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USE OF GEOTHERMAL WATER FOR AGRICULTURE

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ABSTRACT

The use of geothermal resources in agriculture will depend largely upon the site specific conditions of the resources. Both water and heat have many applications in agricultural production and the technologies for their use are generally known. When the quantity, quality, and the location of the geothermal water supply is known, the value of the water for irrigation can be readily estimated. The value for other uses such as for food and feed processing, space heating and cooling for crops and for animals is less readily determined.

Application of geothermal water for irrigation purposes as well as other farm uses is extensively discussed. Advantages and disadvantages of the use of geothermal water for animal production are presented. An extensive set of references are included to aid the reader in gaining additional insight into the water quantity and quality requirements for agricultural applications.

PREFACE

The work included in this report was performed by the Department of Agricultural and Irrigation Engineering of Utah State University at Logan, Utah, and was coordinated by the Geothermal Projects Branch of Aerojet Nuclear Company, prime contractor to the Energy Research and Development Administration at the Idaho National Engineering Laboratory.

Financial support for this work was supplied through funds assigned by the Energy Research and Development Administration. These funds were made available to make a study and prepare a report on the practicability of utilizing warm geothermal water for agricultural purposes, and to scope a national program of technical and environmental problems associated with the use of warm geothermal water to be used in agricultural projects. The resulting report includes an overview of the present state of the technology and contains a discussion with reference to the agricultural industry and scope which lend themselves to the use of warm geothermal water, the temperature requirements, and the advantages and disadvantages of the use of warm geothermal water. The report also provides recommendations for implementing a national program for the use of warm geothermal water in United States agriculture.

The information presented in this report has been made an integral part of the "National Program Definition Study for the Non-Electrical Utilization of Geothermal Energy", Report ANCR 1214 prepared by the Geothermal Projects Branch of Aerojet Nuclear Company.

This report is being issued separately since it contains considerable valuable information and it is anticipated that this data will be of value to many Government and non-Government enterprises engaged in geothermal agricultural activities.

The staff of the Aerojet Nuclear Company Geothermal Projects Branch wishes to thank the contributors to this report, particularly Dr. Alvin A. Bishop and Dr. Howard Peterson of the Depart of Agricultural and Irrigation Engineering; Utah State University, Logan, Utah, and their cohorts for their fine work and for this valuable contribution.

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USE OF GEOTHERMAL WATER FOR AGRICULTURE

The use of geothermal resources in agriculture will depend largely upon the site specific conditions of the resource. Both water and heat have many applications in agricultural production and the technologies for their use are generally known. When the quantity, quality, and the location of the geothermal water supply is known, the value of the water for irrigation can be readily estimated. The value for other uses such as for food and feed processing, space heating and cooling for crops and for animals is less readily determined.

Water for Irrigation

One of the most important possible by-products of geothermal developments will be an increase in the water supply at the development area. In most of the arid western United States, the amount of irrigable land far exceeds the amount that can be irrigated due to the imbalance between the water supply and the land area.

A rough indication of areas of water surplus and deficiencies is given in Figure 1. The water deficient area and the area of high water withdrawal (Figure 2) for irrigation are almost identical. Unfortunately, the saline ground water Figure 3 and the saline surface water Figure 4 are also in the same general regions. Much of the geothermal resources are in the area of water deficiencies. The currently known thermal springs are shown in Figure 5. Population densities are shown in Figure 6.

Soils of the U. S. have been classified and land suitable for irrigation can readily be selected once the location of the geothermal

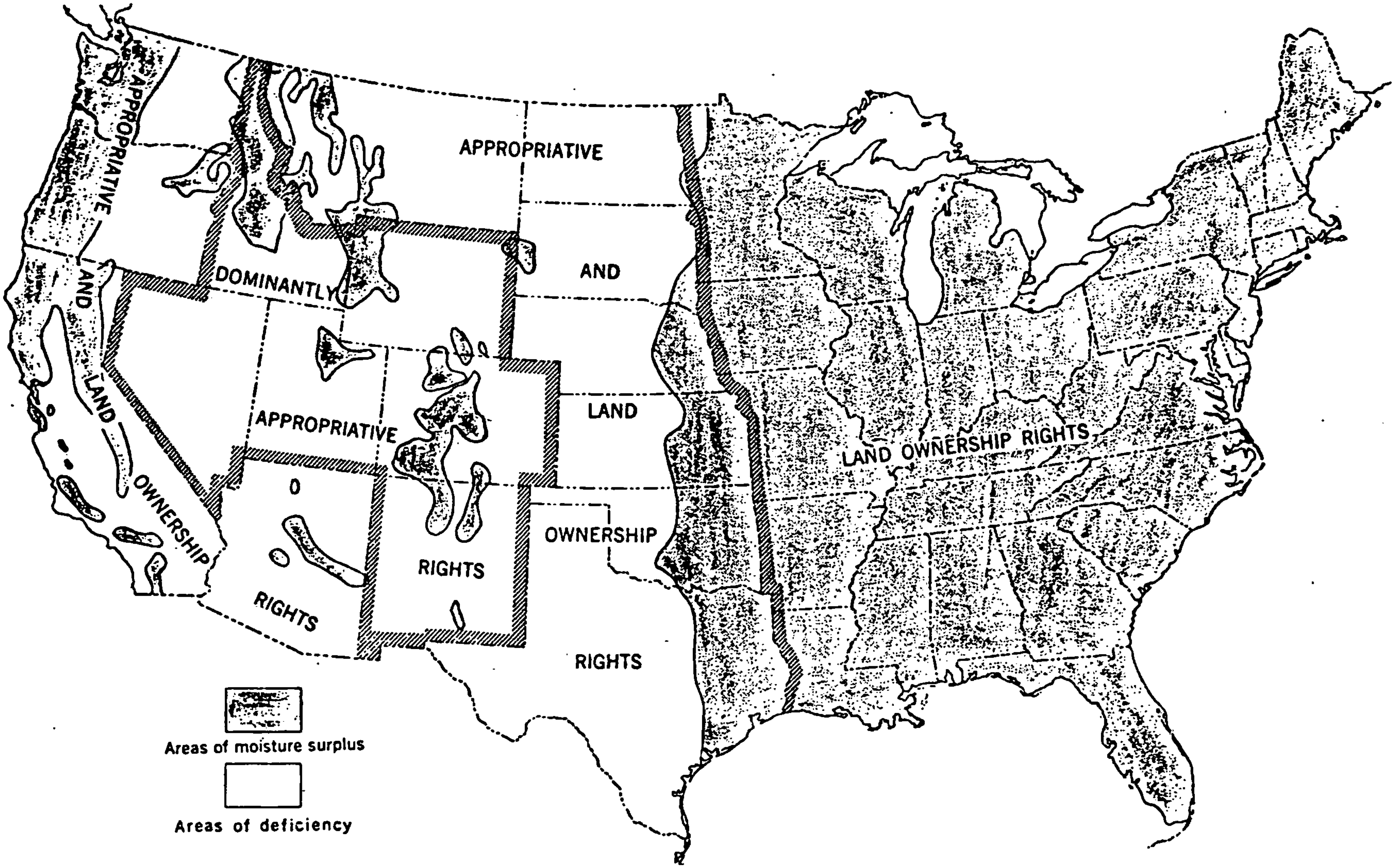

Figure 1. Map of the United States showing areas of moisture surplus and deficiency as outlined by Thornthwaite and basis of water rights by States. (U.S.G.S. Circular 347) (1)

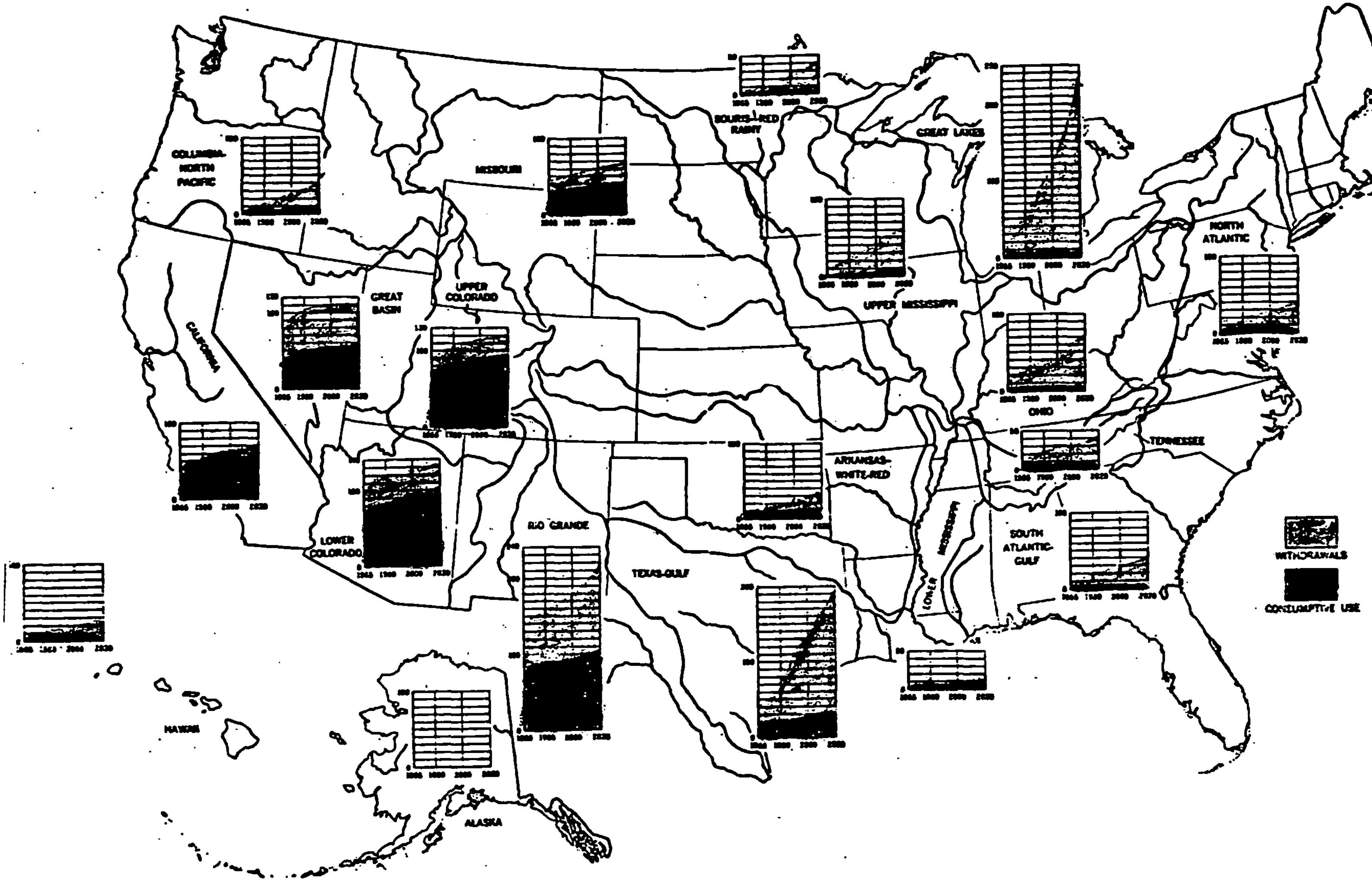

Figure 2. Regional indices of projected water withdrawals and consumptive uses, 1965-2020 (estimated average supply equals 100). (The Nation's Water Resources Summary Report, 1968) (2)

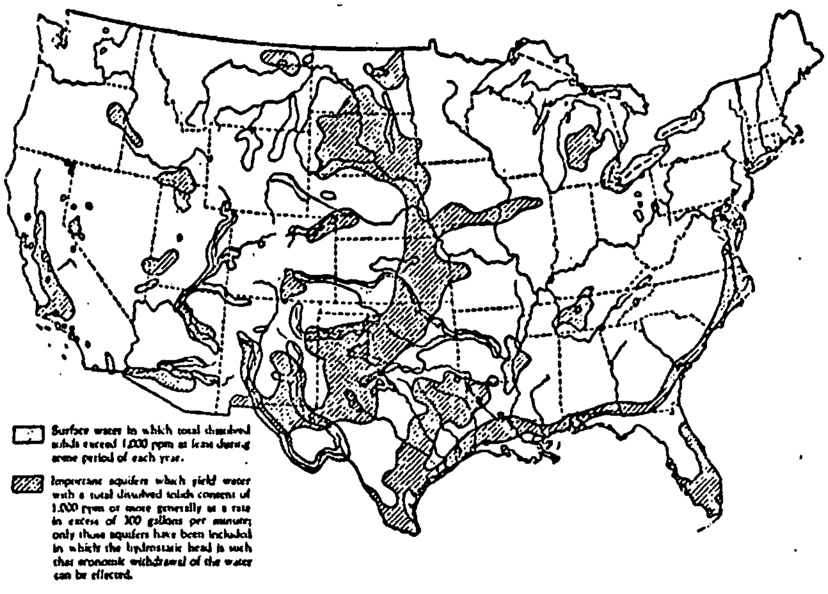

Figure 3. Saline Surfaces and Ground Water in the United States. (Technology in American Water Development) (3)

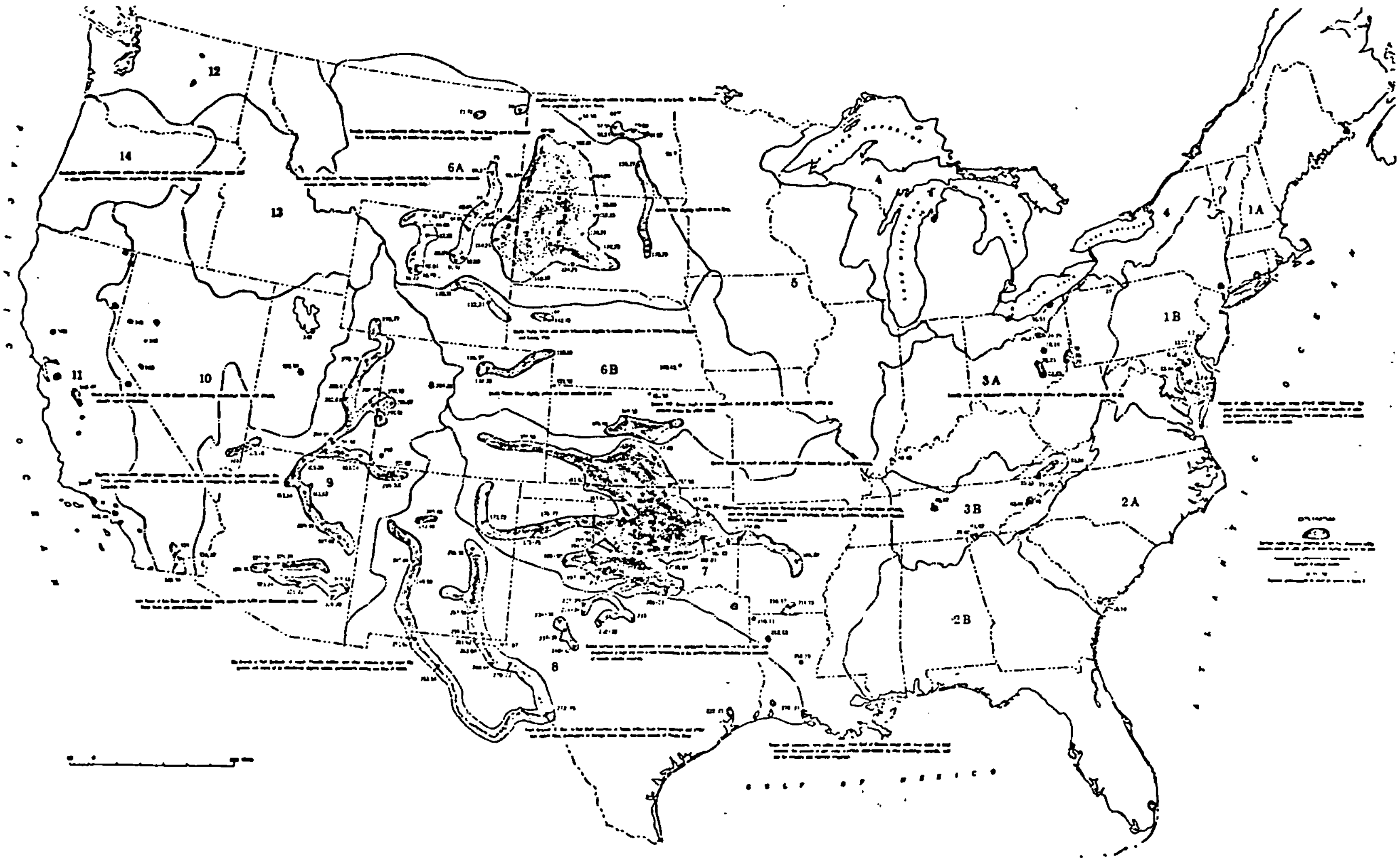

Figure 4. Map of the United States showing Principal Surface-Water Drainage Basins and Areas of Observed Saline Surface Water (U.S.G.S. Water Supply Paper No. 1374) (4)

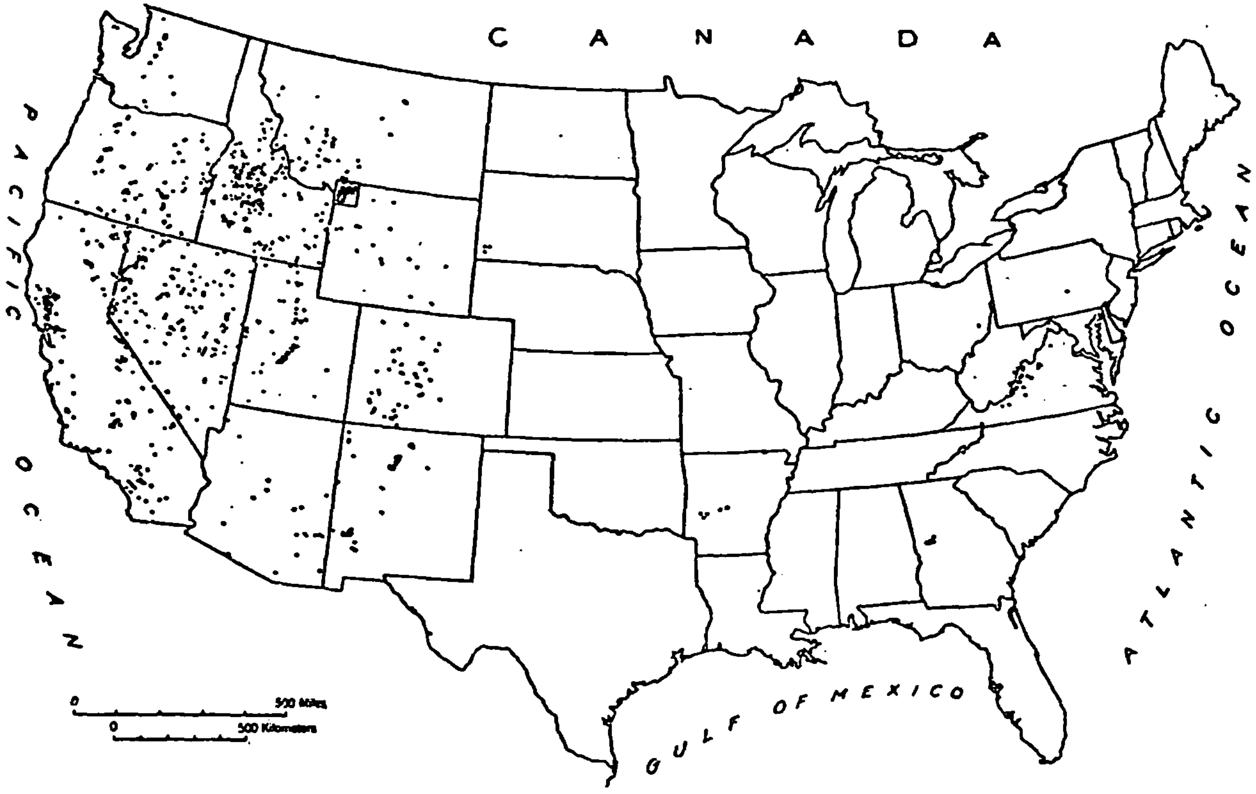

Figure 5. Map of the United States shwoing thermal springs. (U.S.G.S. Water Supply Paper 836-D) (5)

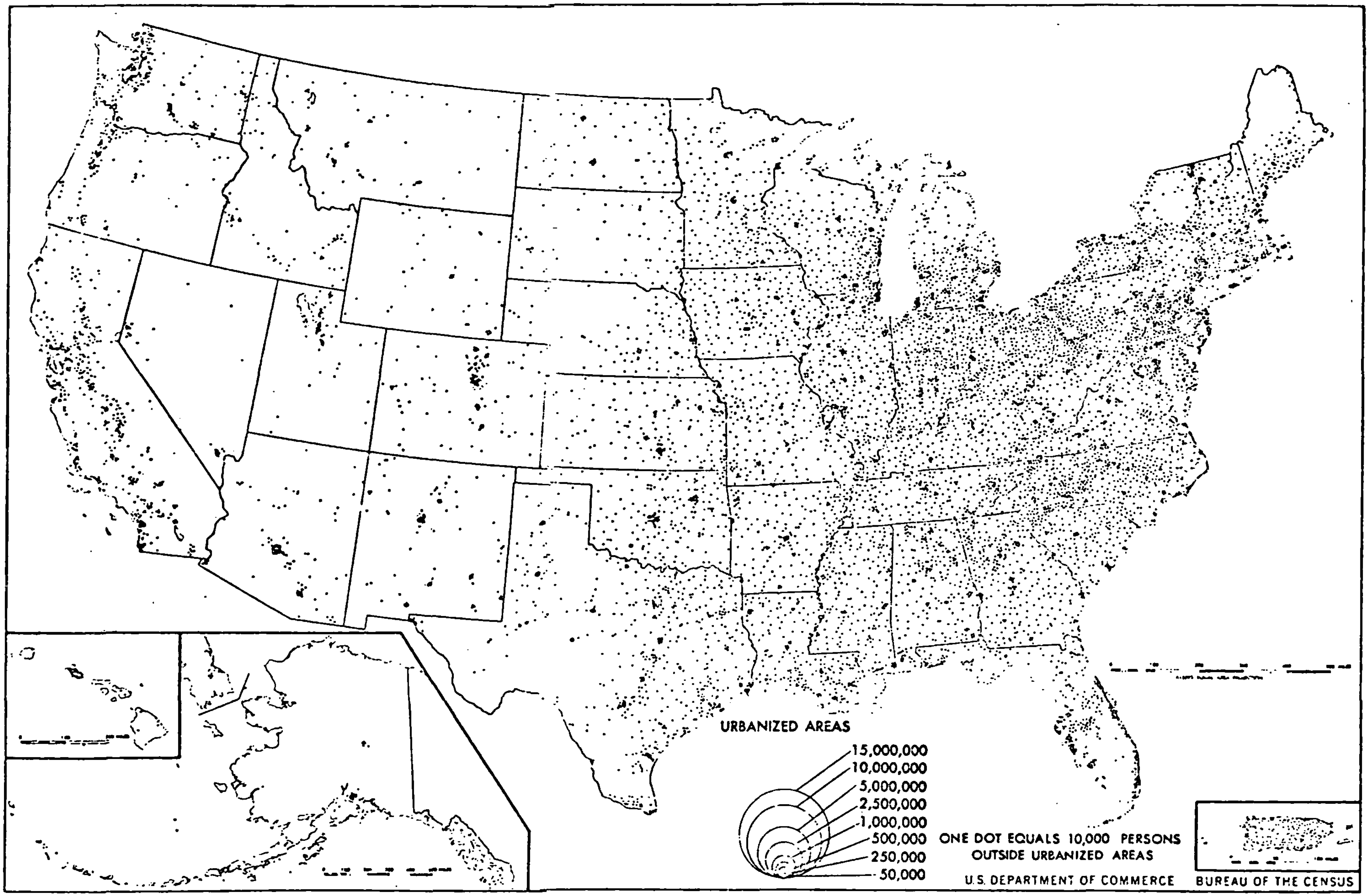

Figure 6. Population density. (1970 Census of Population) (6)

supply is identified and characterized. References (20) and (21) give examples of the soil information available in most states.

If water of acceptable quality is made available from geothermal developments, it will have a ready market for the development of irrigated agriculture. Water quality criteria for various agricultural uses has been developed such as assembled in Reference (7). Additional details are given in such publications as "Water Quality Criteria" (8).

Agricultural crops require large quantities of water in the evapotransporation process. The requirement is continuous while the crop is growing but varies from day to day depending upon the incoming solar energy, the stage of the crop growth, the kind of crop being grown, the availability of soil moisture and other factors. Average crop use "evapotransporation" in the western United States may vary from one-tenth to one-half inch per day with a seasonal average of perhaps one-forth inch per day (One- fourth inch per day amounts to about 68 hundred gallons per acre per day). A recent publication of the American Society of Civil Engineers, "Consumptive Use of Water and Irrigation Water Requirements", (9) gives methods for estimating the daily evapotranspiration demand and presents a summarization of the current information and data. Table 1 taken from this publication shows the seasonal evapotranspiration for well-wattered, common crops in the USA and Canada. Figure 7 also from this publication shows an example of the frequency distribution for daily maximum evapotranspiration for alfalfa at Kimberly, Idaho. Considerable additional data and a list of over 200 references are also presented in the publication.

Since, the evapotransporation process involves the change in state of the water from the liquid to the vapor phase, its requirement is

TABLE 1 SELECTED EXAMPLES OF OBSERVED SEASONAL EVAPOTRANSPIRATION FOR WELL-WATERED, COMMON CROPS IN THE U. S. A. AND CANADA

Crops (1)	Location (2)	Period and years of measurement (3)	Evapotranspiration	
			(mm) (4)	(in.) (5)
Forage Crops				
Alfalfa	Kimberley	--- (1957-58)	594	23.4
Alfalfa	Swift Current, Sask.	--- (1961-64)	615	24.2
Alfalfa	S. Alberta, Can.	--- (1950-61)	648	25.5
Alfalfa	Upham, N. D.	143 days (1954-56)	594	23.4
Alfalfa	Mitchell, Nebr.	--- (1966-68)	747	29.4
Clover, ladino	Prosser, Wash.	23 May-28 Oct. (1955)	859	33.8
Alfalfa	Kimberly, Ida.	1 May-30 Sept. (1969-71)	916	36.1
Alfalfa	Reno, Nev.	124 days (1959-61)	1013	39.9
Alfalfa	Arvin, Calif.	12 months (1961)	1275	50.2
Alfalfa	Mesa and Tempe, Ariz.	12 months (1946, 50, 62-63)	1887	74.3
Alf.-Reed Can. Br.	Swift Current, Sask.	--- (1961-64)	605	23.8
Alf.-Cr. Wht. Grass	Swift Current, Sask.	--- (1961-64)	594	23.4
Alf.-Br. Grass	Swift Current, Sask.	--- (1961-64)	610	24.0
Alf.-Reed Canary	Swift Current, Sask.	--- (1961-64)	643	25.3
Alf.-Inter. Wht. Grass	Swift Current, Sask.	--- (1961-64)	660	26.0
Alf. Timothy	Swift Current, Sask.	--- (1961-64)	691	27.2
Grass	Kimberley, B. C.	--- (1957-59)	579	22.8
Grass pasture	S. Alberta, Can.	--- (1950-61)	599	23.6
Grass	Davis,Calif.(Sacramento Valley)	12 months (1959-71)	1316	51.8
Grass	Arvin,Calif. (San Joaquin Valley)	12 months (1960-65)	1308	51.5
Grass	Thornton, Calif. (Delta)	12 months (1964-68)	1196	47.1
Grass	Soledad, Calif. (Salinas Valley)	12 months (1963-70)	1232	48.5
Grass	Guadalupe, Calif. (Coastal)	12 months (1963-67)	1006	39.6
Grain and Field Crops				
Barley	S. Alberta, Can.	--- (1950-61)	409	16.1
Barley	Powell, Wyo.	18 May-16 Aug. (1956-57)	386	15.2
Barley	Mesa, Ariz.	16 Dec.-15 May (1952-53, 56)	643	25.3
Barley	Davis, Calif.	1 Nov.-31 May (1969-70)	384	15.1
Beans	Powell, Wyo.	28 May-3 Sept. (1957)	396	15.6
Beans	Redfield, S. Dak.	105 days (1952-53)	417	16.4
Beans	Davis, Calif.	21 June-24 Sept. (1968)	404	15.9
Corn	S. Alberta, Can.	--- (1950-61)	373	14.7
Corn	Upham, N. Dak.	107 days (1953-56)	445	17.5
Corn	Redfield, S. Dak.	--- (1951-53)	422	16.6
Corn	Powell, Wyo.	30 May-6 Sept. (1958-60)	414	16.3
Corn	Coshocton, Ohio	23 May-25 Sept. (1961)	470	18.5
Corn	Hot Springs, S. Dak.	124 days (1955)	536	21.1
Corn	Bushland, Tex.	7 May-8 Sept. (1970)	617	24.3
Corn	Davis, Calif.	15 May-20 Sept. (1970-71)	640	25.2
Oats	S. Alberta, Can.	--- (1950-61)	409	16.1
Potatoes	Upham, N. Dak.	112 days (1953-56)	467	18.4
Potatoes	Mandan, N. Dak.	128 days (1953)	455	17.9
Potatoes	S. Alberta, Can.	--- (1950-61)	505	19.9
Potatoes	Phoenix, Ariz.	15 Feb.-15 June (1959-63)	617	24.3
Rice	Davis, Calif.	1 May-30 Sept. (1968-69)	920	36.2
Grain and Field Crops (Continued)				
Sorghum	Garden City, Kans.	--- (1957-58)	551	21.7
Sorghum	Bushland, Tex.	15 June-20 Oct. (1956-59)	549	21.6
Sorghum	Mesa, Ariz.	1 July-31 Oct. (1955-58, 60)	645	25.4
Wheat	Redfield, S. Dak.	--- (1953)	414	16.3
Wheat, hard	S. Alberta, Can.	--- (1950-61)	462	18.2
Wheat, soft	S. Alberta, Can.	--- (1950-61)	493	19.4
Wheat	Mesa, Ariz.	1 Jan.-31 May (1959-60)	582	22.9
Wheat, Mexican	Mesa, Ariz.	15 Nov.-15 May (1969-70)	655	25.8
Wheat, winter	Bushland, Tex.	10 Oct.-25 June (1956-58)	719	28.3

TABLE 1 SELECTED EXAMPLES OF OBSERVED SEASONAL EVAPOTRANSPIRATION FOR WELL-WATERED, COMMON CROPS IN THE U.S.A. AND CANADA (CONTINUED)

Crops (1)	Location (2)	Period and years of measurement (3)	Evapotranspiration (mm) (4)	(In.) (5)
Sugar Crops				
Sugarbeet	S. Alberta, Can.	--- (1950-61)	546	21.5
Sugarbeet	Huntley, Mont.	20 Apr.-27 Sept. (1953)	572	22.5
Sugarbeet	Redfield, S. Dak.	--- (1951-53)	610	24.0
Sugarbeet	Kimberly, Ida.	15 Apr.-17 Oct. (1965-67)	617	24.3
Sugarbeet	Davis, Calif.	25 Mar.-20 Sept. (1966)	851	33.5
Sugarbeet	Garden City, Kans	10 Apr.-1 Nov. (1959-60)	927	36.5
Sugarbeet	Bushland, Tex.	28 Mar.-18 Oct. (1964, 66)	991	39.0
Sugarbeet	Mesa, Ariz.	1 Oct.-17 July (1965-66)	1054	41.5
Oil Crops				
Castorbean	Mesa, Ariz.	15 Apr.-15 Nov. (1958)	1128	44.4
Safflower	Mesa, Ariz.	1 Jan.-15 July (1958-60) and (1963-64)	1153	45.4*
Safflower	Kimberly, Idaho	1 Apr.-30 Sept. (1966)	635	25
Soybean	Redfield, S. Dak.	--- (1952-53)	399	15.7
Soybean	Mesa, Ariz.	16 June-31 Oct. (1944)	564	22.2
Fiber Crops				
Cotton	Arvin, Calif.	12 months (1961)	912	35.9
Cotton	Mesa and Tempe, Ariz.	1 Apr.-15 Nov. (1954-62)	1046	41.2
Flax	S. Alberta, Can.	--- (1950-61)	386	15.2
Flax	Redfield, S. Dak.	105 days (1952-53)	381	15.0
Flax	Mesa, Ariz.	1 Jan.-30 June (1943-44)	795	31.3
Vegetable Crops				
Broccoli	Mesa, Ariz.	1 Sept.-14 Feb. (1960-62)	500	19.7*
Cabbage, early	Mesa, Ariz.	1 Sept.-31 Jan. (1960-62)	437	17.2
Cabbage, late	Mesa, Ariz.	1 Sept.-15 Mar. (1960-62)	622	24.5
Cantaloupe	Mesa, Ariz.	1 Apr.-15 July (1959-62)	485	19.1
Carrots	Mesa, Ariz.	16 Sept.-31 Mar. (1960-62)	422	16.6
Cauliflower	Mesa, Ariz.	16 Sept.-31 Jan. (1960-62)	472	18.6*
Corn, sweet	S. Alberta, Can.	--- (1950-61)	386	15.2
Corn, sweet	Mesa, Ariz.	16 Mar.-15 June (1959,61-62)	498	19.6
Lettuce	Mesa, Ariz.	16 Sept.-31 Dec. (1960-62)	216	8.5
Onion, dry	Mesa, Ariz.	1 Nov.-15 May (1961-62,64)	592	23.3*
Onion, green	Mesa, Ariz.	16 Sept.-31 Jan. (1960-62)	445	17.5
Peas, green	S. Alberta, Can.	--- (1950-61)	340	13.4
Tomato	S. Alberta, Can.	--- (1950-61)	366	14.4
Tomato	Davis, Calif.	30 Apr.-24 Sept. (1969)	681	26.8
Deciduous Fruit				
Apples	B. C., Can.	--- (1962,64)	531	20.9
Apples (grass cover)	Wenatchee, Wash.	1 Apr.-31 Oct. (1955,57-59)	1059	41.7
Plums	Arvin, Calif.	12 months (1962-63)	1072	42.2

TABLE 1 SELECTED EXAMPLES OF OBSERVED SEASONAL EVAPOTRANSPIRATION FOR WELL-WATERED, COMMON CROPS IN THE U.S.A. AND CANADA (CONTINUED)

Crops (1)	Location (2)	Period and years of measurement (3)		Evapotranspiration (mm) (4)	Evapotranspiration (In.) (5)
		Evergreen Fruit			
Grapefruit	Phoenix, Ariz.	12 months	(1931-34)	1217	47.9
Oranges	Phoenix, Ariz.	12 months	(1931-34)	993	39.1
		Lawns and Ornamentals			
Bermuda	Raleigh, N. C.	30 May-22 Sept.	(1958)	450	17.7
Bermuda	Reno, Nev.	112 days	(1965-67)	509	20.0
Bermuda	Mesa and Tempe, Ariz.	16 Apr.-15 Oct	(1959-60,63-64)	1105	43.5
Bermuda and St. Augustine	Fort Lauderdale, Fla.	12 months	(5 yr. avg.)	1087	42.8
Turf	Reno, Nev.	112 days	(1965-67)	554	21.8

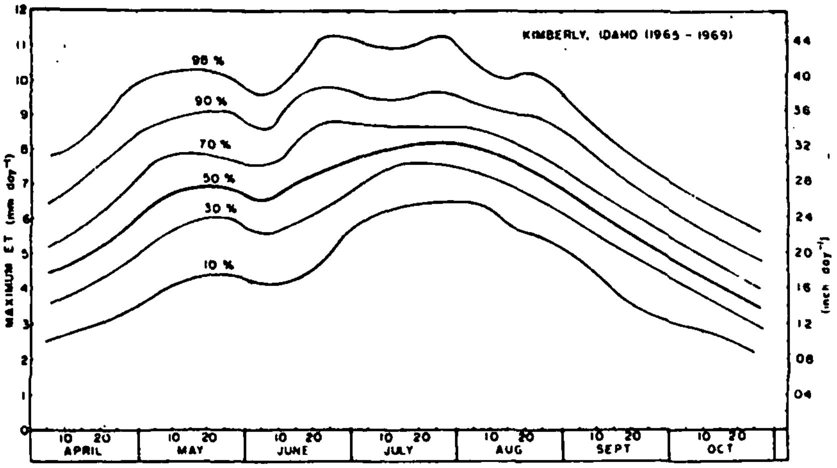

Figure 7. Frequency distributions for estimated daily maximum ET for well watered crop of alfalfa with full cover calculated from 5 year of data from Kimberly, Idaho. (9)

essentially a distilled water demand. Thus any dissolved solids or other impurities in the water used for irrigation are left behind to be incorporated in the plant tissue, left in the soil to become part of the soil mantle, or leached away with any waters percolating through the soil profile. The irrigation demand, therefore, exceeds the evapotransporation requirements depending upon the leaching fraction needed to maintain a fertile soil. Provisions must also be made for any nonuniformities of application and other unavoidable management losses incurred in the irrigation process.

In the vast field of irrigation science, much is known about the water requirements of crops, the interrelationships with soil water applications methods, daily crop demands, tolerance of certain crops of various kinds of dissolved solids (salinity). The knowledge now available can be used directly in appraising the irrigation potential of a given water supply once the quantity, quality and availability factors are known. This will largely be a case by case determination based on the data available from a given geothermal site. If the water supply comes primarily from condensates of high pressure steam resulting in essentially pure water, then the allowances for leaching could be reduced resulting in a greater portion of the water going into crop production through the evapotransporation process. If on the other hand, the water supply comes as direct flow from geothermal wells, and contains appreciable quantities of dissolved solids there may be serious quality constraints so far as using the water for irrigation is concerned, even to the point of being unacceptable without renovation of the quality.

The possible positive or negative value of warm or even hot water for irrigation would probably need additional research. It is known for example, that prewarming of cold waters used in the irrigation of rice has a positive influence on the growth and yield. The plant stresses induced by the application of irrigation water above or below the ambient soil or air temperatures are not very well documented, and the advantages or disadvantages of using warm geothermal waters on cold soils for example, may or may not induce extraneous environmental conditions that will be beneficial to the plant. Use of warm water offers some possible benefits such as:

Lengthening the growing season for forage crops and thus extending the grazing seasons for animals - earlier spring feed and later fall pasture.

Fall frost protection of crops such as fruits.

Spring frost protection of crops at critical stages such as blossom time of fruits.

The regular use of warm water on cold-sensative crops in the spring may advance growth and increase the probability of frost damage if a large convective cold mass moves into the area.

In the geothermal scene, the tolerance of crops to hot water needs to be determined if surface irrigation methods are to be used. With sprinkler irrigation the evaporative cooling of the sprinkler spray results in the droplets reaching the soil at about the ambient air temperatures. Thus if hot water is to be used for irrigation it might require sprinkler application in order for it to be most beneficial.

Water of a given salt concentration and composition is more harmful when applied to the crop by sprinkler. In general the saltier the water and the warmer the temperature (air and water), the greater the crop damage. Research is needed to identify critical temperatures and concentrations for the various crops. (This is a rather complicated study in that the wind velocity, humidity and rate of sprinkler rotation are all factors). These particular water problems are not specific to geothermal use.

The South West U. S. is a water deficient area and the salinity of the water is the cause of many problems. One major problem now receiving attention is the salinity of the Colorado River in the U. S. and when it flows into Mexico. The U. S. government has agreed to control the salinity of the Colorado River so as not to exceed 1500 ppm when it flows to Mexico. In order to do this a major salinity control program is proposed which includes a desalting plant.

In the Imperial Valley of California is the Salton Sea which is below sea level. In the early 1900's the Colorado River jumped its banks and flowed into the valley instead of the Gulf of California. Before it could be put back in its channels the Salton Sea was created. It is being perpetuated by drainage from the irrigated lands and with some minor contribution from natural runoff. While the drainage flows have some salinity, they are the principal source of dilution of the highly saline Sea. The salinity of the Sea had remained almost constant (about the same as ocean water) until recent years because of the rising surface level. However, the Sea has been increasing in salinity since its level has stabilized. Evaporation rates are high and with a stabilized inflow and elevation, the salinity will continue to increase. Allowing it to increase further will decrease the recreational value because it would become uninhabitable for sports fish and undesirable for some water-type recreation activities.

The Department of Interior (10) has developed a plan to utilize the geothermal resources of the area to reduce the salinity in the Salton Sea, and provide more high quality water for Mexico. Their report describes the need for augmenting the Colorado River with high quality water, and shows how the hot geothermal brines of the Imperial Valley could be used to supply this need through multipurpose development of the resource. The following paragraphs are taken from the report.

> The Imperial Valley geothermal resource consists of vast quantities of hot brine. This hot brine will flash into a mixture of steam and brine when pressures are relieved by a well. This mixture will flow to the surface and can be used to produce not only electric power, but also desalted water and possibly mineral by-products. A multi-purpose development will not only produce lower cost products than single-purpose development, but will produce essentially the same quantity of electric energy. A further advantage of multi-purpose development would be to lower the unit cost of replacement fluids by the economies of scale inherent in large-scale transport. Replacement fluids are considered necessary to prevent land subsidence due to fluids withdrawal from the underground reservoir. Five sources of replacement fluids are considered in the report: Pacific Ocean, Gulf of California, Salton Sea, Wellton-Mohawk Drain, and groundwater.
>
> On the basis of preliminary studies, developmental concepts for water and energy production have been prepared and presented in this report with a discussion of the many factors that must be considered for optimum utilization of the resource. The geothermal program outlined herein would be developed in three stages: the Research and Development Stage, the Demonstration Stage, and the Large-Scale Development Stage.

<u>Stage 1</u>: Research and Development Stage

> This stage would, through extensive geological, geophysical, and water chemistry investigations, determine the potential and extent of the geothermal resource. Test and disposal wells would be drilled to obtain fluids for testing and determining feasibility of injecting residual and replacement fluids into the periphery of producing zones. Pilot and prototype desalting plants would be constructed and operated to develop data for subsequent stages. Alternative concepts would be investigated to determine the most feasible plan of developing the total resource. This joint program of the Bureau of Reclamation and the Office of Saline Water would require expenditures of about $16 million over a 7-year period.

<u>Stage 2</u>: Demonstration Stage

> This stage would demonstrate the feasibility of a large-scale development. The concept presented would use a local salt or brackish water supply for replacement fluids such as Salton Sea, Wellton-Mohawk Drain, or groundwater. The magnitude of the development would be about 100,000 acre-feet of fresh water per year and about 400-500 megawatts of electric power. Cost of desalted water produced and delivered would range from $85 to $130 per acre-foot

and electric energy would be produced at 3 to 5 mills per kilowatt-hour. This analysis does not reflect the large benefits that would accrue by saving the Salton Sea from further destructive salinity buildup if Salton Sea water were used for replacement.

Stage 3: Large-Scale Development Stage

This stage would augment the Colorado River by delivering as much as 2.5 million acre-feet of desalted water annually with electric power production of about 10,000 mw. This volume of output would require importation of Pacific Ocean or Gulf of California water for replacement fluids.

It is likely that where good quality geothermal water is available, it could be used for irrigation and the salty waters from the irrigation drainage systems could be used as reinjection water. For example, in the San Joaquin Valley of California the drainage water is so high in salts that for quality reasons, it cannot be returned to the river and a drain must be constructed to the San Francisco Bay. It is estimated that by the year 2000, the concentration of salt in the drainage water will reach 6,500 ppm in 500,000 acre feet of water (11). If such waters could be used for desalting and reinjection, the disposal costs would be greatly reduced.

It can be concluded that water is a resource much needed in the west and any waters made available through geothermal development will probably have an impact on the agriculture of the region either through direct irrigation, water exchange or other indirect benefits.

Other Uses of Water in Agriculture

Besides water for irrigation, agriculture requires water for many other additional uses. Stock watering depending upon the type of enterprise may require as little as 10 gallons/day for 100 chickens to 35 gallons/day per dairy cow. Wash water is important for product cleaning as well as for cleaning milking parlors, dairy barns and other buildings. Culinary water for drinking, cooking and sanitary use at living quarters and farm business buildings. Process water for washing, conveyance, cooling and other uses at agricultural processing plants. (A modern dairy for example uses about 50 tons of water for each ton of dairy product processed). The requirements, both quantity and quality vary according to the use and may be able to use geothermal water with or without renovation depending upon the site specific conditions and the use.

Environmental Control

Geothermal waters can be used for space heating and cooling for crop and animal production.

Crop Production. The technology is available for the production of "off season" vegetables and flowers in controlled temperature environments. Numerous plastic and glass houses are in operation throughout the world with most using heat energy sources other than geothermal. Van der Horst (12) has considered use of waste heat in greenhouses. In Ontario, Canada, the cost of production has been determined which indicates that the fuel costs are about 15 percent of the total production (13). During 1973-74 the fuel costs were greatly increased and a large grower in Utah indicated the percentage for fuel was likely more than the 15. In the U. S. an estimate must be made of the market potential in the areas of geothermal development. A study of the relative cost of and quality of products from the greenhouses in comparison to those shipped from the South (Texas, Mexico and Central America) will also be necessary.

One problem with marketing the greenhouse crops may be location. Much of the geothermal resource is in areas of sparce population as indicated in Figures 5 and 6.

It is apparent that greenhouse plant production could be a part of an integrated plan to make sequential use of water after leaving the generators. In such a plan the wastes from the vegetable production could go into a waste treatment system such as outlined in Figure 8, where the waste problems would be solved. The biomass from fermentation of the vegetable processing waste could produce methane and at the same time be concentrated for animal feed.

Animal Production. Space heating and/or cooling for animals such as chickens, pigs, dairy, beef and, to some extent, sheep can be beneficial.

There is evidence that animals grow and produce better if they remain within the environment in which they are born, stay in the same family unit - herd, flock, etc. and never move to strange places or with strange members (14). This fact would be an important consideration in raising animals under controlled conditions. The animal scientists and agricultural engineers are currently very active in research dealing with identification of the effects of environmental control on the performance of animals. It seems there is or soon will be a vast fund of data from which it will be possible to make cost-benefit determinations (14, 15).

Some of the identified benefits are:

1. Improved health of animals.
2. More efficient use of feed.
    a. Beef. A common estimate is a reduction in gain of beef animals of .5 lb/animal/per day on the same feed when animals are under cold stress.
    b. Dairy. In dairy cattle there is a milk production decline (see Fig. 7 Hahn and Osburn (16)).

Fluctuating cold temperatures are more critical (harmful) than cold temperatures per se. In contrast, fluctuating hot temperatures are less harmful than more constant hot temperature stress.

3. Better Reproduction

   Stress has an adverse effect on reproduction of animals. This results in losses from reduced lactation in case of dairy cows. There is a loss of efficiency in the use of feeds as well as loss of production from each animal.

4. *Energy saving through more efficient use of feed.*

   When there is a saving of feed there is a domino effect in the saving of energy. There are numerous energy inputs in the production of feed such as for:

   Production transportation and application of fertilizers
   Irrigation
   Drying, harvesting and conditioning of the crop
   Transportation of feed crop
   Supporting farm workers
   Animal production
   Waste control

With the high energy requirements for production of food and feed (17, 18, 19) and the increasing costs of liquid fuels, it seems likely that improved efficiency in utilization of feeds as a result of environmental controls made possible through use of geothermal energy should be attractive. In a controlled environment the wastes from the animals is more easily controlled and can be processed and utilized.

Other Uses

Crop Drying and/or Dehydrating. Alfalfa and grains are excellent crops to be grown under irrigation in the sparsely settled western states. Many thousands of bushels of grain are lost in storage as a result of too high a moisture content at harvest. Hay being dried in the field is damaged by rains while being cured. There is an excellent foreign market for dehydrated alfalfa. It can be readily handled and shipped when dehydrated and compressed into pellets. A relatively small unit such as Figure 10 for drying or dehydrating could be used as a pilot plant.

Tests on Broiler Chickens: Of three treatment temperatures applied for a 10-day period at approximately 6 weeks of age on broiler chickens, feed efficiency was indicated to be best at 30°C, next best at 23°C and least at 33°C. The highest feed efficiency was noted to occur at temperatures above optimum for maximum growth rates.

Tests on Fattening Hogs: Exposure of fattening hogs to elevated temperature for a 17-day period at a weight of approximately 75 lb/pig indicated feed conversion was most efficient at 30°C, slightly less and about the same at 33°C and 23°C, and least efficient at 36°C. Here again the highest feed efficiency was noted to occur at temperatures above optimum for maximum growth rates.

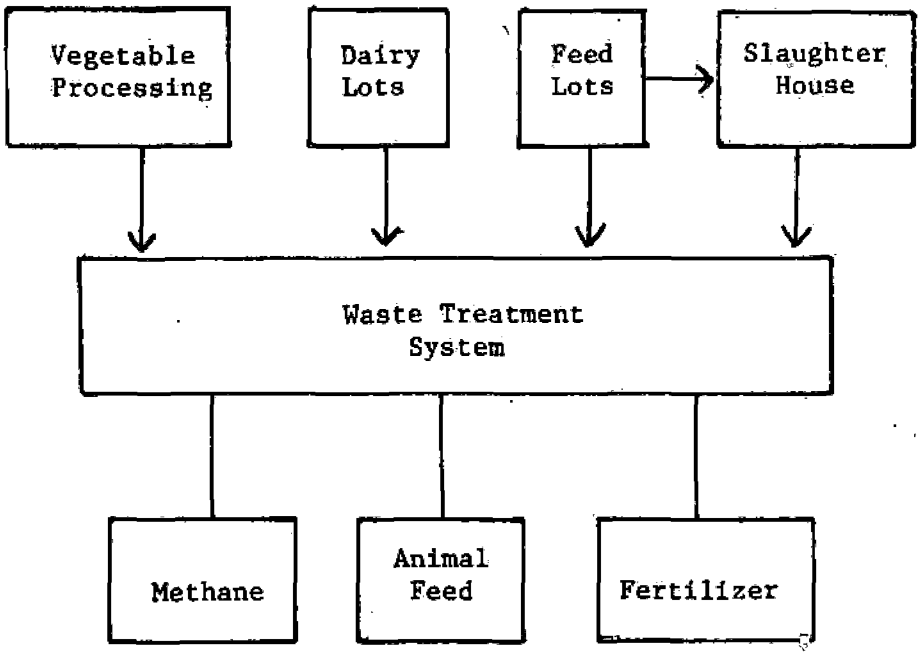

Figure 8. Waste treatment system.

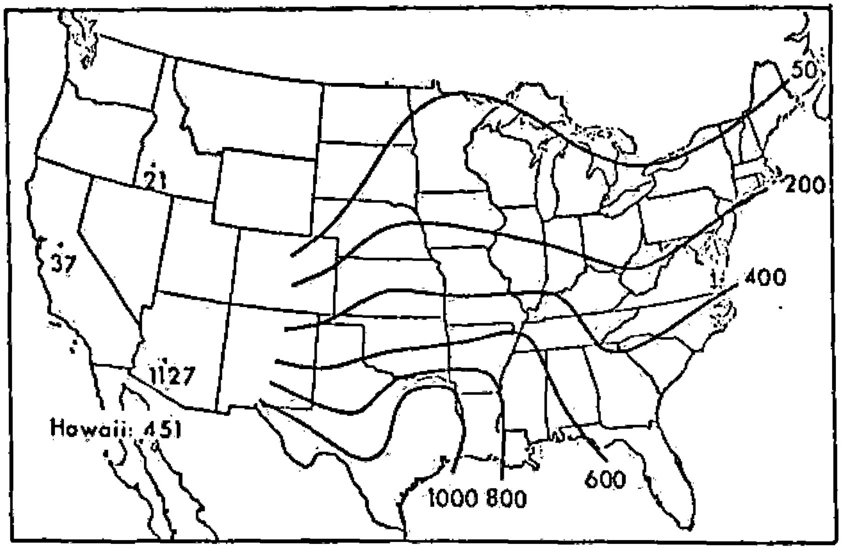

Figure 9. Expected milk production losses (lb/cow) for the 122-day period, June 1 through September 30, for cows of 70 lb/day production level shaded from direct solar radiation (Hahn and Osburn, 1969). If shades are not provided, the production losses would be larger. (16)

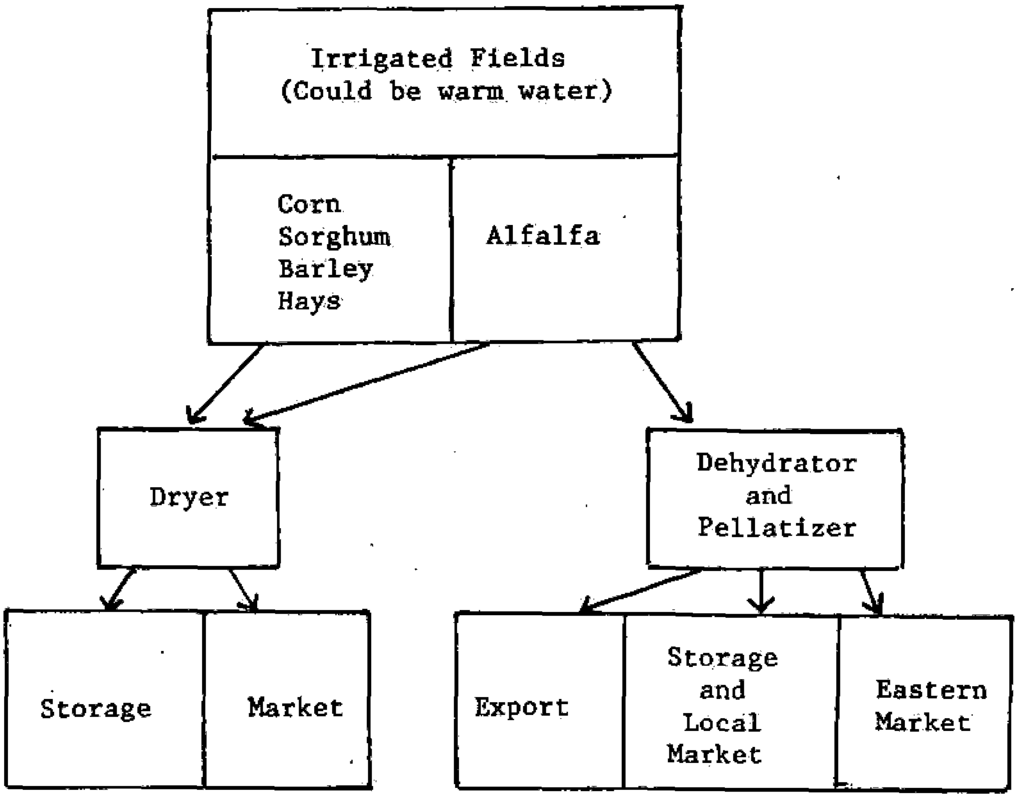

Figure 10. Crop drying, dehydration and processing.

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