituents For Which Water Taken	Sampling Vessel	Pre-Sampling Treatment[a]	Sampling Frequency
Volatile Organics	40-mL Teflon-faced, septum-capped glass vials	35 mg $Na_2S_2O_3$	3 hourly samples in a.m. and p.m.
Nonvolatile Organics	2-L, Teflon-capped amber glass bottles	35 mg $Na_2S_2O_3$ added per L per ppm free chlorine residual	8 hourly samples composited on-site
Metals	Polyethylene bottles[c]	Acid cleaning	8 hourly samples composited on-site
Bacteria and Virus[b]	236-mL, metal-capped plastic bottles	Autoclaved; 10 mg $Na_2S_2O_3$ added	8 hourly samples
Hydrogen Sulfide	Borosilicate glass bottle	Zinc acetate in NH_4OH	8 hourly samples composited on-site

[a] See text for further discussion.

[b] Collection of samples for Legionella pneumophila analysis is discussed in the text.

[c] Borosilicate glass bottles were used for mercury sample collection.

sampling frequency for each of the classes of cooling water constituents for which the sampling was performed. At each sampling time, four grab samples were taken for subsequent volatile organic analyses (VOA); two were preserved with sodium thiosulfate and two were not. VOA samples were not composited; rather, representative grab samples for the morning and afternoon of each test day were chosen for analysis (in duplicate). The amount of $Na_2S_2O_3$ added to the sample to be analyzed for volatile organics depended in each case on the concentration of free chlorine residual, as measured in the field.

Except as noted otherwise, the sampling schedule was as follows. SAI personnel arrived at the site early in the morning and began sample collection before 0900 hours. Grab samples were taken every hour thereafter for seven or eight hours. All water sample bottles were stored on ice until their arrival at SAI's Laboratory in La Jolla, where they were immediately refrigerated. Samples for microbiological analysis were kept refrigerated overnight and delivered by 0800 hours the next day to Morning Star Laboratories in Vernon, California.

The remote location of the geothermal facility and the unanticipated cancellation of all flights to San Diego on the evening of the sampling made it impossible to deliver samples rapidly to our laboratory. Samples were kept in an ice chest overnight in San Francisco and then delivered to La Jolla by 1030 hours the next day.

Water samples for Legionella pneumophila assay were collected in sterilized polyethylene bottles provided by the Centers for Disease Control (CDC). Collection vessel types and purposes are described in Table 6.2-2. Four bottles were sent to the U.S. Environmental Protection Agency's Municipal Environmental Research Laboratory (USEPA/MERL) in Cincinnati, Ohio, while two were sent to the CDC in Atlanta, Georgia. In each case, samples were packed in ice and sent by air freight on the night of the sampling day; all arrived by 0800 hours on the following day. The USEPA/MERL analyzed makeup and cold water basin samples for sodium, potassium, magnesium, chloride, and sulfate ions.

6.2.2 On-Site Measurements

Water temperature, pH and free residual chlorine were measured at each of the sampling points. A mercury immersion thermometer having a 0 to 50

Table 6.2-2

WATER COLLECTION PROTOCOL FOR LEGIONELLA SAMPLING

Bottle No.	Volume	Reagent Added	Sampling Point	Destination[a]
1	1 L	None	Cold water basin	CDC
2	1 L	None	Cold water basin	EPA
3	1 L	2ml of 95% H_2SO_4	Cold water basin	EPA
4	500 ml	0.4 ml of 10% $Na_2S_2O_3$	Cold water basin	CDC
5	250 ml	None	Makeup water	EPA
6	1 L	37.3 ml merthiolate	Cold water basin	EPA

Source: CDC, 1979.

[a] CDC = Center for Disease Control, Atlanta, Georgia.

EPA = U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Wastewater Research Division, Cincinnati, Ohio.

^{o}C range and divisions of 0.1 ^{o}C was placed directly in the water trough, basin or inlet stream, as appropriate. Readings are reported to the nearest 0.1 ^{o}C. A Beckman Expand-Mate portable pH meter was used for pH measurement at all the towers except Burbank/Magnolia 4; in that case a Beckman SelectMate device was used. For temperature compensation, the instrument was set before each reading to the average temperature of the water sources sampled. At the start of the test day, the meter was calibrated with pH 7 and pH 10 buffer solution, and before each set of hourly readings it was re-calibrated with the pH 7 solution. Each of the Beckman meters has an expanded scale for pH readings between 6 and 8, for which the measurement accuracy is 0.01 pH unit. Because some drift was noted, readings were taken one minute after the electrode was immersed in the sample. Results are reported to the nearest 0.1 pH unit.

Free residual chlorine was measured with a Fischer-Porter Model 17T1010 amperometric titrator loaned to the project by the University of California at Davis, Department of Civil Engineering. The instrument has a nominal accuracy of 0.01 ppm; however, the drops of titrant were so large that readings could only be made to the nearest 0.03 ppm. For the testing at Industrial Tower No. 1, the microammeter was connected in parallel with a Soltec VP-6723S strip chart recorder, so that the end point could be more readily discerned. Chlorine concentrations are reported to the nearest 0.1 ppm. As the amperometric titrator was unavailable for the Task 3 testing at Burbank/Magnolia 4, chlorine analyses were not performed.

6.2.3 Analysis

Volatile Organics

Detailed descriptions of our analytical protocols may be found in Appendix B. Water samples for volatile organic analysis were purged with pre-purified nitrogen gas. The stripped volatile organics were then collected on a column of Tenax-GC, which was desorbed onto a gas chromatograph (GC) equipped with a flame ionization detector (FID). Compounds were identified by comparing chromatographic peaks with those obtained by injecting a standard solution into the GC. (Standard chromatograms are also presented in Appendix B.) Peak integration and quantitation were performed automatically by a Hewlett Packard 3385A automation terminal. For further compound confirmation, several samples were analyzed by computer-assisted gas chromatography/mass spectrometry (GC/MS).

Nonvolatile Organics

Samples for nonvolatile organic analysis were processed by the EPA Method 625 base-neutral/acid extraction procedure. The base-neutral extract was analyzed by both flame ionization detection gas chromatography and electron capture detection GC to screen for semi-volatile and non-volatile compounds. Standard chromatograms are shown in Appendix B. In cases where chromatograms were too complex for adequate interpretation, the base-neutral extract was fractionated on silica gel to yield aliphatic and aromatic fractions. These fractions were analyzed by FID GC. The acid extract was analyzed by FID GC for phenols.

Total Suspended and Dissolved Solids, Electroconductivity, and Metals

Whole water analyses were performed only on the Burbank/Olive 1 composite sample; for the other towers, separate analyses were performed on particulate and dissolved fractions. Filtrates were acidified with HNO_3 and refrigerated until the time of analysis. The 0.4 μm, 47-mm diameter Nucleopore filters used for the filtration were dried and reweighed for determination of total suspended material (TSM) concentration. Separate aliquots of filtrate were analyzed for total dissolved solids (TDS) and conductivity.

All metals except for mercury were analyzed by atomic absorption spectroscopy (AAS) using a graphite furnace. Samples were analyzed for mercury by cold vapor atomic absorption spectroscopy (CVAAS) using a Laboratory Data Control Model 1234 mercury monitor. Instrument operating conditions and detection limits for the different inorganic species are described in Appendix B.

Hydrogen Sulfide and Ammonia

Hydrogen sulfide (H_2S) concentrations were determined as sulfide by the titrimetric (iodine) method, Standard Method 428 D (APHA, et al., 1976). Ammonia (NH_3) concentrations were determined colorimetrically, using the phenate method, Standard Method 418 C (APHA, et al., 1976). Absorbance was measured at 640 nm with a Perkin Elmer-Hitachi Model 111 uv-visible spectrophotometer.

Indicator Microorganisms

All microbiological analyses were performed by Morning Star Laboratories of Vernon, California. Total coliforms were assayed by Standard Method 908 A, multiple tube fermentation. Fecal coliforms were quantified by Standard Method 908 C; in this case cultures of *Escherichia coli* and *Enterobacter aerogenes* were used as positive and negative controls respectively. The fecal streptococcus assay was Standard Method 910 A, the multiple tube technique. In all the bacteriological assays, both presumptive and confirmed tests were made.

For the bacterial virus assay, Morning Star Laboratories used a method developed by Atlantic Research Corporation and described in detail by Margler and Rogozen (1980). In this method, 0.5-, 1- and 5-ml volumes of sample are apportioned to culture tubes containing 4 ml of sterile, melted semi-solid nutrient broth (0.75 percent agar) held at 45 ^{o}C. To each tube, 0.5 ml of an 18- to 24-hour nutrient broth culture of *E. coli* C. is added. The tubes are shaken on a vortex mixer and poured over nutrient agar plates, which are then incubated for 6 hours at 35 ^{o}C.

Analytical methods used by the UCD team are described in detail by Fanelli et al. (1981). Aliquots of water were vacuum filtered through a 0.45-)m HA Millipore filter immediately after sample collection. Filters were place in sterile selenite cystine enrichment broth. The next day, the broth was incubated at 37 ^{o}C for 18 to 24 hours and then streaked on MacConkey and hektoen enteric agar plates. The plates were then incubated at 37 ^{o}C for 18 to 24 hours and colonies resembling salmonellae were examined morphologically, biochemically and serologically. All non-lactose fermenting organisms were examined. *Pseudomonas aeruginosa* was assayed by Standard Method 914 D, membrane filter technic (tentative). Departures from this method are mentioned where applicable.

Legionnaires' Disease Assay

Water samples were analyzed for *Legionella pneumophila* using methods described by Morris et al. (1979). Samples are first screened with direct fluorescence antibody (DFA) to determine which contain FA-positive bacteria and are most likely to yield isolates when cultured. Guinea pigs are inoculated with an amount of sample depending upon the number of colony-forming

units on Feeley-Gorman and charcoal yeast extract agars. Animal tissues are then examined for the bacterium.

6.3 TASK 3 SAMPLING AT MUNICIPAL TOWER NO.1 (BURBANK/OLIVE 1)

6.3.1 Site Description and Sampling Conditions

Task 3 sampling was conducted on 27 November 1979 on the cooling tower serving the Burbank Public Service Department's Olive 1 power plant. The day was clear and warm, with negligible wind; water vapor plumes from all operating cooling towers at the plant were vertical.

The Olive 1 tower, which is shown in Figures 6.3-1 and 6.3-2, is a five-cell, crossflow, mechanical induced-draft unit manufactured by Marley. Its circulating water rate is nominally 2.15 m^3/s (34,000 gpm) and its makeup water rate is estimated by the plant operator to be 0.062 m^3/s (980 gpm). Figure 6.3-3 shows how Olive 1 and its twin, Olive 2, are interconnected. Under normal operating conditions, flows from the cold water basins of both towers are combined and pumped through a 91-cm (36-in) suction line to the power plant condenser. Hot water is returned to the two towers by risers leading to the hot water trough associated with each cell. The cold water basin of Olive 1 is equipped with a sensor which measures the water level. When this level is too low, makeup water is added to the cold water basin of Olive 2; since circulating water flows from and to the two towers are combined, the makeup water eventually is partitioned between the towers. Blowdown is taken from the cold water basin of Olive 1. On the day of our sampling, Olive 2 was not operating.

To the best of our knowledge, the power plant and cooling tower were operating under normal conditions. At about 1700 hours, hypochlorite was added to the south end of the cold water basin. According to the plant operator, the purpose of this shock loading was to achieve a 1-ppm residual in the system for the next 24 hours.

6.3.2 Procedures

SAI staff were accompanied by members of the University of California at Davis (UCD) research team, who were collecting water samples for assay of salmonellae and *Pseudomonas aeruginosa*. Their collection points and sampling times were the same as SAI's. Samples were collected on the hour from 1200 to 1900 hours. At 1700 hours, just before the addition of chlorine,

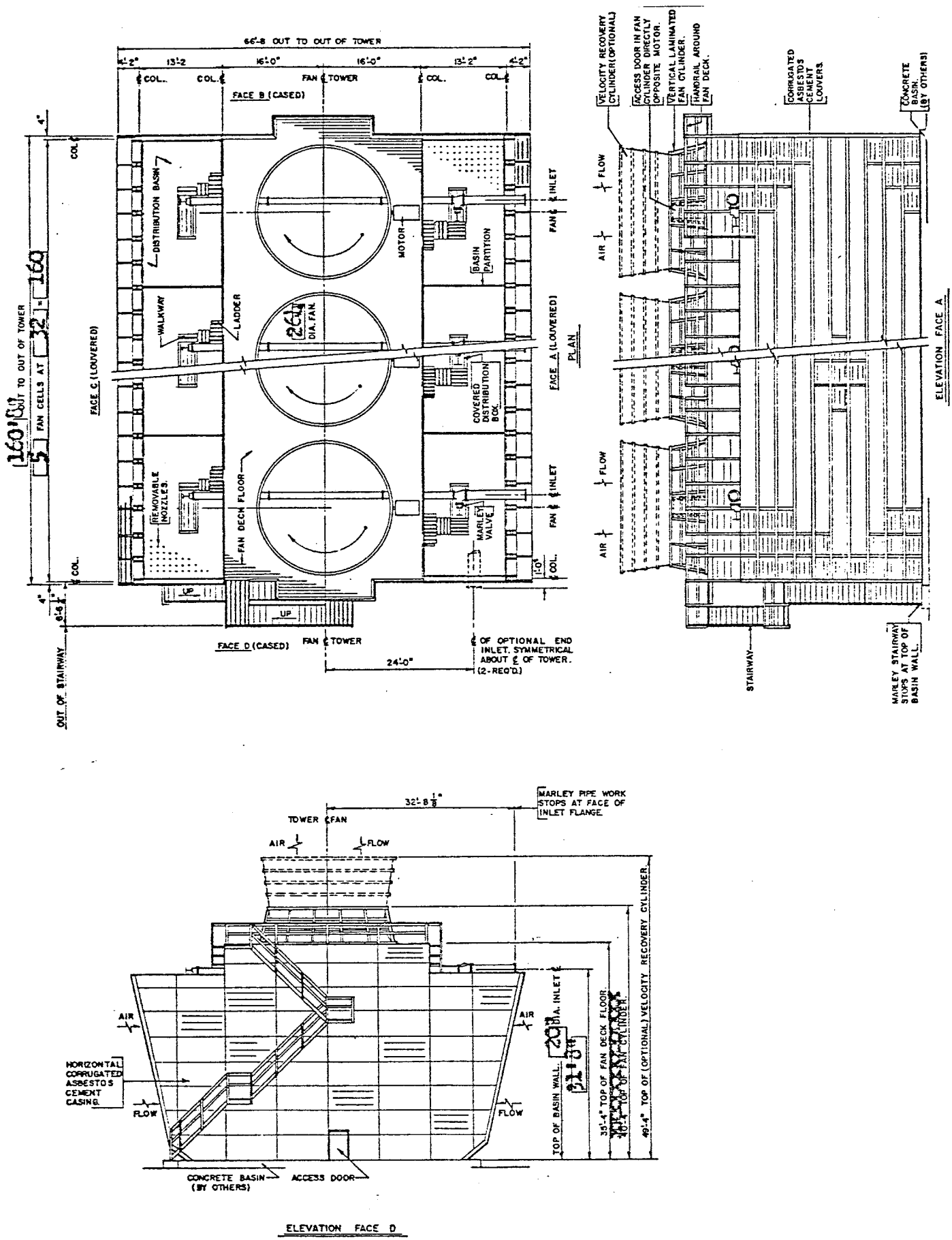

Figure 6.3-1. Plan and Elevation of Burbank/Olive 1 Cooling Tower.

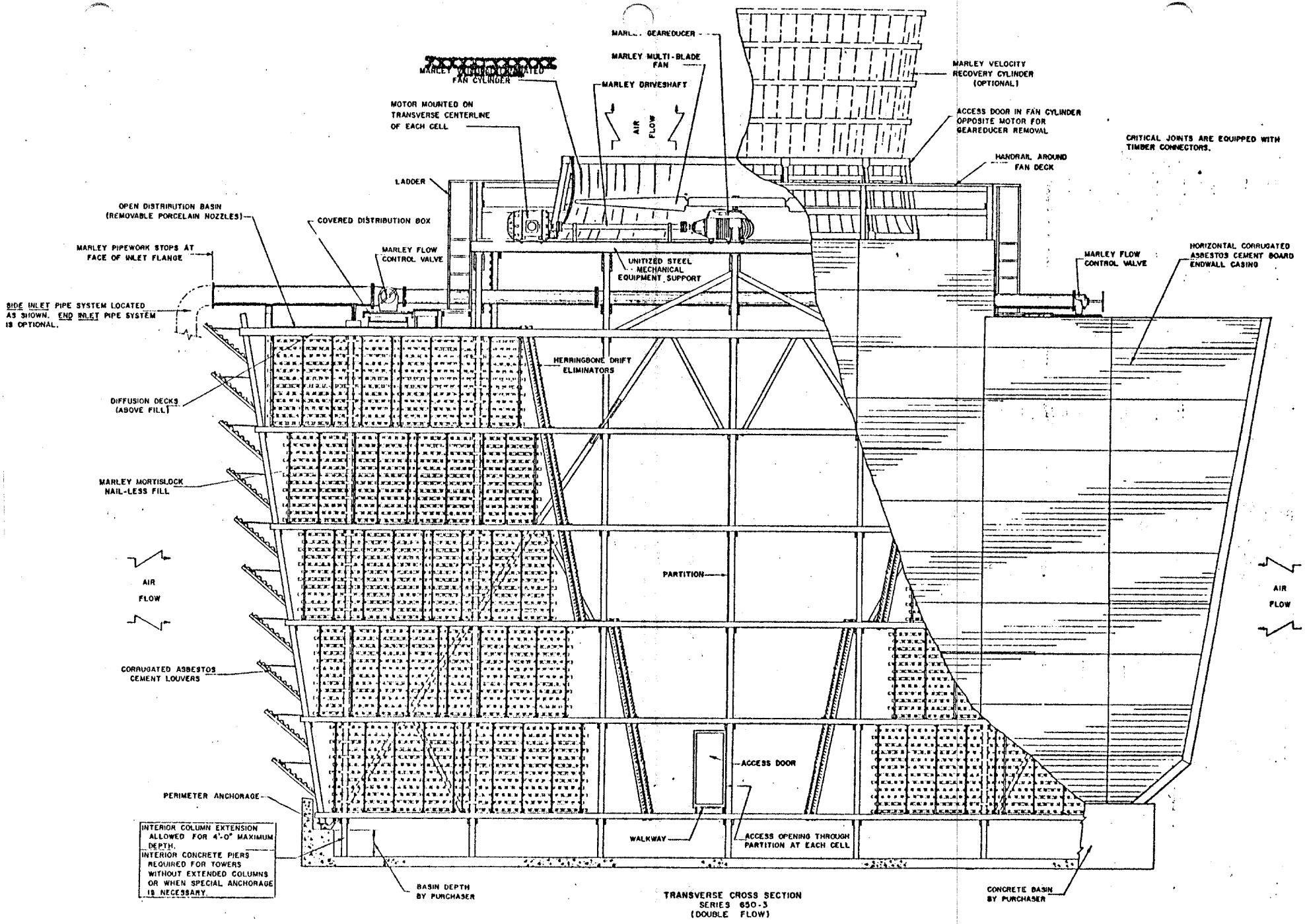

Figure 6.3-2. Cutaway View of Burbank/Olive 1 Cooling Tower.

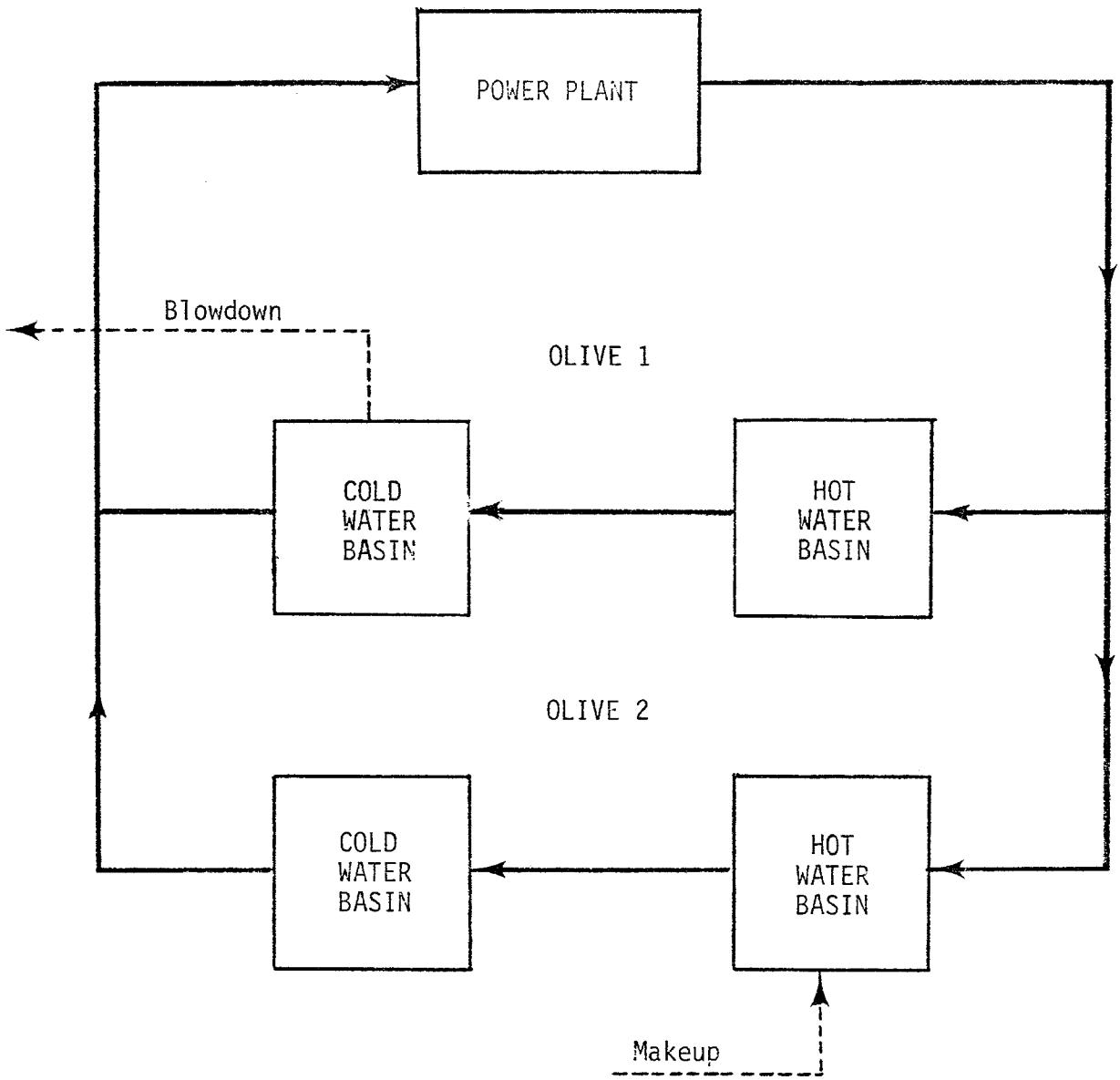

Figure 6.3-3. Schematic of Cooling Water Flows at Burbank's Olive Power Plant.

samples for Legionella pneumophila assay were collected from the cold water basin and the makeup water supply. Samples for volatile organic analysis were collected in the morning and shortly after chlorination.

Our water collection locations are shown in Figure 6.3-3. The mouth of the makeup water pipe was about 1.5 m above the surface of the cold water basin of Olive 2 tower, just inside the fiberglass louvers on the east side. To collect the water samples, it was necessary for the technician to crawl between the louvers while being held by the feet. (Later, when we performed Task 4 sampling, a sampling line had been added to the makeup water inlet pipe.) Hot water basin samples were collected from the trough which runs around the tower perimeter and is accessible through hatches in the top deck. The sampling point was on the west side of the tower, opposite the central cell, and about 2 m from the discharge of the hot water riser. To obtain the cold water basin sample, it was necessary to enter the tower through a door on the north side and walk on wooden planks through the plenum chanbers. Samples were taken from the exact center of the central cell.

Collection and analysis procedures were as described in Section 6.2, with two differences in the UCD protocol. In the Salmonella and Pseudomonas assays, 100 and 10 ml of water were filtered, respectively. In addition, the M-PA agar used for the Pseudomonas aeruginosa tests lacked the antibiotics nalidixic acid and actidione.

6.3.3 Results and Discussion

General Observations

All water samples, including makeup, were pale yellow in color and had a strong, unidentified chemical odor. The cold water basin surface was covered entirely with a 10-cm thick layer of white foam. At 1700 hours, when the chlorine was added, the odor of that disinfectant became intense throughout the tower area, but especially at the hot water basin sampling point. Hot and cold water was turbid; filtration of more than 100 ml was very difficult.

Temperature, pH and Chlorine

Figure 6.3-4 shows the measured values of temperature, pH and total residual chlorine for each hour of the testing period. The time when chlorine was added is indicated by an arrow. It is evident that the heat load on the

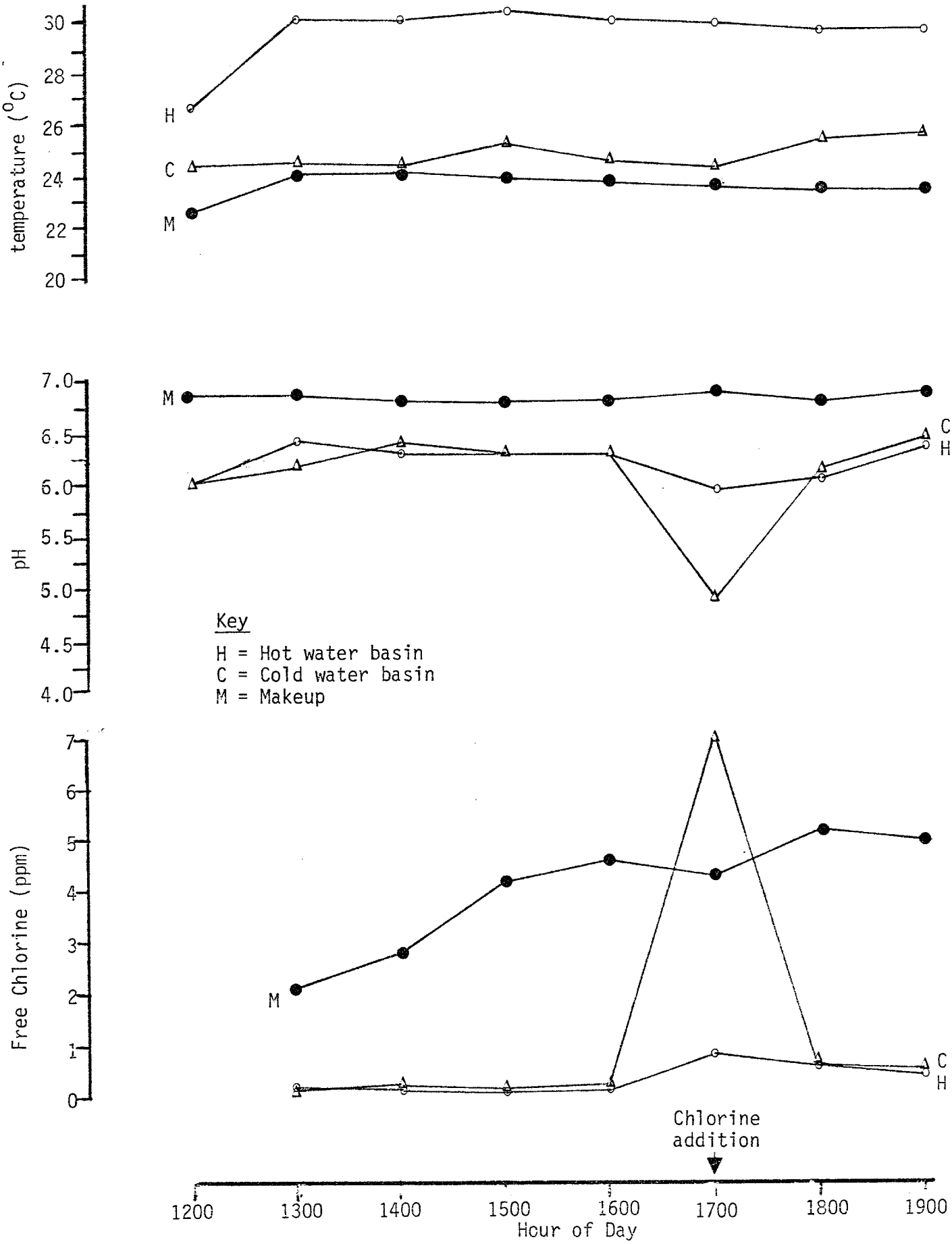

Figure 6.3-4. Temperature, pH and Free Chlorine Residual, Burbank Olive 1 Cooling Tower, 27 November 1979 Sampling.

tower was relatively constant. The circulating water pH remained slightly below the operator's target value of 6.6, except when the chlorine was added. At that time, the hot water pH dropped to 4.9. Within two hours, however, the pH returned to, or exceeded, its former levels. Evidently, the minerals dissolved in the recirculating water have a strong buffering effect. Chlorine levels in the makeup water increased steadily throughout the day, while those in the tower remained constant until 1700 hours.

Inorganic Constituents

Table 6.3-1 shows the results of SAI's analyses of the inorganic constituents of the makeup water, hot water basin and cold water basin samples. Makeup water concentrations of lead, mercury and zinc are considerably lower than those reported earlier for the Burbank Water Reclamation Plant effluent and shown in Table 5.1-6. Total dissolved solids (TDS), total suspended solids (TSS), and cadmium levels are comparable, and data for comparing other elemental concentrations are lacking. One reason for the lower Pb, Hg and Zn concentrations in our samples may be the following. The data in Table 5.1-6 were for samples collected during a period of relatively low hydraulic flows through the water reclamation plant (0.07 to 0.12 m^3/s versus "normal" flows of 0.26 to 0.31 m^3/s). The fact that TDS and TSS concentrations are comparable implies that, in general, mineral concentrations in the sewage plant effluent are independent of hydraulic flow rate. However, if the mass loading of Pb, Hg, and Zn, from industrial activities, for example, were constant throughout the year, then the concentrations of these elements would be expected to increase during periods of low flow. This explanation is both supported and weakened by examination of monthly concentration and flow data from the Los Angeles-Glendale Water Reclamation plant, a similar facility. TDS levels are independent of hydraulic flows ($r = -0.633$), but so are concentrations of Cd, Pb, Hg and Zn. The best correlation between flow and metal concentration is that for Zn ($r = -0.733$). It should be noted that the Burbank wastewater treatment plant effluent values reported in Table 5.1-6 are for 24-hour composite samples taken once per calendar quarter. We thus have no idea how concentrations are statistically distributed. Where our sample values fall in the "true" distribution is a matter of speculation.

Table 6.3-1

INORGANIC CONSTITUENTS IN BURBANK/OLIVE 1 COOLING TOWER WATER, 27 NOVEMBER 1979 SAMPLING[a]

Constituent	Units of Concentration	Makeup Water	Hot Water Basin Conc.	Hot Water Basin HW/M[b]	Cold Water Basin Conc.	Cold Water Basin CW/M[c]
Cadmium	ppb	5	16	3.2	17	3.4
Chromium	ppb	24	15	0.625	15	0.625
Copper	ppb	18	193	10.7	188	10.4
Lead	ppb	6	40	6.67	45	7.5
Mercury	pptr	44	180	4.09	160	3.64
Zinc	ppb	<4	4270	1068	<1910	477
Tot. Susp. Sol.	ppm	8.93	21.4	2.40	17.9	2.00
Tot. Diss. Sol.	ppm	692	1947	2.81	1962	2.84
Conductivity	μmho/cm	1130	2050	1.81	2300	2.04

[a] Whole (unfiltered) water samples.

[b] HW/M = ratio of hot water basin concentration to makeup water concentration.

[c] CW/M = ratio of cold water basin concentration to makeup water concentration.

Our results can be used to obtain a picture of how various constituents become more or less concentrated as the result of loss of water from the tower by evaporation and drift. As was noted in Section 4.3.1, the plant operators' target is 2.5 cycles of concentration. In Table 6.3.1, the ratio of basin water concentration to makeup water concentration is shown for each basin. Since TDS levels are increased by a factor of about 2.8, it appears that the tower was operating under normal conditions. Basin concentration of chromium are lower than those in the makeup water; apparently some chromium is lost from the system. All the other metals increase to a greater extent than do total dissolved solids. Most striking are an order-of-magnitude increase in copper and a three orders-of-magnitude increase in zinc. The most likely source of the zinc was not the makeup water, but rather a zinc-based corrosion inhibitor (Olin 2100), which was used throughout 1979 (MacDougall, 1980). According to the plant operators, the large increase in copper was probably due to corrosion of condenser pipes.

Finally, it is seen that, except for zinc, the hot water and cold water basin concentrations of the inorganic constituents are quite similar. Differences are so slight that variations are probably due to experimental error.

While the USEPA/MERL did not analyze our samples for pollutants of potential air pollution concern, their results are of general interest. Concentrations of Na^+, K^+, Mg^{++}, and Cl^- in the cold water basin were 373, 32, 62 and 355 ppm, respectively. The phosphate concentration of 17.7 ppm was the highest for all of the toweres sampled. The ratio of cold water basin to makeup water concentration for chloride ion varied from 2.19 to 2.78. Thus, while chloride may not be considered a truly conservative constituent, the estimated cycles of conceentration are comparable to those determined from our results.

Volatile Organics

Results of the analyses for volatile organic compounds are shown in Table 6.3-2. Note that the afternoon water samples were taken immediately after hypochlorite solution was added to the hot water basin. Chloroform and dibromochloromethane concentrations in the cooling tower water were similar to those measured by Jolley et al. (1977) in two cooling towers at Oak Ridge National Laboratory. (See Table 5.6-3.) From our data, it appears that at

Table 6.3-2

VOLATILE ORGANIC COMPOUND CONCENTRATIONS IN
BURBANK/OLIVE 1 COOLING TOWER WATER, 27 NOVEMBER 1979 SAMPLING
(Concentrations in ppb)

Compound	Makeup Water		Hot Water Basin		Cold Water Basin	
	Morning	Afternoon[a]	Morning	Afternoon[a]	Morning	Afternoon[a]
Chloroform	22	22	14	20	17	15
Trichloroethane	18	80	ND[b]	ND	ND	ND
Trichloroethene	ND	8	ND	ND	ND	ND
Dibromochloromethane	<5	<5	ND	<5	ND	ND

[a] Samples taken immediately after tower was chlorinated.

[b] ND = Not detected (<1 ppb).

least some of the chloroform entering via the makeup water is lost from the system, i.e. evaporated. Apparently all the trichloroethane is lost.

Nonvolatile Organics

Before they were fractionated, base-neutral extracts of the three composite water samples were analyzed by electron capture gas chromatography to determine if any chlorinated compounds were present. Components with retention times similar to those of the pesticides lindane and aldrin were present at 40 and 150 parts per trillion, respectively, in the makeup water. These compounds were not detected in the hot and cold water basin samples.

Table 6.3-3 shows the total organic compound concentrations found in the acid and base-neutral extracts of all the water samples. Individual species were not identified. However, to judge from the results of gas chromatographic analysis of the nonvolatile organics in the Glendale cooling towers (see Section 6.5), the concentration of any given component is probably very low. Hot and cold water basin concentrations of all fractions of the sample are about 1.6 times those in the makeup water, indicating a buildup of nonvolatile organics in the system.

Indicator Microorganisms

Table 6.3-4 presents the results of the analyses of our eight-hour composite samples of makeup and cooling tower basin water. The total coliform concentration in the makeup water was higher than the Regional Water Quality Control Board's standard of 2.2 MPN/100 ml in the Burbank Water Reclamation Plant effluent. Apparently, the tower provides an excellent environment for growth of these indicator organisms. Fecal coliforms, which were barely detectable in the makeup, also grow in the tower water. Fecal streptococcus concentrations remain about the same, while concentrations of E. coliphage appear to decrease in the system.

Fecal coliform concentrations in the hot and cold water basins were considerably below the 100 and 200 MPN/100 ml reported for two dates in 1977 by Adams et al. (1978). Since analytical methods were different, the results may not be comparable.

Fanelli et al. (1981) have reported on the results of the UC Davis team's concurrent sampling for pathogens. No salmonellae were found in any of the eight hourly samples taken at Burbank/Olive 1. Species of Citrobacter (C.

Table 6.3-3

CONCENTRATIONS OF TOTAL NONVOLATILE ORGANIC COMPOUNDS
EXTRACTED FROM BURBANK/OLIVE 1 COOLING TOWER,
27 NOVEMBER 1979 SAMPLING

(Concentrations in ppb)[a]

	Makeup Water	Hot Water Basin	Cold Water Basin
Acid Extract	< 0.6	< 0.6	< 0.6
Base-Neutral Extract			
Aliphatic	trace	0.81	0.72
Aromatic	1.85	2.5	2.4
Total Base Neutral	1.85	3.31	3.12
Total Nonvolatiles	1.85-2.45	3.31-3.91	3.12-3.72

[a]Concentrations are based upon average response factors for standard n-alkanes eluting within the range of sample elution times.

Table 6.3-4

INDICATOR MICROORGANISMS IN COMPOSITE SAMPLES
FROM BURBANK/OLIVE 1 TOWER, 27 NOVEMBER 1979 SAMPLING

Organism	Units	Makeup Water	Hot Water Basin	Cold Water Basin
Total coliforms	MPN/100 ml	15	≥2400	≥2400
Fecal coliforms	MPN/100 ml	<3	15	23
Fecal streptococcus	MPN/100 ml	7	7	9
E. coliphage[a]	Plaques/ml[b]	7.1	1.6	2.1

[a]Average of duplicate assays of each composite water sample.

[b]Values reported as (plaques/5 ml + plaques/1 ml + plaques/0.5 ml)/6.5

freundii and C. intermedium) were identified in two of the hot water basin samples and five of the cold water basin samples. Klebsiella pneumoniae was isolated from one makeup water sample. It is interesting to note that the chlorination at 1700 hours apparently did not destroy the Citrobacter intermedium, although data for assessing changes in population are unavailable.

According to Fanelli et al., results of the examination of the water for Pseudomonas aeruginosa are inconclusive. Pseudomonads were definitely present, but, since an incomplete M-PA agar was used, it was not possible to differentiate P. aeruginosa from other species. In any event, the total growth of pseudomonads from the cooling tower basin samples was four orders of magnitude greater than that observed for the makeup water samples. As will be discussed in Section 6.4, the results of the analysis of water taken from the Glendale tower indicate that P. aeruginosa constitutes only a small fraction of the total pseudomonad population in the basin water.

According to the Centers for Disease Control, the cold water basin samples were negative for Legionella pneumophila on cultures, including passage through guinea pigs (Broome, 1980).

6.4 TASK 3 SAMPLING AT MUNICIPAL TOWER NO. 2 (BURBANK/MAGNOLIA 4)

6.4.1 Site Description and Sampling Condition

As noted above, it was necessary to choose an additional tower at the Burbank or Glendale power plant, since other wastewater-using towers would not come on line in time for our sampling effort. After inspecting several towers at the two facilities, we decided upon the one associated with the Burbank Public Service Department's Magnolia 4 power plant. This tower was particularly attractive because (1) it is a counterflow device, while the Olive 1 tower has a crossflow design; (2) its fanstacks are low enough so that scaffolding was not necessary; and (3) water sampling points were very accessible.

The Magnolia 4 tower is a six-cell counterflow unit designed by Fluor and has a nominal circulating water flow rate of 1.64 m^3/s (26,000 gpm) and a makeup water rate of 0.036 m^3/s (570 gpm). Although it shares the same makeup water source as Magnolia 3, a smaller tower of similar design, and the two Olive towers, it does not share its circulating water with any other

tower. On the day of our sampling, the Magnolia 3 and Olive 1 cooling towers were not operating. To the best of our knowledge, the Magnolia 4 tower was operating under normal conditions. The last addition of chlorine had been at 1900 hours of the previous day, and no chlorine was added during our tests.

The day of our Task 3 sampling, 21 January 1981, was overcast and cold, with moderate winds after 1400 hours. In the morning a dense vapor plume issued from the fanstacks, but by noon emissions were invisible.

6.4.2 Procedures

SAI staff were accompanied by two members of the UC Davis team, who collected samples from the same places as we. Samples for microbiological analysis were collected at 0800, 0900, 1200, 1300, 1500, and 1600 hours. Duplicate samples for volatile organic analysis were collected only at 1000 and 1400 hours. Samples for metals and chlorine analysis were collected on the hour from 1000 to 1500 hours and were composited.

Makeup water samples were taken from an open pipe which discharges into the cold water basin of the Magnolia 3 tower. Cold water basin samples were taken from the northwest corner of the basin, which extends about 1 m from the tower walls and is exposed to the atmosphere. Hot water samples were collected from a tap off the riser to the cell on the north end of the tower.

6.4.3 Results and Discussion

General Observations

Both makeup and recirculating water were similar in appearance and odor to the water collected from the Olive 1 tower. In the late morning, a strong odor of sewage was present in the cooling tower area.

Temperature, and pH

Figure 6.4-1 shows the measured values of temperature and pH for each hour of the testing period. While the makeup water temperature was nearly constant, the heat load on the tower rose steadily until mid-afternoon, reflecting the normal pattern of electrical demand. All water temperatures were lower than those for the Olive 1 tower. After the 1100 hours pH reading, it was noticed that a connection in the pH meter was loose. Although the pH readings taken at 0900, 1000 and 1100 hours appear to be in line with those

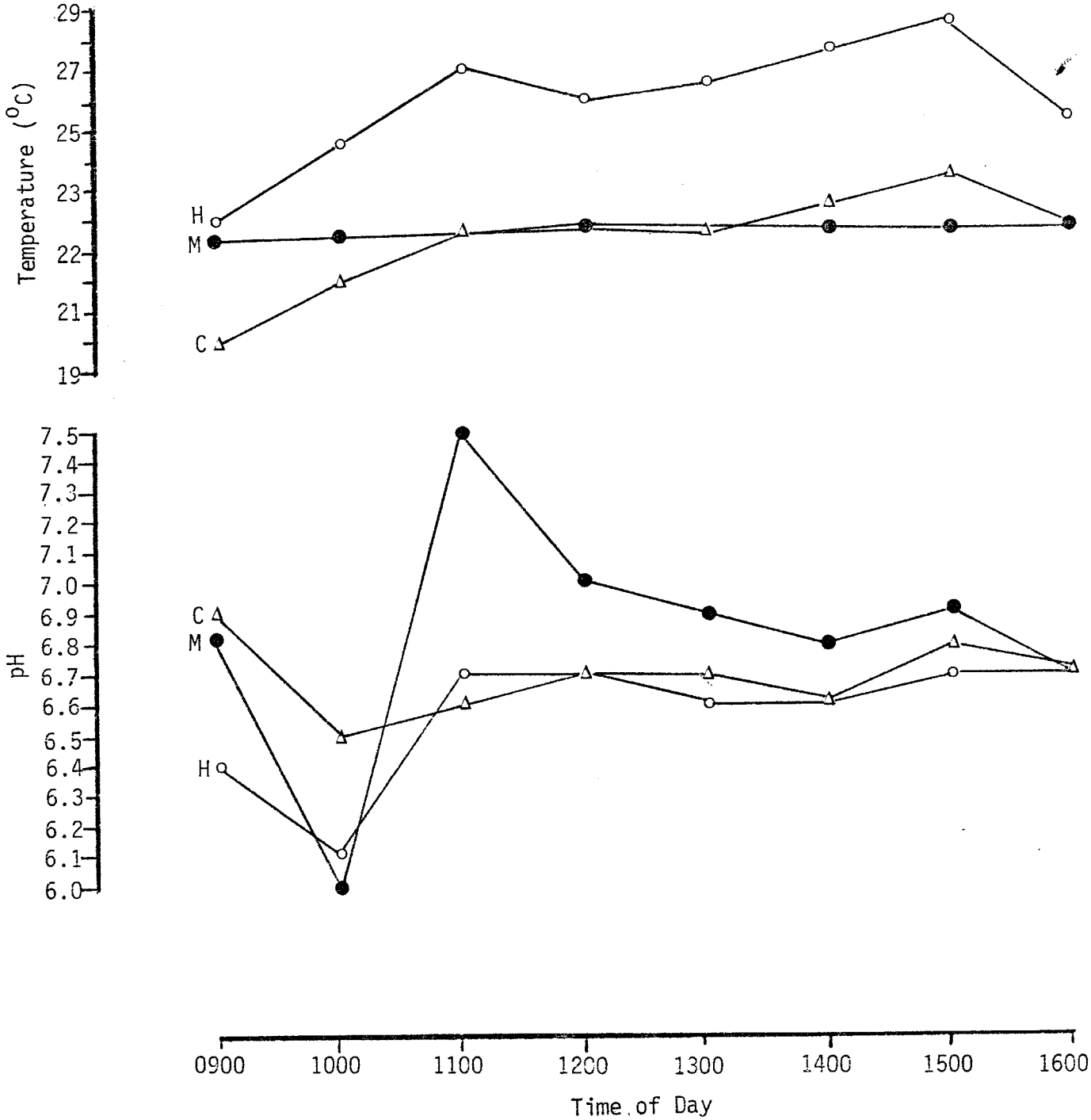

Figure 6.4-1. Temperature and pH, Burbank/Magnolia 4 Cooling Tower, 21 January 1981 Sampling

taken during the rest of the day, there is a possibility that they are incorrect. As with Olive 1, circulating water pH values measured from 1200 hours and afterward were close to the operators' target of 6.6 for most of the sampling period.

Inorganic Constituents

Table 6.4-1 shows the results of our analyses of the inorganic constituents of the makeup water, hot water basin and cold water basin samples. It is interesting to compare basin concentrations with those found in Municipal Tower No. 1 (see Table 6.3-1), since both towers have the same makeup water source. Makeup water quality was roughly comparable in the two cases, although the chromium concentration was over twice that measured in 1979, and the zinc concentration was over 13 times as high. The Magnolia 4 tower appears to have nearly the same cycles of concentration as Olive 1; for example, the ratio of cold water basin TDS to makeup TDS is 2.87 in Magnolia 4 and 2.84 in Olive 1. The buildup of individual species concentration from makeup to circulating water, however, is quite different for the two towers. Mercury concentrations increase in Olive 1 and decrease in Magnolia 4. Lead and zinc increase in both towers, but to a much smaller extent in Magnolia 4. On the other hand, Magnolia 4 circulating water copper concentrations are an order of magnitude higher than those in Olive 1, presumably the result of relatively severe condenser tube corrosion. As with Olive 1, chromium decreases in concentration from makeup to circulating water at Magnolia 4, inferring loss from the system. However, Magnolia 4's basin water chromium concentrations are the highest of the five towers studied to which chromium is not deliberately added.

Volatile Organics

Figure 6.4-2 shows the gas chromatograms for morning water samples from the makeup source and the cold water basin. The chromatograms for the afternoon samples, including those from the hot water basin, were essentially the same. The only discernable peaks correspond to methylene chloride and hexane. Since these species are common laboratory contaminants and appear in chromatograms run on sample blanks, we conclude that volatile organic compounds of interest are essentially absent in the makeup water and the hot and cold water basin samples. (Limits of detection for standard compounds are presented in Appendix B.)

Table 6.4-1

INORGANIC CONSTITUENTS IN BURBANK/MAGNOLIA COOLING TOWER WATER, 21 JANUARY 1981 SAMPLING[a]

Constituent	Units of Concentration	Makeup Water	Hot Water Basin Conc.	Hot Water Basin HW/M[b]	Cold Water Basin Conc.	Cold Water Basin CW/M[c]
Cadmium	ppb	14	14	1.0	14	1.0
Chromium	ppb	50	45	0.9	48	0.96
Copper	ppb	26	1230	47.3	1299	50.0
Lead	ppb	1	1	1	2	2
Mercury	pptr	42.9	41	0.96	41.7	0.97
Zinc	ppb	53	617	11.6	635	12.0
Tot. Susp. Sol.	ppm	3.26	22.2	6.81	23.1	7.09
Tot. Diss. Sol.	ppm	564	1490	2.64	1618	2.87
Conductivity	μmho/cm	875	1920	2.19	1900	2.17

[a]Whole (unfiltered) water samples.

[b]HW/M = ratio of hot water basin concentration to makeup water concentration.

[c]CW/M = ratio of cold water basin concentration to makeup water concentration.

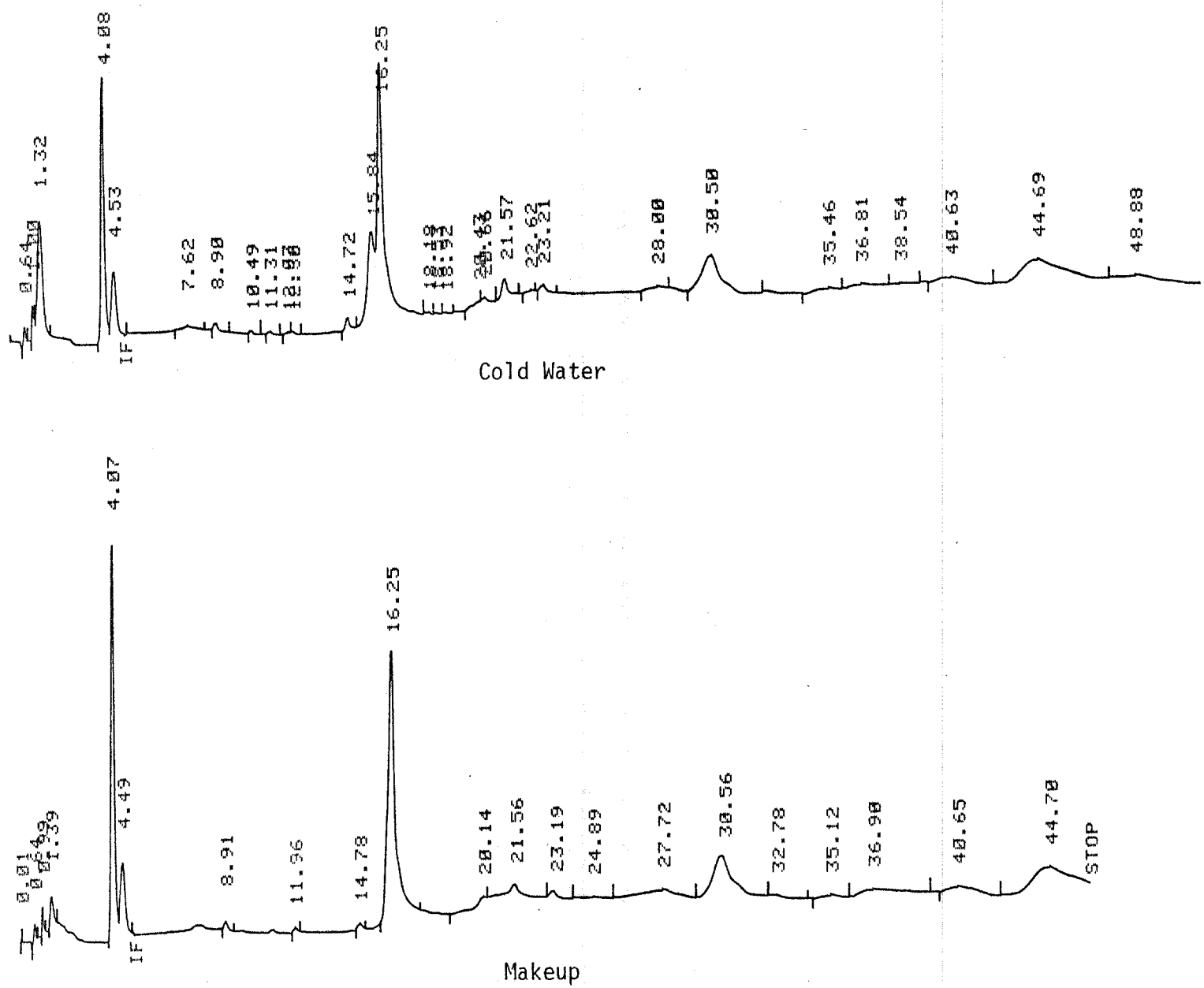

Figure 6.4-2. Gas Chromatograms of Makeup and Cold Water Basin Samples, Burbank/Magnolia 4 Cooling Tower, 21 January 1981.

Nonvolatile Organics

Analysis of makeup and hot water basin samples by GC electron capture detection indicated the possible presence of the pesticides parathion in the makeup (60 pptr) and malathion in the hot water basin (300 pptr). FID GC analysis of the base-neutral and acid extracts of both makeup and hot water basin samples revealed no significant components to be present.

Indicator Microorganisms

Samples for microbiological assay were combined into morning (0800 and 0900), mid-day (1200 and 1300) and afternoon (1500 and 1600) composites. Results of the analyses are shown in Table 6.4-2. The makeup water apparently had higher concentrations of indicator bacteria than during our Task 3 sampling at Olive 1 in 1979. Coliform concentrations in the recirculating water were lower, while fecal streptococcus and E. coliphage concentrations were higher. Some variation of indicator organism concentrations with time is seen. A rise in concentrations from morning to midday might be a result of diminishing effects of chlorine. Data are insufficient to make any generalizations, however.

The UC Davis team found Enterobacteriaceae only in the makeup water. *Citrobacter* spp. were isolated in three of the nine hourly samples, *Proteus* spp. were detected in two, and *Klebsiella pneumoniae* were isolated in one (Fanelli et al., 1981). It was suggested, however, that the presence of *K. pneumonia* in the hot and cold water basins may have been masked by the larger numbers of coliforms detected by the SAI tests.

None of the Burbank/Magnolia 4 samples contained a sufficient number of *Pseudomonas aeruginosa* in 10 ml of water to be recovered by the isolation methods used.

6.5 TASK 3 SAMPLING AT MUNICIPAL TOWER NO. 3 (GLENDALE)

6.5.1 Site Description and Sampling Conditions

Task 3 sampling was conducted on 22 April 1980 on the Number 4 cooling tower at the City of Glendale's Grayson Power Plant. The day was cold and overcast with light to heavy rain during the sampling period. The Number 4 tower is an eight-cell Foster-Wheeler counterflow, mechanical induced-draft unit with a nominal circulating water rate of 2.11 m^3/s (33,400 gpm) and a

Table 6.4-2

INDICATOR MICROORGANISMS IN COMPOSITE SAMPLES
FROM BURBANK/MAGNOLIA 4 TOWER, 21 JANUARY 1981 SAMPLING

Organism	Units	Makeup Water			Hot Water Basin			Cold Water Basin		
		0800 +0900	1200 +1300	1500 +1600	0800 +0900	1200 +1300	1500 +1600	0800 +0900	1200 +1300	1500 +1600
Total coliforms	MPN/100 ml	23	93	<3	240	460	93	240	460	240
Fecal coliforms	MPN/100 ml	<3	4	<3	9	4	4	43	9	4
Fecal streptococcus	MPN/100 ml	4	15	15	15	23	15	23	21	28
E. coliphage	Plaques/ml[a]	3.0	13.8	4.0	2.0	3.1	4.9	2.8	2.3	1.8

[a]Values reported as (plaques/5 ml + plaques/1 ml + plaques/0.5 ml)/6.5

makeup water flow rate of 0.019 to 0.025 m^3/s (300 to 400 gpm). To the best of our knowledge, the tower was being operated under normal conditions, at 6 to 9 cycles of concentration. Chlorine gas is slug fed to the cold water basin 3 times per day for 60 minutes at a time, to achieve a free chlorine residual of 0.5 to 1.5 ppm (Kendall, 1979).

6.5.2 Procedures

SAI staff were accompanied by a member of the UC Davis team. Filtration equipment and other instruments were set up in a storage shed next to the Number 5 cooling tower. Makeup water samples were taken from a tap on the incoming line from the phosphate removal plant, about 100 m from the tower. Hot water samples were collected from a tap on a riser, and cold water basin samples were taken directly from the cold water basin, which extends to about 1 m beyond the tower walls. Samples were collected on the quarter hour from 1015 to 1715 hours. Collection and analysis procedures were as described in Section 6.2.

6.5.3 RESULTS AND DISCUSSION

All water samples were markedly clearer than those collected at Burbank/Olive 1. Filtration for the UC Davis team's bacteriological analysis was considerably easier. The cold water was slimy to the touch. At the 1415 sampling, foaming was observed in the cold water basin.

Temperature, pH and Chlorine

Figure 6.5-1 shows the measured values of temperature, pH, and total residual chlorine for each hour of the testing period. The pH meter's electrode was accidentally broken after the 1615 reading. Amperometric titrator readings for the 1015 samples were not repeatable, and were thus omitted; later measurements showed good repeatability. From Figure 6.5-1 it can be seen that the heat load on the tower declined gradually during the afternoon. Cold and hot water basin pH were above 7.7 throughout the day. The reason for the jump in makeup water pH at 1415 hours is unknown, although its effect upon recirculating water pH was apparently negligible. System pH is higher than at Burbank because the phosphorus removal plant process requires that the treated solution be highly basic; according to the plant operator, sulfuric acid is later added to bring the makeup water pH down to about 8 (Kendall, 1979). Makeup water chlorine levels declined steadily

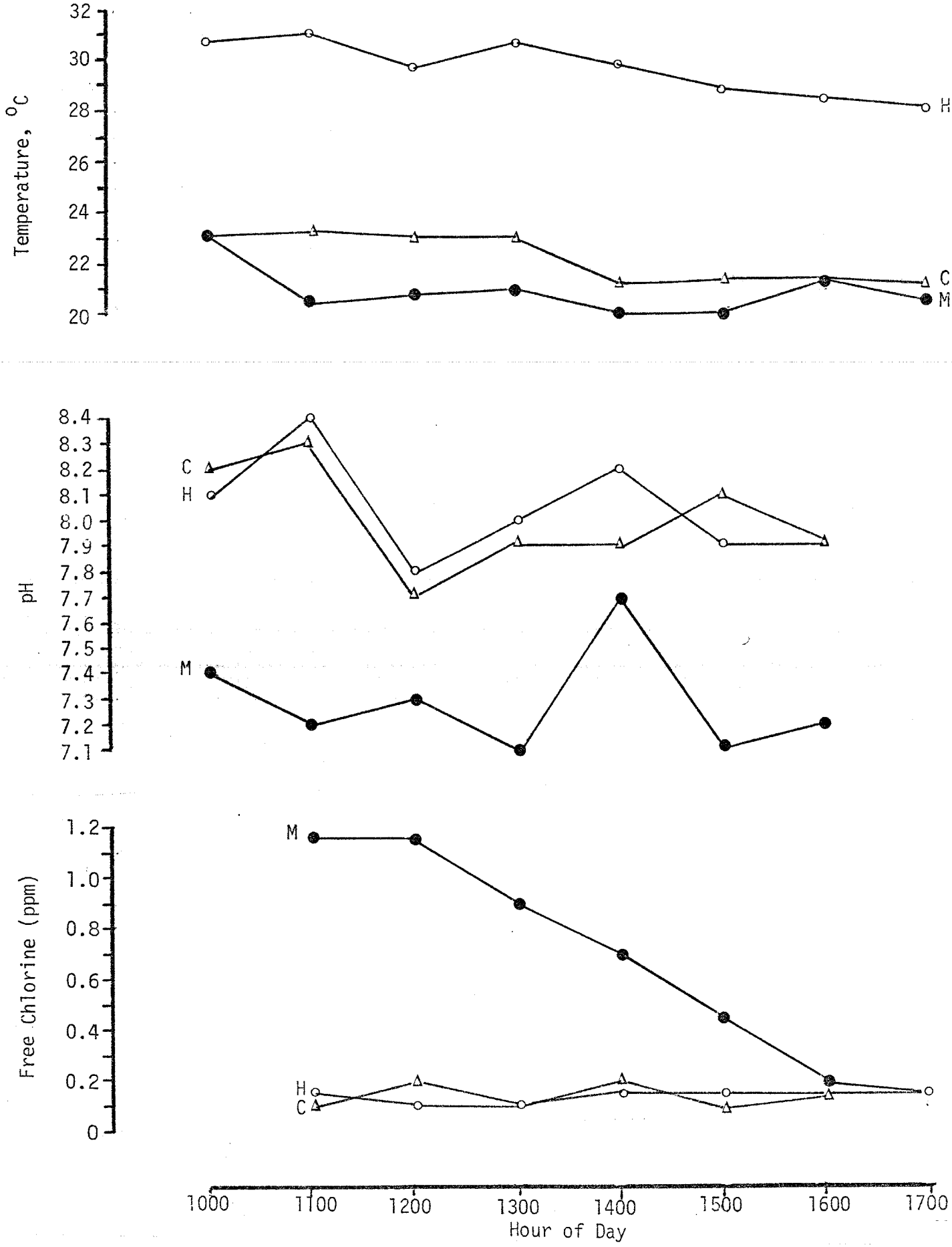

Figure 6.5-1. Temperature, pH, and Free Chlorine Residual, Glendale Cooling Tower, 22 April 1980 Sampling.

throughout the day, while circulating water chlorine concentrations were nearly constant. As seen in Figure 6.5-1, the target of 1 to 1.5 ppm chlorine residual was not achieved during the sampling period.

Inorganic Constituents

Table 6.5-1 shows the results of our analyses of the inorganic constituents of the makeup water, hot water basin and cold water basin samples. Analyses were performed only on the filtrates of the composite samples. Makeup water concentrations compare favorably with those reported earlier for the Los Angeles Glendale Water Reclamation Plant effluent (see Table 5.1-8), except that those for lead and mercury are considerably lower in our samples. One possible reason for this may be that these two metals may exist largely are in particulate forms and were thus not analyzed in the filtrate.

From the TDS and conductivity results, it would appear that about five cycles of concentration were achieved during our sampling period. The most striking increases in metal concentrations within the system are those for copper and zinc. According to the plant operator (Kendall, 1981), the system pH occasionally drops to a level that promotes a significant amount of corrosion of condenser tubes, which are composed of a zinc-copper alloy. If such a pH upset had occurred shortly before our sampling, then considerable levels of zinc and copper would still be in the system. Meanwhile both cadmium and chromium appear to be either lost from the recirculating water or present primarily as unanalyzed particulate matter.

Table 6.5-2 shows the results of the USEPA/MERL's analyses of the makeup and cold water basin samples. Of the ionic species measured, magnesium is probably the most conservative one in the system; i.e. it is not deliberately added to the recirculating water and does not leave the system through evaporation. Its cycles of concentration are within the target range of 6 to 9, as are those of chloride.

Volatile Organics

Figure 6.5-2 shows FID chromatograms for makeup, hot water basin and cold water basin samples. Difference in volatile organic composition among the three water sources appear to be insignificant. Compounds were identified and quantified by mass spectral analysis. Figure 6.5-3 shows the

Table 6.5-1

INORGANIC CONSTITUENTS IN GLENDALE COOLING TOWER WATER, 22 APRIL 1980 SAMPLING[a]

Constitent	Units of Concentration	Makeup Water	Hot Water Basin Conc.	Hot Water Basin HW/M[b]	Cold Water Basin Conc.	Cold Water Basin CW/M[c]
Cadmium	ppb	18	11	0.61	19	1.06
Chromium	ppb	65	22	0.34	22	0.34
Copper	ppb	9	956	106	994	110
Lead	ppb	<1	3	>3	4	>4
Mercury	ppt	16	61	3.81	34	2.13
Zinc	ppb	243	3670	15.1	203	0.84
Tot. Susp. Sol.	ppm	0.86	25.6	29.8	26.9	31.3
Tot. Diss. Sol.	ppm	698	3314	4.75	3255	4.66
Conductivity	μmho/cm	930	3880	4.17	3970	4.27

[a]Analyses done on filtrates.

[b]HW/M = ratio of hot water basin concentration to makeup water concentration.

[c]CW/M = ratio of cold water basin concentration to makeup water concentration.

Table 6.5-2

RESULTS OF USEPA/MERL ANALYSES OF COOLING TOWER WATER SAMPLES FROM GLENDALE TOWER, 22 APRIL 1980 SAMPLING

(All concentrations in ppm)

Constituent	Makeup Water	Cold Water Basin[a]	Cycles of Conc.
Na^+	116	552	4.76
K^+	12.6	45.5	3.61
Mg^{++}	17	106	6.24
Cl^-	80	675	8.44
$SO_4^=$	NM[b]	1850	-
Total Fe	NM	0.98[c]	-
Total PO_4^{3-}	NM	1.0[c]	-

Source: Neill, 1981.

[a]Average of two measurements, except where otherwise noted.

[b]Not measured

[c]One measurement

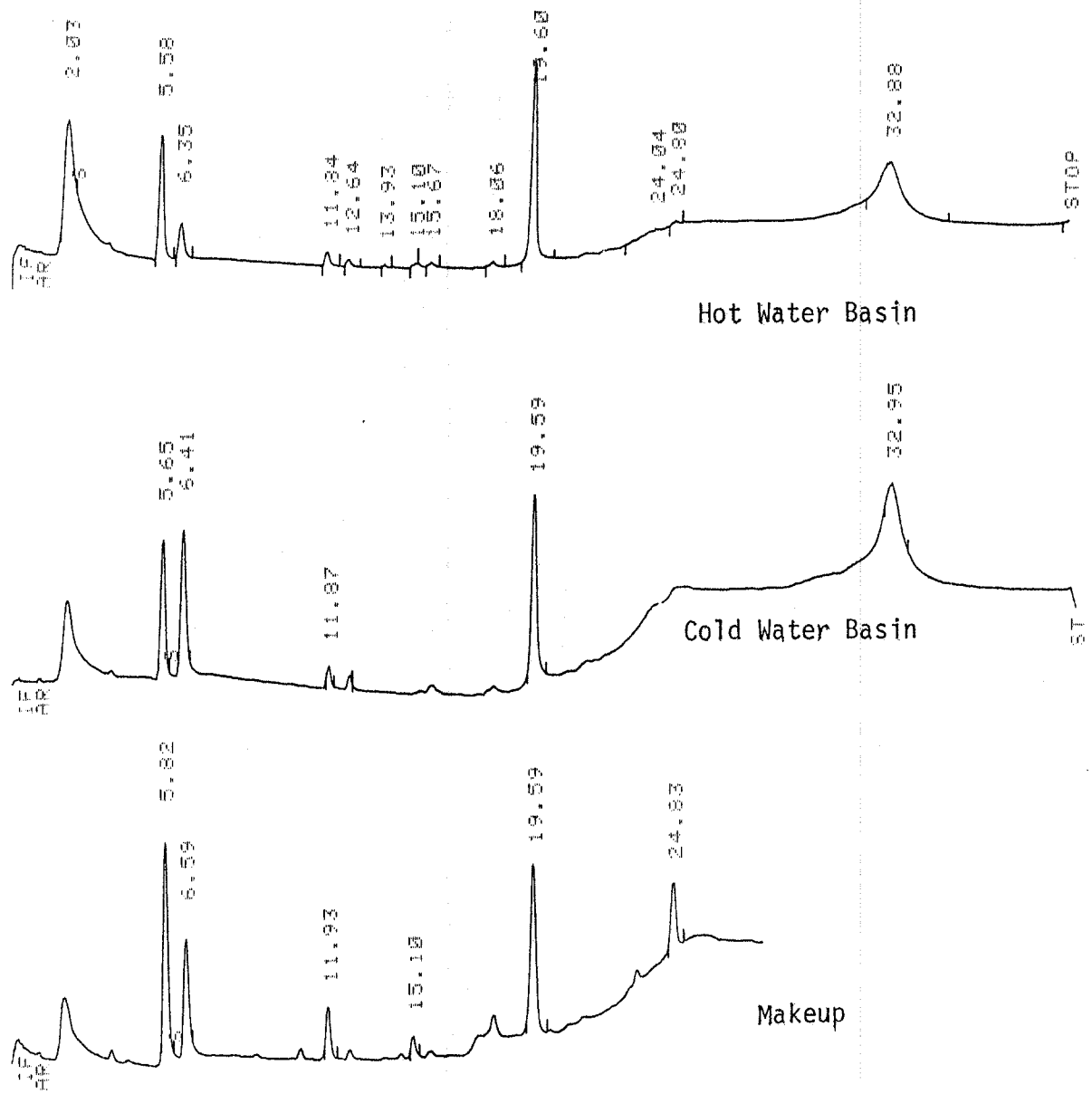

Figure 6.5-2. Gas Chromatograms of Makeup and Circulating Water Samples, Glendale Cooling Tower, 22 April 1980 Sampling.

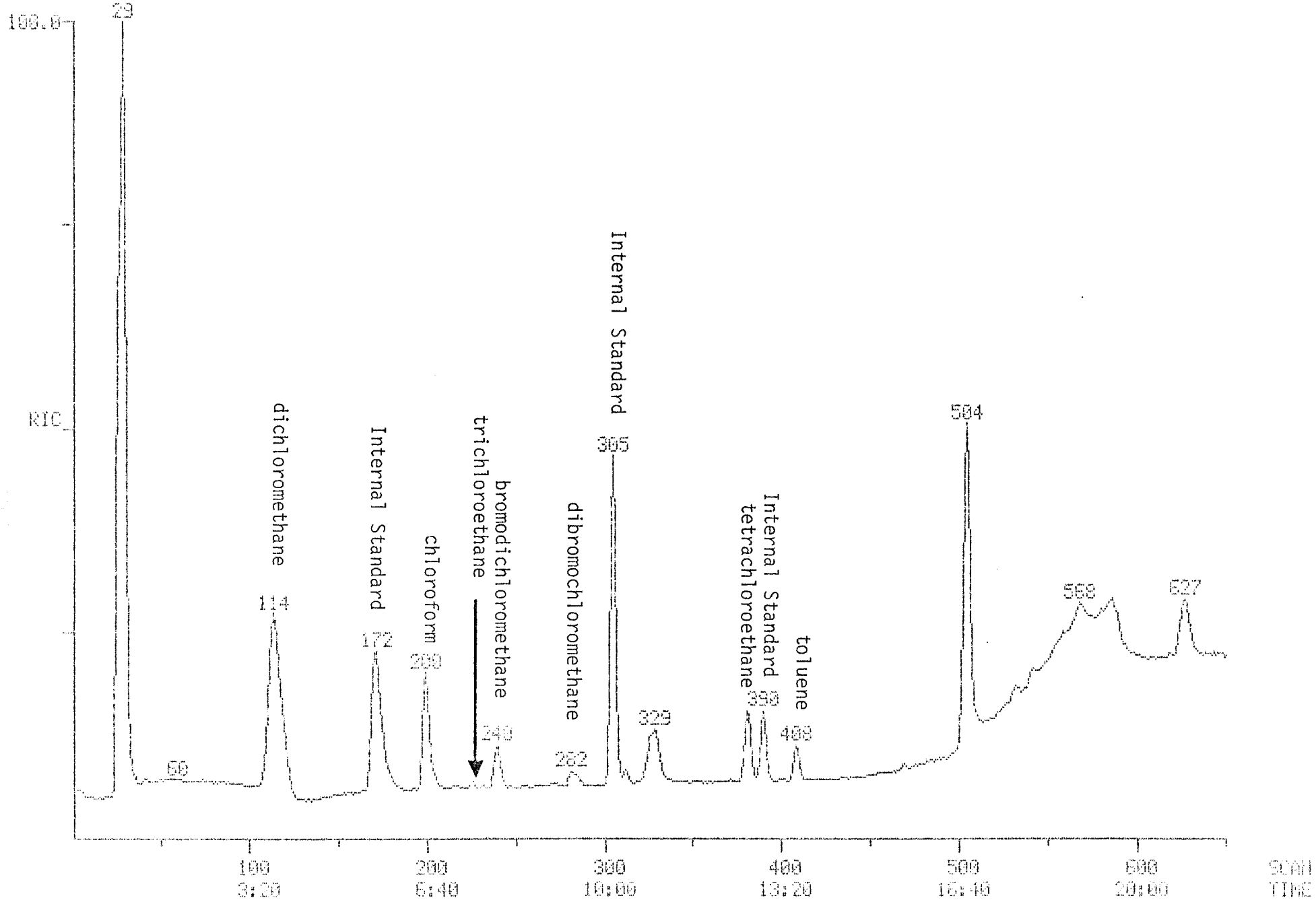

Figure 6.5-3. Mass Spectrum of Makeup Water Sample, Glendale Cooling Tower, 22 April 1980

chromatographic mass spectrum for the makeup water sample. Concentrations of the major identified volatile organic compounds are shown in Table 6.5-3. Very low levels of four halomethanes, tetrachloroethene, and toluene were detected in the makeup water. All volatile organic compound concentrations in the recirculating water were below 1 ppb, and benzene was absent from both the makeup and recirculating water.

Nonvolatile Organics

Gas chromatography with electron capture detection showed no chlorinated pesticides to be present in the Glendale samples. Table 6.5-4 reports total concentrations of nonvolatile compounds in the acid and base-neutral extracts. Most of the total of about 35 ppb of organics were found in the acid fraction. As seen in Figure 6.5-4, which shows the gas chromatograms of the acid extracts of the makeup and cold water basin samples, most of the compounds have more than 20 carbons, and are thus decidedly nonvolatile. There appears to be some loss of phenol and one or two unidentified low-molecular weight compounds from the makeup water. Analysis of the aliphatic and aromatic fractions of the base-neutral extracts showed negligible concentrations of pollutants of concern.

Indicator Microorganisms and Pathogens

Table 6.5-5 shows the results of the microbiological assays of the composite samples. The makeup water apparently has very low concentrations of indicator organisms, possibly because of the flocculation and settling which occurs in the phosphorus removal plant. Concentrations of total and fecal coliforms in the recirculating water were lower than those measured at Burbank/Olive 1, while fecal streptococcus concentrations are comparable. Perhaps the higher pH of the Glendale tower creates a less favorable environment for growth.

According to the UC Davis team's report on the sampling (Fanelli et al., 1981), no salmonellae were detected in the makeup or recirculating water. Other Enterobacteriaceae were found in five of the hot water and three of the cold water basin samples, however; these include *Citrobacter intermedius* and/or *Proteus* spp. and *Pseudomonas*. At least one pseudomonad organism per 10 ml was found in all samples, and by using a complete M-PA agar, the UC Davis group was able to isolate and quantify *Pseudomonas aeruginosa*. All samples had

Table 6.5-3

VOLATILE ORGANIC COMPOUND CONCENTRATIONS IN GLENDALE COOLING TOWER WATER, 22 APRIL 1980 SAMPLING

(Concentrations in ppb)

Compound	Makeup Water	Hot Water Basin	Cold Water Basin
Chloroform	6	<1	<1
Trichloroethane	<1	<1	<1
Bromodichloromethane	5	<1	<1
Dibromochloromethane	3	<1	<1
Tetrachloroethene	1	<1	<1
Benzene	ND[a]	ND	ND
Toluene	<1	<1	<1

[a]ND = Not detected.

Table 6.5-4

CONCENTRATIONS OF NONVOLATILE ORGANIC COMPOUNDS
EXTRACTED FROM GLENDALE COOLING TOWER
22 APRIL 1980 SAMPLING

(Concentrations in ppb[a])

	Makeup Water	Hot Water Basin	Cold Water Basin
Acid Extract	6.4	19.8	2.9
Base-Neutral Extract			
Aliphatic	0.72	0.94	0.82
Aromatic	0.86	1.2	1.4
Total Base-Neutral	1.58	2.14	2.22
Total Nonvolatiles	7.98	21.94	5.12

[a]Concentrations are based upon average response factors for standard n-alkanes eluting within the range of sample elution times.

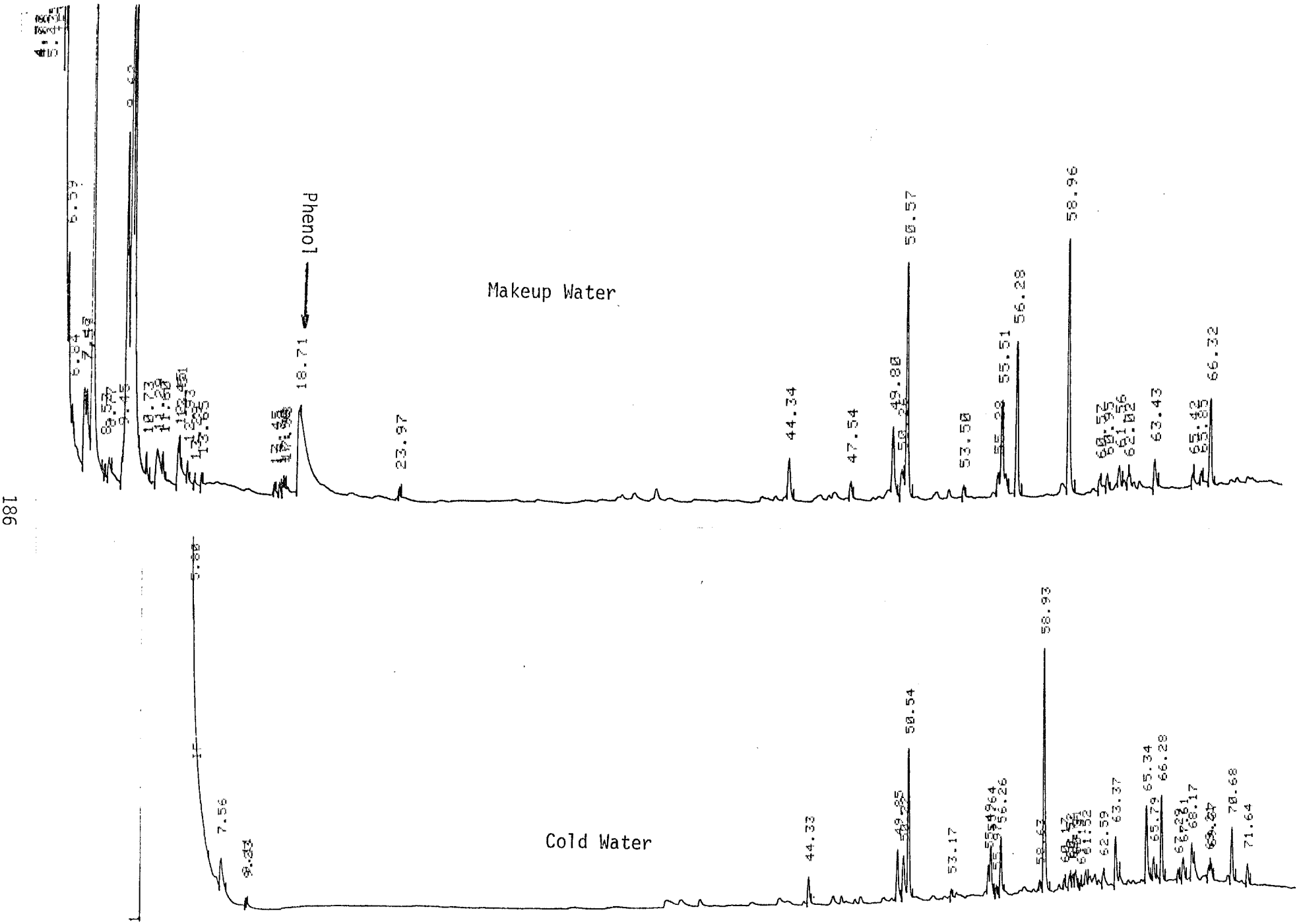

Figure 6.5-4. Gas Chromatograms of Acid Extracts of Makeup and Cold Water Basin Samples, Glendale Cooling Tower, 22 April 1980 Sampling.

Table 6.5-5

INDICATOR MICROORGANISMS IN COMPOSITE SAMPLES
FROM GLENDALE COOLING TOWER, 22 APRIL 1980

Organism	Units	Makeup Water	Hot Water Basin	Cold Water Basin
Total coliforms	MPN/100 ml	<3	9	7
Fecal coliforms	MPN/100 ml	<3	4	4
Fecal streptococcus	MPN/100 ml	<3	4	15
E. coliphage[a]	Plaques/ml	0	0	0

[a]Average of duplicate assays of each composite water sample.

one P. aeruginosa organism per 10 ml, except for the hot water basin sample taken at 1515 hours, which had two.

Although samples were sent to the CDC for Legionella assay, the tests were not performed.

6.6 TASK 3 SAMPLING AT INDUSTRIAL TOWER NO. 1

6.6.1 Site Description and Sampling Conditions

Task 3 sampling was conducted on 5 August 1980 on a four-cell counterflow tower operated by a large industrial facility. The tower, which was built by Fluor in 1949, has four octagonal cells served by 30.5-cm (12-in) risers, and has a nominal circulating water rate of 0.241 m^3/s (3820 gpm) and a makeup water flow rate of about 0.0039 m^3/s (62 gpm). According to the tower operator, circulating water flows have not been measured, and the stated estimate is highly uncertain.

According to the tower operator, chlorine and sulfuric acid are fed continuously to the tower. Betz C-30 biocide is slug-fed as needed. In addition, Zimmite ZC 324, a corrosion inhibitor and dispersant containing chromate, polyacrylates, phosphonates, and a surfactant, is added to the tower at the rate of 15 ml/min.

The morning of the sampling day was cool and overcast. After 1100 hours, the sky was clear and the outdoor ambient air temperature was about 27 ^{o}C ($80^{o}F$). Winds were negligible and no plume was visible.

6.6.2 Procedures

Samples were taken at 0845, 0945, 1050, 1150, 1250, 1345, 1400 and 1500 hours by SAI staff. At 1455 an additional sample was taken for Legionella assay. Makeup water samples were taken from an open pipe which discharges into the cold water basin on the northwest corner of the tower; the clearance between the mouth of the pipe and the basin water surface was about 0.5 m. Makeup water flow was monitored by means of a meter installed for the occasion by the tower operator. Throughout the test day, the makeup water flow rate was 0.0039 m^3/s (62 gpm), of which about 27 percent was reclaimed industrial process water. Hot water samples were taken from a tap on the riser to the northernmost cell. Cold water was collected from a tap in the outflow pump circuit.