AN EVALUATION OF COOLING WATER REQUIREMENTS AND AVAILABILITY FOR SOLAR POWER PLANTS IN THE SOUTHWESTERN UNITED STATES

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ABSTRACT

Solar power plants are no different than other types of power plants in that they require cooling water to remove waste heat. A significant consideration with solar power plant siting is the availability of suitable supplies of cooling water. This consideration is compounded by the arid nature of proposed solar power plant sites, which provide ample sunlight and land, but little if any water for cooling.

Previous power plant siting studies were investigated to determine if cooling water supplies were available at the suitable power plant sites. Previous studies show that the southeastern desert regions of California and southwestern regions in Arizona are most suitable for solar power plant sitings, based upon criteria other than cooling water availability. Unfortunately these regions have very little surface water available for power plant cooling. The major source of surface water in this region, the Colorado River, has been previously allocated.

It was found that cooling water is potentially available from ground water and return irrigation flows; however, there exist agency regulations, laws, and other institutional barriers which must be overcome. It also appears that cooling water can be made available through innovative methods, including conjunctive use of surface and groundwater, and wastewater recycle. After mitigation of institutional problems or development of innovative techniques, sufficient cooling water will be available for a 1000 MWE solar power plant.

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I. INTRODUCTION - SCOPE OF STUDY

The intention of this study is to assess the water resources for a solar-thermal power plant in the southwestern United Sates. It has been demonstrated that such a power plant is technologically feasible; however, a recurring theme in discussing the application of solar power in this area of the country is the lack of cooling water. It is apparent that water is in scarce supply and that much of what does exist is already allocated or unattainable. There is clearly a need for reassessment of water resources based on changes in legislative policices, hydrologic evidence, and technological advances in water use and supply. The purpose of such a reassessment is to better understand the current status of water availability.

A central issue of this study is therefore the extent to which water is a constraint to power plant siting, if at all. This issue is addressed in this study by identifying the relevant sources of cooling water, the availability and patterns of allocation of this water, and the legal and environmental barriers which interfere with attaining a suitable supply of water. The identification of these aspects of cooling water supply will hopefully be an aid in further determining the feasibility of solar thermal production of electricity in the southwestern United States.

II. POWER PLANTS IN GENERAL

II. A. Fossil Fuel, Nuclear, Solar

Power plants that use heat energy all operate according to the same basic concepts regardless of whether the heat source is from fossil fuels, nuclear reactions, or direct solar radiation. The operation following the heat input uses thermodynamic cycles to convert heat energy to electrical energy. This is done by heating water, which results in an increase in volume during the phase change from liquid to vapor. This volume increase is as much as 1600-fold when pressure is kept constant (Krenz, 1976). Work is done when the expanding vapor is made to push against something, such as the pistons of steam engines or the blades of a turbine, which can then be used to produce electricity. After pushing through the steam turbines, the steam is condensed back into water, which is then pumped back to the boiler where it is heated to remake steam, and the cycle is complete. Figure 1 shows this cycle.

II.A. 1. Steam and the Rankine Cycle

Steam cycles are different by virtue of how and when the temperature/pressure/volume levels are reached with respect ot the phase change described previously. The cycle used in conventional steam turbine power plants is the Rankine cycle (described first by Rankine in 1859, Krenz, 1976). Another and earlier heat power cycle is the Carnot cycle, proposed in 1824 (Warner, 1960). Phase change diagrams for these two steam cycles are shown in Figures 2 and 3. The heat input, Q_2, results in vaporization of liquid along the path a-b which takes place in the boiler under ideal conditions of constant pressure. The vapor expands at point b as it enters the turbine--doing work--and loses pressure along the path b-c. Point c represents the condenser, where the steam cools until a certain amount liquifies. It is from this

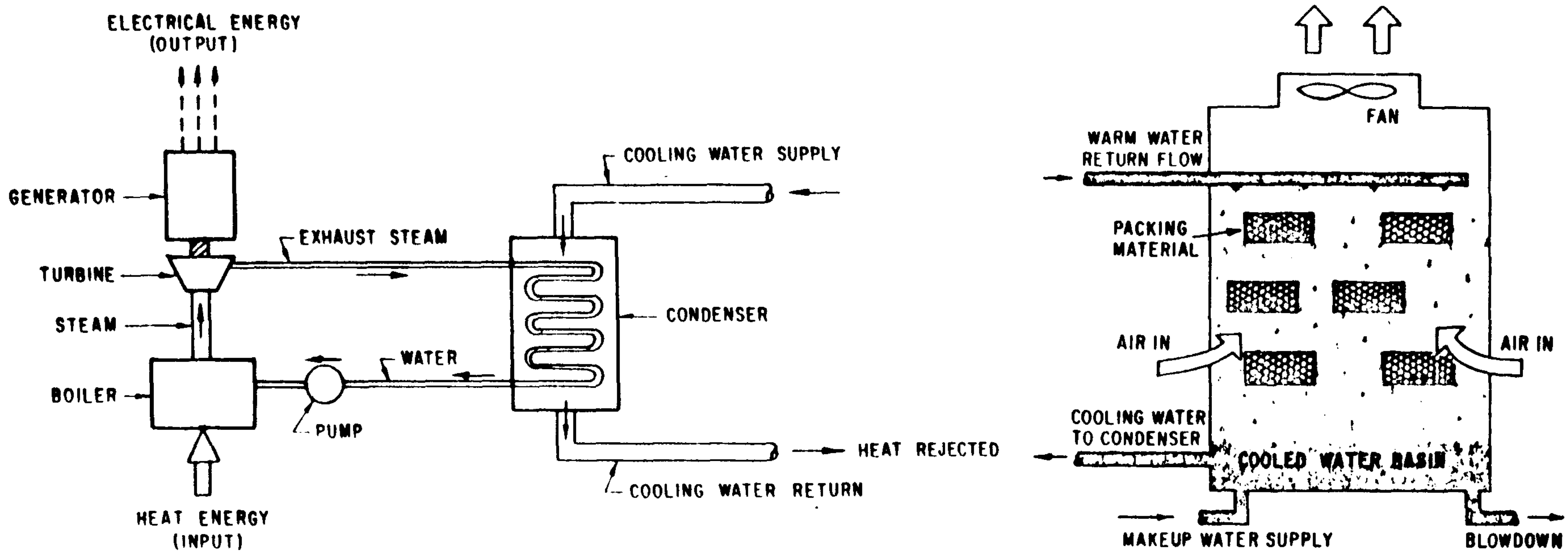

FIGURE 1. DIAGRAM OF THE BASIC STEAM CYCLE AND COLLING WATER FLOW FOR POWER GENERATION (DWR, 1977)

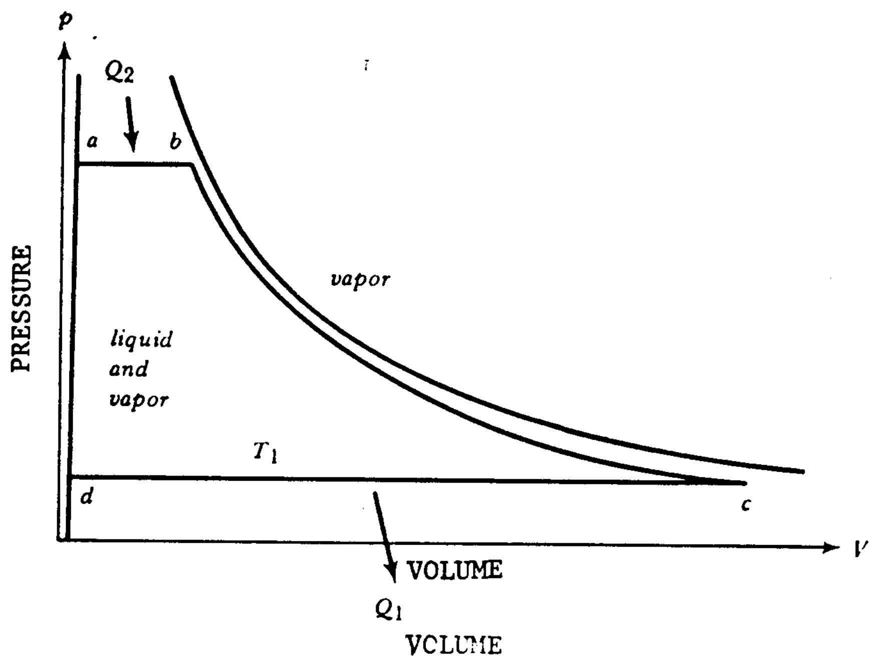

FIGURE 2. RANKINE STEAM CYCLE
(from Krenz, 1976)

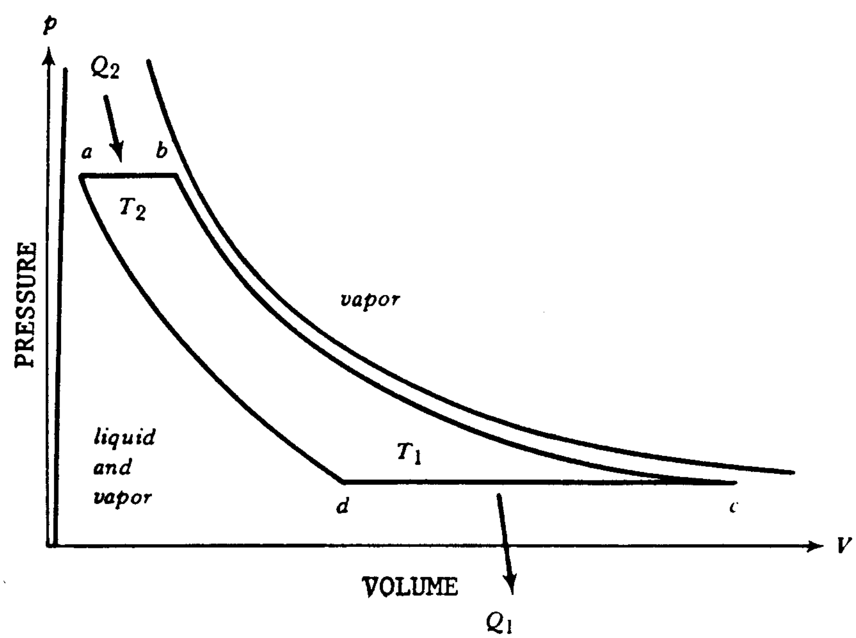

FIGURE 3. CARNOT STEAM CYCLE
(from Krenz, 1976)

last step (c-d), and the next step when the water is pressurized and returned to the boiler (d-a), that the two cycles differ: The Rankine cycle removes sufficient heat, Q_1, so that all the steam becomes water, and then pressurizes the water with pump (at d) to the pressure of point a. The Carnot cycle, on the other hand, removes only enough heat, Q_1, to partially cool the vapor, thereby saving on the eventual heat input as compared to the Rankine cycle.

II. A. 2. Thermal Efficiency and Water Use

The amount of heat converted to useful work when compared to the total heat input is the thermal efficiency of a process. Thus, the Rankine cycle is said to be less efficient than the Carnot cycle because more waste heat is produced per unit of heat input. Modern Rankine Cycle-based power plants have thermal efficiencies in the range of 30-40%. (Krenz, 1976) This means that an amount of heat input equivalent to 1000 MW, for example, results in 300-400 MW of electrical output (MWE). The output of a pwer plant is properly indicated by MWE, meaning megawatts electricity, yet this distinction is often not included in the literature.

Loss in efficiency due to waste heat is defined by the second law of thermodynamics. This law states that it is impossible to convert heat into work if this is the only and final result (Fermi, 1936, on Kelvin's Postulate); waste heat must result. For electrical power plants, this waste heat is the vaporized water that becomes too cool to do more work. This "remaining heat" must be absorbed, which causes condensation of the vapor. For a power plant, the absorbtion of heat must occur by a heat sink capable of efficient heat transfer - hence the need for cooling water. Water of lower temperature than that of the steam is made to circulate around the condenser. Clausius' Postulate (expression of the second law) guarantees the flow of heat into the cooling water by conduction (Fermi, 1936).

It is obvious that high thermal efficiencies result in low cooling water needs since less waste heat is produced. High thermal efficiency (35%)is attained when the boiler reaches temperatures of about 1000° F (Backus and Brown, 1975). This allows more "usable" work before the vapor reaches lower temperatures and loses its effectiveness. Backus and Brown (1975) state that a boiler capable of reaching 500° F results in efficiencies of about 20%, while 800°F corresponds to efficiencies of 30%. Technology capable of increasing a plant's efficiency thus results in lower cooling water needs for each MWE produced.

II.B. Solar Power

There are two basic types of solar power: photovoltaic and thermal. Photovoltaic solar cells are those which directly utilize the energetic photons of the sun's incident radiation. The photons interact within solar cells which are made of semiconductor material such as silicon (Backus and Brown, 1975). In this way electricity is produced without any moving parts or waste heat. Solar cells are reported to have efficiencies of 20% (Backus & Brown, 1975) and 11% (Kranz, 1976).

Solar thermal electricity is produced by the conversion of the sun's photons into heat energy, which is then converted to electricity by conventional thermodynamic cycles. The workings of a solar plant are nearly identical to those of coal or nuclear plants, all of which use steam-driven turbines to produce electricity. The main difference is the type of heat input used to produce the steam. In a solar thermal plant, the sun's heat energy is collected and concentrated by using mirrors which focus the sunlight to a central collector, which is usually filled with fluid. Tracking systems keep the mirrors, or heliostats, moving as the sun changes position. It is desirable to maintain the high temperatures (900 - 1100°F) presently used in conventional power plants (Krenz, 1976).

The following are different types of collecting devices, after Backus & Brown (1975).

<u>Parabolic Cylindrical Trough</u> - This concentrates the sun's normal intensity by 10 to 20 times. It consists of mirrored troughs which focus light onto a pipe which runs lengthwise in the center of the trough. It is limited to temperatures of 500° F and thermodynamic efficiencies of 15 to 20%.

Central Receiver - This device is also known as the 'power tower', and has been given top priority for funding by NSF. It consists of flat, moveable mirrors which direct sunlight to a central receiver located on a high tower. High temperatures are achievable so that efficiencies typical of conventional turbines (30 - 40%) can be obtained.

Fixed Mirror - This device keeps the mirrors fixed and moves the central absorbing unit along with the sun. High temperatures (800-900^{o} F) and thermodynamic efficiencies of 25-30% are possible with the fixed-mirror design.

Solar Pond - This consists of a large, shallow pond designed to absorb heat while reducing heat loss. Methods of reducing heat loss include a saline water gradient to keep heated water at the bottom of the pond, and plastic covers to prevent evaporation. Both temperatures and efficiencies are typically low (200^{o} F and 5 - 10%, respectively).

The above designs are not all commercially available or economical at present. The most promising of the four designs appears to be the central receiver design which was recently evaluated by the Department of Energy (DOE). Four aerospace firms (Martin Marietta, Honeywell, McDonald. Douglas and Boeing) were contracted to produce detailed designs for a small pilot facility (10 MWE) to be built near Barstow, California. The power plant is a joint venture by DOE, Southern California Edison, the Los Angeles Department of Water and Power, and the California Energy Commission.

A particularity important aspect of the central receiver (often referred to as "power tower") is the heliostat design. The official cost goal of DOE was $70 per square meter of collector (1975 dollars); however, the final cost appears to be around $145 per square meter. Initial estimates by the four design contractors ranged from $40 to $96 per square meter.

The present cost of the heliostats and central receiver for a 1000 MWE power plant appears to prohibit solar power plant construction. Present cost estimates (Metz and Hammond, 1978) indicate that solar power plants will be 15 times the cost as an equivalent nuclear plant and 35 times the cost of an equivalent coal-fired plant. It is anticipated that heliostat construction cost will decline or their demand increases and technology improves; however, significant advances must be made before solar power plants become economically attractive.

II. C. Water Needs

II. C. 1. Types of Cooling Strategies

The amount of cooling water needed depends upon the type of cooling system used. The two main types are once-through and closed cooling.

Once-through cooling - As the name implies, the water that flows past the condenser is used only once with this system. Water is discharged, usually to the body of intake water, following a prescribed rise in temperature. Since the water is not cooled any further, the effectiveness of this system is limited by the temperature effects of the heated water on the receiving water. Large bodies of water, e.g. lakes and ocean-water, are needed both for the necessary intake amounts and for temperature dilution. This type of cooling strategy is usually the most inefficient with respect to water needs.

The cooling taking place at the condenser is called liquid phase cooling (Backus and Brown, 1975). The water absorbs the heat by conduction. Large amounts of water flowing through the condenser are necessary because conduction is not as efficient at transferring heat as radiation or convection. The amount of water (L), in gallons per minute per MWE produced, is given by

$$L = \frac{6823\ (1-n)}{T\ n} \qquad (1)$$

where T = temperature rise of the cooling water, in ^{o}F, and

n = thermodynamic efficiency of the plant, expressed as a decimal fraction.

Closed-cooling - A drastic reduction in water requirements is achieved by avoiding the discharge of cooling water once it has absorbed heat from the condenser. Instead, the water itself is cooled and recycled. While this technology is more expensive than once-through cooling, it partially removes the constraint of water availability in power plant siting by greatly reducing water needs.

Particularly important to the amount of water used is the number of cycles characterizing the type of closed-cooling system. Water is saved because of recirculation in a higher cycle system. The number of cycles depends on the technology of the system with respect to tolerable temperatures, water quality, and discharge requirements. Good water quality allows a longer retention time, hence a higher number of cycles before new water must be introduced into the system. Five to 11 cycles have been commonly used to maintain circulating water quality (Leung, 1975).

The different types of closed-cooling systems include: 1) evaporative towers, 2) dry towers, 3) hybrid towers, and 4) ponds and spray-ponds.

Evaporative towers - Also known as wet cooling towers, this system cools the water by rejecting sensible and latent heat (Croley, et al., 1975). The water returning from the condenser is routed to a cooling tower, inside which is packing material which breaks up the flow into droplets. The drops cool primarily by evaporation as they fall to the bottom of the cooling tower. There are natural draft towers which are tall and hyperbolic-shaped. They rely on convective, upward currents of air flowing counter current to the water. There are also mechanical draft towers which can be smaller due to fans which increase air flow. There are forced-air designs, which have the fans at the bottom of the tower, and induced-air designs with fans at the top. In addition, the air flow can be characterized as crossflow (perpendicular to falling water), or counter current (in the direction opposite to the falling water). The most commonly found wet cooling tower is a mechanical draft, crossflow (induced-air) tower.

The total water consumption of an evaporative tower is known as make-up-water. This represents the water continously added to recoup the system following losses from evaporation, drift (water entrained by upward-moving air and carried out of the tower), and blowdown (water removed from circulation so new water can be added, thereby keeping water quality at an acceptable level despite the effects of evaporation).

Table 1 summarizes various estimates of cooling water consumption for evaporative towers for various types of power plants. Discrepancies among similar types of plants may be due to differences in blowdown and temperature requirements and specific operating conditions. They may also be due to using a figure for the latent heat of vaporization which is too high. The accurate figure of 1048 BTU/lb (Croley, et al., 1975) and the commonly used figure of 1000 BTU/lb (Leung, 1975) are considered by Leung (1975) as disregarding of the effects of the ambient air conditions (relative and absolute humidities), and the sensible heat transfer (non-evaporative) capacity of the air. He states that this inaccuracy results in an estimate of water needs that is 10-20% lower than that which actually occurs. This could result in additional water needs of 1-4 AF/MWE-yr over those indicated in Table 1 if Leung's (1975) observations are true.

TABLE I: Evaporative cooling tower water consumption

Amount [1] ---AF/MW-yr-----	Type of Plant[2]	Cited by
11.4	fossil fuel	DWR, 1977
12	fossil fuel	
12.2	fossil fuel	Leung, 1975
13.8	- - - - - -	Krenz, 1976
14.5[3]	- - - - - -	Croley, et al.,1975
15	solar thermal	Aerospace Corp., 1974
16.5	- - - - - -	Backus and Brown, 1975
16.9[4]	- - - - - -	Croley, et al., 1975
18.4	nuclear	DWR, 1977
20	coal-fired	UCLA, 1976
21.7	nuclear	Heitz, 1975
22	solar thermal	
25.3[5]	- - - - - -	Croley, et al., 1975
mean = 16.9		

[1] includes evaporative, drift, and blowdown consumption

[2] where not indicated, represents general power plant of 40% efficiency

[3] $c/c_o = 1/8$

[4] $c/c_o = 1/4$

[5] $c/c_o = 1/2$

Drift losses are minor (.002% for mechanical draft and .0005% for natural draft, according to Leung, 1975) and are often ignored. Blowdown losses, however, are significant, especially if available water quality is poor. Poor quality restricts the amount of cycles due to concentrations of scale forming or corrosive substances. To see what effect water quality has on ultimate water demand, consider the following ratios of c/c_o, where c = hardness concentration of make-up water, and c_o = allowable hardness concentration of the cooling water. For relatively high quality make-up water which is only 1/8 the hardness of the allowable concentration, the make-up requirements are 14.5 AF/MWE-yr. Alternatively, for c/c_o equal to one-half, the consumption is almost 75% greater, or 25.3 AF/MWE-yr. These figures are derived by Croley, et al. (1975) who characterize the make-up water (W), in gpm, required to replace evaporation and blowdown as

$$W = \left[E \frac{1}{1 - C/C_o}\right], \tag{2}$$

where E = evaporative water loss = $aQ(1.91145 \times 10^{-6})$ for a typical mean water temperature of 80^oF (26.7^oC), where a = the fraction of heat dissipated as latent heat of evaporation, and Q = rate of heat rejection by plant, in BTU/hr. For evaporative towers, a = 75% to 85%, and $Q = 3414426\ P\frac{1 - e}{e}$, where P is the rated capacity of the plant in MW, and e = efficiency of plant expressed as a fraction.

Regardless of the losses from evaporation and blowdown, wet cooling represents a substantial savings of water. Krenz (1976) estimates that a wet cooling tower could reduce the ultimate water need to only 1.8% of the water which would be required by an open cooling system. A figure of 13.8 AF/MWE-yr is thus obtained from Krenz's (1976) figure for a once-through system of 767 AF/MWE-yr. This reduction, of course, is due to evaporation of cooling water, which indirectly accounts for 75%-85% of the heat removed (Croley, et al., 1975). Brown and Backus (1975) note that water vaporized removes about 1000 times the amount of heat removed by conduction alone. Their function to estimate evaporative cooling water consumption is

$$E = 6.82\ (1 - \eta)/\eta. \qquad (3)$$

where E = consumption (total) in gal/MWE-min, and η = efficiency. This results in 16.5 AF/MWE-yr for a 40% efficient plant, and is also 1.8% of their previous function for once-through cooling given a 18^{O}F temperature rise.

Dry-cooling towers - This cooling system eliminates make-up water requirements by using non-evaporative heat exchangers, somewhat like automobile radiators. In a dry tower, air passes on the outside of what are commonly called finned-tube heat exchangers. These have a large surface area for maximum cooling. In the direct system, the steam flows directly to the exchangers and is condensed by air flow. In the indirect system, the steam is first condensed by water flowing around a condenser, as in wet cooling; the heated water is then run through the exchangers and cooled by the surrounding air.

This process, whether direct or indirect, relies on the transfer of sensible heat (convection and some conduction), rather than latent heat (evaporation) for cooling (Leung, 1975). Since no mass is transferred, no water is consumed. The absence of make-up water is clearly an advantage. Savings associated with this include the flexibility of site-location, and the absence of treatment and discharge costs of blowdown. Further, corrosion problems are avoided as are problems with icing and fogging associated with drift (Croley, et al., 1975).

This seemingly-ideal technology is made less attractive by several uneconomical aspects. First, the heat exchanger surface area is much greater than that required for a similar wet cooling tower. This makes dry cooling both land- and capital-intensive. Leung (1975) estimates that a dry-cooling system represents 6 to 8 percent of total plant capital cost, whereas a wet-cooling system represents 3 to 5 percent of total plant capital cost. Of course, O & M costs are largely avoided in a dry system. Secondly, the cooling efficiency is dependent on the ambient (dry-bulb) air temperature. Since the power plant design must provide for cooling in all seasons, the necessary surface area of a tower in hot climates precludes their practical use (Croley, et al., 1975). Third, high water temperatures are characteristic of dry-cooling operations, which in turn cause the power plant turbine's back pressure to reach as high as 10-15 in Hg Abs (Leung, 1975). High back pressures such as these reduce the plant's annual efficiency by six to eight percent (National Water Commission, 1972; Leung, 1975). Finally, the thermal plume from a dry-tower may cause entrainment of pollutants.

Regardless of these disadvantages, most authors agree that as available water becomes more expensive, the economic cost of dry-towers will make their use justifiable for certain areas. Leung (1975) notes that it is indeed dry cooling tower cost, and not their technological validity, which currently precludes their use. He cites numerous installations, albeit with small outputs (20-330 MWE) where they are currently used in the United States, England, Germany, South Africa, and the U.S.S.R.

Hybrid Towers - These are combined wet-dry towers which are able to be used as wet towers, dry towers, or both. So far, they have not been used for large capacity power plants (DWR, 1977). The design incorporates separate wet and dry sections. Different configurations for the tower include air flow through both sections simultaneously, and partial or total restriction of air flow through either section with the use of moveable windows, doors, and separate fans. Several combinations of the wet-dry tower are possible, depending on output demand and air temperature. The dry section would be used during cool weather or when power demands are low. The combined tower would be used for higher air temperatures, especially during peak energy needs. Because of the restrictions of dry towers mentioned previously, the combination tower has limited value in hot climates, where the wet section of the tower would necessarily provide most cooling. The large surface area of the dry section, which is necessary in hotter climates, proves uneconomical compared to using a wet tower alone, especially where water costs are low. Croley, et al. (1975) present an economic optimization model with several combinations of dry-wet cooling systems, climates, and water costs, and rates respective water consumption for each. They do not incorporate limitations in water availability, however, so that the respective degree of cooling by either section is mainly a function of water cost and climate. With a dry-bulb mean of 90° F and wet-bulb mean of 80°F, it is shown that the greatest reduction in water use from using the dry-cooling section is 20%, when the water cost is low ($.0022/1000 gal). When the water cost is high ($.30/1000 gal) the model predicts more dry cooling, and consumption is reduced by 56%. With a dry-bulb mean temperature of 42°F and wet-bulb mean temperature of 32°F, the predicted reduction in water use with low- and high-cost water is 67% and 95%, respectively. It is noted that the water consumption realized from constructing a dry tower along with a wet one is uneconomical in hotter climates. In contrast with Croley et. al. (1975), DWR (1977) states that a 75% reduction can be realized with a combined wet-dry tower for a nuclear plant in hot, dry Bakersfield. For such a high savings in water consumption, the dry section of the tower would have to be very land- and capital-intensive.

Ponds and Spray Ponds - Water can also be cooled in a pond. It is evaporation. and sensible heat loss which accounts for the heat release. The amount of evaporation can be greatly increased by spraying the water into the pond, such as with a water fountain. This process is very land intensive, and surface area requirements for each megawatt produced have been cited as 1-to-2 acres (DWR, 1977) and 1.4 acres (Humenick, et al., 1972). Water consumption is from processes similar to wet cooling towers; evaporation, drift, and blowdown. Croley, et al. (1975) list make-up water for a spray pond as 13.5 AF/MW-yr for water quality of $c/c_o = 1/8$, 15.8 AF/MW-yr with $c/c_o = 1/4$, and 23.7 AF/MW-yr with $c/c_o = 1/2$; this is a water requirement of about 6.5% less than that for an evaporative tower. A consideration for using cooling ponds is that the large volume and retention time can alter water quality characteristics such as suspended solids and BOD (Nelson, 1974). Also the pond can create water quality problems.

The cooling strategy adopted has to be suited to plant size, area availability, and water and monetary resources at any one location. The trade-off between water savings and capital-/land-costs must also be evaluated in terms of the benefits of an inexpensive, renewable, and environmentally acceptable source of power.

II. C. 2. Alternate Cooling Strategies

Technologies most often discussed when addressing savings in cooling water are dry or wet/dry cooling towers and increased efficiency steam engines. Alternate types of cooling towers have been discussed previously.

Although the DOE considers the Rankine cycle when proposing plans for powerplants, the concept favored by the Electric Power Research Institute is the Brayton cycle (Metz and Hammond, 1978) which has been discussed by Krenz (1976). This cycle requires little or no cooling. Another cycle recommended by Metz and Hammond (1978) is the Stirling cycle, which is said to be more efficient than the Rankine cycle in the 1100-1500^{o}F temperature range. Producing temperatures in this range presents additional problems, especially with the collectors. Metz and Hammond (1978) have discussed collectors for this purpose, and this work should be consulted for additional information.

II. D. Water Quality Concerns

When considering water quality from a cooling system standpoint, the primary concern is that it does not form a scale, coating, or film on the condenser tubes. A scale thickness of 1 mm can reduce the heat transfer by one-half (Ege, 1975). Another concern, especially with semi-noble metal systems, is that no corroding constituents are present in the water. Unfortunately, much of the control processes that reduce scale also act to enhance corrosion. Water quality control must therefore be done carefully and on an individual basis with respect to the specific water being used.

II. D. 1. Water Quality Problems -

The following processes and associated constituents have been implicated by Ege (1975), Betz Laboratories, Inc. (1976), and Carey, et al. (1977) as causing problems in cooling system performance.

Scale formation - Scale is caused by dissolved solids precipitations on the condenser tubes. Scale forms readily on the hotter surfaces of the system since the solubility of most scale-forming minerals decreases with increasing temperatures. The main minerals of concern are Calcium (Ca), Magnesium (Mg), and Silica (Si). Calcium and magnesium carbonate are often formed on exchanger surfaces. Silica reacts with Calcium and Magnesium to form scale-causing silicates. sodium, calcium and magnesium also can cause problem-causing sulfates. If these cations are not tied to the sulfate or carbonate anion such as with NaCl, $CaCl_2$, and $MgCl_2$, there is little likelihood of scaling.

Corrosion - Corrosion is primarily caused by dissolved gases such as oxygen, hydrogen sulfide and ammonia. Corroding agents are particularly responsive to the pH of the water. For example, a higher pH reduces the oxidation of carbon steel caused by dissolved oxygen. Any wood in the tower media or structure is also susceptible to a type of corrosion--actually delignification--caused by alkaline water. Finally, chlorides commonly cause pitting and stress corrosion cracking on stainless steel.

Corrosion additionally results in products which enter the circulating water, such as iron oxide particles. The accumulation of these, called tuberculation, can clog pipes and reduce the pressure-head, and is a form of depostion.

Recirculating systems are particularly susceptible to corrosion because of continual replenishment of O_2, continual concentration of DS, and increased operating temperatures.

Deposition - This is caused by suspended matter settling out into the cooling system. This includes iron that has become $Fe(OH)_3$ as well as dirt, clay, sand, particulates from the atmosphere, chemical additives, corrosion products, algae, and interestingly, algaecides. Algaecides have an affinity for the suspended matter in the cooling system. Consequently, the settled solids often have a higher concentration of algaecide than is indicated in the cooling water itself.

Slime - Slime can be caused by both oily substances and biological growth. Biological growth is of particular concern because of the growth-promoting temperatures and constant aeration of the cooling water. It includes bacteria, algae, and fungi, and is often increased with higher nutrient levels in the water. Slime in general reduces heat transfer in the condenser tubes and may plug the holes in the fill material. Fungi can additionally cause wood rot at the surface and internally. Biological growth presents the unique problem of developing strains which are resistant to the control method being used because of their evolving nature.

D. 2. Water Quality Criteria - So that the problems mentioned above will be minimized, the following criteria for water quality have been suggested. These include water for circulation and for make-up. (see the two tables). In addition, Ege (1975) has suggested a typical balance of impurities, as follows, where Q = flow and C = concentration of dissolved solids.

TABLE 2 - Cooling Water Containments Balance.

IN	Q(#/hr) @	C(ppm)	OUT	Q(#/hr) @	C(ppm)
make-up	1.0	100	Evaporation	.8	0
			Drift	.003	500
			Blowdown	.197	500

This is for a system using five cycles.

TABLE 3

Circulating Water Quality Limitations[d]

Characteristic	Limitation[a]
pH and Hardness	Langelier Saturation Index[c] = 1.0
pH and Hardness with addition of proprietary chemicals for deposit control	Langelier Saturation Index = 2.5
Sulfate and Calcium[b]	$(C_{SO_4}) \times (C_{Ca}) = 500{,}000$
Silica	$(C_{SiO_2}) = 150$
Magnesium and Silica[b]	$(C_{Mg}) \times (C_{SiO_2}) = 35{,}000$
Suspended Solids	$(C_{ss}) = 400$ mg/ℓ

a. All concentrations, e.g., (C_{SO_4}), in mg/ℓ

b. Mg and Ca concentrations are in mg/ℓ as $CaCO_3$

c. Langelier Saturation Index = measured pH - pH at saturation with $CaCo_3$ (see Ref. 6.133).

d. from Nelson (1974)

TABLE 4

Acceptable Cooling-System Makeup Water Quality Characteristics [a]

Constituent	Concentration (mg/ℓ)
Calcium, as $CaCO_3$	40 - 200
Magnesium, as $CaCO_3$	10 - 50
M Alkalinity, as $CaCO_3$	5 - 50
Sulfate, as SO_4	20 - 140
Chloride, as Cl	10 - 150
Silica, as SiO_2	2 - 50
Iron, as Fe	0.2 - 10.0
Manganese, as Mn	0.1 - 1.0
Oil	1 - 5.0
Suspended Solids	10 - 200
pH	5.5 - 7.5 (pH units)
Specific Conductance	100 - 500 (μmhos, 18°C)

a. from Nelson (1974)

II. D. 3. Control of Problem-causing Constituents

The following control methods and chemical treatment are suggested by Ege (1975) and Betz Laboratories, Inc. (1976) for the mitigation of water quality problems.

Scale - The most common method of control is to add acid, such as sulfuric acid: $Ca(HCO_3)_2 + H_2SO_4 = CaSO_4 + 2CO_2 + 2H_2O$. HCl can also be added instead of H_2SO_4 if already high amounts of sulfates in the water supply threaten to form sulfate scales. Water softening is another effective method of calcium reduction. Calcium precipitation can also be controlled by the addition of nitrate or phosphate ions. Care must be taken with these ions which are potential nutrients for biological growth. Phosphate is present in several anti-scaling agents recommended by manufacturers, such as polyphosphates and phosphonates. These agents limit crystal growth by adsorption onto growing crystals and inclusion into crystal nuclei. Their properties are enhanced by additions of polymers and/or surface active agents. These anti-scaling agents may not be permissable in blowdown water, however.

The tendency to form scale can be predicted using two qualitative indices -- the Langelier Saturation Index and the Ryznar Stability Index. The former indicates that scale will form when the following value is positive: $pH - pH_s$, where $pH_s = (pK_2 - pK_s) + pCa + pAlk$, where K_2 = second dissociation constant for $CaCO_3$ and K_s = solubility product constant for $CaCO_3$. The Ryznar Stability Index uses the above equality for pH_s in the following value: $2(pH_s) - pH$. This index indicates that scale will form when the value is less than or equal to 6.0. Note that these are basically qualitative; that is, a value of 2.0 does not indicate that more or less scale will form than at a value of 3.0. A problem characteristic of deep water wells, and to a lesser degree with surface water, is silica (SiO_2) scaling. This compound can be removed with cold lime softening processes.

Corrosion - is aided by the very treatments which reduce scale, i.e., acid additions. A midway point between conditions conducive to corrosion and scale is sometimes recommended in order to form a thin protective coating of $CaCO_3$ scale. This must be highly regulated, however, and is impractical for heat transfer processes (such as power plant cooling) because of uneven scale formation in areas of uneven temperatures. Other effective means of controlling corrosion include deaeration and the use of corrosion-inhibiting chemicals.

Deaeration controls corrosion by removing the dissolved oxygen from the water. Corrosion due to dissolved oxygen is particularly bothersome at higher temperatures. Vacuum deaeration as well as chemical deaeration can be used. The latter consists of the addition of sodium sulfite which bonds with oxygen to form sodium sulfate. Deaeration is costly, however and is potentially uneconomical with recirculating systems because of constant aeration in cooling towers.

Corrosion-inhibiting chemicals include chromates, polyphosphates and the less effective silicates. The addition of zinc results in increased protection from pitting. Corrosion inhibitors which operate by inducing a protective metal oxide film on the metal surface are known as passivators. Others of this type include chromate salts, nitrates, amines, and various organic agents. Chromates are the most effective at controlling corrosion, but almost always produce disposal problems with blowdown water. Phosphates are environmentally more acceptable and effective at 20-25 ppm. When used together, the CrO_4 and PO_4 concentrations can be 30 and 70 ppm, respectively.

The addition of Zn further reduces these concentrations. Phosphate inhibition must often be used with one of the scale control agents because of its tendency to revert to orthosphosphate whcih causes heavy scale deposition.

The EPA (1974) recommends the following construction materials for corrosion prone cooling towers: asbestos cement, certain types of concrete, paint and epoxy coated materials, plastics including reinforced fiberglass and PVC, stainless steel, silicon bronze, and pressure treated wood.

Deposition - Suspended solids can be controlled with the use of a side stream filter. This method is especially effective when coagulants are used prior to filtration. Other methods of reducing turbidity include the use of dispersants to reduce attractive forces and surfactants to keep the particles in suspension.

Biological growth - Principal types of control agents are biocides, which kill, and biostats, which inhibit growth and reproduction. Both types of control agents can be divided into major groups; oxidizing and non-oxidizing agents. The former includes the most common method of control, which is chlorination. When using wood cooling towers, care must be taken to keep the concentration low. Chlorine dioxide is also used although the treatment is more expensive than gasseous chlorination.

Non-oxidizing agents are used with organisms that are resistant to chlorine treatment. Chlorinated phenols - - sodium pentachlorophenate alone or with trichlorophenate - - are commonly used,soluble, and stable. Quanternary ammonium compounds are also used yet tend to volatilize in cooling towers. Copper salts, such as copper sulfate, are effective in reducing wood rot. These can cause iron and steel corrosion, however.

Wood for use in cooling towers if often pressure-treated to protect against internal decay. Mercurial compounds, although highly toxic to biological growth, also tend to corrode less-noble metals such as iron, steel, and aluminum.

When using biocides and biostats one must be aware of the EPA policies on specific toxic chemicals. Control chemicals are regularly removed form the market due to toxicity problems.

II. D. 4. Discharge Requirement

Problems with meeting cooling tower blow-down discharge requirements can be severe. Typically, cooling tower blow-down will be high in total dissolved solids concentration and high in organics and nutrients derived from biocides and algicides.

The problem is usually compounded due to the nature of water needs. Where water is scarce, cooling towers are usually cycled-up to conserve water, which results in poorer blow-down water quality. Since water is scarce, there will usually be insufficient dilution water in the river or lake where the blow-down water can be severe. One sometimes discovers that the blow-down water must be treated to a level which would permit it to be used for make-up water.

The specific requirements for blown-discharge are a function of each specific site, and are unique. Each case must comply with its own NPDES permit. Table 5 lists the EPA's guideline discharge requirements. Generally these requirements must be modified for specific locations.

III. INVESTIGATION OF WATER AVAILABILITY FOR A 1000 MW EVAPORATIVELY COOLED SOLAR PLANT IN THE SOUTHWESTERN UNITED STATES

III. A. Definition of Area

Water resources for power plant cooling on a site-specific basis have been considered by Holmes and Narver, Inc. (1973), the Aerospace Corporation (1974), Carey, Purtich, Rogozen, and Anderson (1977), and The Department of Water Resources (1977). These reports have in common a discussion of one or more water-types (e.g., surface water, wastewater), the areas where they are found, and amounts available. Carey, et al. (1977) additionally discuss legal availability and water quality for individual sites.

The initial area selection in the present investigation follows that of the Aerospace Corporation (1974) report, which imposes a succession of limiting criteria on the southwestern United States. This resulted in the exclusion of 98% of the eight designated states when the most stringent criteria were applied. Note that the Aerospace criteria do not include potential sources of cooling water. It is thus possible that no water exists in areas otherwise considered acceptable. The criteria and resulting areas deemed feasible for a solar thermal power plant are shown in Table 6 and Figure 4. The suitable area in the southwest desert is comprised by the Colorado and Mojave Deserts in California, and parts of the Lower Colorado Basin Region in southern Nevada and eastern Arizona. In addition, the site summary by Holmes and Narver, Inc. (1973) is shown in Figure 5. As can be seen the areas of highest potential suitability are the desert areas in southeastern California and the Central Valley. This report considered nuclear power plants only. Seismic risk may not be as crucial in considering a site for a solarpowerplant and, therefore, more of the area termed "Colorado Desert" in figure 5 may be potentially available.

Withing this study area, the following sources of cooling water are presently investigated: surface water, groundwater, irrigation return flow, and wastewater. Each source is discussed in the following sections.

III.B. Potential Sources of Cooling Water

III. B. 1. Surface Water

Surface water in the study area varies according to the location of hydrologic basins. Average runoff in the desert basins of California represents only 0.3%, or 200,000 AF, of the State's total. Much of this drainage terminates in playas which are either small and dispersed or dry due to evaporation and seepage. It is generally agreed that this area's surface water is insufficient and/or unattainable for powerplant cooling water (Homes and Narver, Inc., 1973; Sathaye and Ritschard, 1977; Carey, et al., 1977). Table 7 shows major surface waters of the southern California desert area. Most of the existing flow, such as that of the Mojave River, is developed and regulated. The diversions and impoundments of the Colorado River are also allocated and regulated. In addition, the use of these waters is further complicated by the general policy of the DWR which precludes the use of State Water Project and MWD water for power plant cooling (Sathaye and Ritschard, 1977). This policy, however, does not include transfers of water to replace, for example, used irrigation drainage which would normally be returned to the original source. Recognizing this, the recent Lanterman Act of 1974 allows the transaction of Colorado River water for cooling water use in desert sites (Sathaye and Ritschard, 1977). Although MWD's allotment of Colorado River water will be cut back to 550,000 AF/yr when California's allotment is reduced to 4.4 MAF/yr in 1985, MWD has nevertheless agreed to supply 100,000 AF/yr to various utilities forpowerplants in the desert area (Carey, et. al. 1977, DWR, 1977). Southern California Edison will receive 50% of the 100,000 AF/yr, LADWP will receive 33,000 AF/yr, and SDGE will receive 17,000 AF/yr. Flow from the Palo Verde outfall drain accounts for 60,000 AF of the above allocations. This is discussed further under "irrigation return flow" below.

Sathaye and Ritschard (1977) additionally note that the California Aqueduct will have excess capacity for several years. This could be used to recharge overdrawn grondwater basins in southern California. This is also discussed later. Figure 6 summarizes inland California Water Resources (Holmes and Narver, Inc. 1973.)

Table 5 - EPA's Guidelines for Cooling Water Discharge

Effluent Water Quality Parameter	One-Day Maximum Concentration (mg/l)	Thirty-Day Maximum Average Concentration (mg/l)
1. Free Chlorine	0.5	0.2
2. Zinc	1.0	1.0
3. Chromimum	0.2	0.2
4. Phosphorous	5.0	5.0
5. Other parameters limits will be established on a site specific basis.		

Notes

1. New Sources must not contain detectable amounts of corrosion control chemicals in blowdown.
2. pH must range from 6 to 9.
3. No discharge of PCB's is allowed.

Table 6 - Exclusion Area Criteria[a]

Issue	Technical Requirements
Terrain	20% grade
Erosion	Frequent gullies
Soil	(No separate distinction)
Vegetation	Significant impact
Agricultural	Grain, produce, fibre, and grazing land
Surface	Probable mineral resources
Federal Lands	All areas within legal boundaries
Indian Lands	
Military	

[a]from The Aerospace Corporation (1974) for most stringent criteria

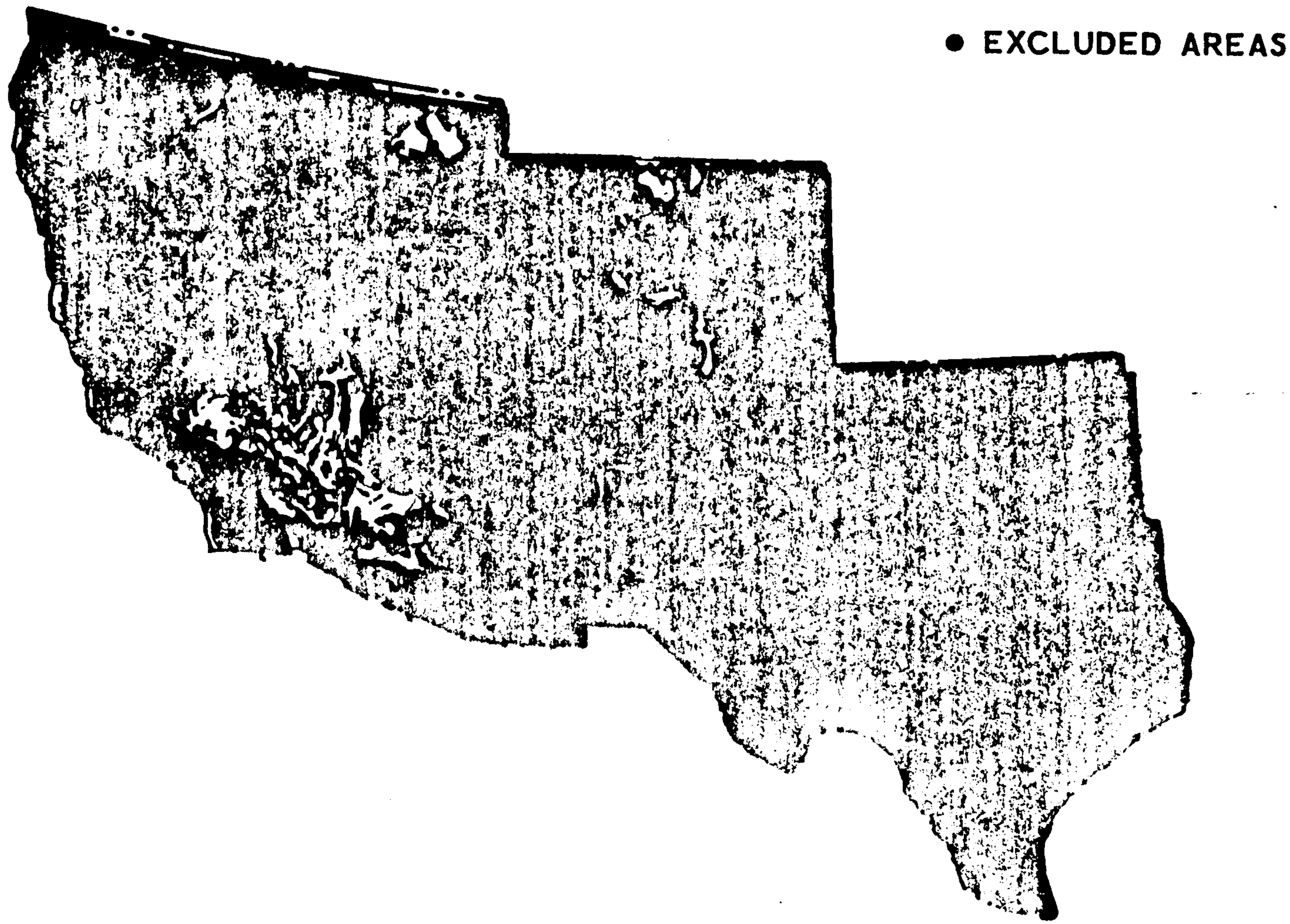

Figure 4: Feasible Power Plant Sites (from Aersopace Corp, 1974)

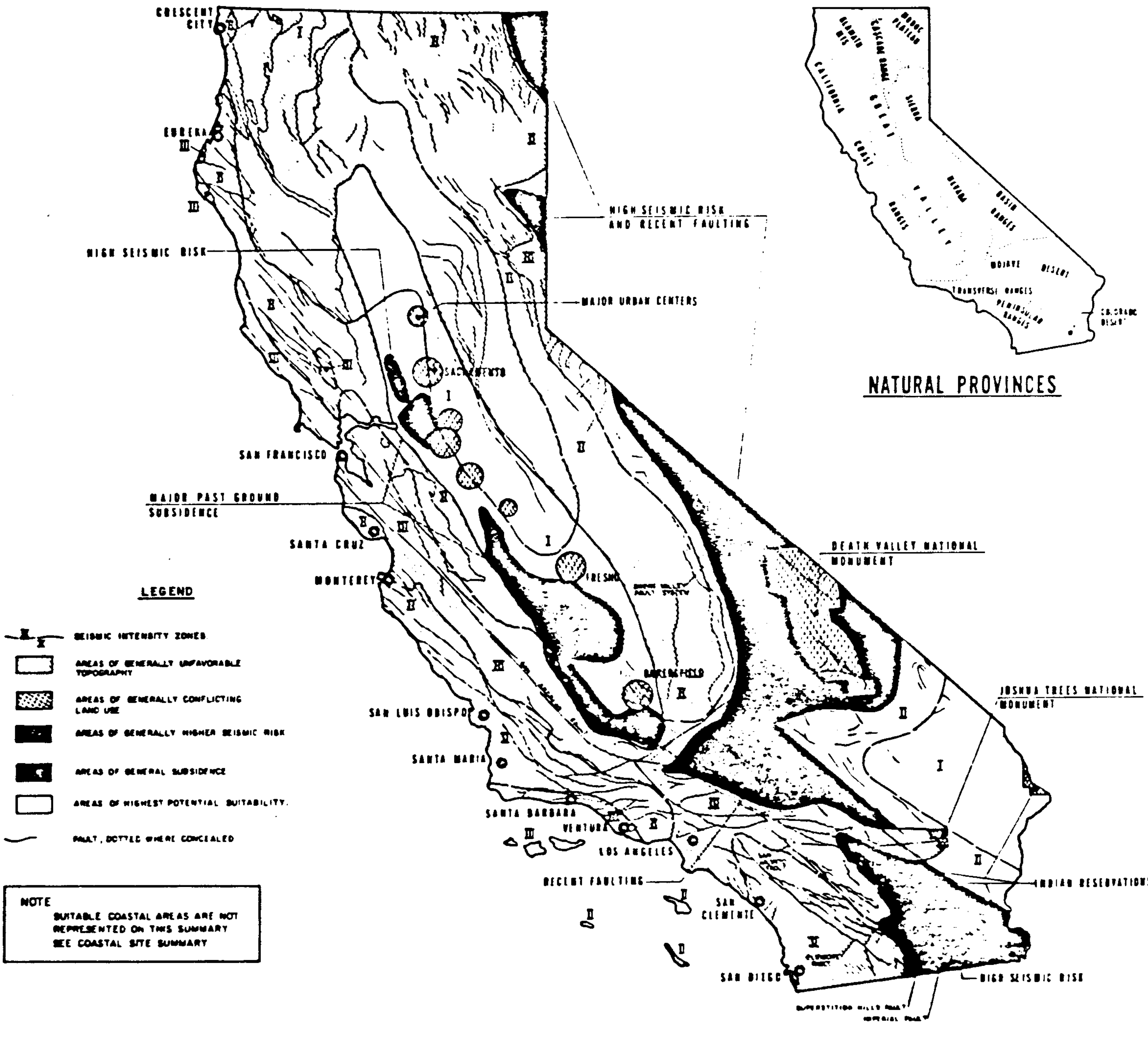

FIGURE 5. FEASIBLE POWER PLANT SITES (from Holmes and Narver, Inc. 1973)

Table 7 - Southern California Surface Water Resources

Resources by Type	References
Rivers	
Colorado	Homes & Naver, Inc. (1973)
Mojave	"
Alamo	DWR (1977)
New	DWR (1977)
Lakes	
Havasu	Holmes & Naver, Inc. (1973)
Salton Sea	"
Mono	"
Owens	"
Reservoirs	
Imperial	Holmes & Naver, Inc. (1973)
Laguna	"
Bouquet	"
Bridgeport, Haiwee, Lake Crowley	"
Aqueducts	
California	Holmes & Naver, Inc. (1973)
Los Angeles	"
Colorado	"
Canals	
Palo Verde	Holmes & Naver, Inc. (1973)
Highland	"
Coachella	"
Westside Main	"
All American	"

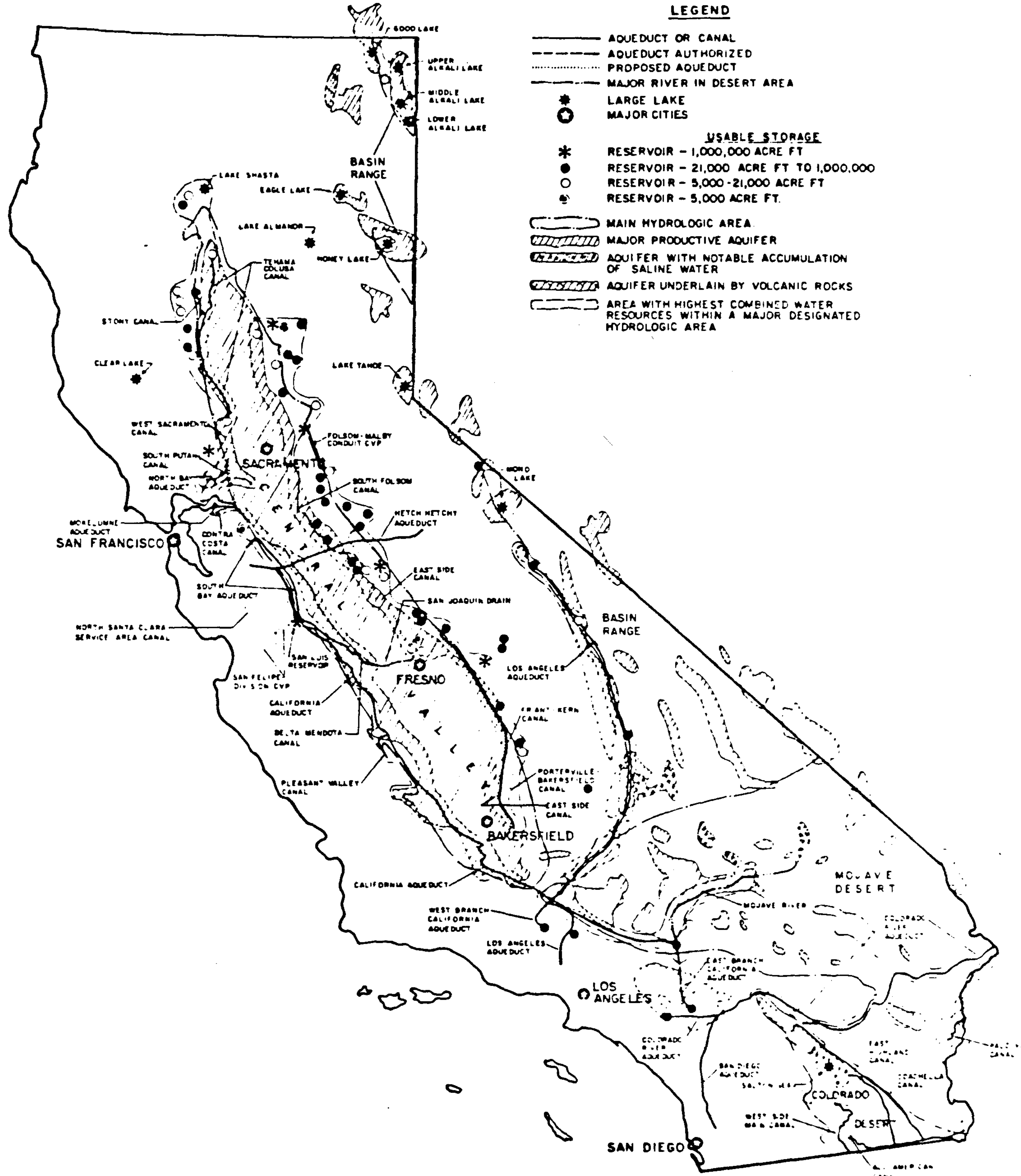

FIGURE 6. INLAND WATER RESOURCES (from Holmes and Narver, Inc. 1973)

III. B. 2. Groundwater

There are approximately 270 groundwater basins in California, of which 97 have a storage capacity exceeding 1 million acre-feet (DWR, 1977). As much as 410 million AF may be stored in the aquifers of the South Lahontan and Colorado Desert hydrologic areas alone (Carey, et al. 1977). Unfortunately, where the water quality is good and easily attainable, it is already appropriated for irrigation and municipal water supply. Other groundwater of poorer quality may be suitable for cooling purposes, yet has restrictions against overdrafts. Annual recharge of less than 1% in the areas considered acceptable seriously limits the use of this groundwater unless legal concessions allowing the use of this largely unused groundwater can be made. The legality of this is discussed below.

The southeastern desert area of California rated as acceptable by the Aerospace Corporation (1974) contains several groundwater basins. In a number of these, water use is limited by saline deposits in the sediments, and so only small amounts of water are used at present (DWR, 1977). DWR estimates, however, that sufficient water exists for power plant cooling for 30 years at 20,000 AF/year in several of these otherwise unused basins. They note that as overdrafts lower the water table, increased pumping lifts occur and the water quality may decrease. Nevertheless, if the legal problems can be overcome, and water quality problems mitigated, then these basins have potential as cooling water sources. Their location, and data on amounts and quality, are shown in Figure 7 and Table 8 respectively. This table combines the resources listed in Carey, et.al. (1976) which are generally in agreement with the DWR (1977) report. It is noted that the highest concentrations in the "range of TDS" column for Bristol Valley, Ward Valley, and Ivanpah Valley are from well in dry lake beds. These values thus reflect localized mineralization due to evaporation and leaching.

Carey et al. (1977) conceptualize six plant sites based on the location of the surrounding basins. As can be seen in Table 8, the Goffs site comprises the most groundwater basins, some of which are 40-60 miles from the proposed plant site.

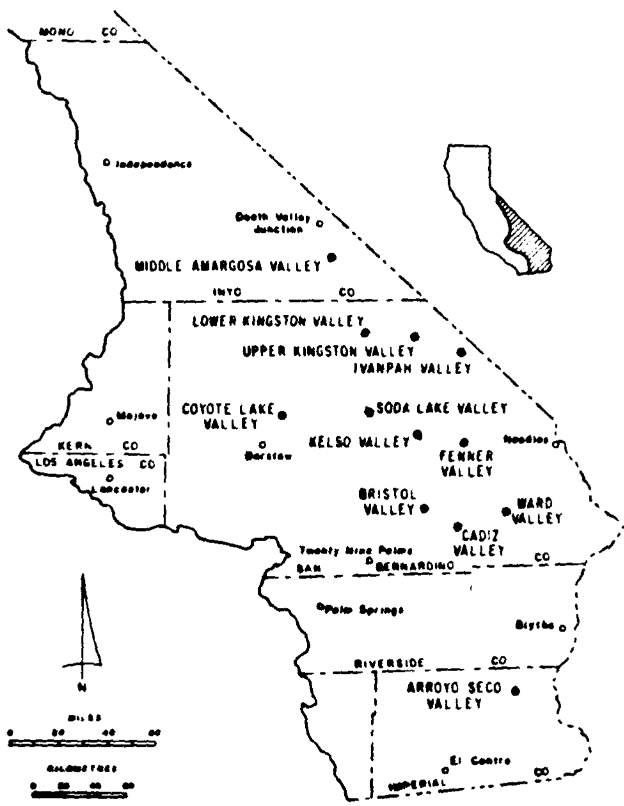

FIGURE 7. GROUND WATER BASINS (DWR, 1977)

TABLE 8 - CALIFORNIA GROUND WATER RESOURCES
WELL YIELDS

BASIN NAME	PLANT SITE	AREA (mi^2)	STORAGE CAPACITY (MAF)		Max	AVE	PRESENT USE	RANGE OF TDS (mg/1)	DEPTH TO WATER (ft)	REFERENCE
Middle Amargosa Valley		620	6.8	-	-	-	Dom. Irr. Industry	480 - 33,000 (14)	-	DWR (1977)
Lower Kinston Vally		290	3.39	-	-	-	NONE	5400-8200 (2)	-	DWR (1977)
Upper Kingston Valley		270	2.13	-	-	-	Dom. Livestock	340-1100 (12)	-	DWR (1977)
Ivanpah Valley	Goffs	300	3.09	-	600	400	Dom. Irrig. Ind. Livestock	140-27,500 (44)	59-278	DWR (1977) Carey, et.al '77
Kelso Valley	Goffs	370	5.34	-	370	290	Dom. Irrig.	440-590 (3)	200-420	DWR (1977) Carey, et.al '77
Soda Lake	Goffs	590	9.3	-	2100	1100	Dom. Irrig. Indust. Munic.	910 (1)	17-65	DWR Carey et.al(1977
Pahrump Valley	Goffs	400	.69	-	300	150	Irrig. Dom.	-	50	Carey et al(1977
Mesquite Valley	Goffs	460	.58	-	1500	1020	Dom.	-	15-84	Carey et al (197
Lanfair Valley	Goffs	280	3.0	-	35	16	Dom. Livestock	-	100-500	Carey et al (197
Rice Valley	Rice	300	2.28	-	90	-	Dom.	-	13-450	Carey et al (197
Vidal Valley	Rice	160	1.60	-	1800	675	Dom.	-	13-450	Carey et al (1977)
Cadiz Valley	Cadiz	430	4.3	800	300	66	Dom.	610 (1)	142-260	DWR (1977) Carey et al '77
Bristol Valley	Cadiz	710	7.0	2100	500	125	Dom.	280-390,000 (31)	10-125	DWR (1977) Carey et.al(1977
Harper Valley	Barstow	510	6.98	-	3000	725	Dom. Irrig.	-	10-150	Carey et.al(1977
Upper Mojave River	Barstow	600	26.53	-	3600	630	Irrig. Munic. Military, Indust.	-	33-270	Carey et.al(1977
Amos Valley	Glamis	220	2.9	-	100	50	Dom. Indust.	-	0-200	Carey et al(1977
Ogilby Valley	Glamis	220	2.9	-	100	50	Dom. Indust.	-	0-220	Carey et al(1977
Parker Valley	Parker Valley	170	-	-	2180	450	Dom. Irrig.	-	0-15	Carey et al(1977
Palo Verde Mesa	Blythe	280	6.84	-	2750	1650	Dom. Irrig.	-	0-300	Carey et al(1977
Palo Verde Valley (incl. Cibola Valley)	Blythe	200	4.96	-	2180	670	Dom. Irrig.	-	0-200	Carey et al(1977

TABLE 8 cont.

BASIN	AREA (mi^2)	STORAGE CAPACITY (MAF)		WELL YIELDS Max	AVE	PRESENT USE	RANGE OF TDS (mg/1)	DEPTH TO WATER (ft)	REF.
Coyote Lake Valley	150	7.53	-	-	-	Dom.Irrig.	310-4700 (12)	-	DWR (1977)
Fenner Valley	720	5.6	3000	-	-	Dom. Indust. Livestock	120-1100 (27)	-	DWR (1977)
Ward Valley	770	8.7	2700	-	-	Dom. Livestock	400-21600 (6)	-	DWR (1977)
Arroyo Seco Valley	430	7.0	1500	-	-	Dom.	280-2000 (10)	-	DWR (1977)

III B. 3 - Irrigation Return Flow.

The concept of using irrigation return flows requires the use of water after it has served its function for irrigation. Also known as agricultural wastewater, this water must be exported from its area of use so that increasing mineralization of the land does not occur. Agricultural areas having large quantities of irrigation return flow and which correspond to the "suitable area" in California include the Palo Verde and Imperial Valley irrigation districts (DWR, 1977).

Palo Verde Irrigation District to Colorado River - Wastewater from the Palo Verde district is returned to the Colorado River via the Palo Verde Outfall Drain, near the town of Palo Verde (Carey, et al. 1977). Of an original 800,000 AF/yr diversion, 447,000 AF were returned to the Colorado River in 1972; this figure has continued to decline form 580,000 AF/yr which were returned a decade earlier (Carey, et al. 1977). Water quality also suffers because of this re-routing for irrigation: water taken for irrigation at Palo Verde Valley has a salinity of about 800 mg/l whereas the salinity rises to within 1500-2100 mg/l after it is used (DWR, 1997). Carey et al. (1977) point out that a powerplant's water requirement represents only a small fraction of this return flow. Yet even this cannot be spared from being returned to the Colorado River since the PVID uses its full consumptive use allocation of Colorado River water. Carey et al. (1977) further note that either an increase in allocation or a reduction in irrigated acreage is necessary to allow a diversion of return flows for use in power-plant cooling. They also explain a scenario of the San Diego Gas and Electric Company designed to supply up to 38,800 AF/yr for cooling two 950 MWE reactors originally planned for the cancelled Sundesert Nuclear Power Plant. The plan, also mentioned by DWR (1977), includes releasing of 17,000 AF/yr from Parker

Dam by the MWD to compensate for 17,000 AF/yr used for power plant cooling. DWR (1977) notes that the substitution of Parker Dam water for irrigation return flow would improve the downstream river water quality by 12 mg TDS/1. The other 21,800 AF/yr would be used by virtue of water rights resulting from the PVID pruchase of 7,259 acres of land, which would be taken out of production (Carey, et al., 1977; DWR, 1977). This practice is controversial because seepage and runoff is not taken into account. The above arrangements would not be necessary in their entirety for a solar thermal power plant since the water requirements are lower than those for the proposed Sundesert facility (greater electricity production and larger water needs per MWE).

Imperial Valley Irrigation District to Salton Sea - The drainage which results from Imperial Valley irrigation water flows into the Salton Sea. Most of it is conveyed via two natural channels - the Alamo and New Rivers - along with municipal wastewater treatment plant effluent from this part of California and Mexicali, Mexico (DWR, 1977). Table 9 shows input of these two rivers, and the total flow into the Salton Sea which includes these two rivers, San Felipe Creek, and 22 drains and wasteways (DWR, 1977). The increased flow, resulting in record height levels, causes flooding of shoreline developments.

TABLE 9: FLOW INTO SALTON SEA FROM VARIOUS SOURCES

SOURCE	PERIOD FROM 1943-1967 high (AF/yr)	low	1967	1968	1971
Alamo R.	760.000	490,000	620,000 AF	--	--
TDS	--	--	2,500 mg/l	--	--
New R.	540,000	358,000	383,000 AF	--	--
TDS	--	--	3,500 AF	--	--
All sources	--	--	--	1,097,000AF	1,185,000 AF
TDS	--	--	--	--	2,000-4,000 mg/l

(from DWR, 1977)

The removal of water from either river for power plant cooling would lower the level of the Sea, but would increase the TDS of the sea, which is already too high. Post-treatment of Sea water could also result in improved water quality if the returned blowdown is cleaner (less BOD, pathogens) than current inputs. The ultimate effect of decreased flow to the Sea and blowdown discharge to the Sea would have to be examined in detail.

III. C. Municipal Wastewater

At least 70% of urban wastewater in Southern California is discharged to saline and brackish water and is not further used (DWR, 1977). This water if treated has potential for power plant cooling. The considerations for its use include the quantities available in any one location, the quality of the water before and after the current minicipal treatment, and the legal right to the water.

The question "Who owns the wastewater?" has not been answered, and must be resolved before institutional barriers to reclaiming wastewater can be resolved. A second institutional barrier is the question of ultimate treatment responsibility. The definition of "Best Practicable Technology" for a domestic water can be quite different than for a power plant. It is possible that a power plant could, by definition, be required to implement additional treatment in exchange for the priveleges of recycling the wastewater. Such instiutional problems may seem trivial to solve; however, these trivial problems have presented water recycle in the past.

Regardless of any legal responsibility of the power industry to treat the wastewater itself, there are economic observations by Humenick, et al. (1972) that warrant consideration. They argue that pre-treatment of already received wastewater---a requirement for further quality control in the cooling system---introduces a separate cost to the utility which results in the total cost of treatment from sewage to cooling water, shared by the Sanitation District and the Utility, being far in excess of what it would be if all of the treatment were done at the same time. Thus, the concept of joint treatment as an economic incentive.

Humenick, et al. (1972) further state that a 1000 MWE power system should have a maximum flow of wastewater of 50 MGD to avoid summertime odors and nuisance conditions. A minimum flow would have to be established in order to avoid salt build-up, especially in summer months. There are two major factors for consideration: 1) the cooling system, and 2) the wastewater treatment system. The first includes the surface area needed for heat dissipation, the minimum inflow to sustain system losses, and the water quality necessary for cooling. The considerations for treatment systems include the range of retention time necessary and/or tolerable, the assimilative capacity of the pond, and the treatment necessary to meet discharge standards. Problems associated with this type of plan are similar to cooling water problems in general yet are intensified due to the nature of wastewater. For example, biological fouling of condenser systems from increased algae, nitrogen, and phosphorous would lead to a greater degree of scale and corrosion unless it were carefully monitored. (Humenick, et al., 1972).

Quantities Available - It is assumed that 15,000 AF/yr is the minimum requirement of treated wastewater at the cooling site. This requires that an average flow of 13.4 MGD be maintained. In an analysis of water available for nuclear plants, DWR (1977) rated the counties in California according to availability with a minimum requirement of 20,000 AF/yr. They concluded, (see Table 10) that 20 counties could make this amount of water available. Those counties which are in the present study area in California are San Bernadino and Riverside. Together, these counties produce 65,900 AF/yr of wastewater. An immediate problem surfaces when considering the geographic spread of the wastewater facilities and the fact that the average output for each plant is only 5,500 AF/yr. (range = 100 AF - 17,900). The transportation costs are a major limiting factor unless an optimal group of nearby plants can be found. Nevertheless, wastewater recycle appears to be one of the more promising sources for cooling water.

TABLE 10
TREATMENT PLANTS PRODUCING MUNICIPAL AND INDUSTRIAL WASTE WATER THAT COULD BE USED FOR POWER PLANT COOLING
1973 [1]

County	Treatment Plant	Quantity Produced			
		cubic hectometres		1000's of acre-feet	
Alameda	East Bay Municipal Utility District				
	Combined Plants[3]		131.8[4]		106.9[4]
	Hayward, City of	18.5[4]		15.0[4]	
	Oro Loma Sanitary District	22.8[4]		18.5[4]	
	San Leandro, City of	9.9[4]		8.0[4]	
	Total for group		51.2[4]		41.5[4]
	TOTAL FOR COUNTY		183.0[4]		148.4[4]
Contra Costa	Central Contra Costa Sanitary District		39.9[4]		32.4[4]
	Combined Plants[3]				
	Pinole, City of	1.9[4]		1.5[4]	
	Richmond, City of	11.2[4]		9.1[4]	
	Rodeo, City of	10.0[4]		0.8[4]	
	San Pablo Sanitary District	11.0[4]		9.0[4]	
	Total for group		34.1[4]		20.4[4]
	TOTAL FOR COUNTY		74.0[4]		52.8[4]
Fresno	Fresno, City of		42.1		34.2
Humboldt	Crown Simpson Pulp Co., Samoa		27.6[4]		22.4[4]
	Louisiana Pacific Co., Samoa		36.6[4]		29.7[4]
	TOTAL FOR COUNTY		64.2		52.1
Kern	Combined Plants[3]				
	Bakersfield, City of (3 plants)	20.3		16.5	
	Mt. Vernon County Sanitary District[3]	5.3		4.3	
	North of River Sanitary District No. 1[3]	3.2		2.6	
	TOTAL FOR GROUP AND COUNTY		28.8		23.4
Los Angeles	Hyperion Plant		468.2[4]		379.6[4]
	Los Angeles County Sanitation Dist.[3]				
	Joint Water Pollution Control Plant		496.1[4]		402.2[4]
	San Jose Creek[3]		36.2		29.4
	Combined Plants[3]				
	Long Beach Plant	9.9[4]		8.1[4]	
	Los Coyotes Plant	11.4		9.3	
	Terminal Island	14.1[4]		11.5[4]	
	Total for group		35.4		28.9
	TOTAL FOR COUNTY		1 035.9		840.1
Marin	Combined Plants[3]				
	Marin County Sanitary District No. 1	9.6[4]		7.8[4]	
	Marin County Sanitary District No. 6, Novato	4.2		3.4	
	Marin County Sanitary District	1.2		1.0	
	San Quentin Prison	0.9[4]		0.7[4]	
	San Rafael Sanitary District	4.9		4.0	
	Las Gallinas Valley Sanitary District	4.2		3.4	
	TOTAL FOR GROUP AND COUNTY		25.0		20.3
Napa-Solano	Combined Plants[3]				
	Napa Sanitary District	11.4[4]		9.3[4]	
	Benecia, City of	1.4[4]		1.2[4]	
	Vallejo Sanitation and Flood Control District	11.7[4]		9.5[4]	
	Mare Island Naval Shipyard	1.0[4]		0.8[4]	
	TOTAL FOR GROUP AND COUNTIES		25.5[4]		20.8[4]
Orange	Orange County Sanitation Districts				
	Plant No 1		66.4[4]		53.9[4]
	Plant No. 2		143.1[4]		116.0[4]
	TOTAL FOR COUNTY		209.5[4]		169.9[4]
Riverside-San Bernardino	Riverside, City of		24.6		20.0
	Combined Plants[3]				
	Chino Basin Municipal Water District				
	Masingale Plant	13.9		11.3	
	Chino Plant	3.5		2.8	
	Corona, City of	4.2		3.4	
	Perris, City of	0.4		0.3	
	California Institute for Women	0.3		0.2	
	Jurupa Community Services District	1.4		1.1	
	Sunkist Growers, Inc., Corona	1.6		1.3	
	Total for group		25.3		20.4
	Colton, City of	3.1		2.5	
	Redlands, City of	3.5		2.8	
	Rialto, City of	2.7		2.2	
	San Bernardino, City of	22.0		17.9	
	Norton Air Force Base	0.1		0.1	
	Total for group		31.4		25.5
	TOTAL FOR COUNTIES		81.3		65.9

(From DWR, 1977)

Table 10 (continued)

TREATMENT PLANTS PRODUCING MUNICIPAL AND INDUSTRIAL WASTE WATER THAT COULD BE USED FOR POWER PLANT COOLING 1973 [1]

County	Treatment Plant	*Quanity Produced*			
		Cubic hectometres		*1000's of acre-feet*	
Sacramento	Sacramento, City of (main plant)		70.9		57.5
	Combined Plants[2]				
	Arden Plant	8.5		6.9	
	Cordova Plant	2.6		2.1	
	North Highlands Plant	2.5		2.0	
	Northeast Plant	18.2		14.8	
	Total for group		31.8		25.8
	Sacramento County Central Plant	21.8		17.7	
	Sacramento City Meadowview Plant	2.0		1.6	
	Total for group		23.8		19.3
	TOTAL FOR COUNTY		126.5		102.6
San Diego	San Diego City Point Loma Plant		137.4[4]		111.4[4]
San Francisco	North Point Plant		88.3[4]		71.6[4]
	Richmond-Sunset Plant		30.7[4]		24.9[4]
	Southeast Plant		31.2[4]		25.3[4]
	TOTAL FOR COUNTY		150.2[4]		121.8[4]
San Joaquin	Stockton, City Main Plant		27.5		22.3
San Mateo	Combined Plants[2]				
	Estero Municipal Improvement District	2.2[4]		1.8[4]	
	Burlingame, City of	6.4[4]		5.2[4]	
	Millbrae, City of	3.3[4]		2.7[4]	
	International airport Plant	1.1[4]		0.9[4]	
	San Mateo, City of	17.1[4]		13.8[4]	
	Total for group		30.1[4]		24.4[4]
	Menlo Park Sanitary District	7.6[4]		6.2[4]	
	Redwood City, City of	11.3[4]		9.2[4]	
	San Carlos-Belmont, Cities of	9.6[4]		7.8[4]	
	Total for group		28.5[4]		23.2[4]
	TOTAL FOR COUNTY		58.6[4]		47.6[4]
Santa Clara	Palo Alto, City of		37.0[4]		30.0[4]
	San Jose, City of		115.0[4]		93.5[4]
	Sunnyvale, City of		23.4[4]		19.0[4]
	TOTAL FOR COUNTY		175.4[4]		142.5[4]
Shasta	Combined Plants[2]				
	Anderson, City of	1.6		1.3	
	Enterprise Public Utility District	2.1		1.7	
	Redding, City of	6.1		5.0	
	Simpson-Lee Paper Co. (Anderson)	15.2		12.3	
	Champion Papers Inc. (Anderson)	2.9		2.4	
	TOTAL FOR GROUP AND COUNTY		27.9		22.7
Stanislaus	Combined Plants[2]				
	Modesto, City of	27.1[5]		22.0[5]	
	Oakdale, City of	1.7		1.4	
	Patterson, City of	1.7		1.4	
	Riverbank, City of	2.7		2.2	
	Salida Sanitary District	0.9		0.7	
	Ripon (San Joaquin County)	2.1		1.7	
	TOAL FOR GROUP AND COUNTY		36.2		29.4
Ventura	Combined Plants[2]				
	Oxnard, City of	15.7[4]		12.8[4]	
	San Buenaventura, City of	6.2[4]		5.0[4]	
	Ventura Regional County Sanitary District	4.2[4]		3.4[4]	
	TOTAL FOR GROUP AND COUNTY		26.1[4]		21.2[4]
	GRAND TOTAL		2 523.1		2,049.4

[1] Department of Water Resources Bulletin No. 68-73. "Inventory of Waste Water Production and Waste Water Reclamation in California, 1973." April 1975

[2] Treatment plants within a 5-mile radius producing less than 25 cubic hectometres (20,000 acre-feet) of waste water, which could be collected to provide sufficient water for power plant cooling.

[3] A portion of waste water is reclaimed. Source: California Department of Public Health. "Reliability of Wastewater Reclamation Facilities". 1976

[4] This waste water is discharged to brackish or saline water and could be used in lieu of fresh water for water for power plant cooling

[5] Includes industrial waste water not reported in DWR Bulletin No. 68-73

III.C. Cost Considerations

The intention of this section is to list the factors which will affect and possibly determine the choice of water sources, and, hence, the location of a power plant. Actual site costs and calculations will not be made.

Any water resource requires development so that it can be delivered to and be used by a power plant. This includes a pipeline which taps a river source as well as treatment for low quality water or wastewater, and pumping. The cost factors affecting the use of any particular source are the following;

1) distance, as related to the existence of pipelines or need for their construction.
2) distance, and change in elevation, as related to the energy necessary to pump water up wells or through pipelines.
3) existence of wells or the need for their construction.
4) the actual water cost, per unit volume, of different sources.
5) the need for treatment: this includes pretreatment of water to remove SS, DS, and high concentrations of particularly adverse compounds; post-treatment of blowdown which depends on post-use quality, regulations of the area, and availability of safe disposal methods; and primary/secondary treatment of wastewater recycled for cooling water.

IV. ASSESSMENT OF FEASIBLE SITES

The proceeding discussion has shown that there exist significant possibilities for cooling water acquisition in southern California. Cooling water is potentially available from several sources, including surface waters, ground waters, wastewater recycle flows (including irrigation return flows), and transfer of existing water rights. However, there exist a number of technical and institutional problems which must be solved. Nevertheless the aspects for cooling water availability appear promising.

Most of the potentially available sources of water are adjacent to land suitable for power plant construction. This is evident from the previously cited siting studies and can be inferred from commercial plans to construct fossil-fueled and nuclear-fueled power plants. The amount of potentially available cooling water will in large part depend on the eventual outcome of existing power plant siting studies; construction of nuclear and fossil fueled power plants may pre-empt potentially available cooling water for solar thermal power plants. For example, there is 60,000 AC/ft-year of cooling water available from the Palo Verde Irrigation District which could be used for a solar thermal facility; however, it is questionable if this water will still be available by the time the final plans for a solar thermal facility are made. Several projects have already incorporated this water into power plant siting plans (the SDGE Sun Desert Nuclear facility, for example).

There are several areas where ground water is potentially available. Table 11 shows a summary of ground water by location. In most places, the cooling water requirements of 1000 MWE solar thermal power plant will exceed safe ground water yields and will violate National Water Commission rules. Consequently, ground water mining will require legislative action to modify the existing, prohibitive statutes.

It may be possible to reallocate water rights from existing users to the proposed new power plants. This procedure would undoubtedly involve cumbersome financial arrangements and would probably require that farm acreage be withdrawn from production. This method of acquiring cooling water will undoubtedly become more attractive as energy costs increase.

The potential for acquiring high quality surface water for direct use as cooling water appears to be low. Most surface waters are already allocated and the existing local economy depends upon continued use of these surface waters. Additionally, the use of Colorado River water in 1985 for the Central Arizona Project will make water very scarce in southern California, and make cooling waters even more difficult to find. Possible exceptions may exist in Arizona after 1985 when Colorado River Water becomes availabe. Since the present economy of Arizona does not depend upon this additional Colorado River water, acquisition of rights to this water may be possible in Arizona. Existing statutes regarding the use of this cooling water must be modified for this approach to be successful.

Perhaps the best approach to obtaining cooling water for the proposed solar thermal power plant are innovative approaches using a combination of ground water, surface water, and wastewater recycle flows. There are several possibilities for such innovative approaches. One approach involves using poor quality ground water shown in Table 11. In many instances these waters are so poor that their use for agricultural and domestic purposes is limited. If high quality surface water were available (such as the 100,000 AC/ft year from DWR), the marginal quality groundwater could be used for cooling water, while replacing it with high quality surface water. This plan would have an additional benefit of improving groundwater qulaity, and may overcome the objection to groundwater mining.

Furthermore this concept could be extended to use seasonally available surface waters. At present, there is excess state water project water in the rainy season. This water could be used to recharge groundwater supplies which would be used in dry seasons. This type of conjunctive use of surface and groundwater will be a viable option until the state water project is completed.

A second and perhaps more innovative approach is to reuse the large quantities of municipal wastewater presently discharged to salt water by the large coastal cities. Obviously the direct use of these waters by pumping them to suitable solar thermal sites is very uneconomical. However, an alternate approach is to reuse these wastewaters in coastal or near-coastal plants where fresh water is used for cooling. The water conserved could then be reallocated to thermal facilities. Such a water "swap" may be possible and perhaps economical when one considers the cost of pumping Colorado River Water to the coast. Unfortunately the quantities of water which can be conserved by this method are unknown and have not been investigated. This method of cooling water acquisition is specifically recommended for further study.

In summarizing the findings of this investigation, it appears that the major obstacles to finding suitable supplies of cooling are institutional problems. There are suitable supplies of ground water and wastewater recycle flows available in a number of areas adjacent to suitable solar thermal power plant sites. The Palo Verde Irrigation District return flows are perhaps the best example of available cooling water. This water is very attractive since it appears to be the most "legally available." Acquisitions of cooling waters will entail more institutional work than technical work.

Table 11

Water Quality Rating of California Water Sources

by Sites

Location	Hardness	TDS	$SO_4^=$	Cl
Rice	very high	mod-high	low	mod
Cadiz	mod-high	low-mod	low	low
Goffs	mod-very high	mod	low	low
Barstow	mod-high	low-mod	mod	low-high
Glaniss	high-very high	high	high	high
Blythe	high-very high	mod	high	low-mod
Parker Valley	very high	high	very high	mod-high
Palo Verde Irrigation District*	very high	high	very high	high

*irrigation drainage

(from Carey, et. al., 1977)

V. RESEARCH NEEDS

In conducting this investigation several areas needing research and development have been identified. It is appropriate to indicate these areas:

1. Development of more efficient power plants. Obviously this can reduce cooling water requirements while conserving resources. It is also obvious that this is a technically and scientifically challenging problem.
2. Isolation and charaterization of the institutional problems with obtaining cooling water. This problem can most efficiently be solved by an interdisciplinary team of researchers, which is composed of individuals trained in law, political science,and the social sciences, as well as those trained in science and engineering.
3. Development of innovative methods of using wastewater recycle flows for cooling water. This research could produce, in effect, additional water for the southwestern United States, in addition to alleviating wastewater treatment problems.
4. Wet/Dry Cooling Towers. The development of more efficient cooling towers could drastically decrease cooling water requirements.

Appendix A - References

Aerospace Corporation, The. Energy and Resources Division. 1974. Solar Thermal Conversion Mission Analysis. Volume V: "Area Definition and Siting Analysis:Southwestern United States." Aerospace Report No. ATR-74(7417-16)-2, Vol V. Contract No. NSF - C797. November 15, 1974.

Arizona Water Commission. 1977. Phase II, Arizona State Water Plan, Alternative Futures.

Backus, C.E. and M.L. Brown. 1975. "Water Requirements for Solar Energy," in Gloyna, E.F.; H.H. Woodson; and H.R. Drew, Water Management by the Electric Power Industry, Water Resources Symposium #8, Center for Research in Water Resources, The University of Texas at Austin, pp. 270-279.

Betz Laboratories, Inc. 1976. Betz Handbook of Industrial Water Conditioning. Pennsylvania: Betz Laboratories, Inc., 344 pp.

Bowden, C. 1975. The Impact of Energy Development on Water Resources in Arid Lands. Literature review and annotated bibliography. Arid Lands Resource Information Paper no. 6, University of Arizona; Office of Arid Lands Studies.

Carey, et al., (eds). 1976. Study of Alternative Locations of Coal fired Electirc Generating Plants to Supply Energy from Western Coal to the Department of Water Resources. Institute of Geophysics and Planetary Physics, and Environmental Science and Engineering, UCLA. Joint funding by DWR and the California Energy Resources Conservation and Development Commission, Contract B-57027. February, 10, 1976.

Chalmers, J.R. 1974. Southwestern Groundwater Law. A textual and bibliographic Interpretation. Arid Lands Resource Information Paper no. 4. University of Arizona, Office of Arid Lands Studies.

Chavez, P., et. al. 1971. Lower Colorado Region Comprehensive Framework Study, Appendix XIV: Electric Power. Lower Colorado Region State-Federal Interagency Group.

Croley II. T.E., V.C. Patel, and M-S Cheng. 1975. The water and total optimizations of wet and dry-wet cooling towers for electric power plants. Iowa Institute of Hydraulic Research Report No. 163. The University of Iowa, Iowa City, Iowa, January, 1975.

Department of Water Resources. 1977. Water for Power Plant Cooling, Bulletin No. 204, July, 1977.

Dewsnup, R.L., D.W. Jensen, and R.W. Swenson, eds. 1973. A Summary-Digest of State Water Laws. National Water Commission, 826 pp.

Ege, H.D. Jr. 1975. "Mangaement of Water Quality in Evaporation Systems and Residual Blowdown." Gloyna, E.F., H.H. Woodson, and H.R. Drew, Water Management by the Electric Power Industry, Water Resources Symposium #8, Center for Research in Water Resources, The University of Texas at Austin, pp. 172-182.

Fermi, E. 1936. Thermodynamics. New York: Dover Publications. 160 pp.

Foote, G.L., R.W. Hill, and D.H. Hoggan. 1971. Hydrologic Inventory of the Great Salt Lake Desert Area. PRW640-7, Utah Water Research Laboratory, Utah State University.

Heitz, L.F. Jr., 1975. The Potential For Nuclear & Geothermal Power Plant Siting in Idaho as Related to Water Resources. Master's Thesis. University of Idaho Graduate School, Dept. of Engineering; March 1975.

Holmes and Narver, Inc. 1973. California Power Plant Siting Study, vol. II. HN-8145.4. UC-12. May, 1973.

Humenick, M.J., W.E. Megan, E.G. Fruh. 1972. Wastewater Effluent to Power Plant Cooling. Center for Research in Water Resources, The University of Texas at Austin. CRWR-95.

Krenz, J.H. 1976. Energy: Conversion and Utilization. Boston: Allyn and Bacon, Inc. 359 pp.

Krieg, B., I. Losater, and C. Blunstein. 1977. Electric load management for the California water system. LBL-6367. Lawrence Berkeley Laboratory; University of California, Berkeley.

Leung, P. 1975. "Evaporative and Dry-Type Cooling Towers and Their Application to Utility Systems," in Gloyna, E.F., H.H. Woodson, and H.R. Drew, Water Management by the Electric Power Industry, Water Resources Symposium #8, Center for Research in Water Resources, The University of Texas at Austin,pp. 106-116.

Mann, D.E. 1976. Water Policy and Decision Making in the Colorado River Basin. Lake Powell Research Project Bulletin number 24.

Meltz, W.D., A.L. Hammond. 1978. Solar Energy in America; Washington, D.C.; America Association for the Advancement of Science, 239 pp.

National Water Commission, Consulting Panel on Waste Heat. 1972. The Water Use and Management Aspects of Steam Electric Power Generation. NWC-EES-72-046.

Nelson, G.R. 1974. Water recycle/reuse possibilities: power plant boiler and cooling systems. EPA -660/2-74-089.

Riley, J.P., C.G. Clyde, W.J. Grenney, Y. Y. Haimes, and C.T. Jones. 1975. Development of a management framework of the Great Salt Lake. Utah Water Research Laboratory, Utah State University.

Sathaye,J.A., and R.L. Ritschard. 1977. Water Requirements for Future Energy Production in California. Lawrence Berkeley Laboratory.

Sieckman, D.L., et.al., 1971. Lower Colorado Region Comprehensive Freamework Study, Appendix V; Water Resources. Lower Colorado Region State-Federal Interagency Group.

Warner, C.F. 1966. Thermodynamic Fundamentals For Engineers, with problems and solutions. New Jersey; Littlefield, Adams, & Co. 250 pp.

Appendix B

Annotated References

Aerospace Corporation, The. Energy and Resources Division. 1974. Solar Thermal Conversion Mission Analysis. Volume V: "Area Definition and Siting Analysis: Southwestern United States." Aerospace Report No. ATR-74(7417-16)-2, Vol V. Contract No. NSF - C797. November 15, 1974.

Potentially suitable area is nearly all in the four sub-basins of the Colorado River Basin where cooling water availability cannot be assured. A review of water resources of the lower Colorado Basin was made and found to be considerably short of the amount required with present (1974) cooling tower performance.

Water resources were not estimated outside of this basin although a large area was found otherwise suitable under the least stringent set of criteria.

From 21,500 to 161,000 square miles of area out of a total of 1,031,000 square miles defined as the Southwestern U.S. are potentially suitable depending upon the stringency of the criteria applied.

Available water resources of the lower Colorado River Basin were estimated in 1974 as approximately 471,000 AF/yr. This could support 31,400 MW-yr/yr or 275 x 10^9 kWh/yr. This energy represents 14% of total Southwest energy needs in the year 2000 (which is 2,023 x 10^9 kWh/yr.).

The total flow of the Colorado R. is 14,952,000 AF/yr. The amount of water listed as "available", above, reflects the total of each state's allocation for power and industrial usage. It is noted that the water assumed available is entirely from the Colorado R. Basin, yet much of the total energy need (about 40% of the total 2,023 billion kWh/yr) is outside of the basin. Further it is noted that the needs of other power plants have been neglected.

Arizona Water Commission. 1977. Phase II, Arizona State Water Plan, Alternative Futures.

A well-conceived report presenting the State's water resources divided by use categories. Additionally includes factors such as water cost, legal rights, and water quality in determining present and future use patterns. The section on steam electric power plants includes projections of water demand for this use until 2020. The counties of interest to the present study are Maricopa and Yerma. The former is noted as eventually being the center of power generation in the State, partially due to good water availability. Yuma County, however, which consists of the majority of the study area delineated by Aerospace (1974), is said to have its sizeable water supplies already assigned to agricultural production. However, trade-offs between these two counties' depletions for power generation is noted as an undeniable possibility.

Backus, C.E. and M.L. Brown. 1975. "Water Requirements for Solar Energy," in Gloyna, E.F.; H.H. Woodson; and H.R. Drew, Water Management by the Electric Power Industry, Water Resources Symposium #8, Center for Research in Water Resources, The University of Texas at Austin, pp. 270-279.

Cooling water requirements plus simple discussions of the various types of solar thermal plants are presented.

Cooling water requirements per unit electricity produced depend mostly upon the plant's thermodynamic efficiency (ratio of heat input and electrical output). The four solar thermal concepts discussed (central receiver, fixed mirror, parabolic cylindrical troughs, and solar ponds) vary in efficiency from 5-55%. Lower efficiency results in lower cost per unit electrical output ($/kWh) but greater amounts of water required.

Moderate temperature steam-turbines would use the Rankine cycle. Low temperature turbines (solar pond) might better utilize a low-vapor pressure Rankine cycle, while high-temperature turbines (central receiver) might increase their efficiency above those permitted by modern steam technology by using a closed Brayton cycle. The Brayton cycle additionally could be economically dry cooled.

Betz Laboratories, Inc. 1976. Betz Handbook of Industrial Water Conditioning. Pennsylvania: Betz Laboratories, Inc., 344 p.

A user's book with technical information, including treatment chemicals and amounts, for quality control of industrial water. Was separate chapters for power plant cooling water on scale, corrosion, etc.

Bowden, C. 1975. The Impact of Energy Development on Water Resources in Arid Lands. Literature review and annotated bibliography, Arid Lands Resource Information Paper no. 6, University of Arizona, Office of Arid Lands Studies.

Discusses impacts of energy projects in lands where water is scarce. Provides historical perspective of water for energy use, and impacts to air, water and land from the different energy alternatives, including solar energy. Case study of Colorado River Basin extraction and its effects.

Notes that the TDS of the lower Colorado are near or beyond threshhold limits for some uses. Agriculture in Imperial, Coachella, Gila, and Yuma Valleys is threatened unless control of salinity takes place. Blames irrigation and energy development (reservoirs).

Salinity of Colorado R. at Lee Ferry, Arizona, in 1974 = 609 mg/1 and flow = 10,376,000 AF.

Chavez, P. (Chairman), _et al._ 1971. _Lower Colorado Region. Comprehensive Framework Study_. Appendix XIV: Electric Power, Lower Colorado Region State-Federal Interagency Group.

Estimates the energy demand to the year 2020, along with costs of generation and water needs. The regions annual consumptive water use for power purposes as 36,600 AF in 1980, and 106,500 AF in 2000.

Carey, D. L., R.R. Durtich, M. B. Rogozen, and O. L. Anderson, (eds). 1976. Study of Alternative Locations of Coal-fired Electric Generating Plants to Supply Energy from Western Coal to the Department of Water Resources. Presented by the Institute of Geophysics and Planetary Physics, UCLA. Joint funding by DWR and the California Energy Resources Conservation and Development Commission, Contract B-57027. February, 10, 1976.

A compendium of information related to sites for a coal-fired power plant supplying electricity for California. Air quality requirements were the primary limiting factors, although also considered were proximity to coal transportation routes and facilities, water supply, legal, political, environmental, and economic factors.

Water supply questions mainly centered around agricultural return flows and groundwater as sources for power-plant cooling waters. Obtaining Colorado or Mojave R. water was considered more a legal and political problem than a technical problem, yet these surface water supplies are discussed.

Water needs are stated as 30,000 AF/yr for a 1000 MWE coal-fired plant. The water would be for cooling system makeup, boiler makeup, metal equipment cleaning, ash transport, and local domestic supply. Cooling system water alone is estimated as 20,000 AF/yr which translates into 20 AF/MW-yr.

Cooling technology is envisioned as a mechanical draft, crossflow (induced draft) wet evaporative tower because, it is noted, the State of California has greatly restricted the use of water for once-through cooling.

Extensive legal and environmental analysis is included for several states in the Southwest; discusses groundwater and interstate transfer rights.

Chalmers, J.R. 1974. Southwestern Groundwater Law. A textual and bibliographic Interpretation. Arid lands Resource Information Paper No. 4. University of Arizona, Office of Arid Lands Studies.

Primarily concerned with present groundwater laws and previous litigation for the seven southwestern states, generally reviews water amounts, and utilization. Has good maps and tables on location of resources, amounts, and uses. Does not discuss availability in the future due to changed legislation. No mention of power plants.

Croley II, T.E., V.C. Patel, and M. -S Cheng. 1975. The water and total optimizations of wet and dry-wet cooling towers for electric power plants. Iowa Institute of Hydraulic Research Report No. 163, The University of Iowa, Iowa City, Iowa, January, 1975.

Investigates the possibilities of greatly reducing consumptive water use by combining dry and wet cooling towers in different proportions.

It is shown that it does not pay to construct dry towers along with wet towers in hotter climates because very little water conservation is achieved.

A cost optimization model is used which incorporates much of the known theoretical and empirical information on temperature effects on evaporation, heat rejection, turbine back pressure, fuel consumption, costs, fogging, quality of water, etc.

With a dry-bulb temp. mean of 90^{o}F and wet-bulb of 80^{o}F (the highest temperatures used in this specific section of the model) the greatest reduction of water use attained by adding a dry tower to a wet tower was 20%, when the water cost was low. Higher water costs resulted in the model using more cooling from the dry tower portion and consumption was reduced by 56%.

Department of Water Resources. 1977. Water for Power Plant Cooling. Bulletin no. 204, July, 1977.

Discusses projected demands for cooling water, different cooling strategies, sources of cooling water, and scenarios of proposed powerplant sites in California.

Ege, H. D. Jr. 1975. "Management of Water Quality in Evaporation Systems and Residual Blowdown." pp. 172-182 in Gloyna, E.F.; H.H. Woodson, and H.R. Drew. Water Management by the Electric Power Industry, Water Symposium #8, Center for Research in Water Resources, the University of Texas at Austin.

Good discussion on water quality and mitigation measures for power plants, including the occurrence of scale, corrosion, and deposition.

Federal Power Commission, Bureau of Power. 1975. Potential pumped storage projects in the Pacific Southwest NTIS, PB - 242 798.

Describes potential sites for hydroelectric plants. These plants would be pumped storage for use during peak hours of energy demand. The study lists sites which are feasible for plants and reservoirs. Unrelated to cooling water sites.

Heitz, L. F. Jr., 1975. The Potential For Nuclear & Geothermal Power Plant Siting in Idaho as Related to Water Resources. Master's Thesis. University of Idaho Graduate School, Dept. of Engineering; March 1975.

Investigates the physical requirements for cooling systems. Water quality standards and water rights laws in Idaho are examined. A survey of existing surface and subsurface supplies of water is made.

A 1000 MW tower cooled (evaporative) nuclear power plant is reported to use 30 cfs as consumptive water, which equals 21,719 AF/year

= 21.7 AF/MW yr

Holmes and Narver, Inc. 1973. California Power Plant Siting Study, vol. II. HN-8145.4. UC - 12. May, 1973. A Study conducted for the Resources Agency State of California and the U.S. Atomic Energy Commission.

The state goal of this study is to find alternate concepts ("concepts" being building-types) for nuclear power plants throughout California without pre-empting other potential uses in close proximity. Several designs were considered so as to maximize available sites, such as floating lagoon, underground, hillside, inland, and coastal designs. Cost, safety, environmental impacts were considered. Information or water sources is included as well as potential sites.

Humenick, M. J., W. E. Morgan, E. G. Fruh. 1972. Wastewater Effluent for Power Plant Cooling. Center for Research in Water Resources, The University of Texas at Austin. CRWR - 95.

Investigates feasibility of integrating wastewater treatment with power plant cooling.

Krenz, J.H. 1976. Energy: Conversion and Utilization. Boston: Allyn and Bacon, Inc. 359 pp.

A good source of technical background.

Provides output needed percapita, and input necessary given 40% conversion ratio. (efficiency ratio).

"The simplest method of removing waste heat is through a system using a flow of water to directly cool the condenser. Large quantities of water needed so only suitable for plants adjacent to rivers or large bodies of water."

Waste heat removal from producing of 1 MW (including boiler efficiency of 90% resulting in 0.25 MW lost in the stacks from an original input of 2.5 MW of heat) = 25 x 10^{10} calories. Requires 2.5 x 10^6 kg water = 2.1 AF/day or an average flow of 0.03 m^3/s assuming the water temperature rise is 10°C.

A wet cooling tower which cools through evaporation reduces this water need to 1.8% of the 2.1 AF/day. This results in a yearly need of 13.8 AF which compares well with Aerospace Corp. (1974) estimate of 15 AF/MW-yr.

A dry cooling tower requires no water beyond that which is already in the system, yet tends to be larger, more expensive, and because of poorer heat transfer, results in a small reduction of the power plants overall efficiency.

Desalinization has been proposed for the use of waste heat for plants located adjacent to large bodies of salt water. see Meinel, A.B. and M.P. Meinel. "Is it time for a new look at solar energy" Bulletin of the Atomic Scientists, Vol 27, no. 8 (October, 1971), pp. 30-37. and Meinel and Meinel, "Physics looks at solar energy" Physics Today, VOL. 25, no. 2 (February, 1972): 44-50.

Krieg, B., I. Lasater, and C. Blunstein. 1977. Electric load management for the California water system. LBL-6367. Lawrence Berkeley Laboratory, University of California, Berkeley.

Provides statewide water use, conveyance methods, electrical demand of pumping, and management alternatives for the electrical demand. Concerned with energy needed for water supply rather than water needed for energy supply. Points out the practicality of hydro-electric plants

Leung, P. 1975. "Evaporative and Dry-Type Cooling Towers and Their Application to Utility Systems," in Gloyna, E.F., H.H. Woodson, and H.R. Drew, Water Management by the Electric Power Industry, Water Resources Symposium #8, Center for Research in Water Resources, The University of Texas at Austin, pp. 106-116.

Discusses the theory and operation of both evaporative and dry cooling towers. Points out that the commonly used rule-of-thumb that 1 lb. water evaporated transfers 1000 Btu of heat disregards the effects of incoming ambient air conditions (relative and absolute humidities). This innacuracy is stated as resulting in a 10-20% lower estimate of water needs than actually occurs.

Mentions problems with the two types of cooling towers, such as drift, blowdown, fan noise, and thermal or vapor plumes.

Mann, D. E. 1976. Water Policy and Decision-Making in the Colorado River Basin. Lake Powell Research Project Bulletin no. 24. Funded by NSF; July, 1976.

A planning report coordinating water policy of the area with new issues of water quality and energy development. Discusses possible reallocation of water by buying rights and changing intended allocations, a practice that could be done by "tired farmers" and which law allows.

Metz, W. D. and A. L. Hammond. 1978. Solar Energy in America. Washington, D. C.: America Association for the Advancement of Science, 239 pp.

Good overview of research strategies, demonstration-project testing, applications of solar designs, and comparisons with other energy-producing technologies.

National Water Commission, Consulting Panel on Waste Heat. 1972. The Water Use and Management Aspects of Steam Electric Power Generation. NWC-EES-72-046.

A planning-type report . Much of this report stresses the need to assess different technologies, economic and environmental considerations, and siting requirements. Has a good section on heat discharge from power plants, but doesn't include solar.

Included is a listing of capital cost for cooling technologies from a 1972 report of the F.P.C. The costs are derived as of 1969. They are perhaps worthwhile for comparison's sake:

once-through	$ 2	-	5	PER KW
cooling ponds	4	-	9	"
evaporative cooling	5	-	13	"
dry cooling	18	-	32	" .

Dry cooling reduces the plants' average annual energy output by "six to eight percent " because of the reduced efficiency which occurs.

Nelson, G. R. 1974. Water recycle/reuse possibilities: power plant boiler and cooling systems. EPA - 660/2-74-089.

Investigates the potential for water reuse in light of an increasing demand, for cooling and boiler water, and stable supply.

Provides quality criteria for recirculating water and make-up water.

Recommends that the flash tank effluent from boiler cleaning processes be reused as make-up water for the cooling system. This is projected to save about .4% of the make-up water requirements.

Sathaye J. A. and R. L. Ritschard. 1977. Water Requirements for Future Energy Production in California. Lawrence Berkeley Laboratory, University of California, Berkeley.

Assesses the impact of energy development on water resources, including the development of electric power plants, mining, gas extraction, etc. Water requirements as well as implications for energy planning in California and Nevada are explored. Annual runoff from hydrologic areas are reported.

Sieckman, D. L., et al. 1971. Lower Colorado Region Comprehensive Framework Study. Appendix V: Water Resources.

This report presents an evaluation of water resources in the Lower Colorado River Basin Region including amounts, quality, water rights, present utilization, and present and future requirements.