Energy and Water Resources

Seminar Conducted by

Water Resources Research Institute

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Preface

A goal of energy self-sufficiency has been proclaimed by both the White House and the Congress. However, potential demands upon our nation's water resources by the various energy programs under consideration are complex and not completely identified. These demands will vary with geography, technology, and economic requirements. There is potential competition between energy development and other water uses -- particularly irrigated agriculture. If more water is used for irrigation, industry, cities or pollution control, more energy will be required.

Competition among users is not the only problem. Other problems which must be faced include scarcity of water, water quality, institutional constraints, availability of capital, and preservation of the environment. Ways must be found to curtail the quantity of water and energy consumed by developing better manufacturing processes, improving irrigation practices, providing better management, and designing other procedures. A realistic awareness of water needs must be encouraged in energy development plans. Energy planners should not be permitted to appropriate scarce resources from other economic sectors. This leaves long-range social and economic dislocations to be remedied at public expense.

Some of these issues were explored in a series of public seminars held during Fall Quarter at Oregon State University under sponsorship of the Institute. Speakers from the academic field, governmental agencies, and private organizations were featured. The papers which were presented are reproduced in this volume to make the information available to a wider audience.

Peter C. Klingeman
Director

Corvallis, Oregon
January 1977

WATER RESOURCES RESEARCH INSTITUTE

The Water Resources Research Institute, located on the Oregon State University Campus, serves the State of Oregon. The Institute fosters, encourages and facilitates water resources research and education involving all aspects of the quality and quantity of water available for beneficial use. The Institute administers and coordinates statewide and regional programs of multidisciplinary research in water and related land resources. The Institute provides a necessary communications and coordination link between the agencies of local, state and federal government, as well as the private sector, and the broad research community at universities in the state on matters of water-related research. The Institute also administers and coordinates the inter-disciplinary graduate education in water resources at Oregon State University.

This seminar series is one of the activities regularly undertaken by the Institute to bring together the research community, the practicing water resource specialists, students of all ages and interests, and the general public, in order to focus attention upon current issues facing our state.

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Presented September 30, 1976 by JACK A. BARNETT, Executive Director,
Western States Water Council, Salt Lake City, Utah.

How Much Water for Energy?

I remember two years ago I received a phone call from a newly-appointed research analyst for an oil shale company. He asked me if there was enough water in the Colorado River for oil shale development. My initial reaction was "what a naive question." Of course, there is enough water in the Colorado River for oil shale development! In fact, for the predictable future, there is enough water in the 11 western states for the energy resource development that is planned. The question really is -- "what is our preference for the use of the water in the Western United States?" Many water resource officials in the states have recently expressed their belief, after analyzing the problem, that a least until 1990, the availability of water resources will not deter the development of energy resources.

The Western States Water Council is an organization that has been created by the 11 western governors so that the states might talk about common water resource problems. About two years ago, the governors received a letter from the Secretary of the Interior asking, if it was determined by the federal government that new federal institutions were needed to allocate water resources for energy development that would take precedent over state established water laws and rights, would there be problems in the Western states? That question, of course, was strongly reacted to by western officials as many of us in the West believe that water rights are real property rights and cannot be taken for any federal need without just compensation. This question, of course, was asked right in the throes of the Arab oil embargo and the "energy crisis" and it led to some discussions in the Western States Water Council as to what the total potential water needs might be in the West for energy development.

Many had discussed, in generalities, the total needs and many had identified needs for specific projects, but no one really knew what the order of magnitude might be for the total need. For this reason, the Western States Water Council entered into a study -- and I would like to highlight that study as a part of my presentation here today.

The publication, as a result of that study, was entitled, "Western States Water Requirements for Energy Development to 1990." First, we needed to determine the planned development. We examined the coal-fired plants that were scheduled in the 11 western states. (Table 1, Page 2) We also looked at the

TABLE 1

COAL-FIRED POWER PLANTS SCHEDULED FOR WSWC MEMBER STATES

As Identified Summer 1974

Operational	Site	Name	Rating mw (Net electric)	Location
Dec. 1972		All existing to Dec. 31, 1972	9,110	West
Jan. 1973	1	Mohave No. 2	60 (rerate)	Nevada
Sept. 1973	2	San Juan No. 2**	330	New Mexico
Jan. 1974	1	Mohave No. 1	30 (rerate)	Nevada
Jan. 1974	1	Mohave No. 2	30 (rerate)	Nevada
Jan. 1974	3	Comanche No. 1	350	Colorado
May 1974	4	Navajo No. 1	750	Arizona
June 1974	5	Jim Bridger No. 1	550	Wyoming
June 1974	6	Huntington Canyon No. 2	430	Utah
May 1975	4	Navajo No. 2	750	Arizona
June 1975	7	R. Gardner No. 3	117	Nevada
July 1975	8	Colstrip No. 1	330	Montana
Sept. 1975	5	Jim Bridger No. 2	500	Wyoming
Jan. 1976	3	Comanche No. 2	350	Colorado
April 1976	9	Hayden No. 2	250	Colorado
May 1976	4	Navajo No. 3	750	Arizona
July 1976	8	Colstrip No. 2	330	Montana
Sept. 1976	5	Jim Bridger No. 3	500	Wyoming
Dec. 1976	2	San Juan No. 1**	340	New Mexico
May 1977	10	Wyodak**	330	Wyoming
June 1977	11	Cholla No. 2	250	Arizona
June 1977	6	Huntington Canyon No. 1	430	Utah
Oct. 1977	12	City of Colorado Springs	180	Colorado
April 1978	*	Public Service of Colorado	500	Colorado
April 1978	9	Craig No. 1	350	Colorado
May 1978	*	Arizona Station No. 1	350	Arizona
June 1978	10	Cholla No. 3	250	Arizona
June 1978	2	San Juan No. 3**	500	New Mexico
June 1978	13	Arrow Canyon No. 1	500	Nevada
Sept. 1978	14	Boardman Fossil	600	Oregona
April 1979	*	Public Service of Colorado	500	Colorado
April 1979	9	Craig No. 2	350	Colorado
May 1979	*	Arizona Station No. 2	350	Arizona
June 1979	*	Cholla No. 4	350	Arizona
June 1979	13	Arrow Canyon No. 2	500	Nevada
June 1979	15	Emery No. 1	530	Utah
July 1979	8	Colstrip No. 4	700	Montana
April 1980	16	Idaho Power Co.	500	Idaho
June 1980	17	Kaiparowits No. 1	1,000	Utah
June 1980	13	Arrow Canyon No. 3	500	Nevada
June 1980	2	San Juan No. 4**	500	New Mexico
July 1980	8	Colstrip No. 3	700	Montana
Oct. 1980	12	City of Colorado Springs	200	Colorado
April 1981	16	Idaho Power Co.	500	Idaho
April 1981	*	Public Service of Colorado	500	Colorado
June 1981	13	Arrow Canyon No. 4	500	Nevada
June 1981	17	Kaiparowits No. 2	1,000	Utah
May 1982	*	Arizona Station No. 3	350	Arizona
June 1982	17	Kaiparowits No. 3	1,000	Utah
		Total since Dec., 1972	21,517mw	
		Total	30,627mw	

*Unassigned
**It is anticipated that some dry cooling will be used at these sites.

TABLE 2

EXISTING & SCHEDULED NUCLEAR POWER PLANTS IN THE WSWC MEMBER STATES

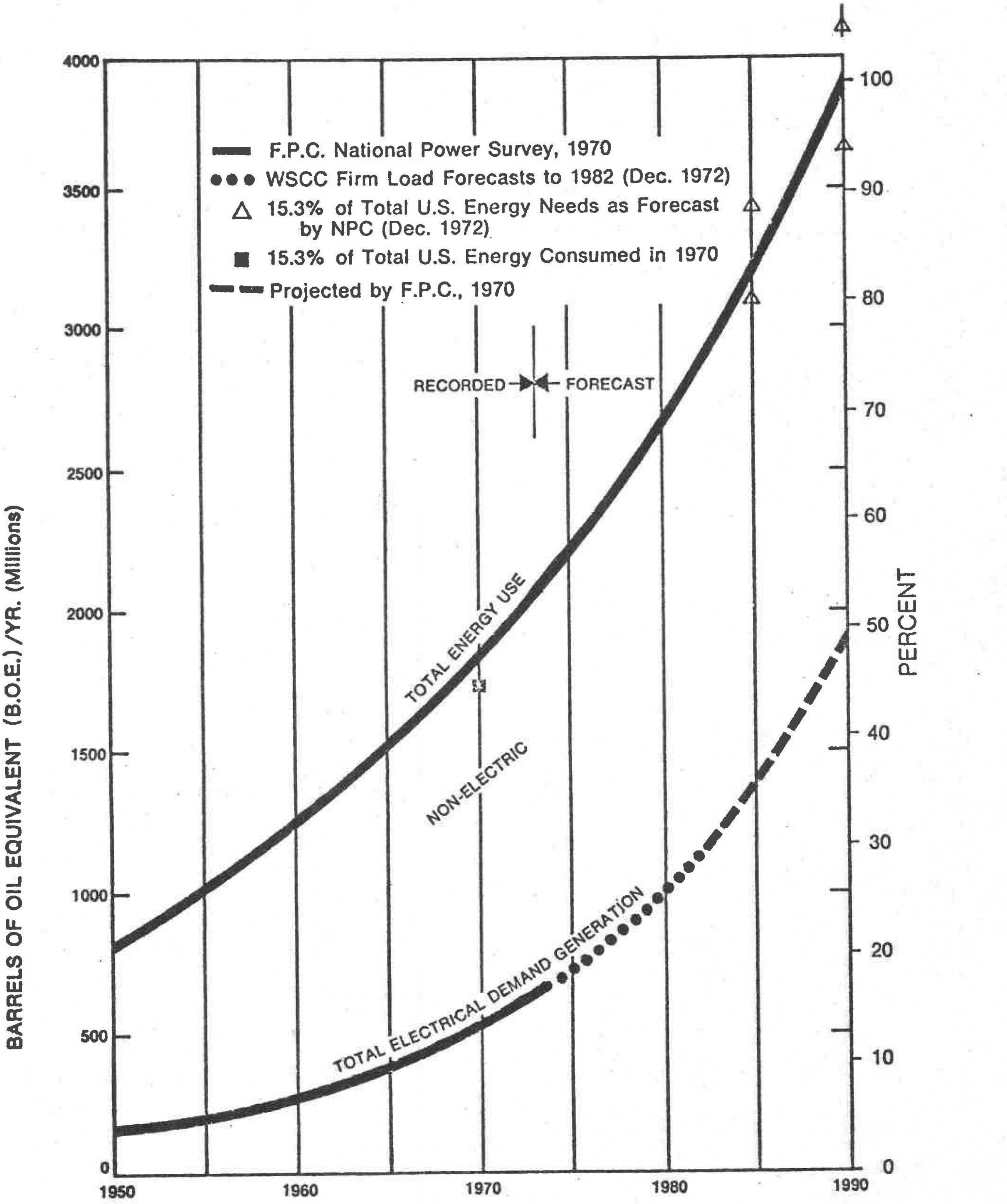
As Identified Summer 1974

Existing	Name	Rating, mw (Net Electric)	State	Site
1963	Humboldt	68	California	A*
1966	Hanford No. 1	800	Washington	B
1967	San Onofre No. 1	430	California	C*
1973	Ft. St. Vrain	330	Colorado	D
1974	Rancho Seco No. 1	913	California	E
	Sub-total	2541		
Planned				
July 1975	Trojan	.1130	Oregon	F
May 1976	Diablo Canyon No. 1	1084	California	G*
Sept. 1976	Diablo Canyon No. 2	1106	California	G*
Sept. 1977	Hanford No. 2	1100	Washington	B
Sept. 1980	San Onofre No. 2	1140	California	C*
Sept. 1980	Hanford No. 1	1250	Washington	B
May 1981	Palo Verde No. 1	1270	Arizona	H
July 1981	Pebble Spring No. 1	1260	Oregon	I
Sept. 1981	WPPSS No. 3	1240	Washington	J
Dec. 1981	San Onofre No. 3	1140	California	C*
June 1982	San Joaquin	1300	California	K
July 1982	Skagit	1200	Washington	L
Nov. 1982	Palo Verde No. 2	1270	Arizona	H
July 1983	Pebble Spring No. 2	1260	Oregon	I
May 1984	Palo Verde No. 3	1270	Arizona	H
June 1984	Vidal	1500	California	M
Sept. 1984	WPPSS No. 4	1300	Washington	B
	Sub-total	19,520mw		
	Total	22,061mw		

*Seawater cooling 4470mw

NOTE: Three additional plants at San Joaquin, California and three plants at Blythe, California, have been identified for construction after 1984. The total planned capacity of these 6 plants is 7,350mw. A ten year lead time is common for nuclear plants and it is anticipated that in the near future, planning efforts will identify additional nuclear plants.

Figure 1



Total Energy Use and Total Electrical Demand Projected for Western U.S.

existing and planned nuclear plants.(Table 2, Page 3) To help us determine the amount of energy development that would occur, we analyzed projections by energy authorities.(Figure 1, Page 4) We learned from that analysis that the western United States was in 1970 using approximately 1,500 million barrels of oil equivalent (B.O.E.) of total energy. Excluding the production of uranium, the eleven western states were within ten percent of being totally self-sufficient and they were consuming 15.3% of the total supply utilized within the nation.

The western United States, and particularly the Northwest, is somewhat unique in its heavy dependence upon electricity and more specifically, in the Northwest, hydro-electric power. Projections show that although in 1970 we were only using about 12% of our energy in the form of electricity that by 1990 we might be using here in the West as much as 50% of our energy in the form of electricity.

To accomplish this, the capacity of installed electrical power plants must be greatly increased. Energy officials have projected the increase capacity of both coal-fired and nuclear plants will exceed 50,000 megawatts by 1990. (Figure 2, Page 7) It was anticipated two years ago, when the study was made, that the production from nuclear plants would exceed the production from coal-fired plants in about 1987.

Once we had determined the total amount of energy that might be produced in the West, we needed to determine the location of that production of energy. Key is the location of the natural resources; as for example, the location of the coal reserves of the West, (Figure 3, Page 8) and the location of the scheduled coal and nuclear power plants (Figure 4, Page 9) as well as the location of the energy load centers in the West. (Figure 5, Page 10)

Another step in our determination of the amount of water that might be needed was an analysis of the water that is required for the development and use of each of the energy sources that will be utilized. The numbers that we used are as follows:

Energy System	Water Needs
Steam-Electric Nuclear	
Evaporative Cooling	17,000 acre-ft/yr/1000mw unit
Pond	12,000 acre-ft/yr/1000mw unit
River	4,000 acre-ft/yr/1000mw unit
Wet-Dry Radiator	2,000 acre-ft/yr/1000mw unit
Steam-Electric Coal	
Evaporative Cooling	15,000 acre-ft/yr/1000mw unit
Pond	10,000 acre-ft/yr/1000mw unit
River	3,600 acre-ft/yr/1000mw unit
Dry Radiator	2,000 acre-ft/yr/1000mw unit
Geothermal	48,000 acre-ft/yr/1000mw unit
Natural Gas	50,000 acre-ft/yr throughout the West
Crude Oil	50,000 acre-ft/yr throughout the West

Refineries	39 gal/Bbl/crude
Oil Shale	7,600 to 18,900 acre-ft/yr/100,000 BPD plant
Coal Gasification	10,000 to 45,000 acre-ft/yr/250 million SCF/day plant
Coal Liquification	20,000 to 130,000 acre-ft/yr/100,000 BPD plant
Coal Slurry Pipeline	20,000 acre-ft/25 million tons coal (1 cfs will transport about 1,000,000 tons per year)
Coal Mining	
Vegetation reestablishment	.5 to 4 acre-ft/acre/yr (some areas may require two years)

By taking the amount of water that is needed for a particular energy use and multiplying that by the units of energy, we are able to project a total potential water demand. We concluded that there may be as much as 840,000 acre feet of water needed by 1990 to cool coal-fired electrical plants and as much as 636,000 acre feet to cool nuclear plants. Knowing what is currently used for cooling, we calculated that there could be a demand by 1990 of an additional million acre feet of water in the West to be evaporated. In fact, some estimates would place the total cooling requirements at close to 2 million acre feet. (Figure 6, Page 11)

The amount of water needed for evaporative cooling of course could be lessened if some of the cooling was accomplished by sea water cooling and some of the cooling accomplished by dry cooling. In addition, less water is needed if cooling is accomplished by once-through cooling processes on rivers or by use of cooling ponds.

We summarized the total water needs in the West, based on the then current energy projections, as follows:

	Annual use acre-ft/yr
Coal-fired Power Plants	836,250
Nuclear Power Plants	633,114
Oil Shale	150,000 to 378,000
Coal Mining Operations	195,000
Coal Gasification -- 18 plants	180,000 to 810,000
Coal Slurry Pipelines	100,000 to 200,000
Geothermal Power Plants	22,000 to 44,000
Other Related Energy Processes	25,000
	2,141,364 to 3,121,364

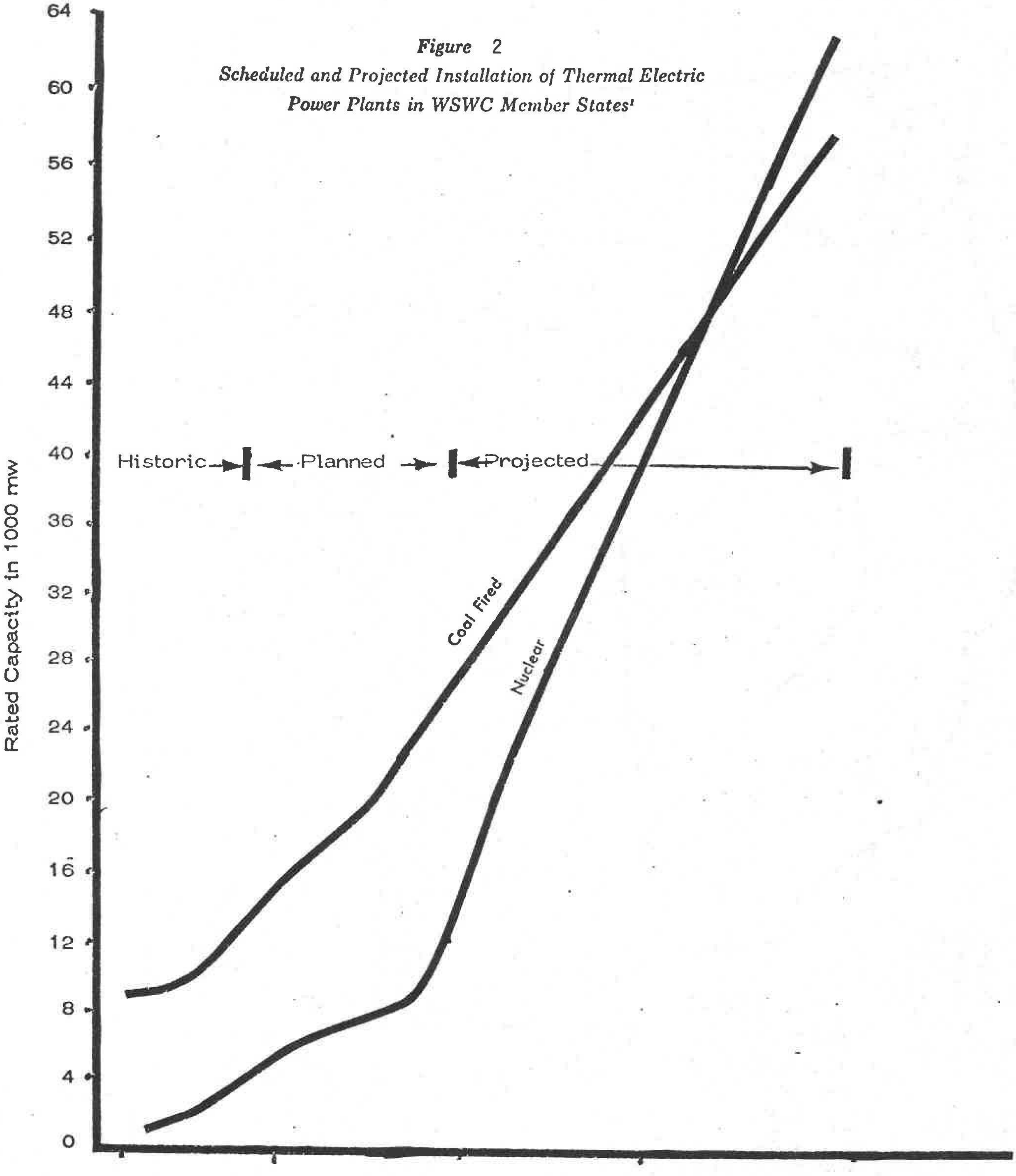
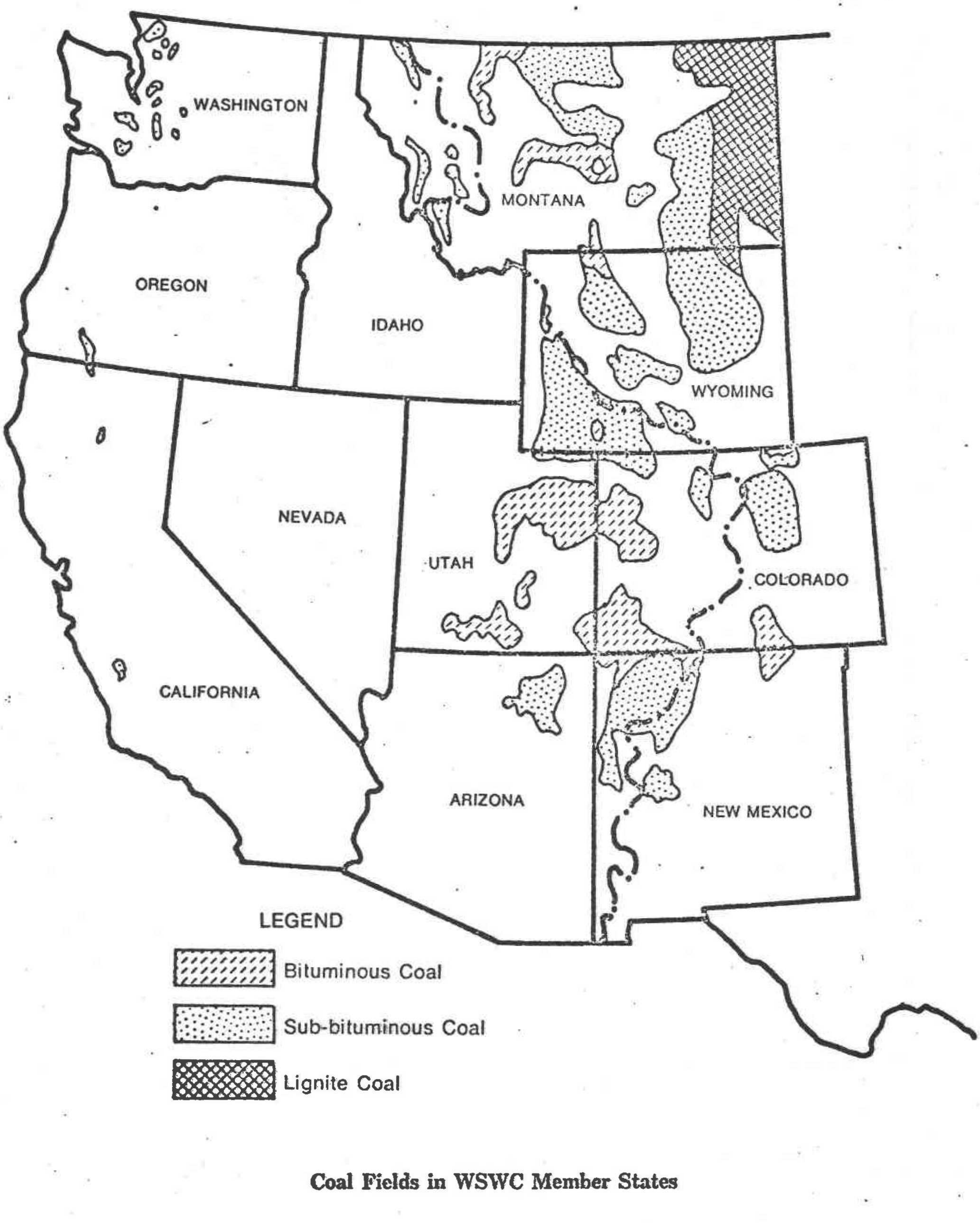


Figure 2
Scheduled and Projected Installation of Thermal Electric Power Plants in WSWC Member States[1]

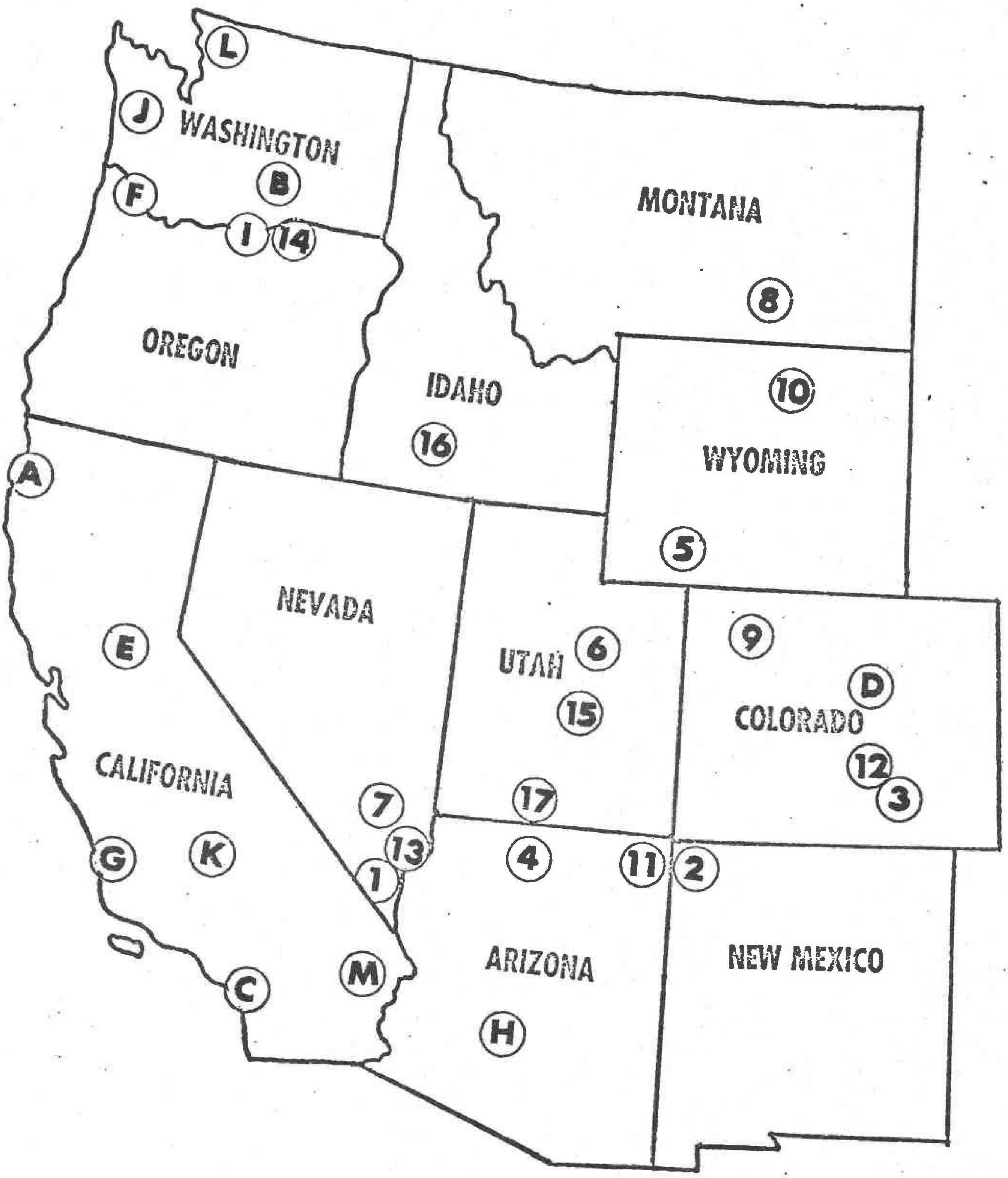
[1]includes plants with dry cooling systems or ocean cooling

Figure 3



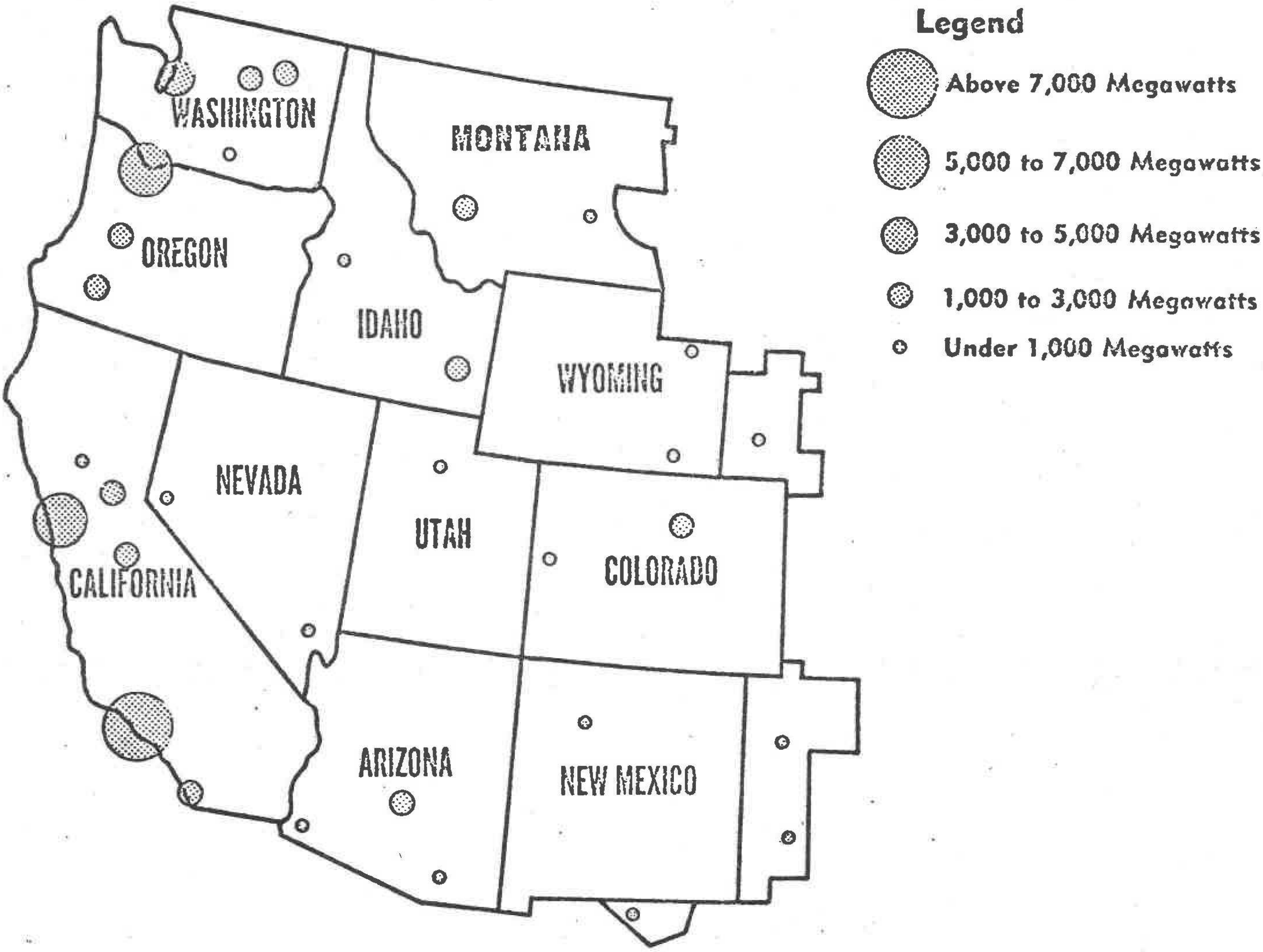
Coal Fields in WSWC Member States

Figure 4



Location of Scheduled New Coal and Nuclear Powered Electrical Generation Facilities

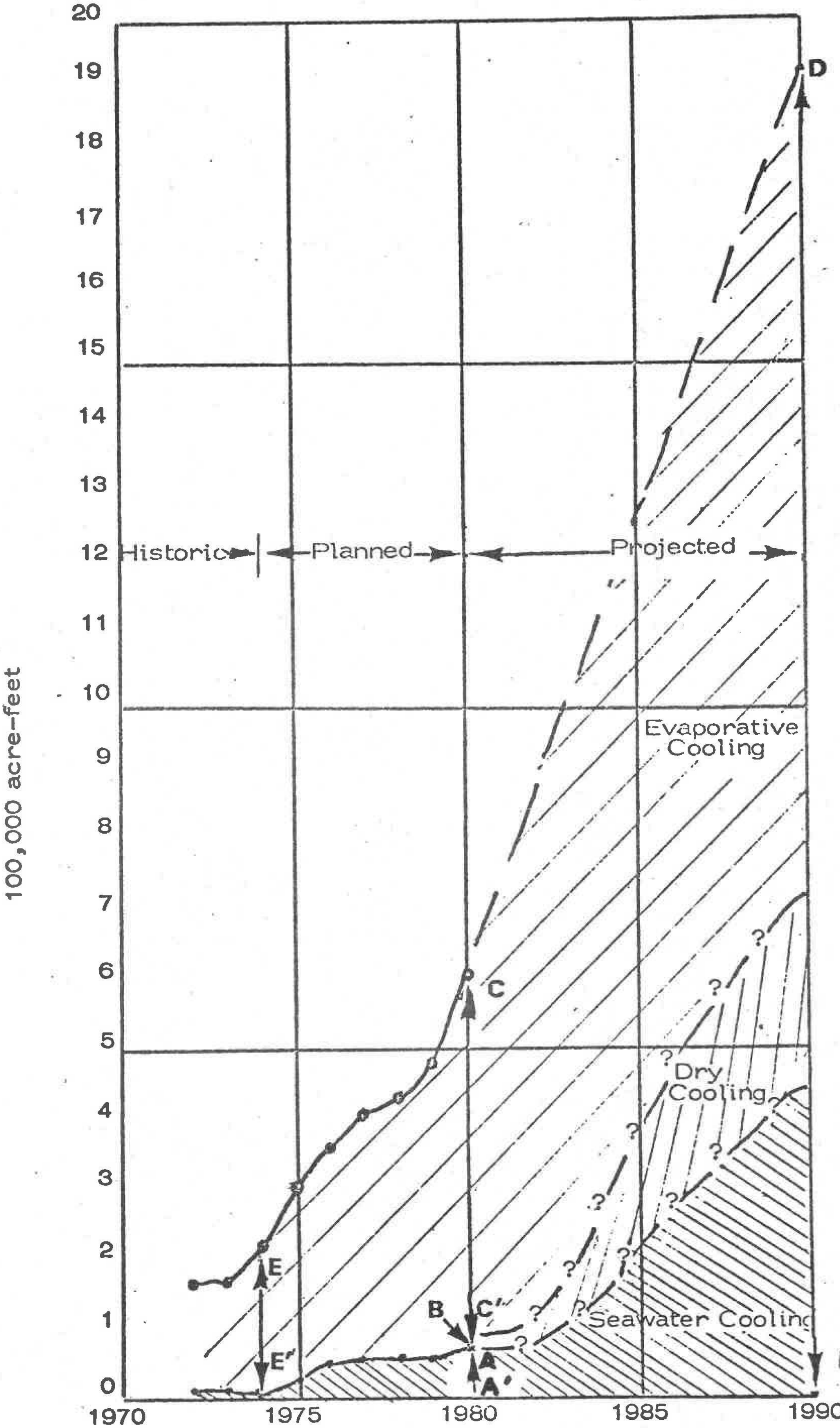
Figure 5



1970 Load Centers of the West Region

Note: To visualize these load centers by 1980, and 1990, multiply these values by 2x and 4x respectively.

Figure 6



Potential Evaporative Cooling Water needs for Scheduled and Projected Coal Fired and Nuclear Power Plants to 1990

We felt that it would be of interest to the states if the study went one step further and attempted to assess in which of the states the various types of development would occur and consequently, which of the states may be required to utilize some of their water resources for energy development. The figures by states are indicated as follows:

Summary of Estimated Increased Water Required
to Meet Growth in Energy Needs of WSWC
Member States in 1000 AF (1972-1990)

State	Coal-fired power plant	Nuclear power plant	Oil shale	Coal mining	Coal gasification	Coal slurry	Geothermal	Other energy processes	Total
Arizona.....	75	73	0	10	11	0	0	2	171
California..	81	276	0	0	0	0	22	13	392
Colorado....	90	14	260	10	11	0	0	2	387
Idaho.......	30	9	0	0	0	0	4	0	43
Montana.....	124	0	0	70	44	40	0	1	279
Nevada......	41	0	0	0	0	0	2	0	43
New Mexico..	20	0	0	3	72	0	2	1	98
Oregon......	18	122	0	0	0	0	4	0	144
Utah........	120	0	40	42	11	0	0	3	216
Washington..	0	126	0	0	0	0	0	0	126
Wyoming.....	118	0	20	60	44	160	0	3	405
								Total	2,304

If this amount of water is utilized in the West for energy development, the amount of water used over today's use by energy will be many times greater and consumption could be between one and two million acre feet of water. Although that may sound like a large amount, it is not a staggering figure if spread westwide and if development were to occur where an abundance of western water resources is located. Energy development at specific sites where there is not an abundance of water resources could take water from other uses. For example, water may be diverted from streams where some would feel the water should remain in the stream for instream uses, for recreational purposes or for aesthetic reasons. Development may be occurring in areas where existing irrigation rights or planned irrigation development may demand all of the dependable water supply beyond instream needs and the energy industry would then be in direct competition for the water resources. In some limited areas, other

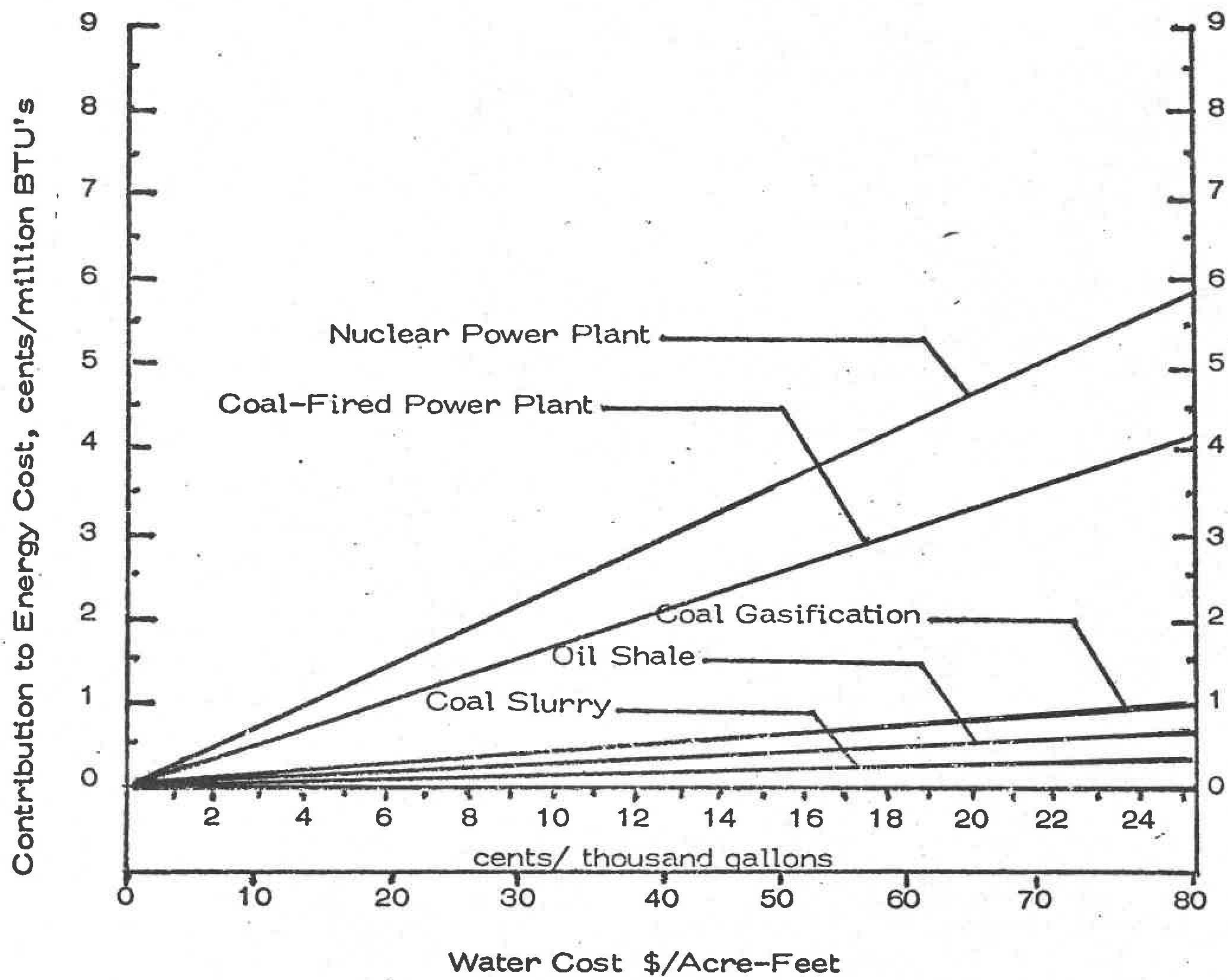
Figure 1

Cost of Water to Various Industrial Energy Developers

Example: 1c million BTU Equivalent to:

—6c/6 million BTU

—6c/Barrel Crude Oil



industrial and municipal needs may call on the same water resources that planned energy developments might require.

We have looked at the cost of water to the energy industry and we find that water is perhaps the cheapest resource used by the water industry. Therefore, price will not be a factor in limiting the amount of water used for energy development. (Figure 7, Page 14) To be more specific, we have learned of energy companies that are willing to pay between one and two hundred dollars an acre foot for their water supply and that this adds only a few cents per million BTU's to their total costs. One to two hundred dollars an acre foot is a high cost of water compared with what municipalities and other users are currently paying. For example, it is common for the irrigation industry to pay between five and twenty dollars an acre foot. Therefore, the energy industry currently can pay more than 10 times the amount for water than irrigators are now paying.

Will this energy development occur and will these water resources be utilized for energy development in the amounts that I have described by 1990? Well, no one knows. We do not have a firm federal energy policy. States, who perhaps once felt they should be in a position to react to a promised federal energy policy, now are starting to formulate their own plans while some of the energy industries are moving ahead with energy development and others are being delayed by federal laws, enviornmental regulations, and local and state deliberations. There is currently being prepared new projections as to the total amount of energy that will be utilized in the West. Those projects, when published, I understand will state that the total electrical demand in the West will be as high as previously predicted. However, more of the energy will be supplied by coal and less by nuclear. This would mean that there would be a shift in the location of the development of the energy resources and that perhaps more water would be utilized in the coal-producing states for coal production and for thermal electric generation and less water would be used in the coastal states because nuclear power would not be playing as significant a role.

I personally believe that there must be some room for conservation practices that would to a small degree limit the growth of energy use, and to a much larger degree, limit the use of water resources in the energy industry. As I have previously indicated, water is not a cost-sensitive ingredient in the energy production effort. Therefore, if water is to be conserved, there has to be other incentives provided, either by laws, regulations, public pressure or awareness, or other means that will encourage or require the energy industry to conserve water resources.

Clearly, the largest savings could be accomplished in the electrical generation area. The evaporative cooling process is by far the largest consumer of water in the energy industry. The regulations of the Environmental Protection Agency have in the past almost mandated that future projects rely on evaporative cooling processes. They are now reviewing those requirements and if other processes for cooling, such as ponds, wet/dry or dry cooling processes are utilized, a large amount of western water resources can be saved.

Presented October 7, 1976 by LARRY BOERSMA, Department of Soil Science, Oregon State University.

Energy, Water Resources, and Agriculture

The most significant problem for mankind in the near future is to learn to cope with rapidly dwindling resources. Important ones are energy resources, land resources for food production, water resources for food production, urban, and industrial uses, and material resources.

The way of life in every corner of the world depends on the ability of all people to respond to these problems in a farsighted manner. This will not be easy -- some say that our way of life may not survive at all. The statistics are very discomforting. During the next 25 years, food consumption will double or triple, water withdrawals will be increased two or three fold, the need for lumber will triple, and the use of iron and steel will double.

Consequences of moving from a time of surplus and abundance to one of scarcity will be experienced by all, but especially by those who benefited most from the abundance. The purpose of this seminar is to put into clearer focus how these problems may affect us in the United States and how they affect our relations with other countries. It is my goal to emphasize that the problems of scarcity are global and that solutions require global considerations.

The place of the people of the U. S. in today's world was described recently by Dr. Kendrick, Vice President of Agricultural Sciences, University of California, Berkeley, in a speech to members of the American Society of Agronomy at the time of their annual meeting in Houston, Texas. He reduced the population of the world to a village of 1000 people. Of these, 60 would be Americans, while the other 940 would represent the remainder of the world population, including 240 living in East Asia, 324 in South Asia, 114 in Western Europe not including the USSR, and 65 in the USSR.

The 60 Americans would receive half the income of the village with the other half being shared by the remaining 940 people. The 60 Americans would share as many possessions as the remaining 940 combined. At least 80 of the townspeople would be members of communist parties, controlling the lives of more than half the people in the village. White people would total 303, while the non-white would number 697.

The 60 Americans would have a life expectancy of 70 years, the 940 others could expect to live no more than 40 years. The 60 Americans would grow 16 percent of all the food available to the people of the village. They would sell some of the food but eat nearly all of it at a rate of better than 50 percent above the normal food requirements. Most of the remaining people in the village would be hungry most of the time. Of the 940 non-Americans, 300 would have malaria, 85 would have schistosomiasis, 3 would have leprosy, 45 would die each year from malaria, cholera, typhoid, and other infectious diseases, and 156 would die from starvation and malnutrition. None of the 60 Americans would ever get any of these diseases or even worry about them.

The Americans and those in the village enjoying similar conditions achieved their favorable position through initiative and hard work. They made most of the scientific inventions and technological advances on which their accomplishments are based. They learned to utilize the abundance of resources available in the world and found little competition for them. These conditions have rapidly changed in the recent past through two major developments. One is the rapid increase in the world population. The second and equally powerful one is the educational and technological advancement being made by the other people in the village. They are no longer content to permit a small minority to use all the resources.

ENERGY RESOURCES

Of all the resource problems, none has been discussed more than that of energy. It is the most acute and tangible and affects our lives the most directly at this time. It is not the most serious problem in the long run!

Country	Energy Use of a Multiple of Nigerian Use
United States	191
United Kingdom	93
West Germany	89
USSR	77
France	67
Japan	55
Italy	45
Mexico	22
China	10
Brazil	8
Philippines	5
India	3
Indonesia	2
Pakistan and Bangladesh	2
Nigeria	1
World Average	33

Table 1. Comparison of energy consumption rates in different countries. (Source: United Nations Statistical Yearbook, 1972)

Table 1 shows that energy is used in the U. S. at a much higher rate than in any other country. The U. S. rate is more than twice that of a group of West-European countries. It is nearly 20 times that of China and Brazil and nearly 200 times that of Nigeria, one of the most advanced African Nations.

The abundant supply of inexpensive energy has been the foundation of our productivity. It has allowed us to build great factories, cultivate large tracts of land, build great ships. It has also allowed us to support an excellent educational system, build and staff large universities, build large hospitals.

It is often said that a direct correlation exists between energy use and gross national product, which is the value of all foods and services produced. Certainly Figure 1 suggests this to be so. Whether or not this diagram represents a true cause and effect relationship is much debated. While the diagram suggests such a relationship, examination of the energy and GNP statistics for most industrialized countries shows a large variation in the ratio of energy use per unit GNP (Figure 2). This variation is cited as evidence that living at standards as practiced in the U. S. does not have to consume the amount of energy it now does. I believe this to be an erroneous conclusion. In judging the information shown in Figure 2, one must keep the structure of the economies that are represented in mind.

The diagram shows three groups. Four countries, England, U.S.A., Canada, and Norway, have a ratio of about 20. The average for these four countries is slightly less than 20. These are all highly industrialized countries with a well-developed social structure. Norway is a very large country with a relatively small population. Because of the kinds of industries it chose to develop and the small population more energy is required to produce the same unit of GNP as would be the case in the countries found in the second group, which is made up of France, West Germany, Sweden, Japan. This second group has a ratio of about 10, or only half that of the countries in the first group. These are all small countries, with a very large population on a unit area basis.

People live in row houses or large apartment buildings. The living space per family is small. Usually only part of the home is heated. Because the distances between cities are small, a good public transporation network exists. They all represent very old societies. The high-energy/GNP countries are those that historically have had cheap energy. The countries in the second group have been relatively fuel-poor, especially since World War II. These and other reasons have made it possible to arrive at the much lower ratio for energy needed per unit GNP. The United States could not lower its ratio and maintain present living standards. Many customs would have to be given up or drastically changed. Particularly those involving construction of home and transporation.

All these considerations would be of little concern if energy were deprived from a non-depletable source. Unfortunately, this is not so. During the last three decades, particularly during the period 1960 to 1970, oil became the principal source of energy in the world. The major reason for this development was that the cost of recovery was extremely low as long as the easily accessible sources were tapped.

Unlimited amounts of this inexpensive energy permitted more than a decade of rapid growth in industrial output. Only recently has it been

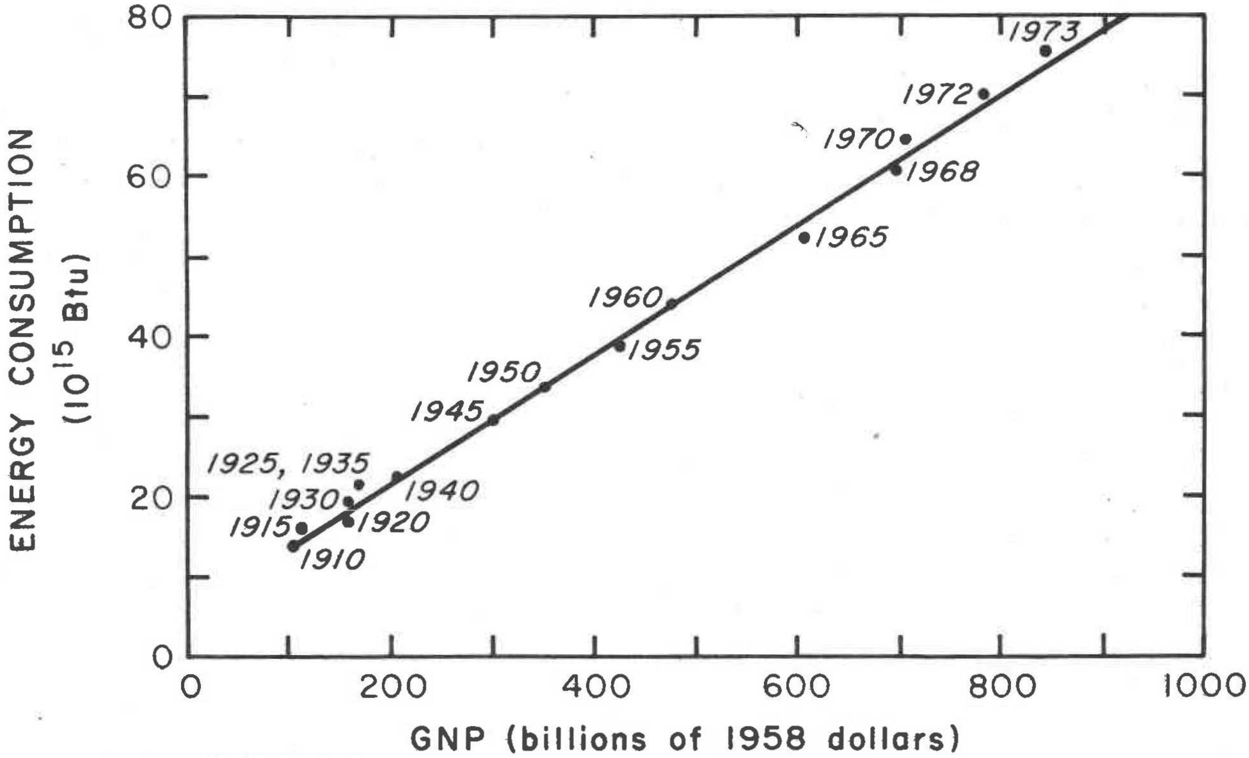


Figure 1. Total energy consumption in the U. S. as a function of gross national product during the period 1910 to 1974.

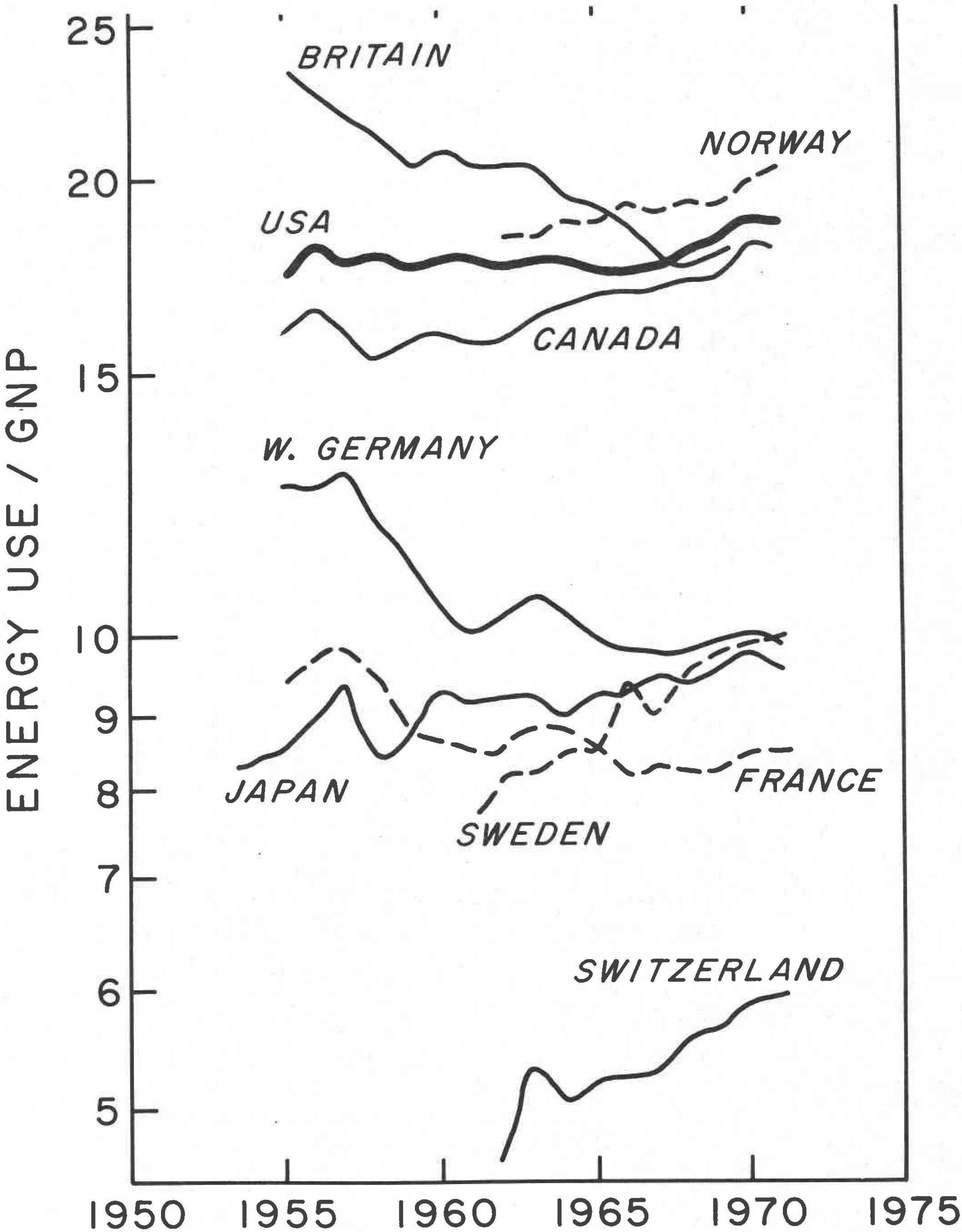


Figure 2. The energy/GNP ratio for several countries over time, with hydroelectric power counted at 3 kwht/kwhe.

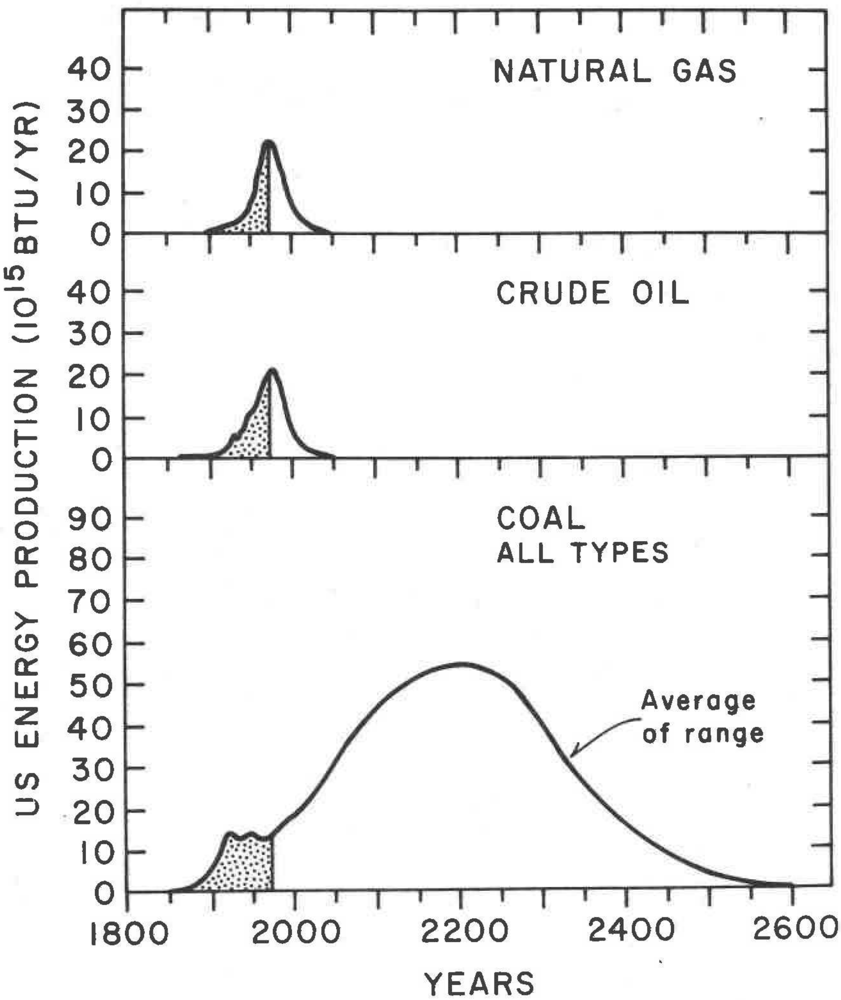


Figure 3. Past and future rates of energy production from oil, coal, and gas.

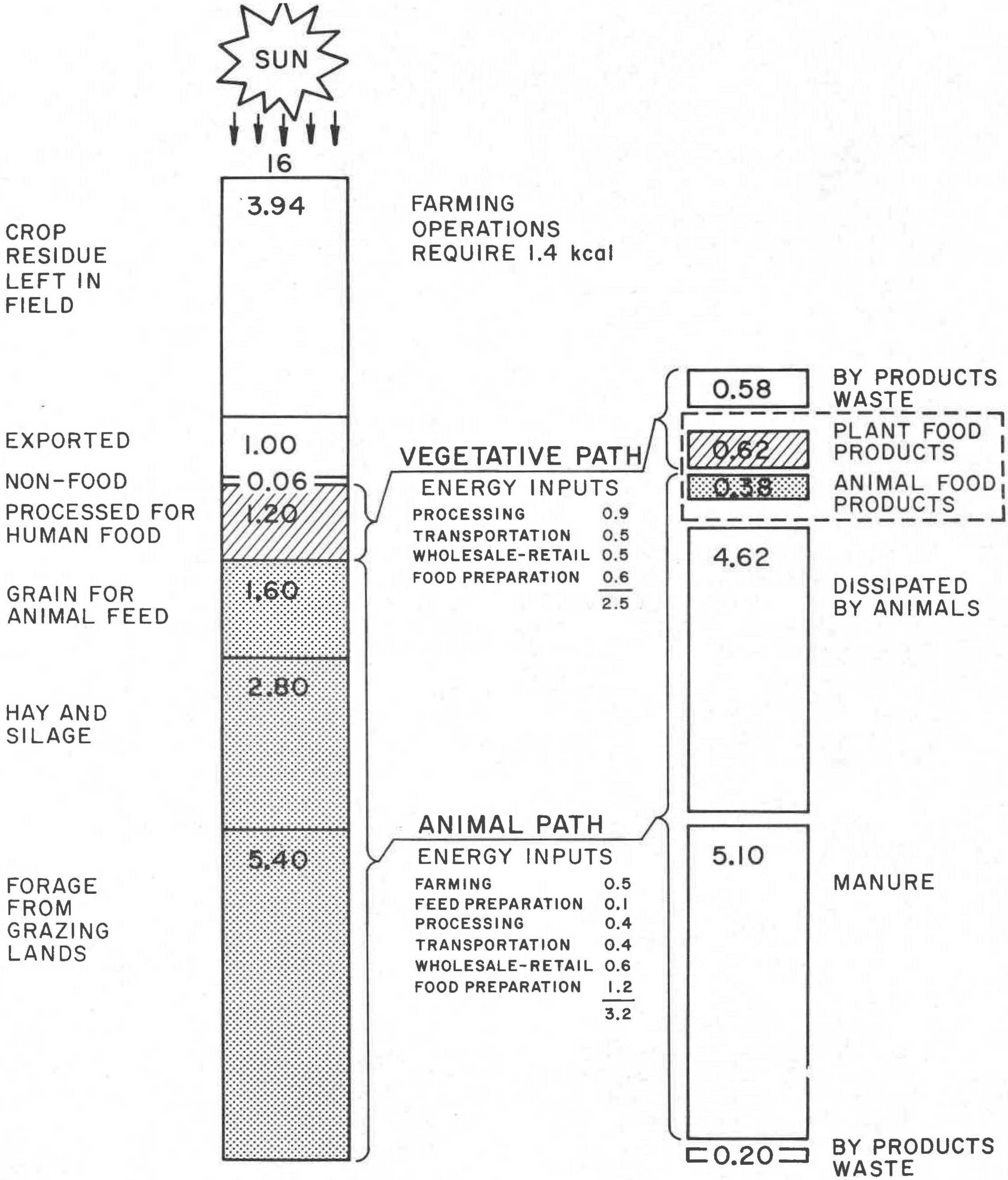


Figure 4. Sixteen units of food energy grown in the field yield 0.62 units of food consisting of plant products and 0.38 units of food consisting of animal products. Activities involved in putting 1.00 unit of food energy in the table require 7.1 units of fossil fuel energy.

recognized that oil is a non-renewable resource (Figure 3). This recognition has prompted a pricing of this resource in accordance with its scarcity.

The implications of the diagram are more dramatic than is generally recognized. We are now living at the time of the highest rate of production of gas and oil in the history of this country. Starting now, oil and gas will be less available from domestic sources while the demand continues to increase. Most young people alive today will be living during a time when gasoline will not be available unless we quickly learn to synthesize it from other raw materials which are renewable. We may also learn to use other energy sources. Many possibilities are available.

ENERGY USE IN AGRICULTURE

Of concern to us is the use of energy for food production. The activities involved in growing, harvesting, processing, and distributing food require a large input of energy derived from fossil fuels. The availability or price of these energy sources may place constraints on agricultural productivity in the future.

An evaluation of the energy needs and efficiency of energy use of modern agricultural practices can be made by comparing the food energy produced per unit of fossil energy used. The quantity of energy present in any form -- coal, oil, gas, electricity, or food -- is measured in a unit common to all of these. The kilocalorie (kcal) will be used for the discussions here.

The production of 1 kcal of food consisting of 0.62 kcal of plant products and 0.38 kcal of animal products is shown in Figure 4. The tracing starts with 16 kcal of plant energy because that is the quantity required to ultimately yield 1 kcal of food energy.

To grow the 16 kcal of plant energy requires an input of 1.4 kcal of fossil fuel energy. Thus, farming is the only industrial process which captures solar energy and yields an energy dividend.

Of the 16 kcal of plant energy produced, 3.94 are left behind in the field as crop residue, 1.00 is exported to other countries where it will be available as food energy, 0.06 consist of non-food products, such as cotton, flax, and tobacco, and 11.0 are available for the domestic food chain.

How the 11 kcal are used is determined by consumer preferences, the need for a balanced diet which includes animal products, and the fact that many plant products can be digested by animals but not by people. The food can follow the vegetative pathway and be consumed in the form of plant material, such as fruits, bread, or cereals, or it can follow the animal pathway and be fed to animals to provide meat, dairy, and poultry products.

In the U. S., 1.2 of the 11 kcal available are processed for consumption as plant products and 9.8 are consumed by animals. Processing the 1.2 kcal along the vegetative path yields 0.62 of food and 0.58 of by-products and waste of which 0.50 are used for animal feed. The animal pathway starts with a total of 10.3 kcal -- 1.6 from grain, 2.8 from hay and silage, 5.4 from grazing land, and 0.50 from the waste products of the vegetative path. These 10.3 kcal produce 0.38 food, 5.1 manure, and 0.2 by-products and waste. The remaining

4.62 kcal were used by the animals to maintain their temperature and expend energy for grazing and other physical activities.

FOOD SUPPLY PROBLEMS

It has been said that potential food supply problems could be greatly alleviated by making more plant products available for direct human consumption. This is not so. The 9.8 kcal used by the animals are made up of 1.6 from grain, 2.8 from hay and silage, and 5.4 from forage collected by grazing animals. Of these, only the 1.6 kcal of grain possibly could be made available for human consumption. The materials collected from pastures and range cannot be digested by humans. The animals are needed to convert plant materials to a form suitable for human consumption.

It has also been suggested that the land from which the roughage is obtained could grow products which could be digested by humans. Some of the land probably could be used in this manner, but only with a great cost of energy and capital. Traditionally, the poorer land -- land with some limitation -- has been reserved for forage production. Limitations include depth of soil, drainage condition, slope, rainfall, or erodibility.

The fossil fuel energy needed to produce the 1 kilocalorie of food energy are also shown in the diagram. Activities on the farm required 1.4 kcal. This accounts for all the energy used for plowing, harrowing, manufacture and distribution of fertilizers, pumping irrigation water, and manufacture and distribution of agricultural chemicals needed for weed and pest control. It also includes the energy needed to manufacture equipment such as tractors, plows, and trucks. Food processing along the vegetative pathway required 2.5 kcal and along the animal pathway 3.2. Adding all the energy inputs shows that 7.1 kcal of fossil energy are needed to produce 1 kcal of food energy consisting of 0.62 of plant products and 0.38 of animal products.

ENERGY CONTENT

The energy content of the food consumed each day by the average person in the United States is about 3,300 kcal. Each person, therefore, needs 7.1 times 3,300 or 23,430 kcal each day to produce his food. The energy needed to produce and process food for the 2 million people in Oregon is about equivalent to the continuous output of two power plants equal in size to the Trojan Plant near Rainier.

A better awareness of the energy needs for food production may be obtained by following the path of a specific product from the field to the point of consumption. We chose this product to be milk. First, one must visualize the dairy herd. The cows need to be fed several times per day. The feed consists of agricultural products which were grown, harvested, processed for animal consumption, transported to the place where the cows are, and finally distributed to the cows. When the milk is extracted from the cow, a large amount of energy has already been invested in the form of cultivating the land, manufacturing the fertilizers put on the land, harvesting, and processing.

Milking is done with a milking machine. The operation also requires clean water and soap for sanitation representing further energy inputs. Upon obtaining the milk, it is stored in stainless containers and maintained at low temperatures until pick-up for transport to a processing plant in refrigerated trucks. Here the following news-item from the Corvallis, Oregon Gazette-Times, January 1, 1977, is of interest.

> REFRIGERATION LAW FORCES AMISH TO SELL DAIRIES
>
> SHIPSHEWANA, Ind. (AP) -- Hundreds of Amish dairy farmers, unwilling to compromise their religious beliefs, are being forced out of business by a state regulation requiring them to cool their milk by modern means.
>
> The regulation going into effect March 1, requires that warm, fresh milk be cooled to 50 degrees Fahrenheit within two hours after it leaves the cow, a process that can only be accomplished by refrigeration. The rapid cooling is intended to prevent growth of bacteria.
>
> But the Amish, who traditionally have cooled their milk with cold water or ice, are forbidden by their religion to use electricity, the source of power for most milk cooling systems. The old method with cold water or ice can only cool milk to 70 degrees within two hours.

When processed for powdered milk, it is passed through drying towers where all the water is evaporated. Since the dry matter content of milk is very low, it is easily understood that large amounts of energy are needed to obtain one gram of milk powder. This is not the end of the process, however. Before the milk reaches its point of consumption, it passes additional steps demanding energy. It needs to be packaged and shipped to a central location for wholesale. This point may well be in a different country and involve transportation by truck and ship. Then repackaging follows and further distribution.

Finally, it reaches a small store and ultimately the home where it is to be used. Even that is not the end of the steps demanding energy. Now the powder is mixed again with water and heated.

Many other examples can be cited. This method of producing, processing, and distributing food has replaced the methods in which nearly every living unit produced and processed its own food. Transportation was not involved. The housewife and her help spent nearly their entire productive lives with activities associated with gathering and preparing food. That condition existed within memory of most people living today. During the 1930's and even during the 1940's, nearly 40 percent of the population was engaged in food production Furthermore, almost all woman were fully occupied with chores involved in food preparation. Now only about 4 percent of the population is involved in food production and most food can be bought in a highly processed form requiring little additional work in the home. It has made it possible for the woman to take jobs outside the home.

The only options available to reduce the energy required for food production are to reduce processing and preparation. Accepting these alternatives would mean less variety of available food products, more work needed in the home to prepare the food, more frequent shopping, and a great change in production techniques. Present distribution systems are based on the availability of highly processed products which can be distributed over long distances. This assures price stability. A return to a lower degree of processing would have far-reaching consequences.

FOOD PRODUCTION

The energy supply problem is clearly a serious one and needs immediate attention. Of far greater concern, however, is the restraint put on the food for a rapidly expanding world population.

Figure 5 shows that the land area needed to supply a basic food ration to all members of the world population at current yield levels is rapidly increasing. The rate of increase shown in the diagram is based on projected growth rates of the world population.

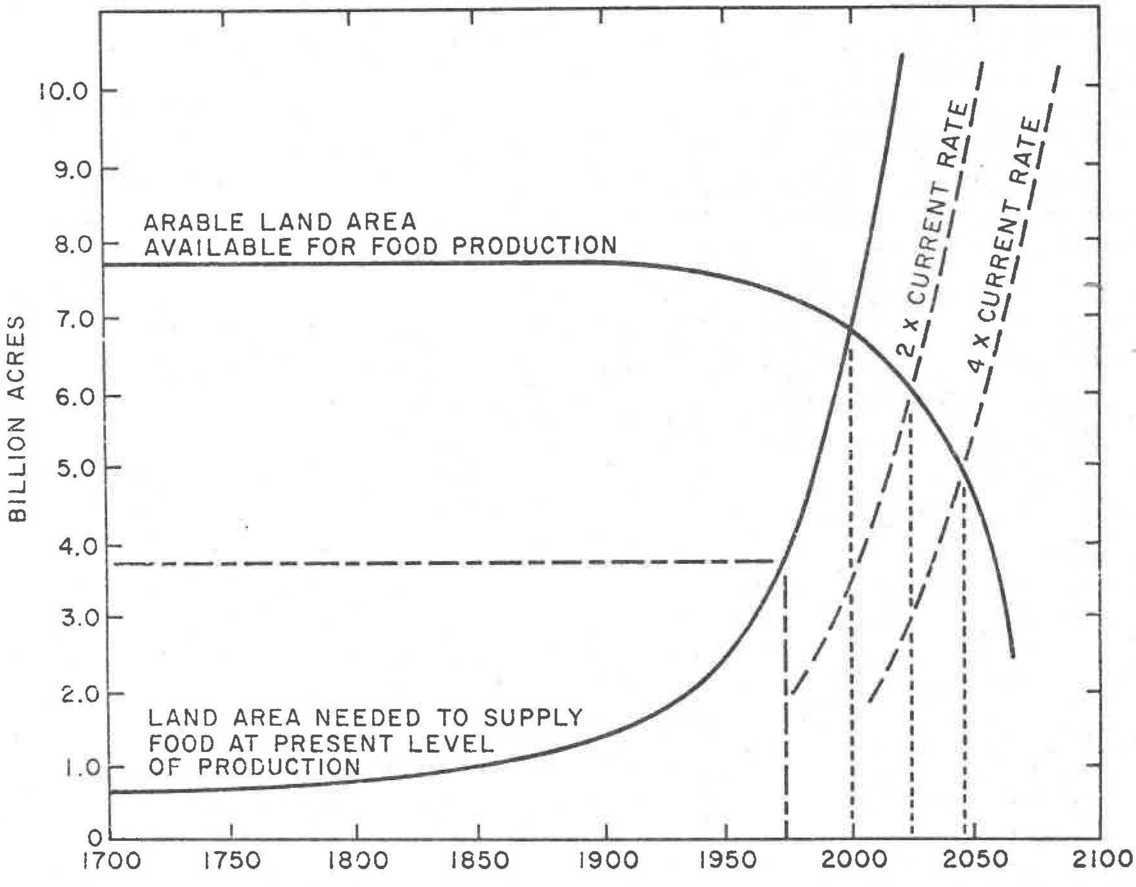


Figure 5. Land area needed to supply a basic food ration to the world population assuming current yield levels, and land area available in the world for food production. The decrease in available acreage of arable land is based on projected use of land for highways, airports, and other non-agricultural uses. At some in the future the number of acres required to produce the food will become equal to the number of acres available to grow it on. The occurrence of this date can be postponed by increasing the yields per acre as indicated by the lines "two times current rate" and "four times current rate."

The earth surface above mean sea level is about 34 billion acres. Of these only about 11% or 3.7 billion acres is suitable for growing crops without large scale irrigation developments, drainage projects, or other special improvements. Nearly all this easily accessible, productive land is now in use. Since the world population is about 4 billion, each person has 0.9 acres available to him for food production. This point is marked in Figure 5 by lines plotting the point "1976" and "3.7 billion acres."

An additional 3.7 billion acres is potentially suitable for cultivation. This land does, however, have limitation which has prevented use. It is either in regions with insufficient rainfall, is subject to frequent flooding, has a low content of phosphorous, potassium, or other necessary nutrient elements, is too acid for most crops because of frequent leaching, the salt content is too high, or it suffers from combinations of these limitations.

Table 2 shows that the percentage of potentially available land now in use is already high in regions with favorable climates and high population densities. The percentage is low in South America and Africa. Both regions suffer from severe climatic and/or soil limitations.

Continent	Percent Cultivated
	%
Asia	83
Europe	88
South America	11
Africa	22
North America	51
USSR	64
Australia	2

Table 2. Percentage of potentially available land now cultivated.

Land available for crops can be expanded by irrigation of dry land, applying fertilizers where fertility is low, draining wet lands, or by developing special crop varieties suited to specific limiting conditions such as acid soils. All these developments would require large inputs of energy for pumping water, building new roads, building and operating more equipment, and for the manufacture and distribution of fertilizers and other agricultural chemicals.

ENERGY FOR IRRIGATION

A large portion of the land areas available for expansion of agricultural production lack water. This must be supplied by irrigation systems. Unfortunately, irrigation is a high energy user. The energy requirement in irrigation is emphasized in Table 3 listing the ratios of harvested food energy to cultural energy for several cropping systems to obtain corn grain. The ratio is 20 for the cultural system used in Ghana where the only input is human labor.

Using more intensive farming systems by combining mechanical inputs with manual labor decreased the ratio to about 4.5 but increased yields substantially. Higher energy inputs increased yields so that the ratio remained constant during the early part of this century. A dramatic decrease occurred, however, where irrigation was required, as shown by the results for California, 1972.

Cultural System	Energy Input	Energy Yield	Ratio
	MKcal/ha/yr		
Rainfed agriculture			
Ghana, 1947	0.22	4.45	20.0
Iowa, 1915	3.95	18.77	4.8
Indiana, 1938	6.92	33.35	4.9
Illinois, 1969	12.84	56.07	4.4
Irrigated agriculture			
California, 1972	30.38	66.94	2.2

Table 3. Response of food energy yield from corn grain to increasing inputs of cultural energy.

The energy cost of lifting the water needed to irrigate 1 acre of corn in the subtropics was estimated to be approximately 8.1 MKcal. A lift of 300 feet was assumed. To increase the cultivated acreage of the world by 3.3×10^9 acres would require 700×10^9 gallons of fuel per year. This is equivalent to 5% of known oil reserves and thus would exhaust these reserves in 20 years.

WATER RESOURCES

The availability of fresh water measured in terms of quantity and place of occurrence is one of the crucial problems in the evaluation of adequacy of resources for the continued development of mankind. This availability may in the future place constraints on the ultimate size of the population and on the standard of living that populations of any density will be able to enjoy. The need for water increases rapidly with higher living standards.

An estimate of the total amount of water in the world and its distribution (Table 4) shows that most of the water is in the oceans. The next largest quantity is locked in ice caps and glaciers. The sources of water available for farming are fresh water lakes, water in stream channels, and the sub-surface waters including the water in the unsaturated zone and the shallow and deep-lying groundwater reservoirs. Most of the present day agriculture is based on use of the 16,000 cubic miles of water stored in the soil, in the unsaturated, aerated zone, during the rainy season. This usually implies the uppermost three feet of soil.

Location	Volume	Percent of Total
	10^3 cubic miles	%
Surface water		
Fresh water lakes	30.0	0.0090
Saline lakes and inland seas	25.0	0.0080
In stream channels	0.3	0.0001
Subsurface water		
Soil water	16.0	0.005
Shallow ground water <0.5 mi.	1,000.0	0.310
Deep ground water >0.5 mi.	1,000.0	0.310
Other location		
Ice caps and glaciers	7,000.0	2.150
Atmosphere	3.1	0.001
Oceans	317,000.0	92.200
Total	326,000.0	100.000

Table 4. Water supplies of the earth.

The amount of water required for growing crops on irrigated land can be estimated by assuming that about 3 ft. of water would be required. This includes losses from storage, from canals, and the amount transpired by crops. Presently about 12% of the cultivated land is being irrigated. Thus on a world-wide basis, the total irrigation requirement would be about 450 cubic miles. This is equivalent to about 2.7% of the water available in the unsaturated zone, or about 1.5% of the water stored in fresh water lakes.

These percentages appear to be small. But the fresh water lakes do not occur where the irrigation water is needed. Most suitable sites for irrigation reservoirs have already been put into use. Those remaining are located where the need for water is least. About one-third of the world's runoff passes through rivers in South America where only one-eighth of the land is located.

Most of the land where crops can be economically grown without supplemental irrigation are now in use as is indicated by Table 2 showing the percentage of potentially arable land now being cultivated. Much of the world's vacant land is in tropical South America and Africa. The vacancy there is not without reason. The land in South America has tropical limitations and the land in Africa has desert and tropical limitations.

While large areas of vacant tropical lands are well-watered, much of it is not. If it is assumed that an additional 3.0 billion acres could be brought into production, provided a water requirement of 3 ft could be satisfied by irrigation, the total irrigation requirement would be 4,000 cubic miles. This quantity corresponds to about 3% of all the water currently stored in fresh water lakes. These numbers indicate that water shortage could indeed become a problem for expansion of agricultural production in the future.

LAND RESOURCES

However, even if all the necessary resources were available indefinitely, there would still be a limit to the total land area that could be brought into cultivation. Estimates vary, but most authorities seem to agree that only about an additional 3.0 billion acres can be brought into use.

In the meantime, land suitable for crop production is decreasing because of the occupation of agricultural land by non-agricultural uses (Figure 5). Among these are highways, shopping centers, and housing developments. For example, the combined acreage used for agriculture and forestry in Benton County, Oregon, was 15,019 acres in 1956. It had decreased to 12,791 acres by 1971. The decrease of 2,228 acres was absorbed by residential (2,014 acres) and commercial (187 acres) developments. Each year, more than one million acres are withdrawn from agricultural use in the U. S.

At the same time, the quality of land is decreasing from over-use or unwise use. Loss of land from erosion is severe in many places. For the United States as a whole the annual soil loss from erosion is estimated to be nearly 4 billion tons, or about 14 tons per acre of cultivated land. This is equivalent to the loss of a layer of top soil 0.1 inches thick each year. This does not seem to be very dramatic. But the forces of nature require at least 10 years to produce 0.1 inches of new top soil from the parent material under conditions which favor this process.

The inevitable conflict between the number of acres needed for food production and the number of acres available is slowly approaching. This conflict could occur as early as the year 2000, according to the indicated projections (Figure 5). The date could be postponed by increasing the yield per acre, by decreasing the rate of population growth, or by developing alternative agricultural production techniques.

SUMMARY

To comprehend the gravity of the approaching conflicts, it must be realized that economic and social disruptions will occur long before the last available acre is plowed. Terrorism and war would be common occurrences in a starving world.

Few options are available to us to deal with the problems of scarcity of energy, land, and water resources. Fortunately, the energy supply problem is manageable. We possess the technical expertise and resources to assure an adequate supply of power in the form of coal and nuclear energy for the near future and fusion power and solar energy for the long term future. In our deliberations over developing our energy resources, we must recognize the central position of energy supply in the process of food production. The commitment to develop the necessary supplies of energy must be accepted.

The limited availability of land on which to grow the food is a much more serious problem than assuring adequate energy supply. The most effective step to be taken is to decrease the rate of growth of the world population.

It would matter little if the U. S. achieved a zero population growth rate as long as other countries continued to have high-growth rates. The U. S. finds itself in a particularly conspicuous place because it contains such a high percentage of the good agricultural land in the world.

It will be difficult to close the store when people in other parts of the world are hungry. While the possibility of a worldwide food crisis in the late 1980's or 1990's looms as a dramatic threat to mankind, the potential to avoid such an occurrence exists.

First, we must be willing to recognize the reality and magnitude of the problem. That is not easy to do when the memory of food surpluses is still fresh in our minds. But we should also remember how quickly waiting lines appeared at filling stations when gas supplies dwindled. One season of unfavorable weather on a global scale would produce a similar condition at the supermarket, only it would be more serious and of longer duration. And the adaptation would not be so easy. It is a lot less painful to forego a weekend drive than to have to miss an evening meal.

Proper planning now, based on a recognition of the problem, can avoid disastrous food shortages in the future. Food production can continue to increase as it has in the past through genetic improvement of crops and better fertilization practices. But those increases will not be able to meet the increased needs as theoretical limits are attained and additional water supplies are not available. New sources of human and animal food must be developed. These will include conversion of waste products to single cell protein by bacteria, yeast, algae, or other microorganisms. In our present method of operation, food is harvested, processed, packaged, delivered, consumed, and eventually excreted. We must change this open-ended system of management into a closed cycle of food regeneration without the great losses that are currently incurred.

Indeed, many options are available to develop new sources of energy and food. The question is: Can we meet the challenge in time?

Presented October 14, 1976 by ROBERT B. WENSINK, Agricultural Engineering Department, Oregon State University.

Energy Conservation in Irrigation

America's on-farm food production system consumes approximately 2.6 percent of the total U.S. Energy budget (Heichel, 1976). As Figure 1 indicates, irrigation consumes 35 x 10^{12} kcal, or 9.7 percent of the on-farm energy (Nelson et. al., 1975). Since less than 10 percent of all U.S. crops are irrigated, those that are irrigated, therefore, consume a substantial amount of energy. In fact, there have been reported cases (Barnes, 1973) of pumping energy requirements for irrigation water in excess of 20 times the energy necessary for all other field operations. These statistics indicate the rationale for allocating this seminar to energy in irrigation.

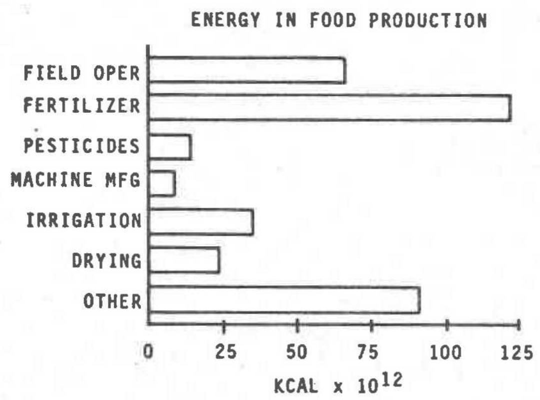


Figure 1. Partition of energy used in American on-farm food production system.

Irrigation is an age-old art, well-documented. There are records and evidence of continuous irrigation for thousands of years in the valley of the Nile, and for comparatively long periods in Syria, Persia, India, Java and Italy. Egypt claims to have the world's oldest dam, 355 feet long and 45 feet high, built 5,000 years ago to store water for drinking and irrigation. Basin irrigation, introduced on the Nile about 3,300 B.C., still plays an important part in Egyptian agriculture.

Irrigation has been transformed from an ancient art to a modern science. In many parts of the world, it is clearly the science of survival. The pressure of survival and the need for ever-increasing food supplies mandate a rapid expansion of irrigation throughout the world. Irrigation is of first importance to Earth's arid regions, but it is also becoming increasingly important in the humid regions which have ample annual precipitation but experience short dry periods.

Irrigation generally is defined as the application of water to soil for the purpose of supplying moisture essential for plant growth. However, modern irrigation systems are utilized for a variety of other purposes. For example, sprinkler irrigation systems are used for frost protection of agricultural crops in many parts of the United States. Peppers and strawberries have been protected from temperatures as low as 21° and 18° F, respectively. In addition, irrigation systems may be adapted for fertilizer, insecticide or herbicide application.

As indicated in Table 1, world irrigated acreages have increased substantially from 1800 to 1969. In 1969, China, India, Pakistan and the USSR irrigated 116.1, 93.0, 29.6 and 24.5 million acres, respectively. The U.S. jumped from 42.0 million in 1969 to over 54 million in 1975. Today, there are over one-half billion acres of irrigated land throughout the world.

WORLD IRRIGATION

Year (A.D.)	Millions Acres
1800	20
1900	119
1949	227
1959	368
1969	494

Table 1. Land irrigated in the world.

To determine the amount of energy consumed by irrigation, one needs to understand the basic types of irrigation systems. Irrigation methods can be partitioned into two broad categories: surface systems and sprinkler systems. Surface systems generally transport water from its source to the field in either an open ditch, which may or may not be lined with an impermeable material, or through low pressure pipes. The water is then distributed by either flooding the complete field or by furrow irrigation, which necessitates the wetting of only part of the surface (from 1/2 to 1/5).

Thus, furrow irrigation may reduce evaporation losses, lessen puddling of heavy soils, and facilitate cultivation of soil sooner after irrigation. Nearly all row crops in the United States are irrigated by the furrow method. There are approximately 43 million acres under surface irrigation in the United States.

SIX SYSTEMS USED

Sprinkler irrigation systems differ from surface in that water is distributed over the field via pressurized irrigation sprinklers. There are six basic types of pressurized systems which range in operating pressure from over 100 psi for guns and some center pivot systems to less than 10 psi for drip systems. The six types of pressurized systems and their corresponding U.S. acreages are: hand move (4.4 million acres), side roll (3.2 million acres), solid set and permanent (with a combined 1.1 million acres), gun (0.6 million acres), center pivot (3.9 million acres), and drip (75,000 acres). These systems collectively irrigate over 11 million acres.

The hand move system is typically hand assembled for a particular irrigation set, operated for approximately 10 hours, disassembled and transported by human labor approximately 50 feet across the field, only to be reassembled and operated for the next set. This method requires sprinkler operating pressures of approximately 50 psi and a significant amount of human labor.

One means of reducing the human labor requirement is to install wheels on the lateral so that the pipe can be rapidly moved from one irrigation set to the next. This system, called the side roll, substantially reduces labor demands. Another means of reducing labor would be to position laterals at 50 foot spacings across the complete field. This system, called the solid set, instead requires a large number of pipes and sprinkler to cover the field. To facilitate harvesting, this set-up is usually disassembled after the last irrigation.

The permanent system is the ultimate in a labor-saving scheme. The system's supply lines and laterals are usually buried and in many cases the complete system is controlled by electronic clocks so that only a minimum of labor is necessary for maintenance operations. The big gun system has attempted to reduce both labor and initial investment by requiring only one large nozzle to irrigate a circular area; however, these systems can require operating pressures in excess of 100 psi.

Another system, called the center pivot, was first introduced in the late 1960's. This method utilizes one lateral to irrigate a circular pattern which usually encompasses 126 acres, requiring a minimum amount of labor and using sprinkler operating pressures between 70 and 90 psi. There are approximately 120,000 acres of center pivot systems in Oregon near the Columbia River; over 80,000 acres of these were installed between 1972 and 1974.

The last type of pressurized method is called the drip or trickle system. This requires low pressures (approximately 10 psi) and reduced labor requirements, and maximizes water application efficiency by providing an individualized emitter to each plant. The drip technique requires a large amount of plastic, polyethylene or PVC tubing which is usually installed directly below the ground surface. In addition to providing high water application efficiencies, the system can be used to irrigate areas which would otherwise be totally impossible to irrigate. For example, avocado orchards in California are irrigated on rocky hillsides with slopes in excess of 55^{o}. Drip systems have been experimentally tested on over 100 different crops with varying degrees of success.

One major problem with this method is the plugging of individual drippers, holes or emitters. However, the drip system has only been under commercial production for a few years and research is continuing to alleviate many of the existing problems.

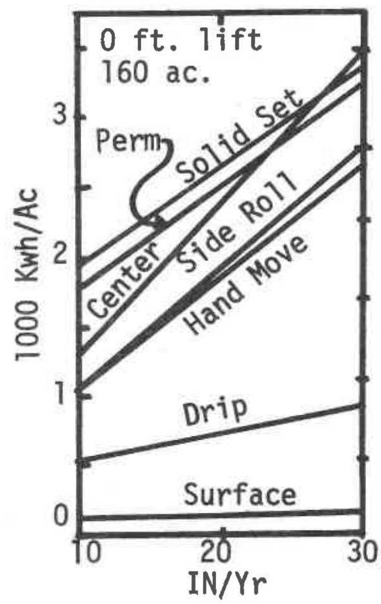


Figure 2. Total annual fossil energy requirements for irrigation systems with 0 feet of pumping lift.

Almost 90 percent of irrigation in the United States occurs in the 17 western states. Oregon irrigates 1.9 million acres, of which 118,000 acres are sprinkler irrigated. To thoroughly understand energy requirements of irrigation systems, one needs to know not only the type of irrigation system but also the source of the irrigation water. Water sources are genergally divided among irrigation districts, surface or ground water (well) sources. Many irrigation districts were developed by the Bureau of Reclamation with the intent of intercepting water as it flows from the mountains to the ocean. Most irrigation districts were designed to facilitate a type of surface irrigation which does not require use of an irrigation pump.

In most cases, surface and ground water (well) sources require pumping (lifting) of water to the field site. In the United States, approximately 42 percent of the water is supplied by irrigation districts, 41 percent from wells, and the remaining 17 percent by surface (lakes, ponds, rivers and streams) sources. Oregon obtains 50 percent of its irrigation water from irrigation districts, approximately 15 percent from wells, and the remaining 45 percent from surface sources.

We in the Department of Agricultural Engineering at OSU have utilized computer models of irrigation systems to determine energy requirements.

Figures 2, 3 and 4 present the total energy requirements for irrigation systems at 0, 200, and 500 feet of water lift to the surface of an irrigated field. The 0-foot lift essentially assumes that water is available at the edge of the field; for example, the energy requirements in Figure 2 could correspond to water supplied by a typical irrigation district.

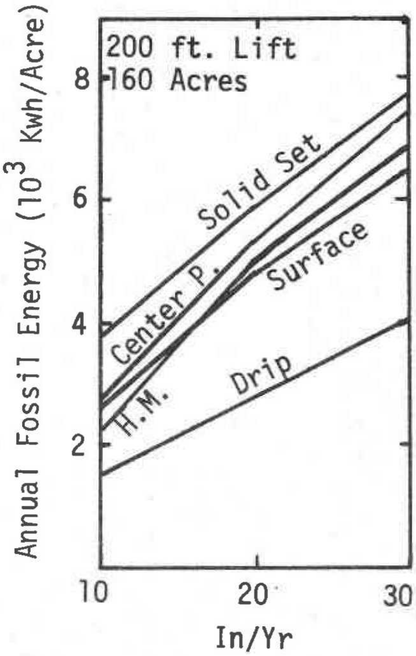


Figure 3. Total annual fossil energy requirements for irrigation systems with 200 feet of pumping lift.

The three figures indicate the total energy requirements for applying a seasonal application of 10 to 30 inches of irrigation water. Here, total energy requirements are defined as total fossil fuel energies necessary to manufacture the irrigation components, install the system, pump the desired amount of water and transport the equipment around the field. Figure 2 indicates that irrigation systems can be partitioned into three categories relative to total energy requirements: surface, drip and sprinkler systems. All sprinkler methods are substantially higher energy consumers than drip or surface systems.

Within sprinkler types, the center pivot curve possesses the greatest slope as water requirements are increased from 10 to 30 inches per year. This observation results primarily from operating the center pivots at higher pressures than the remaining sprinkler systems. They also, however, operate at higher water application efficiencies, resulting in reduced water requirements.

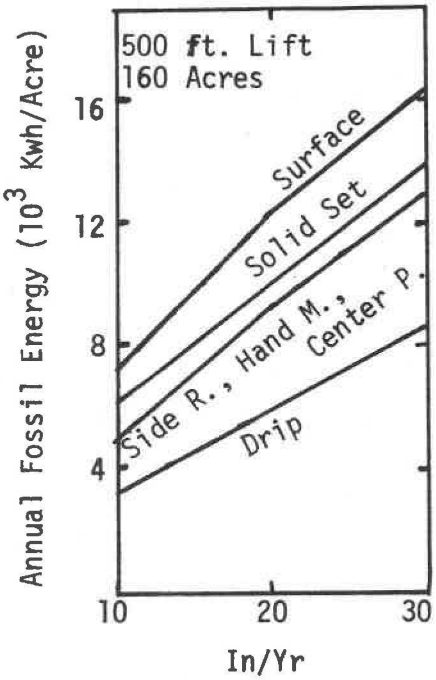


Figure 4. Total annual fossil energy requirements for irrigation systems with 500 feet of pumping lift.

The drip or trickle technique requires approximately 50 percent less total energy per acre than the best sprinkler system (hand move and side roll) at 10-inch yearly applications. The drip system improves relative to the other methods as the water requirements are increased. The primary reason for this energy improvement with increased water requirements is that drip operates at substantially reduced pressures (10-15 psi). Another advantage is that drip possesses extremely high water application efficiencies of 0.9, whereas most irrigation systems (hand move, solid set, permanent) obtain 0.75 efficiency values.

Surface irrigation, though low in energy requirements as indicated in Figure 2, also has the lowest water application efficiency (0.50). The primary reason for excessively low energy needs is that the water is available at the surface of the field so that a pumping plant and its subsequent pumping energies are not required. The only energy requirements for this system are those which arise from initial installation (e.g., surface leveling), and a minimum level of manufacturing energy for the system's components.

As the water lift is increased from 0 to 200 feet, surface irrigation changes its relative energy position. It now requires a pump to lift the water from the well to the surface of the field (200 feet). The primary reason for the drastic increase in energy requirements relative to the remaining systems is water application efficiencies. Surface irrigation requires pumping of almost twice the volume of water to achieve the same net irrigation requirements as the drip technique. In Figure 4, with 500-foot lift, surface requires substantially more energy than all pressurized systems.

As one can easily see, surface irrigation is certainly a very efficient fossil fuel energy system at 0-foot lift. However, relative to the drip and sprinkler methods, that efficiency diminishes rapidly as the water lifts increase.

Figures 2 through 4 also indicate that optimal total energy irrigation systems can be selected for specific design requirements. One of the beauties of mathematical modeling of irrigation systems is that the model categorizes total energy inputs among pumping, manufacturing, installing and transporting energies. Figure 5 provides this breakdown for the 0-foot lift case corresponding to Figure 2.

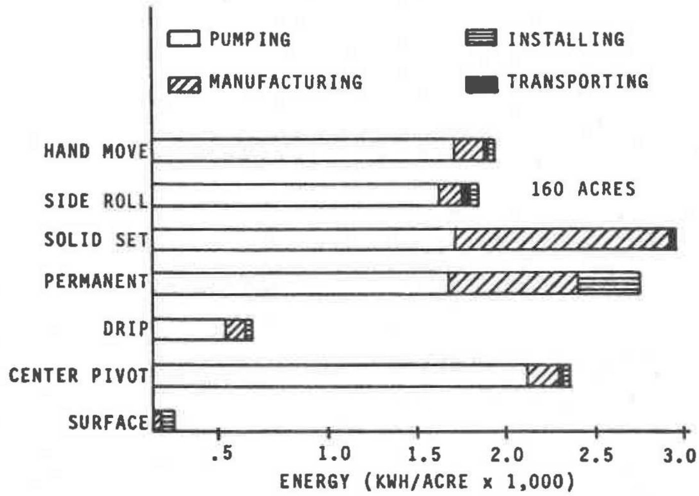


Figure 5. Partitioning of total annual energy requirements for each irrigation system described in Figure 2.

Another way to reduce energy consumption in irrigation is to develop energy design criteria in addition to economic design criteria for specific systems. Again utilizing computer modeling techniques to evaluate thousands of irrigation designs, OSU Agricultural Engineers have determined that energy designs for specific irrigation requirements are always at least one design pipe size larger than the minimum economic design size. In many cases, the difference will be two sizes and in selected cases, may be as much as three sizes larger than the minimum economic design. As the cost of energy (dollars/kilowatt-hour) increases, the minimum economic design approaches the minimum energy design.

A guideline often used by irrigation engineers to design irrigation supply lines is a head loss value of 1 foot per every 100 feet of pipe. Figure 6 displays head loss values as a function of escalating energy cost. As one can see, the 1 foot head loss per 100 feet of pipe is only applicable at energy cost values of $.02 per kilowatt-hour. Two cents is the approximate cost of hydroelectric power in Oregon and energy costs have been reported as high as $.07 per kilowatt-hour in some parts of the eastern United States.

For the 1 foot head loss per 100 feet of pipe value to be optimal, even in Oregon, energy cost must remain at $.02 per kilowatt-hour for the next 15 years. This results from prorating the initial investment over a 15-year service life of the system.

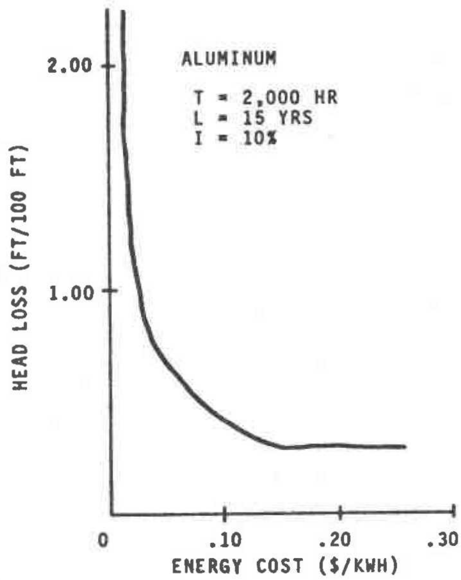


Figure 6. Design head loss values vs. escalating energy cost for aluminum pipe.

If one expects energy costs to average $.10 per kilowatt-hour over the next 15-year period, then an irrigation supply line should be designed with head loss values approximately 0.5 feet per 100 feet of pipe. As expected energy costs are increased, the head loss design values approach those of the optimum energy designs. For example, aluminum pipes approach optimal energy designs of 0.33 feet per 100 feet of pipe. Figure 6 indicates that specific systems can be designed to minimize energy requirements and to compare minimum energy requirements to expected energy costs over the irrigation system's life.

As indicated earlier in this presentation, there are approximately 0.5 billion acres of irrigated land in the world. A 1966 study suggested that the world contained 1.2 billion acres of potentially irrigable land. A 1974 world study of irrigation and drainage conditions indicated that the world contained 12.5 billion acres of potential cropland. This land would require irrigation and large portions would require in excess of 100 inches of water per acre.

POTENTIAL WATER NEEDS

10^9 Ac.	10^3 Cu. Mi.
.5	1.33
1.2	3.29
12.5	18.80

Table 2. Potential annual world water needs for irrigated crop land.

POTENTIAL ANNUAL ENERGY NEEDS (10^{12} kwh)*

10^9 Ac.	Sprinkler	Drip	Surface
.5	5.8	2.4	2.4
1.2	13.8	5.8	5.6
12.5	143.8	60.	58.8

*100 acre-in., 200-foot well.

Table 3. Potential world annual energy needs utilizing selected irrigation systems.

POTENTIAL WATER NEEDS (10^3 Cu. Mi.)

10^9 Ac.	Sprinkler	Drip	Surface
.5	1.77	1.48	2.66
1.2	4.39	3.66	6.58
12.5	25.01	20.89	37.60

Table 4. Potential world annual water needs utilizing selected irrigation systems.

Table 2 contains the annual volume of water required to satisfy the above three acreages. The water requirements were calculated assuming average irrigation requirements of 100 inches of water per acre per year. The potential annual electrical energy needs for sprinkler, drip and surface systems on each of these acreages are listed in Table 3. These values assume an average pump lift of 200 feet. At this depth, sprinkler irrigation requires approximately twice the energy as either the drip or surface systems. Table 4 indicates the corresponding water requirements to deliver and apply 100 acre-inches per acre of water for the sprinkler, drip and surface methods. Here, surface irrigation would require 37,600 cubic miles of water, whereas sprinkler irrigation would require only 25,000 cubic miles of water to irrigate the 12.5 billion acres. If all this land is eventually irrigated, would sufficient water be available?

Table 5 presents the availability of water on earth. Unfortunately, most of the water (ocean, saline lakes, deep ground water, etc.) is unavailable for irrigation purposes. Approximately two percent of the world's water is located on ice caps and glaciers which, to say the least, do not provide optimal environments for crop production.

Approximately 30,000 cubic miles of water are available in fresh water lakes, inland seas and stream channels. Ground water wells less than 0.5 miles deep provide an additional source for irrigation water. However, the above discussion would imply that the energy required to pump water from 2,000-foot wells would certainly be excessive. Though the available volumes reported in Table 5 may not necessarily be accessible on consecutive years, sufficient annual water should still be available to supply all potential irrigable land.

WATER ON EARTH		
Location	10^3 Cu. Mi.	% Total
Surface Water		
Fresh water lakes	30.0	0.0090
Saline lakes & inland seas	25.0	0.0080
Stream channels	0.3	0.0010
Subsurface Water		
Soil water	16.0	0.005
Ground water (< .5 mi.)	1000.0	0.310
Ground water (> .5 mi.)	1000.0	0.310
Other Locations		
Ice caps & glaciers	7000.0	2.150
Atmosphere	3.1	0.001
Oceans	317,000.0	92.200
	326,000.0	100.00

Table 5. Source of world water supplies.

To satisfy global irrigation needs, agriculture will certainly need to compete with all remaining industries for energy and water. Though Table 5 indicates that sufficient water is available for irrigation purposes, one certainly cannot assume that all the world's fresh water will be available for irrigation purposes. Most energy production schemes also need water, with some requiring vast amounts. In isolated cases, agriculture (irrigation) will be forced to compete not only for energy but also with energy for water.

For the American agricultural production system to continue to provide low-cost foodstuffs, sufficient low-cost water must be available for irrigation. Legislatures must consider the consequences of reduced water availabilities for irrigation when water is used to generate energy. So, when you are given an opportunity to express your opinion on a particular source of energy production, consider not only the safety and efficiency of that system, but also the amount of water required and its effect on the immediate agricultural production areas.

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Presented October 21, 1976 by DR. DON KARR, Geo-Heat Utilization Center, Oregon Institute of Technology, Klamath Falls, Oregon

Geothermal Energy and Water Resources

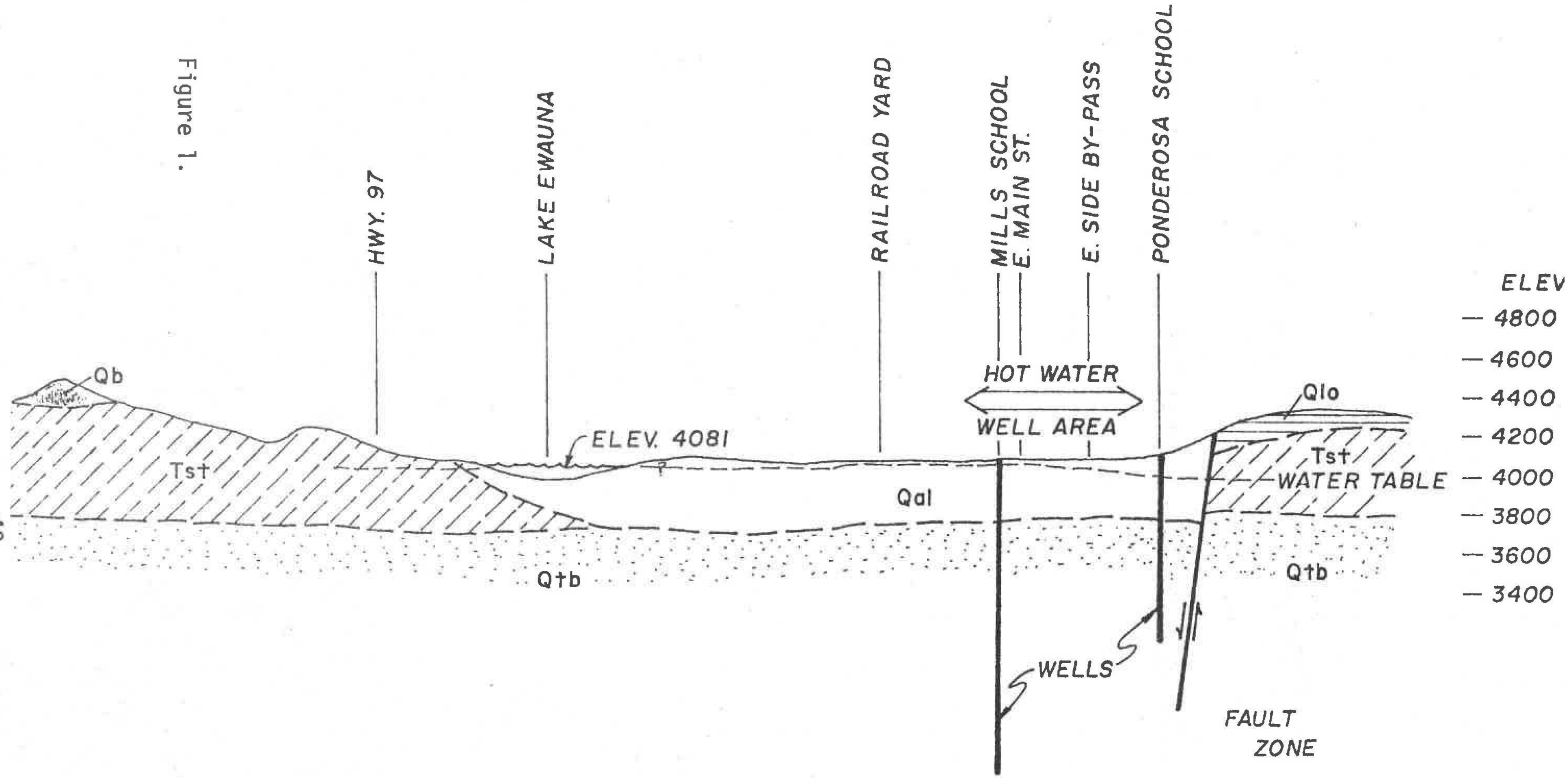
This portion of the "Energy and Water Resources" topic of our seminar series is addressed from a non-competitive viewpoint. The Klamath Falls, Oregon area has been utilizing geothermally heated water (GHW) as an energy source since the turn of the century. To date, the resource has been used predominantly for space heating by a variety of methods with only a few commercial applications. However, since the rapid acceleration of costs for other energy sources, interest in geothermal applications has increased greatly in areas where the resource is available.

Many areas in western United States are heavily endowed with the geothermal resources and Oregon is especially blessed with many areas which can be developed. The known geothermal resource area in the Klamath Basin has the second largest heat content in the United States for hot water convection systems of intermediate temperatures (90° to 150° C.) (White and Williams, 1975). The reservoir assumptions for the basin are a volume of 115 cubic miles with a heat content of 30×10^{18} calories which is equivalent to 20 billion barrels of oil. Nevertheless, the basin's resource area is not uniformly distributed and some financial risks are involved for those who seek the resource.

The location of the reservoir limits, in and near the city of Klamath Falls has been reasonably determined. A geologic cross section of this portion of the basin shows the sunken formation of a typical graben (Geologic Cross Section C-C, Fig. 1). A sketch of the supposed formation at a border of the faulted area reveals a possible method where groundwater is heated by a thermal zone (Fig. 2). Most of the hot wells within Klamath Falls have been drilled in the Hot Springs area (Location Map 1, Fig.3). The depth of the wells ranges from 100 to 1800 feet with most shallower than 300 feet.

The city has more than 400 hot wells, most having temperatures between 175° and 220° F. (80° to 105° C.). These heat more than 500 structures which include single family residences, multi-home uses from a singe well, several churches, seven public schools, the Oregon Institute of Technology (OIT) campus, a hospital, apartment houses, several local businesses and industries.

Figure 1.



GEOLOGIC CROSS SECTION C·C

VERTICAL SCALE: 1" = 800'
HORIZONTAL SCALE: 1" = 2000'

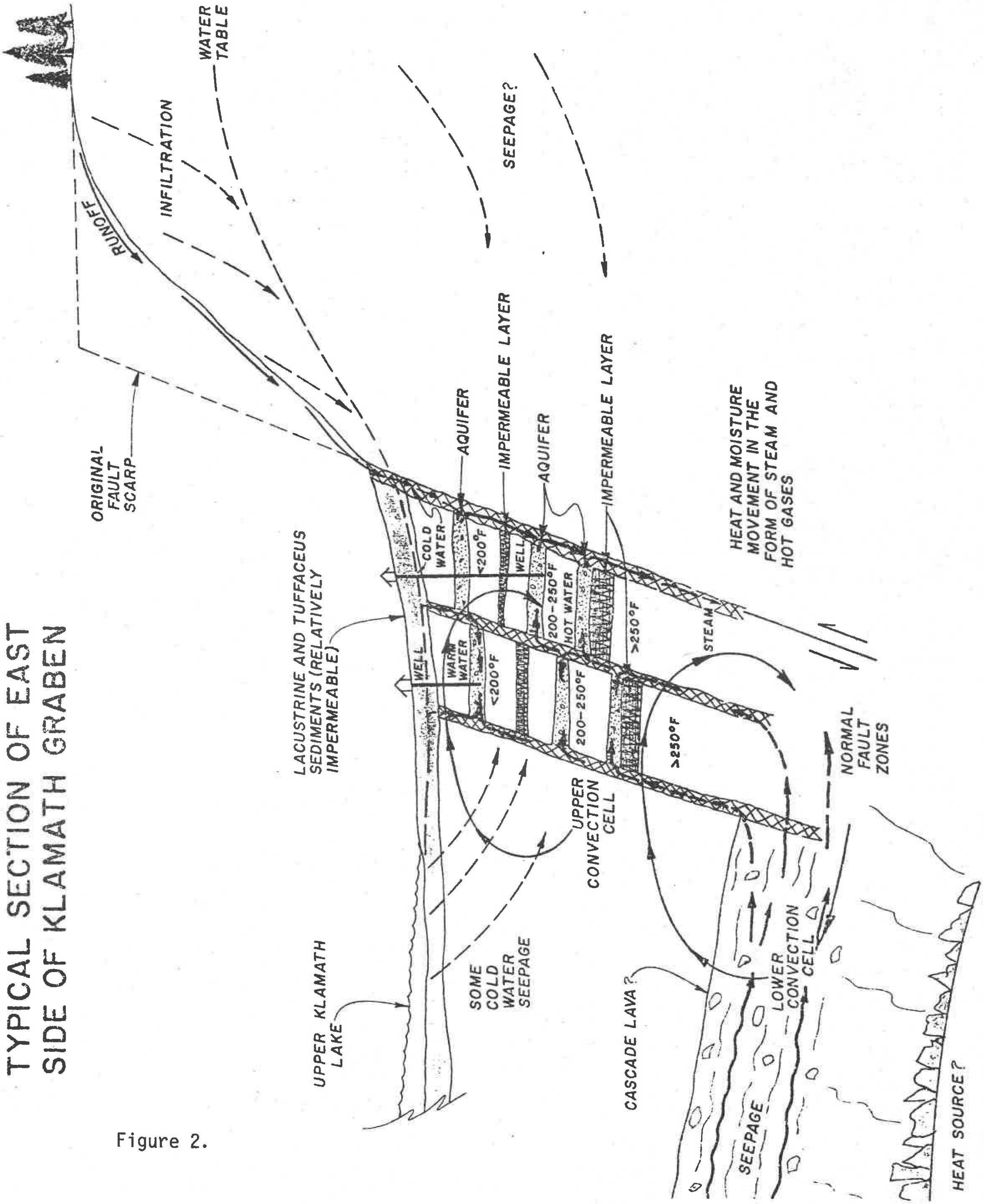

TYPICAL SECTION OF EAST SIDE OF KLAMATH GRABEN
WATER TABLE
SEEPAGE?
INFILTRATION
RUNOFF
ORIGINAL FAULT SCARP
AQUIFER
IMPERMEABLE LAYER
AQUIFER
IMPERMEABLE LAYER
HEAT AND MOISTURE MOVEMENT IN THE FORM OF STEAM AND HOT GASES
LACUSTRINE AND TUFFACEUS SEDIMENTS (RELATIVELY IMPERMEABLE)
COLD WATER
<200°F
WELL
200-250°F HOT WATER
>250°F
STEAM
WELL
WARM WATER
<200°F
200-250°F
>250°F
NORMAL FAULT ZONES
UPPER CONVECTION CELL
UPPER KLAMATH LAKE
SOME COLD WATER SEEPAGE
CASCADE LAVA ?
LOWER CONVECTION CELL
SEEPAGE
HEAT SOURCE?

Figure 2.

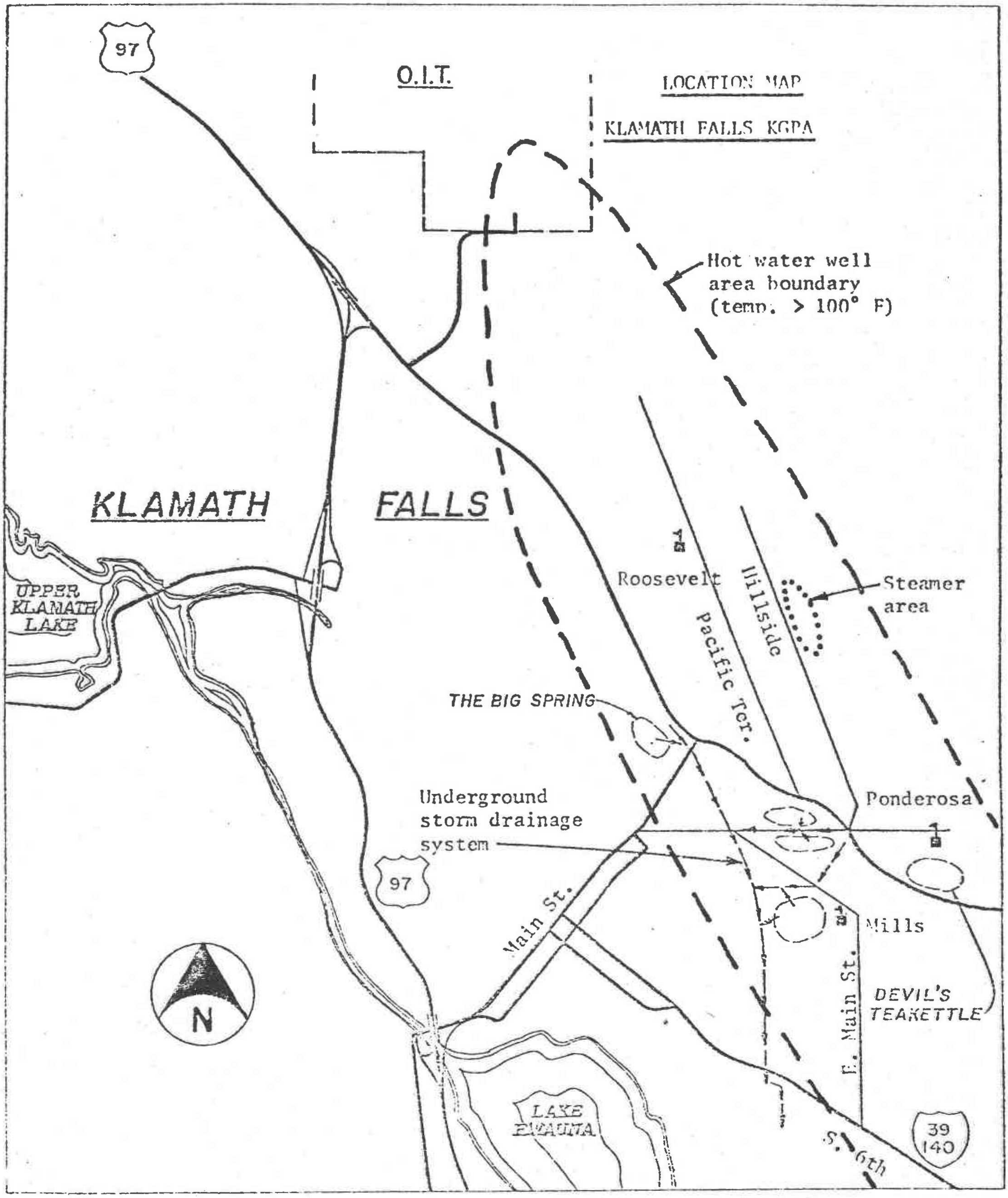
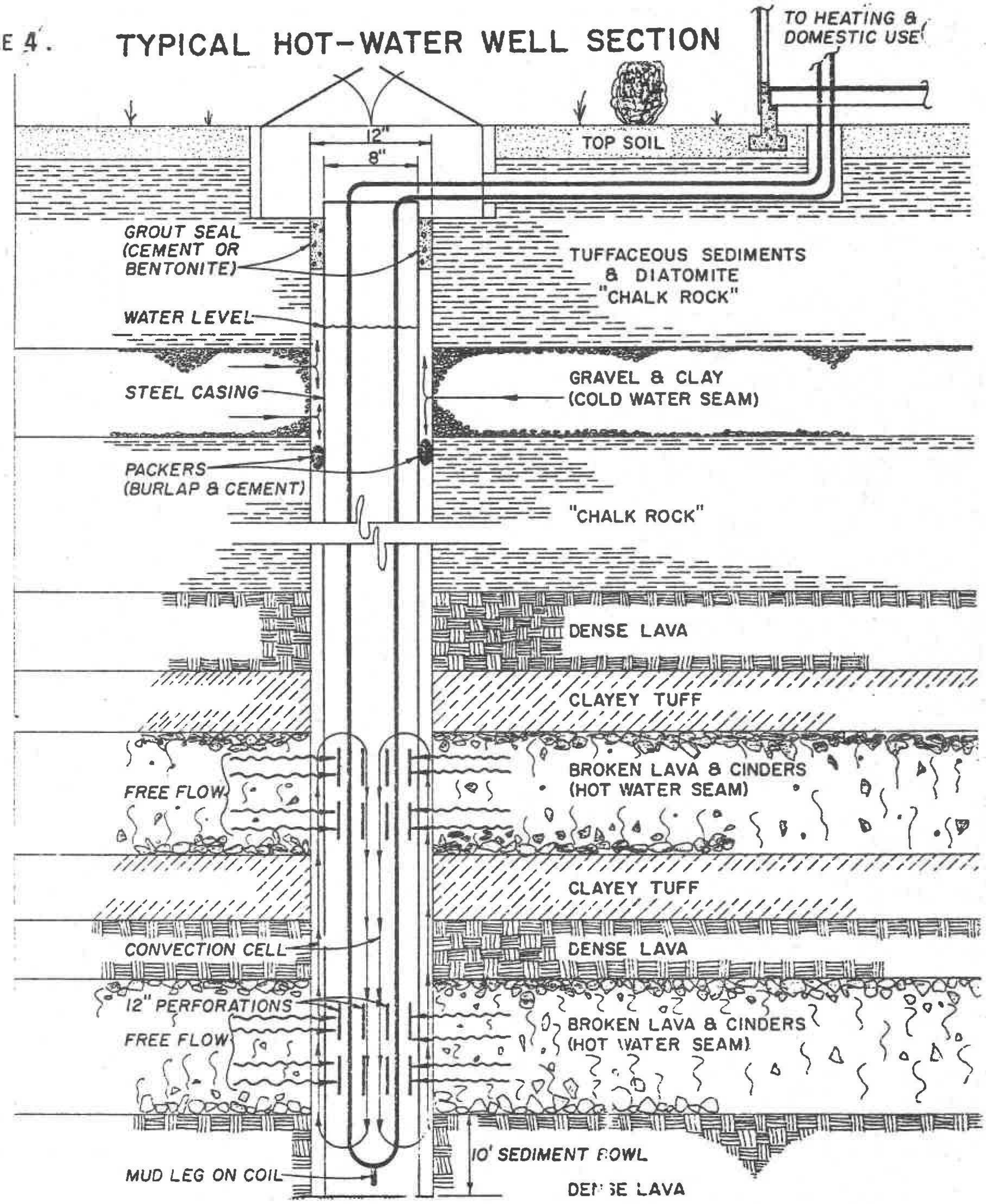


Figure 3. Klamath Falls Known Geothermal Resource Area.

FIGURE 4. TYPICAL HOT-WATER WELL SECTION



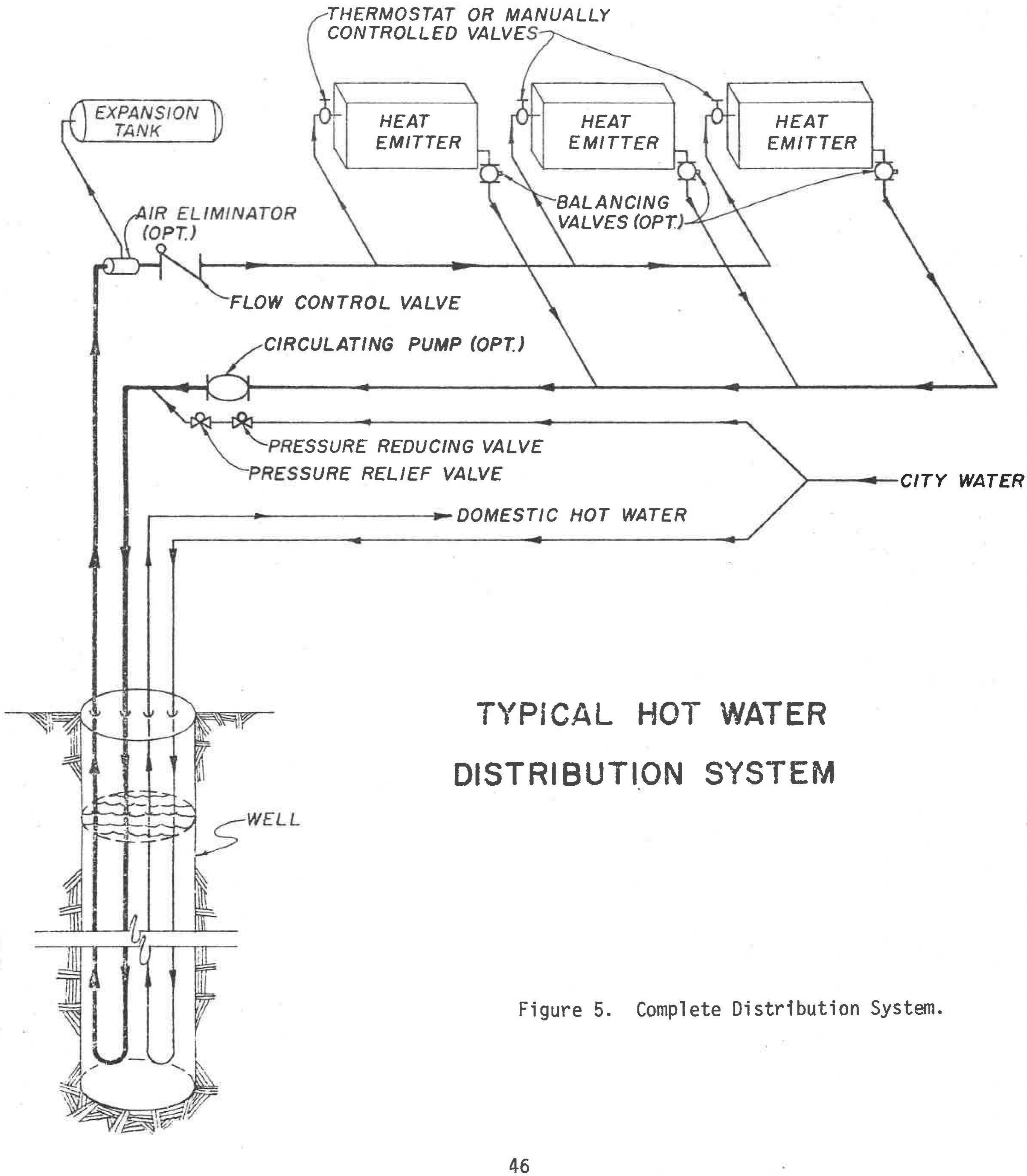


Figure 5. Complete Distribution System.

The gradual development of the hot water resource has been on an individual basis and each system has been more or less custom-built for the owner.

The predominant system which evolved over the past 20 years is a down-hole heat exchanger (DHE) and is considered to be the most successful method in the United States for space heating with GHW (Koenig, 1970). This method extracts the heat in the reservoir without removing any of the geothermal fluid to the surface. Let us examine this type of heat exchanger in detail.

Most of the wells in Klamath Falls are drilled with cable tool drilling equipment. The usual method of approach is to drill a 12-14 inch hole to depths ranging from 100 to 1800 feet. When the driller and owner are satisfied that sufficient free flowing water and a high enough temperature is available, an eight to ten inch casing is inserted into the hole.

Perforations are cut irregularly around the bottom of the first section of casing and also around the section near the top of the hot water area. Packers are usually installed around the casing to keep cold water from entering the hot water area and to keep the GHW from the cold water aquifers. Since the bore is larger than the casing, circulation is believed to exist in the hot water in and around the casing, and a convection cell to be established (Figure 4). A two-inch black iron pipe is fitted into a hairpin-like configuration and inserted into the well.

This pipe is filled from the domestic water supply and sealed into a closed unit for space heating. In some wells a small pump (1/12 to 1/8 horsepower) is installed to circulate the water within the system. In many wells sufficient internal current is created within the system to become self-circulating. Domestic water is heated by inserting an inch galvanized pipe of the same hairpin configuration into the casing with the water supply continuous with the city water system. A complete distribution system is diagrammed in Figure 5.

Three major methods are utilized for extracting the energy from the hot fluid for space heating. The two most common are forcing air across coils and by circulation through radiators. The least popular method is by circulating the hot water through radiant heating pipes in the floor or ceilings. Oftentimes the owner of a well returns his water to the well for reheating through pipes laid in sidewalks and driveways which keeps the areas free of snow during the winter.

Some wells cannot function with the system described above. Most wells in the business area of Klamath Falls are artesian and need to have some continuous flow to remain effective. Also, many of the older wells pump geothermally-heated water directly through their heat exchangers. Both of these types of systems discharge into storm sewers and eventually this water reaches Lake Ewana.

The OIT campus also uses a pump-through system for space heating and domestic water heating. The campus contains more than a half million square feet and consistently keeps the costs for heating below two and one-half cents a square foot. These costs include the salary of the maintenance man. There are three hot wells on campus between 1400 and 1800 feet deep. Except in very cold weather, one well pumping 450 gallons per minute of 192^{o} F. (90^{o} C.) water heats the campus and the other two wells are on stand-by. Heat exchangers are used in each of the nine campus buildings. Greenhouse and aquaculture projects are under construction to further use the energy from the campus effluent water.

Extensive studies conducted for the better utilization of geothermal resources have only recently begun in the United States. Several members of the Geo-Heat Utilization Center at OIT have grants to assist in their studies. The better applications of non-electric uses have developed in several foreign countries. Iceland is probably the world leader in the development of geothermal resources.

Both Iceland and Hungary presently transport the heated fluid more than 50 kilometers if necessary and have developed diverse uses for this type of energy. As better methods of transport and usage develop and the costs of other types of energy increase, other areas in Oregon than Klamath Falls will be looking at the state's geothermal resources. The three major metropolitan areas of the Willamette Valley (Portland, Eugene-Springfield, and Salem) are all located within transmission distances of known geothermal resource areas.

The rules and regulations related to approved usage of the heated groundwater and its eventual disposal have not yet been determined. However, the State Water Resources Department and the Department of Environmental Quality are aware of their responsibilities and are working toward an orderly and acceptable development of the resource.

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Presented October 28, 1976 by DAVID K. McDANIELS, Physics Department, University of Oregon, Eugene

Solar Energy and Water Resources

Water resources play a key role in the utilization of solar energy, just as is the case with our other energy resources. In fact, it is almost impossible to get along without using water. Let us tabulate a few of the places where water and solar energy systems are closely tied together:

1. As a heat-exchange fluid for flat-plate collectors.
2. As a means of storage.
3. As the working fluid in large scale solar-electric schemes.
4. As the source and sink for the generation of power by the ocean temperature difference scheme.
5. To grow kelp, etc., by photosynthesis, which is then converted by photochemical reactions to useful fuels.
6. Even non-thermodynamic cycle processes, such as direct conversion using photovoltaic cells require water to carry away the non-productive heat. (Photo cells are only about 10% efficient.)

The overall format of this talk will be as follows. First, some of the many examples showing the rapid growth of interest in solar energy applications will be pointed out. A brief discussion of the major proposals for solar-electricity generation will then be given. This will be followed by a short summary of some of the economic aspects of implementing solar energy on a widespread basis. The remainder of the talk will focus upon solar heating systems, what they consist of, and my suggestion as to the best approach for solar energy collection in the cloudy Pacific Northwest.

GROWTH OF INTEREST

In 1955, at the international solar energy conference in Tucson, Arizona, a prominent government official estimated that there would be

1-3 million solar homes by 1970. In fact there were only 10, as the rosy hopes for solar development faded before the harsh reality of cheap oil and gas.

With the recent recognition of our problems with oil and natural gas, attention once again has been turned towards solar energy. The energy crisis, coupled with rising fuel costs, has spurred on the economic growth in this area. Let us briefly review some of the prominent developments.

1. From no Federal funding in solar energy in 1970, the government investment has risen to an estimated $160 million in 1977.
2. A 5 year, $50 million housing demonstration program is underway.
3. A multitude of private development is underway.
4. Solar electric research and development is now serious. Most promising are the "power towers", solar cells, and ocean thermal schemes.
5. A national solar institute may soon be started.

In addition to this research and development activity, a tremendous upsurge in solar magazines, articles, etc. has been seen. The membership in the International Solar Society has been practically doubling every two years. Activity in universities includes new research and the start of all kinds of solar energy courses. My own class in solar energy has grown from 20 to 300 students in the past 4 years.

What are some of the reasons for people's interest in capturing solar energy and obtaining useful work?

1. It is a renewable energy source, and it shines on everyone.
2. It is practically non-polluting; this is undoubtedly the most attractive factor.
3. The fuel is free and available to everyone.
4. The space heating and cooling aspect is a low technology field to which many ordinary individuals can contribute.

Let us now look at a few examples of recent solar development:

1. This portion consists of several slides of very recent solar house projects. The important point is that it is happening all over the country.
2. The housing demonstration is in its infancy. But I include here 2 slides of NSF sponsored solar heating projects on (a) Timonium High School in Maryland, and (b) Grover Cleveland Jr. High in Boston.
3. The public utilities are now getting into the act. It is estimated that over 50% are now involved in one way or another. For example, Santa Clara, California, has initiated a program of providing solar energy systems through its Public Utilities Department. In this utility concept the city owns the solar hardware and charges the customer a service installation fee (typically $200 for swimming pools) plus a monthly service fee (typically $28/month from April through September).

SOLAR-ELECTRIC SCHEMES

Utilization of the energy of the sun for space heating and cooling seems well underway, with no major technical problems to be overcome. The generation of electric power from the large-scale conversion of solar energy, however, while feasible, will require a massive program of research and development.

A variety of ideas have been proposed which divide naturally into four categories. The first envisages direct conversion of solar energy to electricity using photovoltaic cells, either spread out over a large surface area, or using a satellite in orbit above the earth. Economic photovoltaic cells are so desirable, with such varied applications, that a separate chapter is devoted to them. Another plan envisages the use of a "solar farm" of distributed collectors of the planar type. Utilizing some augmentation from parabolic reflectors it may be possible to obtain temperatures in the 500°-600°F. range, thus providing reasonable thermodynamic efficiencies. The third proposal would use thousands of individual heliostats to concentrate the rays of the sun onto biolers mounted atop tall towers. The last scheme would generate power using the small temperature gradients present in the ocean between the surface and depths of several hundred feet.

Before going on to discuss some of the details of the above proposals it is worthwhile to note a few general features of the difficulties associated with the large-scale generation of power using solar energy. In the first place, since the incident energy density is low, solar energy power plants must collect light over a large amount of area. Capital expense for the collecting apparatus and power conversion devices is the dominant feature in determining the ultimate cost per kwh of electricity in this case -- the cost of the fuel, of course, is free.

The only real pollution problem to be faced is that of the disposal of waste heat; solar energy is no different from other sources of energy in this respect. On the other hand there is no emission of particulate matter or noxious gases to contend with and no radioactive waste to worry about. Perhaps the worst feature associated with large-scale power generation from solar energy has to do with the daily collection period. Solar energy will be collected only during a few daylight hours. Either the power generated must be used to augment conventional sources, or adequate means of storage of energy must be developed. The technological problems to be overcome in implementing large scale use of solar energy for electrical power offer a tremendous challenge for the years to come.

ECONOMIC ESTIMATES

What percentage of the overall energy budget could come from heating and cooling? Presently, the U.S. consumes about 25% of its energy for this purpose. In making estimates of solar potential, what are the uncertain factors? These include:

1. Competitive fuel costs
2. Government support
3. Local and Federal regulations to provide incentive

Despite the lack of definite knowledge about these important factors a number of estimates have been made of the possible solar impact upon the U.S. energy production. Before reviewing these, let us first look at some of the economic deterrents to the rapid implementation of solar space heating and cooling.

1. The savings made in the use of conventional energy by the "producer" of solar energy are returned to him in dollar savings based on the average cost of present day energy resources. In most areas these do not yet equal interest and amortization costs on the solar equipment. The present day average cost of energy includes both low and high cost contributions. Hydroelectric power is an example of low cost energy, while new coal and nuclear generating plants are examples of high cost energy. The solar user saves society the price of the high cost increment without being compensated for it.

2. The producer of fossil fuels and nuclear energy receives more favorable tax treatment than the producers of solar energy. The individual homeowner receives no investment tax credit, no depreciation allowance and no depletion allowance.

3. The general public now pays for pollution abatement in the form of higher prices for automobiles and many other products. Nothing is offered the solar energy producer which compensates him for pollution prevention.

4. Finally, the solar energy producer benefits the balance of payments problems and thereby makes a contribution to this country's efforts to combat inflation.

Clearly, government incentives to promote solar energy usage are both reasonable from the point of view of the individual solar homeowner and are in the overall national interest. This need is not a permanent one. Inevitably, the costs of conventional energy will rise as a larger and larger proportion is derived from high cost sources. Also, as the production of solar energy equipment becomes a mass production industry, equipment costs will decline. One can look ahead to a future in which the benefits of solar energy utilization can be obtained without incentives.

Another point to consider is the question of obsolescence. It is reasonable to expect that most "state of the art" installations to be made in the near future to exploit alternative energy sources will tend to become obsolete quickly. For example, the first generation production plant for oil shale which might be built starting today could be obsolete before it is completed. While an energy-producing facility may rapidly become technologically obsolete, such that its cost of producing energy becomes non-competititive with newer designs, solar space heating facilities are rather immune to this problem.

The cost of constructing a residential installation based upon a 100 square foot collector design is reasonably low and cannot be expected to be much above that of an advanced future design which may be available years from now. The technology is fundamentally simple, so that the cost per million BTU collected solar energy cannot be expected to go down dramatically. More likely, the reduction in the cost due to improved technology and mass production will be offset by continued inflation.

What kind of energy savings can one expect from solar energy development, even without strong governmental influence in the way of incentives? I summarize several recent estimates in Table 1.

Table 1. Estimates of Solar Energy Utilization[a]

Company	1990[c]	2000[c]
General Electric	1.9	5.5
Westinghouse	0.4	5.8
TRW Systems		1.3
Arthur D. Little (Business as usual)	5.5[b]	
(Accelerated	14.9[b]	

a) Units of 10^{14} BTU/year

b) From 1974 Project Independence report

c) See the "Proceedings of the workshop on solar heating and cooling of buildings, 1974, NSF-RA-N-74-126.

SOLAR ENERGY SYSTEMS

We will not discuss solar cooling schemes in this report. This subject is presently in its infancy and will undoubtedly see large advances in the future. It is probably safe to say that solar cooling is presently less economic than is solar heating. Let us just mention some of the possibilities which have been and are now being studied. These include lithium-bromide and ammonia-water heat activated refrigeration cycles, dehumidification possibilities, low temperature generation of electricity to run a conventional air conditioner and the use of night radiation to cool off hot water from daytime cooling. In the Pacific Northwest, sufficient cooling may result from the reduced heat load upon the roof due to the solar collectors located there.

Solar heating can be roughly divided into two areas, active and passive. Active schemes involve the use of solar collectors, heat-exchange fluids, etc., while passive systems involve good architectural design to capture solar radiation through the properly oriented windows. A brief review of passive house design problems is contained on the next two transparencies. The basic problems are:

1. Large, south facing windows have a high heat loss in winter.

2. On sunny days in October, November and March too much radiation enters. The rooms get too hot and doors must be opened.

3. Insufficient storage capacity for the solar radiation captured.

4. On sunny days in September and March too much light enters. The occupants are oppressed by the glare, rugs fade, etc.

5. The eaves come into play too early in the year.

All of these difficulties can be overcome (at least partially) with improved designs, such as that of Shurcliff shown on the second transparency on passive systems.

Before going on to flat-plate collectors and active solar systems, we should comment on a couple of the important aspects of the solar radiation itself. First, 86% of the incident solar radiation will pass through a plate of glass, as shown on the transparency of the solar spectrum. More importantly, the incident solar radiation can be divided into direct and scattered components. The latter component is obviously a function of the amount of clouds present. Because of the importance of the direct beam, a flat-place solar collector should be tilted up to be perpendicular to the sun's rays. This direct component is very important, even in cloudy climates like ours, as is shown by the transparency showing the direct and scattered radiation for Corvallis.

In Fig. 1 we see a picture of a typical flat-plate collector. The incident solar radiation passes through the glass cover plates and is absorbed by the black metal plate (about 94% efficient). This plate heats up and its energy is transferred to water (or air) flowing by in contact with the plate. The cover plates reduce radiative and convective losses to the outside atmosphere.

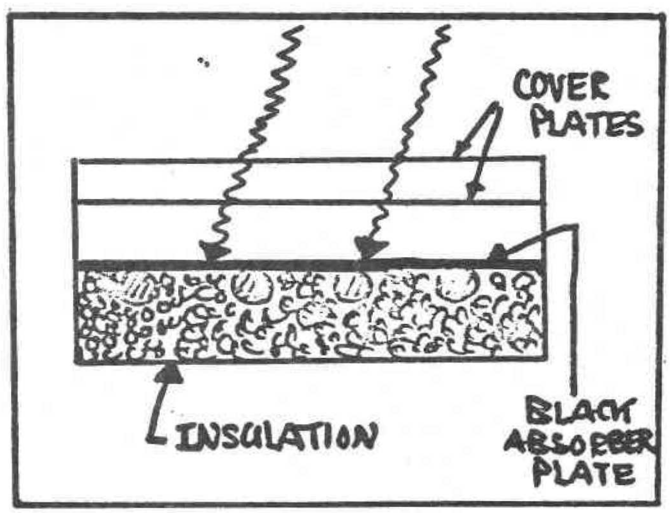

Fig. 1. Illustration of a typical flat plate collector with two glass cover plates.

A typical solar heating system consists of the following components:

1. A flat-plate collector.
2. A heat exchange fluid to collect useful energy.
3. A system of heat storage.
4. A distribution system to transfer useful energy from the storage system to the residence.
5. Controls, such as thermostats.

6. A backup heating system to cover extended cloudy periods. As an example, I show on the next transparency the solar system utilized by Henry Mathew of Coos Bay.

SOLAR ENERGY COLLECTION IN CLOUDY CLIMATES

Little effort has so far gone into carefully formulating and solving the quite common problem of solar energy collection under the partially cloudy conditions which prevail in all of the population centers of the Pacific Northwest (PNW). The collection of useful solar energy under these conditions requires special care not needed in sunnier climates.

The performance of this house has been carefully monitored by architects from the University of Oregon Solar Center and their analysis shows that the reflector has improved the overall energy collected by the regular collector by 50%. We have made a careful mathematical analysis of the use of reflectors in combination with flat-plate collectors.[2] These calculations show that both the thermal efficiency and the net energy collected by a solar thermal collector in northern latitudes can be dramatically enhanced. This paper will summarize the climatic situation prevailing in the Pacific Northwest and quantitatively discuss the optimum configuration for winter collection of solar energy using reflector-collector systems.

Because of the cool, overcast climate of the PNW, the space application of solar energy is the dominant residential use of energy for about nine months of the year. Optimization of a solar heating system should then be done for the six-month, October-through-March insolation pattern. In order to assess the solar energy potential of this region, the solar radiation data for Corvallis, Oregon, a representative Northwest location is compared in Fig. 2 with the equivalent data for Albuquerque, New Mexico and Miami, Florida. The top half of the figure shows the amount of solar radiation incident upon a horizontal surface, while the bottom half shows the insolation incident upon a flat surface oriented to the customary tilted angle equal to the latitude plus 15 degrees.

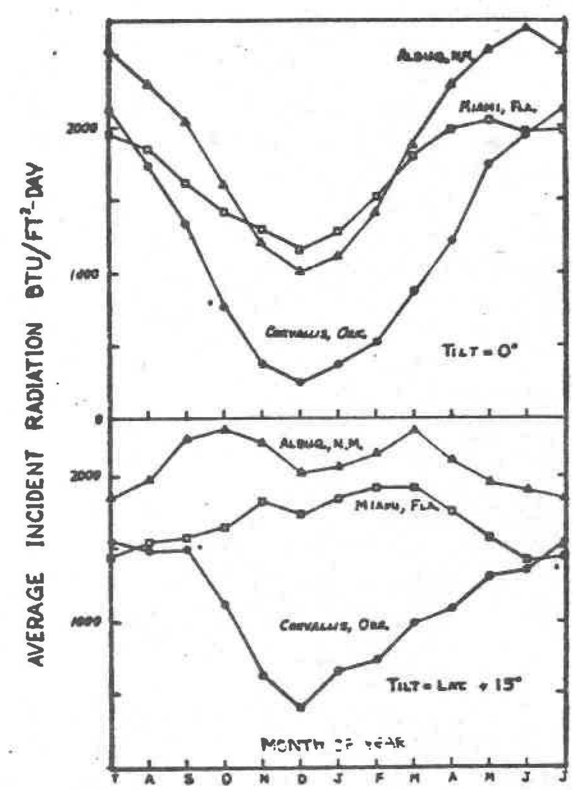

Fig. 2. Comparison of the annual insolation for Albuquerque, New Mexico, Miami, Florida, and Corvallis, Oregon. Top half of the Figure shows data on a horizontal surface, while the bottom half shows the monthly solar radiation incident on a tilted surface.

The insolation upon the tilted surface was obtained from that on the horizontal plane following the procedure of Liu and Jordan.[3] Clearly the PNW is not too bad off compared with Miami for the annual average. Corvallis receives almost 1100 BTU/FT^2-DAY which is about 65-70% that received by Miami, Florida. Unfortunately, the solar radiation received during the crucial six-month winter heating period averages only 770 BTU/FT^2-DAY which is to be compared with 1815 BTU/FT^2-DAY for Miami, i.e., about 42%. Clearly great care must be taken in order to collect useful solar energy in the winter in the PNW.

Before going on to discuss the practical collection of solar radiation, it is worthwhile to look further at the worst case winter data. The data for Corvallis is summarized in more detail in Table 2 for December and January. The horizontal data was obtained as an 8-year average. The direct and diffuse components were obtained following the procedures outlined by Liu and Jordan.[3] It is seen that the total solar radiation incident on the 60° surface is a factor of 1.6-1.8 greater than that incident upon a flat horizontal surface. More importantly, the direct component is much larger upon a tilted surface which has strong implications for the utility of reflector-collector combinations to be described below.

Table 2. Solar Radiation Data for Corvallis, Oregon in BTU/FT^2-DAY

DEC \ TILT	Horizontal	60°
Direct	85	284
Diffuse	169	127
Reflected	0	13
Total	254	424
JAN \ TILT	**Horizontal**	**60°**
Direct	174	521
Diffuse	198	148
Reflected	0	19
Total	372	688

How should one approach the problem of useful solar collection in cloudy climates with flat-plate collectors? Obviously, great care should be taken to utilize well-designed collectors with minimum losses. The use of selective surfaces may be imperative in this regard. A great deal of the time the solar collector may deliver water to the storage tank (if water is utilized as the heat exchange and storage medium) which is not too much warmer than the ambient water temperature. Our own approach has been to study the enhancement of light incident upon the collector which is possible using reflectors. This has led us to find the optimum arrangement for such a system.

A basic understanding of the optimum arrangement for a reflector-collector combination can be obtained qualitatively with aid of Fig. 3. The top diagram shows that the optimum arrangement for a simple collector has the incident beam radiation striking the collector normally when the tilt angle θ_T equals the angle of incidence θ_i. A good winter average for θ_i is to use the latitude plus 10°.

The second diagram shows the obvious fact that the tilt angle must be greater than θ_i (for a horizontal reflector) in order that the reflected beam will strike the collector. Furthermore, the third diagram in Fig. 3 shows that only a finite reflector length is needed. The actual needed reflector length is a function of the day of the year and the time of day.

The bottom drawing shows that the collector orientation for optimum gathering of the reflected intensity occurs when $\theta_T = \pi - \theta_i$. Clearly, if the reflected intensity and that directly incident upon the collector are roughly equal, then the best collector orientation is the average of the optimum angles for the two individual contributions, i.e., the collector should be oriented vertically. This was the conclusion reached by Henry Mathew from his crude experimental measurements made before final construction of his solar home in Coos Bay, Oregon. In order to verify this conclusion and put the whole procedure on a firm conceptual basis, it is necessary to do the requisite geometrical analysis in a quantitative manner.

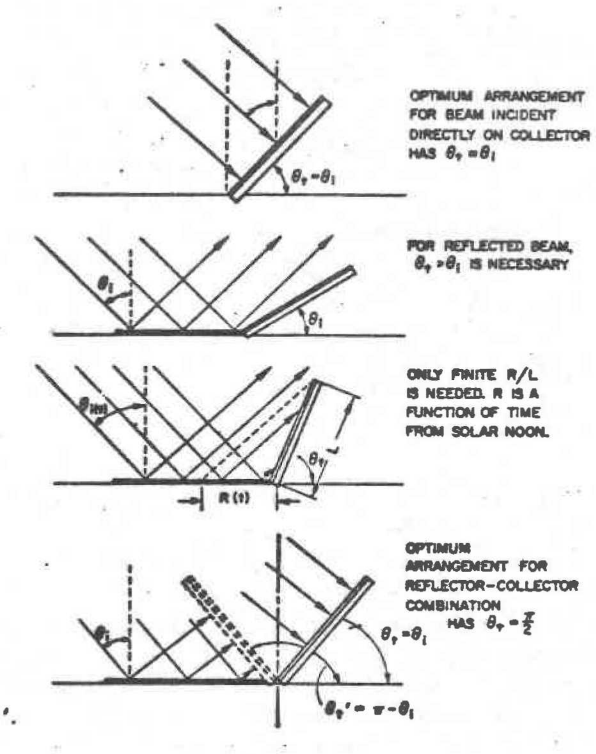

Fig. 3. Qualitative explanation of the reflector-collector system.

The initial step in this program is contained in the analysis of the reflector-collector geometry contained in ref. 2. The total solar flux incident upon the solar thermal collector absorber plate is the sum of the directly collected intensity and that from the reflector,

$$\phi = RW(\underset{\sim}{I}_0 . \hat{n})\bar{\rho}T(\theta_b) + LW(\underset{\sim}{I}_0 . \hat{n})T(\beta) \quad (1)$$

The notation is exactly as in ref. 2. It is important to summarize the key factors included in this calculation: (1) A parallel incident beam of light is assumed, (2) the transmission factors $T(\theta_b)$ and $T(\beta)$ for the reflected and direct intensities respectively passing through the cover plates of the collector are calculated exactly[4] assuming equal fractions of the two different polarizations, (3) the reflectivity of $\bar{\rho}$ of the reflector is taken into account, and (4) finite size effects are included. In the evaluation of the utility of the reflector, the important quantity is the enhancement in light gathering power of the reflector-collector system over that of a standard fixed collector. This is obtained by dividing the flux calculated in eqn. 1 by that for a simple flat-plate collector oriented at the customary tilt angle.

The initial calculations[2] were done over a wide range of the important factors. The two key conclusions were that the optimum angle between the reflector and the collector for winter operation is about 90-100^o, verifying our qualitative answer from Fig. 2, and that the optimum reflector angle is near the horizontal plane for 45^o North latitude winter operation. Unfortunately, the best reflector angle varied rather strongly with time away from solar noon, going from 5^o upwards at noon to 8^o downwards at 4 p.m (or 8 a.m.).

This variation of the optimum reflector angle with time of day has led us to re-do the calculations in a time-integrated manner so that the performance of the reflector-collector system can be evaluated over an entire day.

In addition to studying the optimum reflector orientation, the effects of finite reflector length and width were critically evaluated in order to establish the minimum reflector dimensions consistent with maximum performance over an entire solar collecting day. The details and complete results for this work will be published elsehwere[5], but some of the key results are summarized here. Fig 4. shows again that the angle between the collector and reflector for maximum performance should be about 100° for winter operation and 45° North Latitude.

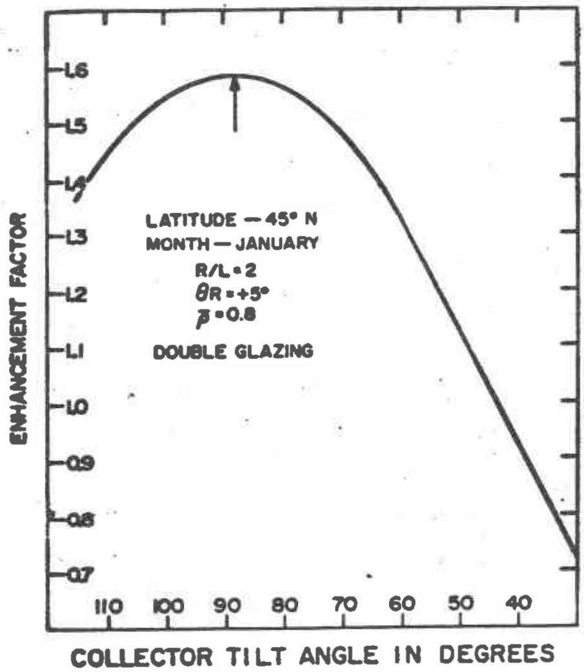

Fig. 4 **The enhancement in the amount of light gathered by the reflector-collector system is plotted as a function of the collector tilt angle. The maximum occurs when the reflector and collector are 98° apart.**

The performance of a typical reflector-collector system as the reflector angle is varied is illustrated in Fig. 5 for November-February operation. A clear favoring of 5° downwards for the reflector orientation angle is indicated, with practically no variation for the November-January period. To determine the effect of finite reflector length upon performance, the enhancement versus reflector length is plotted in Fig. 6. From a practical point of view, not much is gained if the reflector is longer than 1.5-2.0 times the collector height.

We conclude this discussion with a few preliminary comments about the utility of curving the reflector. This is illustrated by the drawings in Fig. 7. In the top diagram, we see that for a straight reflector sloping slightly downwards, the reflector length is severely limited (usually to about 1.5-2.0 L). Light striking the reflector at distances greater than R(t) will bounce over the collector. Curving the reflector would not increase the amount of light striking the collector.

In order to increase the reflector length, it is necessary to slope the reflector upwards as shown in the middle diagram of Fig. 7. In this case, however, the angle of incidence of the light upon the reflector increases, so that only a small increase in the enhancement (less than 10%) is obtained when one goes from $R/_L = 2$ to $R/_L = 6$. However, the use of a curved reflector in the downwards sloping configuration allows a large gain in enhancement to be made, as illustrated in the bottom portion of Fig. 7. By curving the reflector, a much longer length can be utilized, thereby allowing quite large enhancements to be realized. Some crude preliminary measurements indicate that enhancements as high as 2.5-3.0 for $R/_L = 6$ can be obtained over the middle portion of the day. Clearly, the curved reflector can be effectively approximated by a few straight line segments,thus simplifying the practical design. More analytical and experimental work will be done on this subject in the near future.

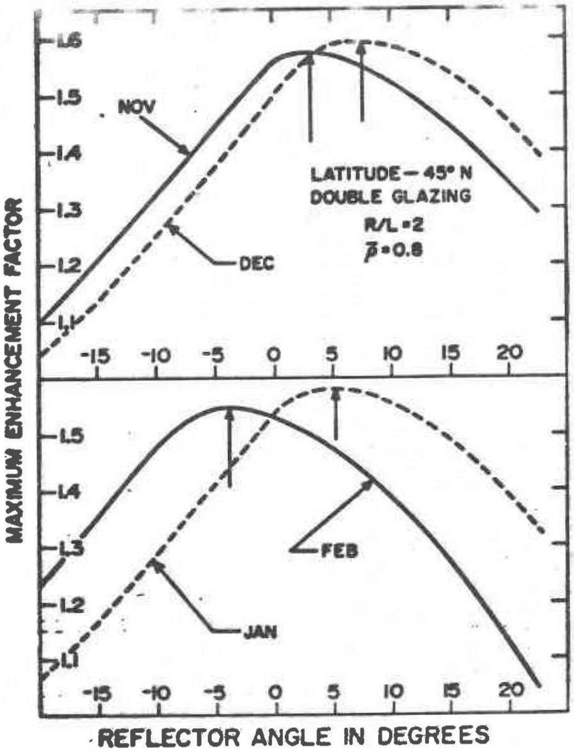

Fig. 5 Determination of the optimum reflector orientation for the winter months at 45° North latitude. Positive reflector angles are for a downwards sloping reflector.

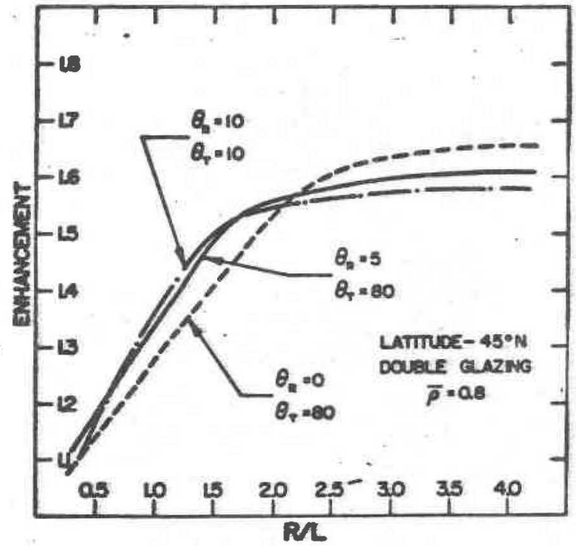

Fig. 6 From a practical architectural standpoint the reflector length should often be minimized. This figure shows that $R/_L$ = 1.5 will suffice to give almost the maximum possible enhancement for winter operation using a straight reflector.

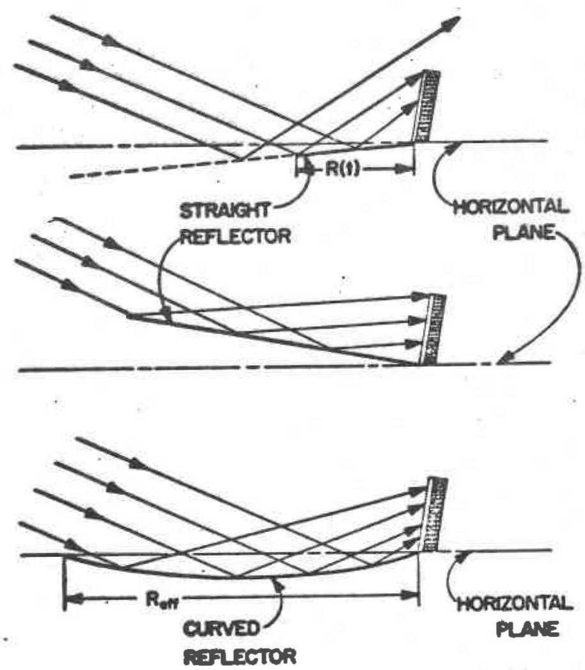

Fig. 7. Qualitative discussion of the advantage of a curved reflector. As described in the text, the point of using a curved reflector is to permit a much longer "effective" reflector length to be utilized.

The author would like to acknowledge the great assistance of Mr. Steve Baker with the numerical calculations and for many useful discussions. Professors D. H. Lowndes and J. Reynolds and Dr. Dan Kaehn of the University of Oregon helped with many of the items discussed in this paper.

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Presented November 4, 1976 by ORVAL W. BRUTON, North Pacific Division, Corps of Engineers, Portland, Oregon.

Hydro-Power and Pumped Storage in the Northwest

The Pacific Northwest is unique, because until recently virtually all of the region's electric power needs have been served by hydropower. The picture is changing, however, as new base-load thermal plants begin to come into service. And as this development takes place, a new source of generation will soon come into the region -- pumped-storage.

THE PACIFIC NORTHWEST POWER SYSTEM

The Pacific Northwest region is defined generally as the area of Washington, Oregon, Idaho, and Western Montana. Nearly all electrical energy, up until 1972, was provided by hydropower generation. In 1972, the Centralia coal-fired generating plant located in Washington, generated its first power. This marked the beginning of the hydro-thermal era in the Pacific Northwest.

The Jim Bridger coal-fired plant, located in Wyoming, and an important resource to the Pacific Northwest, came on the line in 1974. The Trojan nuclear plant, located in Oregon, came into the system the end of 1975. More thermal power plants are planned, and are in various stages of construction. However, hydropower still supplies about 80 percent of our regional power needs, and while the ratio will decrease, it will still be a major source of power in the future. In fact, the existence of this large block of hydropower gives us a unique power system -- unique to any part of the world.

HYDROELECTRIC RESOURCES

The hydro-resources in the coordinated system of the region currently produce about 12,000 megawatts of firm or dependable power. This firm power is equivalent to the generation of about 14 Trojan nuclear plants. It should be recognized that the region could not have attained the present level of development without this valuable hydro-resource.

There are over 100 hydroelectric plants located in the Pacific Northwest, but the bulk of the energy, about 70 percent of it in fact, is generated at eleven plants on the Columbia River itself (see Figure 1). The first four plants on the Lower Columbia River were built by the Corps of Engineers. Bonneville,the first large federal hydro project in the Pacific Northwest, generated its first power in 1937. A second powerhouse is being constructed at Bonneville which will double its peak output. Moving upstream, the next project is The Dalles. Then, John Day is the next project, which was the largest hydro plant in the United States until 1975. The fourth project is McNary. The next five plants are owned by public utility districts (PUD's). The first two of this series are Priest Rapids and Wanapum projects, owned by Grant County PUD. Next is the oldest plant on the Columbia River, Rock Island, owned by Chelan County PUD, which generated its first power in 1933. Rocky Reach and Wells projects follow, which are owned by Douglas County PUD. To complete the eleven project list, the Corps of Engineers' Chief Joseph project is next; and finally the Bureau of Reclamation's Grand Coulee project is the largest plant in the U. S. at over 4,100 megawatts, and the last project on the Columbia before the Canadian border. A third powerplant is being constructed at Grand Coulee where three 600 megawatt units recently came on the line.

With the exception of Grand Coulee, the 11 projects previously described are classified as run-of-river plants. They do not have the capability of storing water from one season to another, and they depend on upstream storage projects to provide seasonal regulation of flow. The remaining hydro plants in the region can be classified into three general categories. There are large headwater storage projects, such as Libby on the Kootenay River in Montana and Dworshak on the Clearwater River in Idaho (Grand Coulee Project also is in this category). There are a great number of run-of-river projects on large and small streams throughout the region, mostly constructed by various utilities. Finally, there are federal multi-purpose storage projects where power is an added function. Examples are Detroit and Green Peter projects in Oregon built by the Corps of Engineers primarily for control and conservation of streamflow. Other types of examples are where the Bureau of Reclamation has installed power plants in several irrigation reservoirs, such as the Palisades and Anderson Ranch projects in Idaho.

COLUMBIA BASIN STORAGE

Most of the larger power projects on the Columbia River, and in the Northwest in general, are located east of the Cascade Mountain range. The streams experience a wide variation in streamflow over the year -- that is an abundance of water in the late spring and early summer, when the Rocky Mountain snowpack is melting -- but low flows the remainder of the year. Unfortunately, this is just the opposite of the seasonal demand for power. In order to use the resource effectively, headwater storage projects have been constructed so that some of the heavy runoff can be stored for release at the times of the year that it will most benefit the system.

Nine major headwater storage projects, plus a few smaller ones, provide 42.5 million acre-feet of usable seasonal storage. This storage enables the hydro system to triple the firm or dependable energy supply on the Columbia River over that which could be attained without storage.

Figure 1. Major Hydroelectric Projects in the Pacific Northwest.

Upstream storage projects greatly benefit the downstream run-of-river projects. An example is the Bureau of Reclamation's Hungry Horse Reservoir, located on the south fork of the Flathead River in Montana. The project stores 3.2 million acre feet of storage and increases power production at nineteen downstream projects. The gain in energy downstream far exceeds the energy produced at the project itself. (See Figure 2).

SYSTEM COORDINATION

As the system developed, it became apparent that a coordinated operation of the seasonal storage would be highly beneficial. During World War II, a voluntary seasonal coordination was first initiated. Then in 1961, the Columbia River Treaty with Canada was signed and coordinated operation became mandatory, and in 1964, following several years of trial operation, the Pacific Northwest Coordination Agreement was signed by the many agencies and utilities involved. As a result, some 119 hydroelectric projects, which are owned by 20 different utilities and agencies, are operated on a seasonal basis as if they were under a single ownership. This operation requires a large effort of coordination and cooperation among these utilities.

FIRM AND SECONDARY ENERGY

The measure of hydro generation is usually based on the output during a dry period of streamflow. The capability is called dependable power or firm power, because it is the most power that can be generated under low stream flow conditions. In a typical year the system produces considerably more power; on the average the regional hydro system produces about 20 percent more energy out of the system than this firm power.

This 20 percent difference is called secondary or interruptible power. Secondary power is not dependable, so it is not counted as a firm resource, but when it is available, it is usually available in large amounts to make it a very important energy resource. Secondary energy is sold at a lower rate to supplement various power needs, or to replace some of the more expensive generation sources, such as high cost thermal generation. Some of the secondary energy is sent to California over the interties, when it is surplus to the needs of the Pacific Northwest.

ENERGY, CAPACITY, AND PLANT EXPANSION

Two basic terms are used in defining power; base load and peaking. Because the daily demand for power varies over the course of the day, reflecting populations' life styles, it is commonly divided into "base load" which is the constant 24-hour-a-day part of the load and "peak load" which is the variable part of the load that is greatest during that part of the day when people are most active (see Figure 3).

Up until a few years ago, hydro served the entire regional power load. Now, large thermal plants are beginning to assume a greater portion of the base load, and the most economical way to operate these thermal plants is to run them at full capacity as much as possible. Hydro-power then moves into

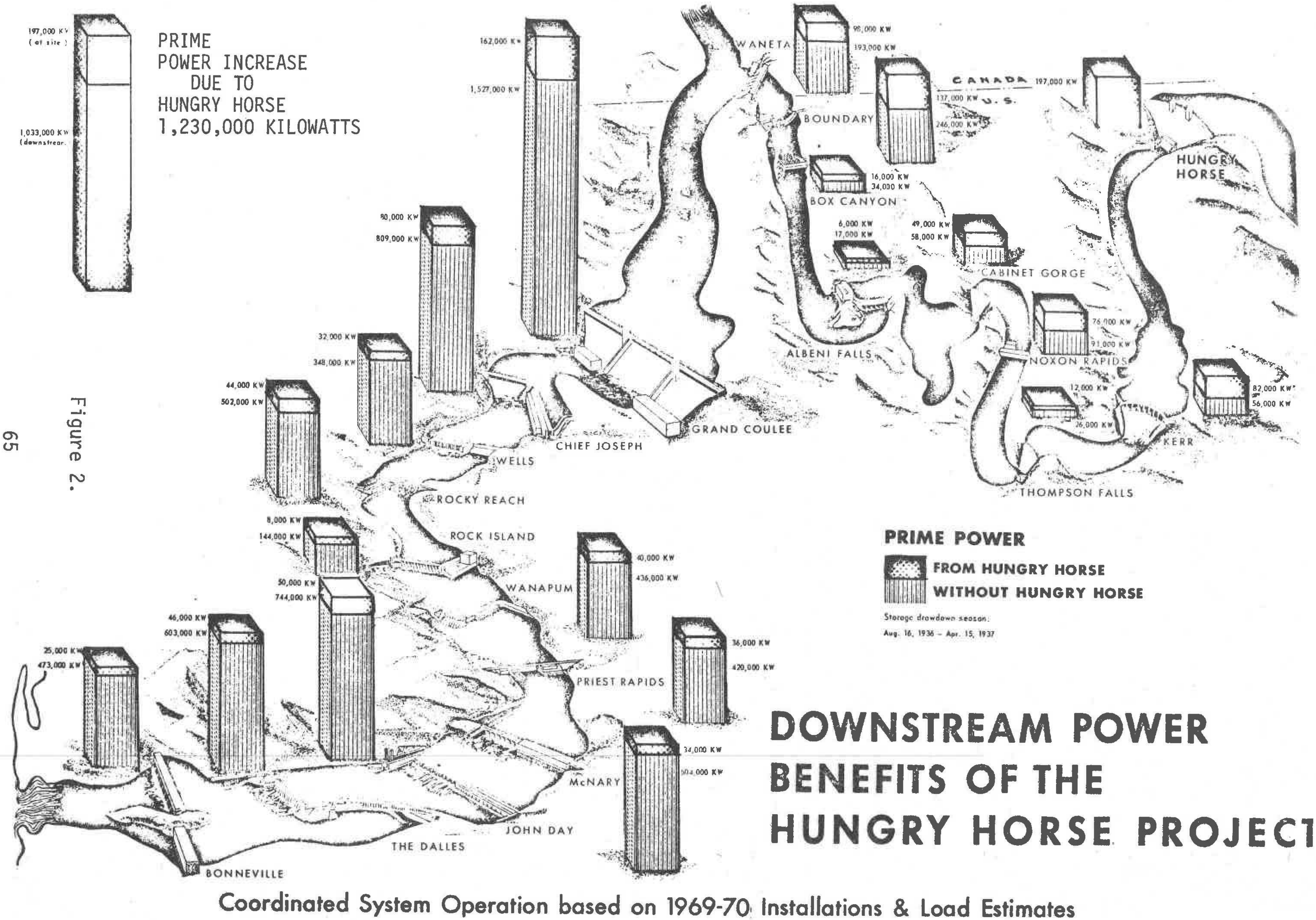
197,000 KW (at site)
1,033,000 KW (downstream)
PRIME
POWER INCREASE
DUE TO
HUNGRY HORSE
1,230,000 KILOWATTS
162,000 KW
1,527,000 KW
80,000 KW
809,000 KW
32,000 KW
348,000 KW
44,000 KW
502,000 KW
8,000 KW
144,000 KW
50,000 KW
744,000 KW
46,000 KW
603,000 KW
25,000 KW
473,000 KW
WANETA
98,000 KW
193,000 KW
CANADA
U.S.
197,000 KW
137,000 KW
246,000 KW
BOUNDARY
16,000 KW
34,000 KW
BOX CANYON
6,000 KW
17,000 KW
49,000 KW
58,000 KW
CABINET GORGE
HUNGRY HORSE
ALBENI FALLS
76,000 KW
91,000 KW
NOXON RAPIDS
12,000 KW
26,000 KW
82,000 KW
56,000 KW
KERR
THOMPSON FALLS
GRAND COULEE
CHIEF JOSEPH
WELLS
ROCKY REACH
ROCK ISLAND
WANAPUM
40,000 KW
436,000 KW
36,000 KW
420,000 KW
PRIEST RAPIDS
34,000 KW
McNARY
JOHN DAY
THE DALLES
BONNEVILLE
PRIME POWER
FROM HUNGRY HORSE
WITHOUT HUNGRY HORSE
Storage drawdown season:
Aug. 16, 1936 – Apr. 15, 1937
DOWNSTREAM POWER
BENEFITS OF THE
HUNGRY HORSE PROJECT
Coordinated System Operation based on 1969-70 Installations & Load Estimates

Figure 2.

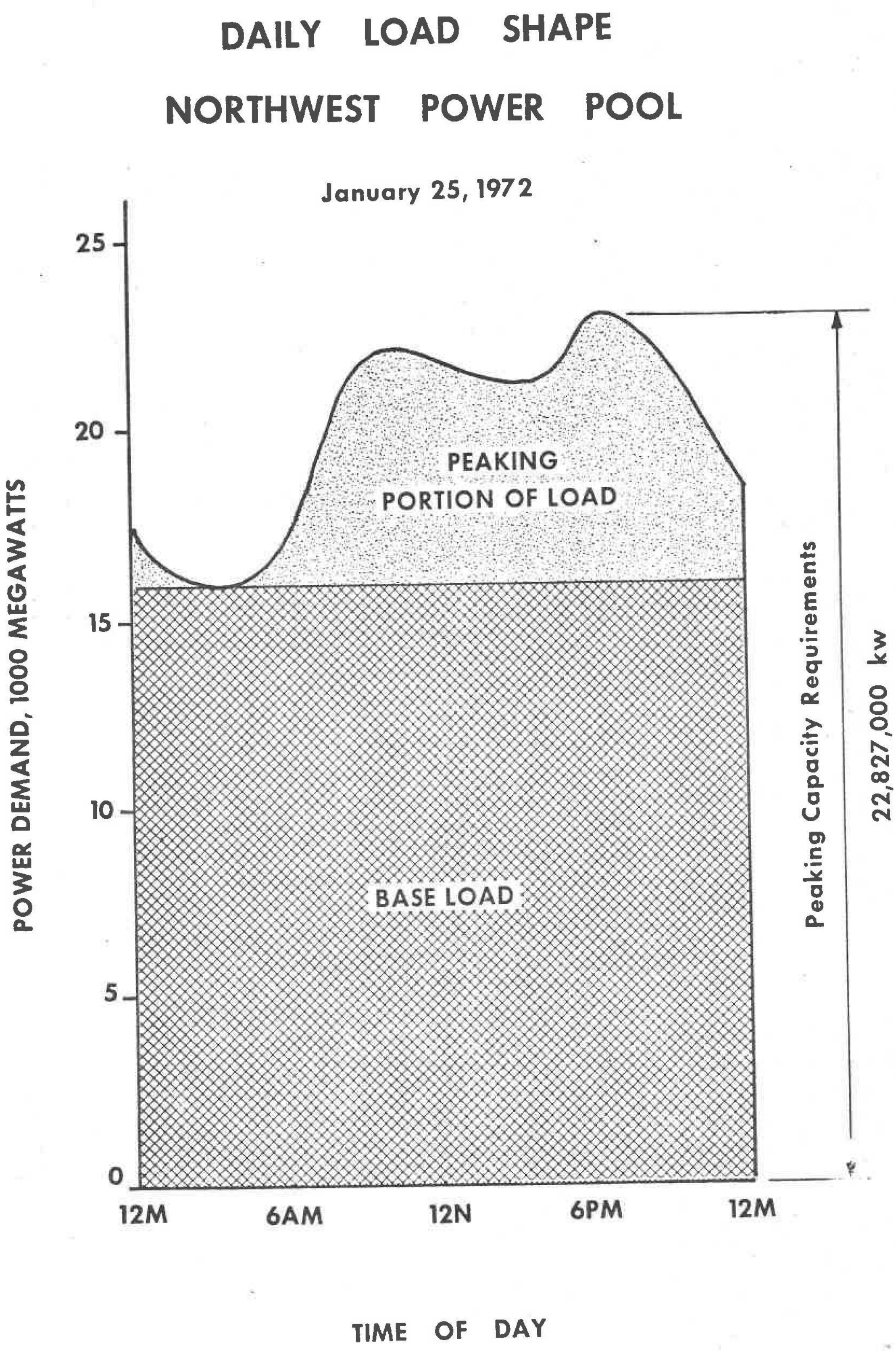

Figure 3. Daily Power Load Shape - Energy and Capacity.

a peaking role. A regional program is now underway of adding more generating units at our existing hydroplants. In many cases, provisions were included for expanding existing power plants when they were first built -- examples of these are the Lower Snake River projects (Ice Harbor, Lower Monumental, etc.)

It should be noted that expanding existing hydro plants adds very little energy (Kw hrs) to the system. The added generating units permit "reshaping" of that energy -- that is the ability to carry a larger load during the peak hours, which in turn results in a lower output during off-peak hours. This is a very important role, however, and if the peaking is not done with hydro it will have to be done with combustion turbine plants or some other expensive thermal source. Again, it should be emphasized that expanding hydro plants will not eliminate the need for nuclear and coal-fired base load plants, peaking and base load plants complement each other.

There is a limit to how much expansion hydro plants can accommodate. There is also a practical limit as to the system operation. It is estimated that increased peaking needs may be met by expanding existing plants to about 1990. Nevertheless, a follow-on-source of peaking generation must be planned, and at this time pumped-storage appears to be the best alternative.

PUMPED-STORAGE

Pumped-storage is perhaps the most promising future source of hydropower. Basically, it involves storing energy by pumping water into a storage reservoir when surplus power is available at night, weekends, during high-flow periods, etc., and releasing it when the power is needed. A pumped-storage operation is merely a refinement of conventional hydro-generation. The cycle starts when water is dropped through a distance and the energy is removed by a turbine, then to complete the cycle the water is pumped back up for reuse again. (see Figure 4) The object is to convert surplus off-peak energy to highly valuable peaking energy by pumping water up and storing it in a higher level reservoir.

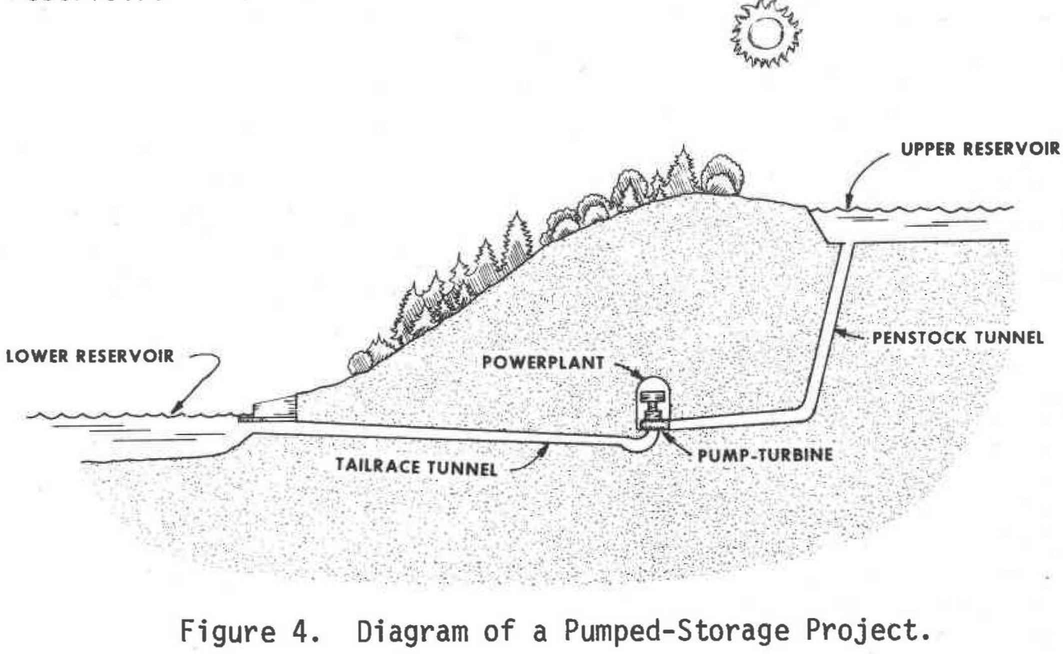

Figure 4. Diagram of a Pumped-Storage Project.

Pumped-storage operation is not without cost. It takes about 1-½ kilowatt-hours of pumping energy for every kilowatt-hour of energy delivered. This is because of losses and system inefficiencies; however, the complete operation is worthwhile because on-peak energy has a much higher value than off-peak energy -- as high as five times as much.

Off-peak pumping energy will most likely come from base load thermal plants, such as the Trojan nuclear plant. These thermal plants are most efficient and economical when they are operated continuously at near-full output; however, the demand for power drops off at night and weekends and these plants would normally reduce their power output. Consequently, an unused source of energy can be made available for pumping, for just the cost of the fuel. In other words, low-cost surplus energy from base load plants is used during off-peak hours to provide more valuable capacity and energy during peak-load hours.

Pumped-storage hydro has been used very effectively in other parts of the country. It has been available about ten years in the eastern United States and even longer in Europe. However, here in the Northwest, development has lagged -- first because an ample supply of conventional hydro for peaking has been available, and second, because there has not been any surplus thermal energy available for pumping. At this time power planners estimate that it will be about 1990 before enough surplus off-peak thermal will be available in the system to provide pumping energy.

SYSTEM FLEXIBILITY

Pumped-storage does do more than provide a source of peaking power. It is an excellent source of emergency reserve generation, which can be brought on very quickly in the event a large generating plant or transmission line in the system should break down. By providing additional system flexibility in many cases the conventional hydro resources can be used more efficiently. It also improves the economics of large base-load thermal plants by keeping them fully loaded during the off-peak hours. Finally, pumped-storage directly saves oil or petroleum products because the power produced would otherwise have to be generated by oil-fired peaking plants.

INVENTORY OF PUMPED-STORAGE SITES

Much of the region is well suited for pumped-storage development. The steep slopes and generally rugged topography provide numerous potential sites. Many of these sites have generating heads in excess of 1,000 feet, and some have heads exceeding 3,000 feet. (Generating head is the difference in elevation between the upper and lower reservoirs and is a key factor in power generation.)

The Corps of Engineers, North Pacific Division office, began developing procedures for inventorying and evaluating pumped-storage sites in 1967. A final report dated 1976 was recently published. The inventory concentrated on pumped-storage sites capable of operating on a weekly cycle basis. That is, water between the reservoirs would be completely cycled by the end of a week. It was assumed that the power plants would be built underground and would, in most cases employ reversible pump-generating units. It was also assumed that relatively

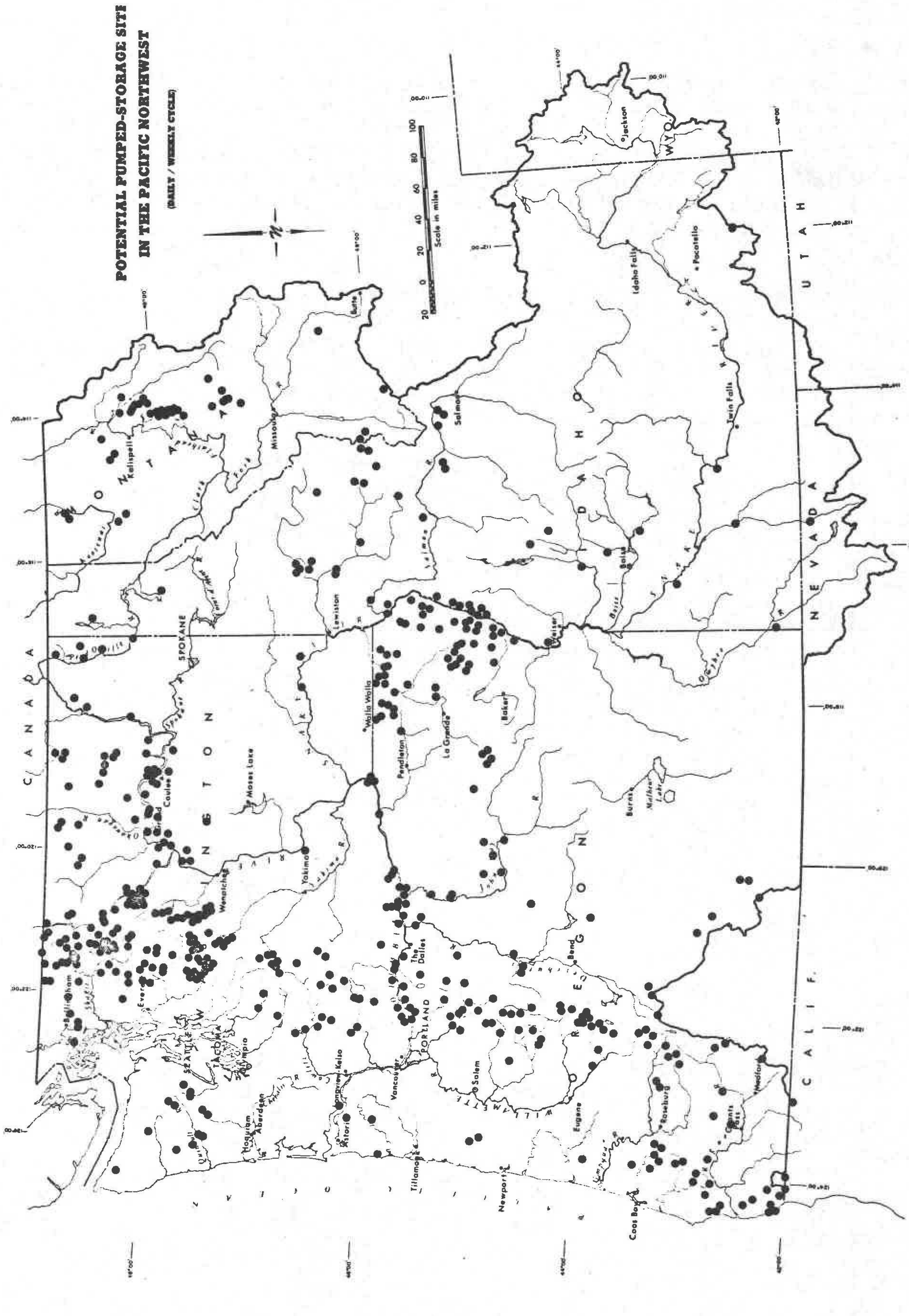

Figure 5. Regional Map of Inventoried Pumped-Storage Sites - Weekly Cycle.

small earthfill dams or dikes would be used to form the reservoirs: and concrete-lined tunnels would be used to connect these reservoirs.

The inventory study was based primarily on a map reconnaissance of the region. The immediate goals were to (1) locate all potential sites, (2) assess the site capabilities, and (3) provide cost estimates for evaluating and comparing different sites.

RESULTS OF THE INVENTORY

The report lists 540 sites in the Pacific Northwest, each capable of generating at least 1,000 megawatts. (See Figure 5) Data to compare each site are included, such as: plant size, generating head, reservoir sizes, drawdown limits, penstock size, and unit costs.

To summarize the inventory, an immense potential pumped-storage capacity exists in the region. While many of these sites will no doubt be eliminated for various reasons, such as environmental considerations and local reaction, it is safe to conclude that a tremendous potential still exists for future pumped-storage development.

CONCLUSION

The pumped-storage potential of the Pacific Northwest is undergoing a careful examination and evaluation, excellent sites are available for possible development. There is no question that the resource is there and the need will soon be here.

The Corps of Engineers is currently addressing some major operational questions like: (1) when is the optimum time to add pumped-storage to the system? (2) how could it best be used once it is in the system? (3) how much reservoir storage will be needed? (4) where will the pumping energy come from?

SUMMARY

The Pacific Northwest has a unique electric power system. Over a period of some 45 years, a vast hydroelectric system has developed along the Columbia River and its major tributaries. The region has recently entered into a hydro-thermal era, where large thermal power plants (nuclear and coal-fired) are beginning to provide energy to the system. As new generating resources are added to the system a new generating concept, pumped storage, will soon supplement the peaking needs of the region.

Presented November 18, 1976, by PETER C. KLINGEMAN, Director, Water Resources Research Institute, Oregon State University.

Energy and Water Diversion

Today, we shall turn to a different facet of water and energy; that of the movement of water and energy from one place to another and some of the trade-offs and consequences involved in such movement. Specifically, I wish to address the topics of energy and water diversion from the Pacific Northwest to other regions in the Western United States.

During the available time, I will first discuss the meaning and some implications of the term "diversion". Secondly, I will briefly review the significance of our region's water and energy resources. In the third portion of my presentation, I will illustrate some features of water and energy diversion. Finally, I hope to identify the major issues which the Pacific Northwest must consider in rationally facing the problems of having sufficient water for people, water for food, and water for energy.

WHAT IS DIVERSION?

Diversion and inter-basin transfer are related terms, although diversion may occur without inter-basin transfer. Water diversion is simply the diverting of water from its natural flow path into some other flow path. Such diversion has been practiced from the beginning of agricultural history, when riverbank pumping systems and irrigation ditches were first used. It is practiced in Corvallis, where water is withdrawn and diverted from the Willamette River and from Rock Creek on Mary's Peak, for city uses.

When diverted water is transported across the natural drainage divide from one river to another, then the diversion may be termed inter-basin transfer or inter-basin diversion. For example, the City of McMinnville, Oregon, on the east side of the Coastal Range, diverts its water supply from the headwaters of the Nestucca River on the west side of the coastal range. However, no major inter-basin water transfers have been yet undertaken in this country that deliver water from one state to another (11).

Two important features of water diversion which bear on the overall water availability in a river basin are the consumptive uses (losses) of diverted water and the return flows to the source river or its tributaries. Consumptive uses are primarily evaporation and transpiration, processes that return the water directly to the atmosphere for further use in the hydrologic cycle. In Corvallis, summertime consumptive use reaches approximately 50% of the diverted water and is primarily associated with yard watering. Return flows are the diverted flows coming back to the river from such places as municipal and industrial effluents (treated or not), agricultural drainage ditches, and groundwater flow from irrigated lands or septic tank drainfields. Return flows play a significant role in maintaining the discharge of a stream, as Hans Brumbaugh repeatedly pointed out for the South Platte River in Michener's bestseller, "Centennial".

Inter-basin water diversion takes with it the return flows. Diversion thus has a greater effect on the source basin's total water availability than does intra-basin diversion.

In contrast to water diversion, energy diversion does not necessarily transfer water out of a basin. Energy production does require water, whether the scheme is a hydroelectric plant at a river or a thermal plant fueled by coal, oil, gas, uranium, or subterranean steam. For each, water is diverted through the machinery to drive the turbines and (for steam systems) to cool some components of the plant. Such schemes leave a significant amount of the region's water supply intact.

The inter-basin transfer that occurs is one of energy rather than water. This has been commonplace on a sub-regional scale for several decades. Perhaps closest to home, energy from the Columbia River Basin has been transferred to the Willamette River Basin since the late 1930's. While this has had other effects upon the Columbia River, it has not diminished the Columbia's water supply. On an inter-basin scale, our most significant example is the Pacific Northwest-Southwest Intertie, the biggest single transmission program ever undertaken in the United States (4).

This connects the hydro-based energy grid of the Columbia Basin to the thermal-based grid of the Pacific Southwest and, since 1965, has allowed an exchange of energy to compensate for out-of-phase energy demands and energy supply capabilities within each region and between regions. Again, there are in-stream effects, but no water is transferred out of the Columbia Basin in this exchange.

In recent years, schemes have been proposed that would couple water diversion with energy production. These will be discussed shortly. But first, it is important to briefly review the reasons why other regions look to the Pacific Northwest for water and energy.

SIGNIFICANCE OF THE PACIFIC NORTHWEST

Previous seminar speakers have pointed out that the Columbia Basin possesses a far greater amount of stream flow than other western regions of the country. The natural annual flow of the Colorado River at the Mexican border averages approximately 13.5 million acre feet. This water is seasonally distributed and derives primarily from spring and summer snowmelt in the Rocky Mountains. In contrast, the annual flow of the Willamette River averages 17 million acre feet at Salem and 24 million acre feet at Portland, with a winter seasonality (12). The annual flow of the Columbia River at Bonneville Dam, upstream of its juncture with the Willamette, averages 128 million acre feet and has a large summer seasonality and somewhat smaller winter seasonality (2).

Supporters of inter-basin transfer immediately contrast the large flow out of the mouth of the Columbia River to the Pacific Ocean (about 200 million acre feet per year)--wasted flow in their eyes--with the trickle in the lower Colorado River reaching the Pacific Ocean (less than 1 million acre feet per year) (9). The recent U.S. Bureau of Reclamation study, Critical Water Problems Facing the Eleven Western States, illustrates this quite graphically with photographs of the broad Columbia River estuary and the Colorado River vanishing into its streambed in Mexico (7).

However, we must not jump to the conclusion that the Pacific Northwest is being wasteful in letting so much river runoff reach the sea. Instead, we must consider two key points. First, the total development of the Southwest involves more than the Colorado River Basin. The Sacramento and San Joaquin Rivers contribute an average annual flow of about 22 million acre feet to that region's water supply, part of which flows to the sea at San Francisco (9). Second, the economy of the Pacific Northwest places far greater dependence on in-stream flows in the Columbia, Snake and Willamette Rivers than does the Pacific Southwest, where diversion for out-of-stream uses is the key to the gigantic agricultural economy of that region. Our regional emphasis on the multi-purpose uses of water resources is far different from that for the Pacific Southwest.

The Pacific Northwest is significant to the nation because of its overall annual abundance of water. But our regional economy has been shaped and developed in accordance with this seeming abundance; it has not developed in some sub-area of the region because of the severe lack of adequate water. Seasonal limitations and variability of water supply have restricted the economic development of large areas east of the Cascade Mountains.

The region is also of great significance to the nation because of our energy resources. The Columbia River Basin has the most highly developed hydroelectric power resource in the world (5). This has been developed at approximately the same pace as the growth in its demand. Power planning has been effective to date in projecting future demands and initiating timely construction so that new generating facilities would be available as needed. If anything, this foresight and the abundance of good hydropower sites has led to relatively cheap energy and a self-fulfilling prophesy of demand.

However, the era of cheap and abundant electric energy in the Pacific Northwest is drawing to an end. In the last 10 years local public sentiment has largely opposed the construction of new dams for whatever purpose, unless the net effect is a betterment of the commercial and sport fishery (e.g., Lost Creek Dam on the Rogue River) without sacrifice of the "wild and scenic" qualities of the river.

Furthermore, our other natural fuels for power production are limited and the known sources are being exploited (e.g., at Centralia coal-fired power station). The region's populace is divided on the issue of nuclear power generation, with its associated problems. The issue of importing coal to generate electricity has corollary issues of whether extensive coal field exploitation in Montana, Wyoming and North Dakota should proceed and whether it would be better to generate energy at the coal field and transmit it to the region.

Thus, the basis for dealing with energy supply and abundance is changing in the Pacific Northwest. At our present level of water resource development "...the Pacific Northwest is not a region of excess usable water supply and must, in fact, face up to the need to establish water use priorities and allocations that will result in an acceptable distribution of available water among uses that are beneficial to the region over the long-term" (3).

NORTHWEST-SOUTHWEST WATER DIVERSION

Water diversion from the Pacific Northwest to the Pacific Southwest became a topic for heated debate by the early 1960's. The Southwest, for a hundred years accustomed to solving water problems by means of water diversions, was looking for a new source to tap. Inter-regional transfer appeared to many as a logical extension of irrigation activities that were initiated by the Homestead Act of 1862.

More than a dozen diversion schemes were advanced during the 1950's and 1960's to bring water to the thirsty Pacific Southwest (10). These included half a dozen diversion routes from the lower Columbia River and the Rogue River to the Upper Sacramento Valley in northern California or across Nevada to Lake Mead and to southern California. Other proposed routes would have led from the Snake River across southern Idaho and Nevada to Lake Mead and southern California. An undersea aqueduct was proposed along the Continental Shelf from southern Oregon to southern California. The most grandiose schemes of all encompassed continental diversion. One plan would have provided water to the Canadian Prairie Provinces and to the Plains States east of the Rocky Mountains. The scheme to end all schemes, NAWAPA (Northern American Water and Power Alliance) would have moved water from near the Arctic Circle across the entire continent to meet water needs in Canada, the United States, and northern Mexico.

These schemes were not detailed engineering plans. Instead, they were preliminary plans to show that technically feasible solutions might exist and could be further investigated. They were supported with varying amounts of economic analyses to give some idea of economic feasibility.

FEATURES OF WATER AND ENERGY DIVERSION

An important feature of all the long-distance diversion schemes proposed in the 1960's was the necessity to pump the diverted water rather than rely solely upon gravity flow. This is required to overcome frictional losses in the pipe or canal conveyance system and to lift the water over high terrain. Thus, water diversion would require the additional expenditure of energy to move the water. If the diverted water is pumped at a steady rate in order to keep the canal filled to capacity (i.e., to make the canal as small as possible for the required flow rate), then firm power rather than intermittent off-peak power would be required.

However, if it is desired to reduce the costs by only using off-peak power when Northwest regional power demands were low (at night or during the summer), then larger pumps and larger canals and pipelines would be required to deliver the same annual flow, unless additional afterbay storage were built into the diversion system to absorb larger pump flows and keep a minimum-size canal full at all times. Obviously, there are trade-offs to consider between costs to convey water and costs to provide pumping capability.

Another important feature of most long-distance diversion schemes proposed in the 1960's was the possibility of producing some power as the water dropped through pipelines from higher to lower terrain. If the conveyance system carries water at a steady flow rate, then continuous power could be produced in minimum-sized turbines. However, if the flow rate varies, then the turbines must be larger and would have a variable power output. Provision of storage just upstream of the power-generating facilities would allow the production of highly variable power outputs--at a greater cost but with the possibility of providing peaking power that has a larger market value. Again, trade-offs between costs of conveying water and power costs are involved.

To illustrate the combination of water conveyance, pumping and power generation, let us examine a hypothetical example involving rather approximate numbers having realistic magnitudes. Suppose that a scheme were proposed to annually divert 10 million acre feet of water from the Snake River near Brownlee Reservoir to the Colorado River at Lake Mead. Suppose further that the water at the Snake River was at an elevation of 2000 feet above sea level and would be at an elevation of 1000 feet when in Lake Mead after having been lifted 2600 feet by pumping, having lost energy equal to 500 feet of elevation due to friction losses, and having been dropped 3100 feet through turbines.

Also, suppose that the motor-pump and the turbine-generator installations were about 85% efficient. With these suppositions, the annual diversion of 10 million acre feet of water at a steady flow rate would require pumping power of 3.6 Gigawatts (more than three Trojan nuclear power plants or six Bonneville Dam hydropower stations) and would generate power at the turbines amounting to 3.1 Gigawatts. Thus, the net power consumption of the diversion scheme would be 0.5 Gigawatts, equivalent to the present total power output at Bonneville Dam.

We can carry this hypothetical example a step further and consider the cost of the consumed power. During the era of cheap regional hydropower, a few years ago, a cost of 2 mils ($0.002) per kilowatt-hour might have been used to compute power costs. From this, the power consumption would have been $9 million/year, amounting to less than $1 per acre foot of diverted water. Today, costs of 10 to 20 mils per kilowatt-hour might be used for new power facilities. Hence, the power consumption of the diversion scheme might now be calculated as $43 million/year to $87 million/year, or $4 to $9 per acre foot of diverted water. Of course, it is possible that the pumping power could be purchased cheaply in the Pacific Northwest as off-peak power (most of the pumping lift would be near the northern end of the diversion) and sold expensively in the Pacific Southwest. Then, even though the consumption of power would still remain, the net cost of the consumed power might be eliminated, or nearly so.

OVERALL ANNUAL COSTS

Incidentally, the overall annual costs (capital, operating and maintenance) of some typical diversion schemes in the early 1960's were estimated to be about $40 per acre foot per year. At today's costs, these estimates might be more than doubled, perhaps tripled (a figure of $100 per acre foot might be realistic). Thus, the energy costs of diverting water would be a small but significant fraction of the total cost of water. Irrigated agriculture is accustomed to paying much less than $10 per acre foot for water; consequently, if the farmer only paid the delivery energy costs for receiving diverted water, all other costs being subsidized, the cost of water would still double for him. In comparison, my water bill in Corvallis last month was the equivalent of $130 per acre foot!

Suppose now that in a different hypothetical, but realistic situation, the same water---10 million acre feet in the Snake River at an elevation of 2000 feet---were instead stored for release to the Pacific Ocean via the Snake and Columbia Rivers. If 75 percent of the elevation head could be converted to power head (the rest lost to friction in river and penstock flow), then that amount of water would be worth the steady power production of 1.75 Gigawatts (more than three Bonneville Dams or one-and-one-half Trojan plants). Furthermore, at the "cheap-power" rate of 2 mils per kilowatt-hour, a revenue of $30 million dollars per year or $3 per acre foot would be produced.

From the above two hypothetical situations, summarized in Table 1, it would appear logical to keep the water in the Columbia Basin rather than to divert it. This is because of the favorable in-basin net power production compared to the unfavorable out-of-basin net power consumption. It would take very appreciable differences in the costs of electricity in the Pacific Northwest and Pacific Southwest to make it profitable to divert water on the basis of energy revenues.

However, energy production and the value of energy in different regions do not tell the full story nor provide a sufficient basis for making decisions on water diversion. It is of the utmost importance to determine the other values of water in order to rationally determine whether or not diversion is advantageous. Once diverted, the water has a tremendous value to the Southwest for agriculture and other purposes by providing again as much water as that region's entitlement from the lower Colorado River (7.5 million acre feet annually). Conversely, the water if left in the Snake and Columbia Rivers has a great existing in-stream value for fishery resources, water-borne commerce and recreation and waste handling. This water also has a potentially great out-of-stream value in the Columbia Basin as irrigated agriculture expands. These are some of the matters that are central to arguments over water diversion from the Pacific Northwest.

TABLE 1

SUMMARY OF HYPOTHETICAL EXAMPLES

10 million acre feet of water per year available in Snake River at elevation 2000 feet, mean sea level:

A: divert to Lake Mead at elevation 1000 feet with 2600 feet of pumping lift, 3100 feet of power generating head and 500 feet of head losses.

B: allow to flow to Pacific Ocean with 1500 feet of power generating head and 500 feet of head losses.

CHOICE	PUMPING POWER REQUIRED, GW	TURBINE POWER GENERATED, GW	NET POWER GAIN/LOSS, GW
A:	3.58	3.08	0.50 Loss
B:	0	1.75	1.75 Gain

CHOICE	VALUE OF NET POWER GAIN/LOSS in dollars per year			VALUE OF NET POWER GAIN/LOSS in dollars/acre foot of water		
	@0.2¢/kw-hr	@1¢/kw-hr	@2¢/kw-hr	@0.2¢/kw-hr	@1c/kw-hr	@2¢/kw-hr
A:	$8,680,000	$43,400,000	$86,800,000	$0.87	$4.34	$8.68
B:	$30,720,000	$153,600,000	$307,200,000	$3.07	$15.36	$30.72

WATER DIVERSION ISSUES

Many issues were raised by the water diversion schemes of the 1960's. Fundamental cultural attitudes involving stewardship, husbandry, and dominion over all things of the earth were involved. Attitudes toward resource development and the government's involvement and assistance in such development were part of the controversy.

The arguments raged. They dealt with questions such as whether a real or imagined need for water existed; whether or not water conservation and water pricing measures could accomplish the same effect as the diversion of new water to the Southwest; whether or not water should be brought to the people or people moved to the water; whether particular crops should be grown where the water supply is more adequate or where the climate allows a longer growing season, particularly if certain crops grow well in both regions; how should legally binding agreements be handled when these agreements were based on limited and non-representative hydrological data, such as over-estimation of the Colorado River yield by ten percent; whether there is an obligation to sustain regional growth, including the population and its economic base, when such growth has occurred by depletion mining of the available water supply and can only be sustained by the importation of large quantities of water, as by the Central Arizona Water Plan; what rights are held by the states of water origin to protect presently unallocated water in order to have it for future development; what obligation must be assumed at the national level, rather than the regional level, to assure Mexico of 1.5 million acre feet of Colorado River water; what effect might technological breakthroughs in water supply and wastewater reclamation have, as with cloud seeding and desalination?

The issues focused on water management. All aspects of water management were challenged: institutions, political, legal, sociological, economic and technological aspects. The Northwest questioned that the Southwest and the involved Federal agencies had seriously explored all management practices that could provide alternatives to inter-basin transfer. The Pacific Northwest was apprehensive that any diversion of water from the Northwest might be a permanent commitment of water that would severely limit the region's future development. The Northwest questioned whether any existing agency would be able to make an unbiased feasibility study: too many vested interests and too little sound data were involved.

In essence, the issues could be summarized from the viewpoint of the Pacific Northwest in one question: Will there be sufficient water available within the region to meet its future needs?

Regional politics and the growing momentum of the conversation movement played a key role toward the end of the debate. In 1968, as part of the Colorado River Basin Project Act (P.L. 97-537), also known as the Central Arizona Project Act, the U. S. Congress declared a 10-year moratorium on Federal

> "reconnaissance studies of any plan for the importation of water into the Colorado River Basin from any other natural drainage basin lying outside the States of Arizona, California, Colorado, New Mexico, and those portions of Nevada, Utah and Wyoming which are in the natural drainage basin of the Colorado River" (8)

This was not a solution to the problem; but it bought valuable time. In the intervening years, the states in the Pacific Northwest have made careful studies of the long-term needs for water. In Oregon, for example, requirements were estimated for 1990, 2020, and 2070 (1). Granted that projections one hundred years into the future may be highly uncertain, even the fifty year projections revealed that most of Oregon would not have sufficient water to satisfy its needs. Such findings in Oregon and elsewhere throughout the region supported the concerns of those who argued against diversion on the basis that it would curtail regional growth. Perhaps of equal significance, the findings provide a basis for considering the possibility of finite-term marketing of water with some basis for setting the time interval in other than an arbitrary manner.

Another significant factor acting to the benefit of the Pacific Northwest was the passage by the U. S. Congress of the Water Resources Planning Act of 1965 (P.L. 89-80). As a result, the Pacific Northwest River Basins Commission was established in 1967 as the first such regional federal-state river basin agency to coordinate the water resource planning efforts of all agencies in the region. Such comprehensive coordination has helped to fit together the water planning of individual state planning agencies, such as Oregon's and Idaho's Department of Water Resources and Washington's Department of Ecology.

More significantly, it has provided a means of viewing the function-oriented planning (e.g., fisheries, hydropower) of other state agencies and of the federal agencies in the context of regional issues and problems. The Commission and its regional predecessor, the Columbia Basin Inter-Agency Committee, have developed and assembled a wealth of information describing in detail the water and related land resources of the basin (e.g.,2, 12). The Commission will complete next year its initially-mandated responsibilities with the publication of a thought-provoking treatise on a Pacific Northwest Regional Program for Water and Related Resources.

Thus we see that the 10-year moratorium on diversion studies has been beneficial in the Pacific Northwest by giving the region time to take stock of its resources and think through its long-range plans and requirements for water.

MORE QUESTIONS

But not all questions have been answered, nor have many of the interregional issues been resolved. Within the region there has not been sufficient time, money or manpower to pursue all questions adequately. For example, water rights remain unadjudicated for many river basins in the region, so that the total allocation of water within the basin is still unknown; conflicts have not been settled among many multiple-purpose uses of the region's rivers and leave unresolved the amounts of water required for in-stream purposes; debates over expanded use of hydroelectric and nuclear power leave uncertain the determination of energy self-sufficiency within the region; regional goals have not yet been backed by local goals and policies regarding land use, economic growth and population growth, making uncertain the prediction of water requirements.

Answers have been found for many questions. But tough questions remain only partially investigated and thus unresolved. Basic research is needed in several areas, particularly regarding the effects of man's river management upon aquatic ecosystems. Too much of what is termed "progress" has been halted by weakly-based ecological arguments. If we in the Northwest really hold nature in such great esteem, it would seem that greater efforts at basic and applied studies of aquatic ecosystems would be funded than has been the case. Physical-chemical studies of the aquatic environment likewise are lagging behind the need for answers by decision makers.

The 10-year moratorium has had another significant effect upon resolution of water diversion issues--it has temporarily removed the urgency of debate over these issues. Without debate, some of these issues will not be resolved. During the moratorium, each side in the argument has had ample time to review its positions. Probably most positions have been reinforced, rather than dropped, as a result of this review.

But there has not been the forum, nor has it yet become timely, to reopen the debate over key issues that cannot be resolved exclusively within one or the other region. Some issues need a national forum for their resolution--such as the issue over whether the Federal government should pay fully for the initial 1.5 million acre feet of water in any diversion scheme to the Colorado River Basin in order to honor its assumed obligations to Mexico from Colorado River water (such an action significantly lowering the marginal cost of supplemental water that might be diverted along with this initial quantity.)

ENERGY SELF-SUFFICIENCY; ADDED ISSUES

The energy "crisis" that began in 1973 led national policy makers to turn from unreliable foreign fuel sources to the pursuit of energy independence and self-sufficiency by 1985. The attention of "Project Independence" focused on the Rocky Mountain oil shale and tar sand deposits and the vast domestic coal resources of the Northern Great Plains and upper Colorado River Basin. Beyond initial major problems of developing fuel conversion technologies and minimizing environmental damage, the energy planners gradually began to realize that water would have a major significance. In the arid regions where such energy development would take place, water is scarce. But water will be needed in large amounts for cooling in the power plants, for stabilizing and irrigating the mined lands in order to reclaim them and prevent erosion, for coal gasification and liquification, and for transporting coal slurries in pipelines if mine-mouth power plants are not used.

Planners became aware that using local and regional water for coal and oil shale energy development could preempt other important water uses and disrupt the irrigated agriculture base of the region. A 1974 estimate (6) of incremental water needs to provide increased energy from domestic resources indicated that about 10 million acre feet per year would be needed by 1985, mainly for cooling water at new fossil fuel and nuclear power plants.

For comparison, the provision of adequate water for energy self-sufficiency would add about 30 percent to the incremental water requirements for 1985 for increased multi-purpose water use in the nation. This "energy" water could be had <u>without</u> increasing the total projected increased water needs _if_ the projected new irrigation water requirements were reduced by 60 percent. In other words, at planned rates of development for new water supplies there would be a notable trade-off between developing new water supplies for irrigation and developing them for energy self-sufficiency.

In both the Upper Colorado River Basin and the Northern Great Plains there is presently available uncommitted water and inefficiently-used water that might be directed to energy production. Eventually, however, continued use of such water for energy production would entail the competition with and preemption of other potential applications--most likely irrigated agriculture.

In the Pacific Northwest, water is absolutely essential for energy production. Our future regional energy mix is predicated upon some base load and most peaking (non-constant) loads from hydroelectric generation. Each unit volume of water stored at the headwaters of the Snake or Columbia River for power generation produces energy at eight or more hydropower stations as it flows to the sea. Simultaneously, it fulfills the in-stream requirements for navigation, fish and wildlife, water-based recreation, water quality maintenance, and aesthetic purposes.

A unit volume of water diverted from the upper basin to enhance energy production elsewhere takes away from regional energy production and other in-stream benefits. Our future regional energy mix is also predicated upon use of cooling towers rather than once-through-cooling for the thermal power plants that will eventually provide the majority of our base load. This choice causes higher evaporative water losses but is deemed desirable to preserve cool in-stream temperatures for the highly important anadromous fishery.

Inter-basin water diversion for energy production elsewhere would have a counteracting effect on energy production in the Northwest. Should inter-basin water transfers take place from the Northwest to allow energy production elsewhere without preempting other water development in those basins, the effect upon the Pacific Northwest would be to increase the competition for water and possibly preempt other water development in our region. In particular, the threat to future irrigation development in the Snake River Basin and to the already debilitated anadromous fishery of the Snake and Columbia Rivers would be very real should inter-basin diversion occur.

The U. S. Water Resources Council sent a questionnaire to all states in 1974 asking some searching questions regarding energy development, legal impediments, program priorities, and anticipated major problems in relation to water and the environment. Potentially threatening was the statement in one question:

> "In order to meet 'energy-water requirements', certain alternative solutions may be proposed at the federal level, including: (a) inter-basin transfer, (b) federal jurisdiction over water rights, (c) reallocation of existing storage."

This raises the possibility of a national energy policy that might override and make subservient all current regional programs for multiple-purpose water resource use. Should that occur, one may expect an intense intra-regional competition for the remaining water that could drastically affect the future development and quality of life in the Pacific Northwest.

CLOSURE

The principal concern in the Pacific Northwest is the nature and manner of regional growth. This most directly deals with a concern about population growth, both in amount and distribution. But the concern is more often expressed and argued via the issues of related growth--particularly economic and industrial.

In broad terms of our regional natural environment, the principal concerns focus on water, land and energy resources. Those three are tightly inter-related by overlapping local, state, regional, and federal policies. Such policies do shift in emphasis and applicability over time and thus, while being somewhat responsive to present needs, cause uncertainty over institutional jurisdictions and responsibilities.

To date, all three resources have been, on the average, quite abundant in the Northwest. However, the 1960's saw a serious questioning of the future adequacy of water supplies, just as the 1970's are seeing a serious questioning of the future adequacy of energy. Perhaps the 1980's will see a similar concern for sufficient land--if the use of water to produce energy has not first preempted the availability of additional water for land development.

The states in the Pacific Northwest have addressed the first issue; they have made their assessments of future water needs. But this effort was undertaken before the spectre of energy shortages arose. The assumptions and projections of the late 1960's are not likely to be correct in the late 1970's, both because of energy constraints and due to changing technology in water use. Reassessment and updating of the completed studies appear to be timely.

Crucial water and energy issues still remain for the region:

a) How self-sufficient should the Pacific Northwest be with respect to water and energy?

b) Should water projects be undertaken within the region to overcome current or future water shortages in parts of the basin?

c) How can the energy needs of the region best be met?

d) How should the region's rivers be managed?

e) How can unique aquatic resources, such as anadromous fisheries and wild-and-scenic rivers, best be protected?

Some of these issues can only be resolved by integration with two additional issues:

f) How should the region's land resource base be managed to restore. protect and enhance its productive capabilities and other values.

g) How should water, energy and land be provided and protected for various segments of the region's agricultural-industrial economic sector?

The issues of water for energy and water for diversion cannot be adequately addressed as considerations separate from those of the nature and manner of regional growth. And while much has been done with respect to regional water and energy planning, there has been little regional leadership in dealing with the most basic question, to which all others relate--regional growth. How this question will ultimately be addressed is uncertain. Present-day sentiment appears to favor local, piecemeal planning. Perhaps only the renewed threat of water and/or energy diversion will bring action on this fundamental issue of regional growth. When that happens, it will become possible to resolve many other issues.

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Energy Consumption of Advanced Wastewater Treatment

Energy utilization and resource consumption in advanced wastewater treatment (AWT) is one aspect of Environmental Assessments that has been and still is largely ignored. It is not the only problem which we have with EIS's of Environmental Assessments, but is is an important area. Before going on to describe the results of our analysis of AWT at Ely, Minnesota, let us digress and briefly review the history of Environmental Impact Statements, as well as EPA's role, and point out some of the basic deficiencies in EIS's. I hope this review will show how resource consumption and energy utilization studies can be fitted into a larger picture.

INTRODUCTION

Early in 1970, many federal agencies chose to either ignore NEPA or prepared Environmental Impact Statements which were of rather low quality.

Two events occurred within one year which basically altered the course of the Environmental Impact Statement. The first event was the decision in April of 1970, when the trans-Alaska pipeline case was taken to Federal Court and the determination was made that the Secretary of the Interior must meet the legal requirements of NEPA. The second major event which occurred, the Calvert Cliffs decision, was related to the operation of a nuclear power plant in Maryland.

This decision was important because it elevated the preparation of Environmental Impact Statements from their former status of proforma reports to required technical documents which must be produced before federal permits for major projects could be issued. In short, the Calvert Cliffs decision converted the Environmental Impact Statement process from one which was primarily preoccupied with form and format into a process concerned primarily with the substantive issues of the nature and extent of environmental effects.

The Council on Environmental Quality has developed guidelines to provide procedural guidance for the preparation of environmental impact statements (c.f. The Fifth Annual Report of the Council on Environmental Quality, 1974 (1)); the technical approaches for meeting EIS objectives are not always available or universally accepted. As a result, there have been a number of methodologies developed in a variety of attempts to meet this need. Despite the proliferation of ad hoc methodologies for the preparation of EIS's, there is no single methodology which adequately assesses the effect of major projects on the interrelationships between man and his environment nor, for that matter, adequately assesses the impact of a project on lower organisms or the physical environment.

The reasons for this deficiency in EIS preparation and analysis are numerous and varied, ranging from the fact that ecosystems are extremely complicated, to the fact that transport systems for pollutants are variable, and it is often impossible to know which receptor is being affected by a given discharge. Further institutional problems have arisen which unnecessarily create obstacles to rational environmental impact assessment. Further, the sheer number of environmental impact statements which have been produced prevent adequate EIS preparation since there probably are not enough trained personnel in the environmental sciences to carry out the work. Our estimate today is that some 7,000 to 8,000 EIS's have been prepared since 1970.

Let me turn briefly to the role of the EPA. EPA has two roles, writing EIS's, which we will discuss later, and reviewing EIS's from other federal agencies. While all federal agencies have the opportunity to review and comment on EIS's, EPA, by virtue of Section 309 of the Clean Air Act, has been placed in a special review role. This section of the Clean Air Act requires that EPA comment in writing on the environmental impact of newly authorized federal actions or legislation posed by other federal agencies.

In the event that the Administrator of EPA determines that any such action is environmentally unsatisfactory or of concern, he will publish his determination and refer the action to the Council on Environmental Quality. As a consequence, EPA reviews essentially all EIS's prepared by other federal agencies. This review includes comments on not only the ecological, social and economic effects but also a discussion as to whether the EIS has adequately treated the energy and resource utilization. The job is generally done in our regional offices. If the project involves a high degree of national controversy, or if the comments are setting new agency policy, the EPA's comments are coordinated through its Office of Federal Activities in Washington, D. C.

REVIEW OF SELECTED ENVIRONMENTAL IMPACT STATEMENTS

The Lake Tahoe EIS

The final Environmental Impact Statement on the wastewater treatment and conveyance system in the North Lake Tahoe-Truckee River Basin provides a classic example of a problem encountered in numerous EIS's. Briefly stated, the problem is that either too much data which are not relevant are collected or data are collected but are not used in the evaluation of environmental impact. This may lead to the generation of data for its own sake. Let us look at a specific example. In Chapter 1 of the Tahoe EIS entitled, "The Environment", we find data on vegetation types, rare and endangered species, hydrological balances, flow rate of Truckee River, air temperature, precipitation, water quality and a number of other environmental factors. In the impact analysis section of the EIS, the unavoidable impacts on the Truckee River of the major interceptor system and the regional wastewater treatment plant at Martis Creek are discussed separately. The following is a direct quote from the analysis of the treatment plant at Martis Creek:

"Impacts of a Regional Wastewater Treatment Plant at Martis Creek

> "A tertiary treatment plant is proposed to be constructed at the confluence of Martis Creek and the Trukee River. An emergency storage pond will also be constructed to store raw or partially treated sewage in the event of process failure.
>
> "The construction of this plant will involve the conversion of 30 acres of sage brush habitat to use as the locale of sewage treatment facilities. This land presently serves as the range of summer deer and other wildlife, and some individuals will be lost due to the conversion of uses. The land in question is by no means unique within the Martis Valley.
>
> "During the construction of the facility, as well as during its normal operation, the noise level in the area will increase, causing a disturbance to the wildlife occupying the surrounding lands. The generation of odors may also disturb animals in the area, and possibly cause a human nuisance as well.
>
> "The construction of a treatment facility at the proposed location will result in a long-term adverse aesthetic impact."

That is the entire analysis of the direct impact associated with the treatment plant. Each of the alternatives to the proposed plan are also treated in a similar superficial manner, as is the analysis of the interceptor line and the secondary impacts of the project. Why then are 81 pages of environmental data of various sorts collected and never used in the impact analysis? This is a common trap that many professional ecologists fall into as well. In fact, even The Institute of Ecology (TIE) in its review of this particular EIS asked for data that would be very difficult to use even if they were available.

For example, TIE states, "...standard water quality indicators such as coliform counts must be supplemented with additional assays. This is necessary because of the extremely oligotrophic conditions at Lake Tahoe... We realize that direct counts are not considered standard procedure in water quality analysis. However, given the unusual clarity and low nutrient levels in Lake Tahoe, special standards need to be established." Is the purpose of collecting these data for a long-term water quality monitoring of Lake Tahoe or is it for analyzing the effect of this specific project? If the purpose is the latter, how will the information be used to make the necessary predictions?

What models or other techniques are available to make these predictions? Asking for more data is a common fault in the scientific community which each of us would have difficulty denying. However, the obligation is on the scientific community to know how the data will be analyzed and to what use the analysis will be put. The same principle applies to resource data--be sure that you know you are going to use the data before you go collect it.

No discussion of accumulate impact -- not only with existing facilities, etc., but in this case the impact analysis section discusses the unavoidable impacts on the Truckee River of the major interceptor line and the regional WWT plant at Martis Creek separately. With this as background as to how EIS's are generally written and reviewed let me turn attention to an environmental assessment of advanced waste water treatment of Ely, Minn.

This paper discusses only one aspect of a complete environmental assessment, namely resource consumption and energy utilization in the operation of the plant. Thirdly, in spite of the fact that Antonucci and Schaumburg completed a study of AWT at S. Lake Tahoe -- no mention is made of energy utilization or resource consumption, nor of potential emissions at locations supplying products to the treatment plant at Martis Creek.

BOUNDARIES ARE NECESSARY

Boundaries for the area of consideration need to be carefully defined in order to assess the resources used and pollutants generated. The following assumptions and limitations imposed on the study were due to both data restrictions and manpower constraints: 1) Only the operation and maintenance of the AWT plant has been considered. Resources utilized and pollutants generated during the construction of the plant have not been considered. (2) Consideration has been given only to the utilization of resources and pollutants generated at the AWT plant and in first order industries. A first order industry is any industry that supplies products directly to the AWT plant at Ely. Resources utilized or pollutants generated by second order industries (i.e. those industries supplying products to first order industries) have not been considered. As an example, pollutants generated as a result of providing electricity to the AWT plant are considered; pollutants generated as a result of supplying electricity for the manufacturing of lime are not considered. (3) The city of Ely was operating a secondary treatment plant. The phosphorus assessment of advanced wastewater treatment might cover only the tertiary phase, or that portion of treatment beyond secondary treatment. This study, however, examined the entire treatment process -- primary, secondary and tertiary. The reasons for studying the entire plant, instead of just the tertiary phase are: a) the tertiary phase of the facility cannot operate without primary and secondary treatment, and b) water quality improvements in Shagawa Lake result from the treatment provided by the entire plant, not just the tertiary plant.

To put the present study into proper perspective, a brief history of the initiation of the AWT plant and a description of the plant itself is necessary. Prior to the operation of the AWT, phosphorus entering the lake was discharged from the secondary facility operated by the City of Ely. The U.S. Environmental Protection Agency (EPA), in cooperation with the City of Ely, funded construction of an advanced wastewater treatment facility to demonstrate that a reduction in phosphorus from a point source could reduce the trophic status of Shagawa Lake (Malueg _et al_, 1975).

The tertiary plant which began operation in the Spring of 1973 was designed to limit the phosphorus content of the effluent to 50 Mg/m^3 (0.05 mg/l[1]) or less. Operating data since that time indicate that the effluent from the plant does indeed meet design criteria. Both the improvement in water quality and the limnological characteristics of Shagawa Lake have been reported in the literature by Malueg _et al_ (1975) and by Larsen _et al_ (1975).

Prior to construction of the tertiary treatment plant, wastewater entered the facility, passed through two parallel grit chambers and then through a bar screen. The waste proceeded through a primary clarifier, trickling filter and secondary clarifier. After the effluent left the secondary clarifier, it was chlorinated and discharged into Shagawa Lake (Brice 1975).

The tertiary treatment system was constructed as a research facility with a maximum of operational flexibility. Because of this, it is possible to pump almost any part of the waste "from anywhere to anywhere". Chemicals can also be introduced at many points in the system.

The effluent from the secondary treatment facility is pumped to a solids-contact clarifier, lime is added as primary method of removing phosphorous. The water then goes through multi-media filters to polish the effluent by removal of suspended solids containing phosphorous. The filter effluent is chlorinated and discharged to Shagawa Lake or pumped back to the plant for use as process water.

It should be noted that an activated carbon feed capability is available for the removal of soluble organic phosphorous. However, due to normal plant efficiency activated carbon is seldom used, consequently the analyses which follow do not include an assessment of the activated carbon system.

The tertiary treatment plant was designed to treat 5,678 m^3 (1.5 mgd) and from April 1, 1973 - March 31, 1974 was treating 4,164 m^3 (1.1 mgd).

Table 1. RESOURCES USED DIRECTLY AT ELY PER YEAR
SHEEHY AND EVANS (1975), BRICE (1975)

Lime (tons)	538.0
CO_2 (tons)	168.0
Chlorine (tons)	5.2
Electricity (kwh)	78×10^4
Fuel Oil (gals)	63×10^3
$FeCl_3$ (tons)	44
Sulfuric Acid (tons)	82
Polymer (lbs)	670
Gasoline (gals)	2450

RESOURCE UTILIZATION AND POLLUTANT GENERATION

On an average annual basis approximately 65 MWh (65,000 kwh)(Table 1) are used monthly at the wastewater treatment facility at Ely, Minn. This electricity is purchased from the City of Ely, which in turn buys electricity from Minnesota Power and Light (MP&L). The environmental analysis which follows is based on fuel mix for the base load of MP&L, which is approximately 80% low sulfur western coal, 12% hydroelectric, and 8% residual fuel oil (Rutka, 1975). The following assumptions were made with regard to the fuels: 1) coal = 0.65% sulfur, (8500 BTU's /lb), ash content = 7%; 2) fuel oil = 1% sulfur and 0.5% ash; and 3 hydroelectric -- no environmental insults are assigned to production of electricity by hydroelectric generation.

Table 2. RESOURCE REQUIREMENTS PER YEAR FOR PRODUCTION OF ELECTRICITY FOR AWT AT ELY, MINNESOTA

Fuel Oil (8%)	4070
Coal (80%), (tons)	359
Hydroelectric (12%)	---

It is recognized that production of electricity by hydroelectric generation creates environmental alteration such as changing a free-flowing stream to a standing water reservoir. This in turn alters recreational opportunities and species composition of the aquatic ecosystem. Further, dams can and do create other potential environmental effects, such as gas bubble disease. However, with present assessment techniques it is not possible to allocate a percentage of these types of effects to the AWT at Ely. It must simply be recognized that the AWT at Ely contributed to the demand for electricity and that demand is being partially satisfied by hydroelectric power.

The resources consumed and pollutants generated were calculated from Pigford et al (1975). (Tables 2 and 3). While Pigford et al have included pollutants generated throughout the entire fuel cycle of both fuel oil and coal, this analysis includes only pollutants generated at the power plant. This paper has not included an analysis of potential environmental effects associated with the extraction, transportation, or processing of fuels prior to burning in the power plant.

Table 3. POLLUTANTS GENERATED PER YEAR IN THE PRODUCTION OF ELECTRICITY FOR AWT AT ELY, MINNESOTA

To Air	SO_2 = 9600 lbs	To Water	Suspended Solids	91
	NO_x = 6950 lbs		H_2SO_4	15
	CO = 426		Chlorine	5
	HC = 77		Phosphates	8
	Part. = 3970		Born	62
			BOD	Neg.
To Land	46,700 Fly Ash			

It is emphasized that the data indicate the pollutants generated as a consequence of electric energy use by the Ely AWT. However, it must be recognized that these pollutants are discharged to the environment at the generating location, not at Ely. Consequently, as with all indirect pollutants generated as a result of operating the AWT, the environmental costs are being borne not be the users of Shagawa Lake or the residents of Ely, but by the residents living near the power plant and the people using the environment at another location.

Table 4. RESOURCE REQUIREMENTS FOR PRODUCTION OF PETROLEUM PRODUCTS FOR AWT AT ELY, MINNESOTA

2450 gals Gasoline and 63,000 gals Fuel Oil per Year

Water (gals)	2.05×10^{12}
Natural Gas (cu ft)	40.2×10^{3}
Propane and Butane (gals)	444
Crude Oil (gals)	25.2

Fuel Oil and Gasoline

Significant quantities of pollutants are generated by burning fuel oil and gasoline at the AWT facility. Further, the oil refineries required to produce these products are the most significant indirect source of pollutant that can be assigned to the operation of the AWT at Ely. Table 4 shows the resources used and refinery of fuel oil and gasoline.

To allocate pollutants generated (Table 5 and 6) and resources consumed at an oil refinery it is necessary to know the percentage of gasoline and fuel oil produced by the total refinery process. For this analysis, it is assumed that gasoline represents 44.7% of the crude input and fuel oil represents 21.7%. Further it should be noted that it represents industry-wide data for 1969. Thus it does not represent the most modern technology; rather is indicative of existing operation in the United States. It is interesting to note that of the total amount of energy consumed as a result of operating the AWT at Ely, 65% can be assigned to the direct use of fuel oil and gasoline and/or the refining of these products. In a wastewater treatment plant that uses digester gas in boilers, significant savings in energy and pollutant discharges, both directly and indirectly, may be realized.

Table 5. ATMOSPHERIC POLLUTANT DISCHARGE DUE TO PRODUCTION OF PETROLEUM PRODUCTS FOR AWT AT ELY, MINNESOTA

2450 gals Gasoline and 63,000 gals Fuel Oil/Year

Particulates	43.9×10^2
Organic	35.0×10^3
NO_x	27.0×10^3
CO	66.5×10^2

Lime

The Ely AWT facility uses (537 tons) of lime per year. Lime is fed into the clarifier to remove the ortho-phosphate. This is the primary mechanism by which phosphorus is removed from the wastewater. In addition, lime is used when necessary as a sludge conditioner.

The analysis and documentation of environmental alterations which are assigned to the Ely AWT plant as a result of using lime include only those associated directly with the processing of limestone.(Table 7), Both the mining of limestone and the transporting of the limestone to the processing plant generate pollutants which are not considered here. All lime used at the AWT plant is purchased from the Cutler-Magner Company of Duluth, Minnesota. The data in this paper is based largely on information supplied by Cutler-Magner Company. Other literature (EPA, 1974; Lewis and Crocker, 1969, Boynton, 1966) all indicate

Table 6. POLLUTANT DISCHARGE TO WATER DUE TO PRODUCTION OF PETROLEUM PRODUCTS FOR AWT AT ELY, MINNESOTA

2450 gals Gasoline and 63,000 gals Fuel Oil/Year

Chlorides (lbs)	37.2×10^3
Grease (lbs)	95.1
NH_3-N (lbs)	95.1
Phosphate (lbs)	4.8
BOD (lbs)	156.4
COD (lbs)	10.1×10^3
Suspended Solids (lbs)	313.0
Dissolved Solids (lbs)	170.0×10^3

that the Cutler-Magner data are generally representative of the industry as a whole.(Table 8) Although there are some suspended solids discharged to the water, in general the water pollutants are negligible.

Table 7. RESOURCE REQUIREMENT FOR PRODUCTION OF LIME FOR AWT AT ELY, MINNESOTA

488 Mg (537 Tons)/Year

Limestone (tons)	10.7×10^2
Fuel Oil (gals)	99.4×10^2
Natural Gas (cu ft)	25.8×20^5
Electricity (kwh)	26.9×10^3
Water (gals)	42.7×10^3

Table 8. ATMOSPHERIC POLLUTANT DISCHARGE DUE TO PRODUCTION OF LIME FOR AWT AT ELY, MINN.

488 Mg (537 Tons)/Year

SO_x (lbs)	21.9×10^2
Particulates (lbs)	172.0
Heat (BTU)	24.0×10^8
NO_x (lbs)	661.0
CO (lbs)	54.0
HC (lbs)	37.8

Polymer

In addition to the lime, a cationic polymer (Betz 1150) is used as a coagulant aid. However, since this polymer is only one of several products being manufactured simultaneously, Betz Laboratories could not furnish detailed information on resource utilization such as energy consumption. The company claims no waste products are given off during the manufacturing process. All constituents which are not used are recycled and used in other production (Pressman, 1975). The resources utilized and energy costs of transporting (659 lbs) of polymer from Trevose, Pennsylvania to Ely, Minnesota, are insignificant compared to other energy and resource requirements of the AWT plant. As a result of these findings, even though the cost of the product, ($7606/ton) would indicate that the process of producing Betz 1150 may be highly energy consuming, no environmental impacts are assigned to the utilization of the polymer at Ely.

Carbon Dioxide

Commercial grade carbon dioxide is added to the second clarifier at a level of 100 glm^3 (mg/l). This reduces the excess calcium by forming calcium carbonate. Carbon dioxide is generally obtained as a by-product of some other reaction and is either emitted to the atmosphere or diverted to a purification and liquefacation plant. There are only two resources required to produce liquefied CO_2 - electrical energy and cooling water (Vorel, 1975). The information on electrical consumption and pollutants generated, as supplied by Cardox products is shown in Table 9. This information is valid only for gas produced as a byproduct of another reaction; not appropriate if gas were produced in an inert gas generator.

Table 9. RESOURCE REQUIREMENT FOR AND POLLUTANT DISCHARGE DUE TO PRODUCTION OF CO_2 FOR AWT AT ELY, MINNESOTA

	168 Tons/Year
Electricity (kwh)	26.8×10^3
Waste Heat to Cooling Water (BTU)	50.3×10^6

Ferric Chloride

Ferric Chloride is added to the processes at two points. First it is added to the second stage lime clarifier. This serves to form complex insoluble phosphorous salts which are precipitated or filtered out.

Second, after the effluent leaves the second stage lime clarifier, chlorine, ferric chloride and sulfuric acid are added. This provides a floc blanket which improves filter efficiency and extends filter runs. There is an annual usage of (44 tons) of ferric chloride.

Table 10. RESOURCE REQUIREMENTS FOR PRODUCTION OF FERRIC CHLORIDE USED AT AWT AT ELY, MINN.

	40 mg (44 Tons)/Year
Waste Pickle Liquor (as Fe) (tons)	15.1
Chlorine (tons)	28.9

There are several different techniques and processes for producing ferric chloride. The analysis which follows is based upon information supplied by Dow Chemical Company (Sharp, 1975). (Table 10) While the reaction $FeCl_3$ is basically exothermic, external heat is used at times to concentrate the final product. Dow claims the energy utilized for this step is insignificant (Sharp, 1975) and is not counted in this analysis.

In the manufacturing of $FeCl_3$, there are no waste products produced that are either discharged to the water or emitted to the air (Sharp, 1975). There are, however, a total of approximately 35 lbs of sludge produced for every ton of product ferric chloride. This means that the amount of solid waste produced each year as a result of using $FeCl_3$ at Ely is approximately (1558 lbs). There is no detailed information on the chemical composition of the sludge but it is expected that it would contain grease, silica, sand, ferric chloride, and iron oxide and hydroxide (EPA, 1975). No environmental insult has been assigned to the chemicals contained in the sludge.

Chlorine

Chlorine is added at a dosage of approximately 3.0 g/m^3 (mg/l) to provide control for potential pathogenic bacteria.

Table 11. RESOURCE REQUIREMENTS FOR PRODUCTION OF CHLORINE FOR AWT AT ELY, MINNESOTA

4.72 Mg (5.20 Tons)/Year

Electrical, MWh (kwh)	64.5×10^2
Steam, GJ (BTU)	21.6×10^6
Rock Salt, Mg (tons)	6.5
Sulfuric Acid, kg (lbs)	63.5
Sodium Carbonate, kg (lbs)	85.3

The industrial process and energy requirements for the production of chlorine has been detailed by Saxton et al (1974) and EPA (1974). (Table 11) The electrolytic processing of brine by either diaphragm or mercury cells accounts for 96% of the total chlorine production in the United States. The remaining 4% is presently produced as a by-product of other industrial processes. Resources were allocated between chlorine and caustic soda on a weight basis. For example, if the co-production of 1 ton of chlorine and 1.13 ton of caustic soda requires 3197 kwh of electricity, 1500 kwh are assigned to the production of 1 ton of chlorine.

In this case, it is legitimate to allocate energy resources between chlorine and caustic soda because both products are in high demand and the dollar value of both products is high. In other words, caustic is not necessarily just a by-product of chlorine production, or vice versa. If caustic was simply a by-product with little or no economic value, it would not be legitimate to allocate resources between the two products. Further, the total process yields hydrogen gas as a by-product which is sold. However, this paper does not allocate any of the resources to the production of hydrogen (i.e., it was consided solely as a by-product of producing chlorine and caustic soda).

Approximately 50% of the electricity used by chlorine industry is produced on the site. Consequently, we calculated atmospheric discharges from the electrical production and included them in our analysis.

Table 12 and 13 show pollutant discharges from chlorine. To calculate these numbers, additional assumptions were made: ash content of coal = 12%; ash content of fuel oil = 0.5%; sulfur content of coal and fuel oil = 1%; and emission controls = 98% particulate removal.

Table 12. ATMOSPHERIC POLLUTANT DISCHARGE DUE TO PRODUCTION OF CHLORINE FOR AWT AT ELY, MINNESOTA

5.20 Tons/Year

Particulates (lbs)	47
SO_2 (lbs)	614
CO (lbs)	47
HC (lbs)	207
NO_x (lbs)	561
CL_2 (lbs)	9360
CO_2 (lbs)	16500

Table 13. POLLUTANT DISCHARGE TO WATER DUE TO PRODUCTION OF CHLORINE FOR AWT AT ELY, MINNESOTA

5.20 Tons/Year

Suspended Solids (lbs)	330
Lead (lbs)	2.6
Mercury	Negligible

Sulfuric Acid

As the wastewater leaves the second stage lime clarifier, sulfuric acid is added at a dosage of approximately 37 g/m^3 (mg/l) which is sufficient to maintain a final effluent pH of 7.0-7.5. This results in the use of 74.5 Mg (82 tons) per year.

SUMMARY

When the values for the AWT at Ely are compared to those of the AWT at Lake Tahoe (Antonucci and Schaumberg, 1975) there are some apparent differences (Table 14):

Table 14. COMPARISON OF RESOURCE REQUIREMENTS PER 10^6 GALLONS FOR AWT AT ELY, MINNESOTA AND LAKE TAHOE, CALIFORNIA

	ELY	TAHOE
Chlorine (lbs)	160	106
Salt (lbs)	27.2	280
Sodium Carbonate (lbs)	0.19	2.6
Lime (lbs)	2520	1600
Limestone (lbs)	5011	3200
Energy (BTU)	58.1×10^6	106×10^6

1) At Ely, chlorine is consumed both directly and indirectly in the manufacturing of $FeCl_3$. At Tahoe, since alum is used instead of $FeCl_3$, chlorine is only consumed directly. Because of this difference in operational procedure, chlorine consumed at Ely is 1.5 times that used at Tahoe. However, when direct consumption of chlorine is considered then the chlorine consumed at Ely is only 0.25 times that used at Tahoe. The difference in these values is due to: 1) the chlorine dosage at Tahoe is 12 mg/l, and 3 mg/l at Ely; and 2) in this study, the resources used in chlorine production were allocated between chlorine and its co-product, caustic soda.

2) Lime is used in greater quantities at the Ely facility primarily because there is a lime recovery system at Tahoe, whereas at Ely the lime sludge is trucked to a sanitary landfill. This must be balanced against energy cost at Tahoe of 35.7×10^6 BTU's to recover lime.

3) Finally, it is apparent that it takes twice as much total energy per million gallons of effluent to operate the Tahoe facility. Of the 106 million BTU's used at Tahoe over 35 million BTU's are used in lime recovery which is not done in Ely. Secondly, the AWT at Ely does not incinerate its organic solids, but mixes them with the lime sludge and hauls them to a landfill. At Tahoe the incineration of these solids results in an energy cost of 6.64 KJ/m^3 (23,800 BTU's per million gallons). The only energy value that was calculated differently in the two studies was the amount of energy required to produce chlorine.

In this study the energy consumed in producing chlorine and caustic soda was allocated between the two end products, whereas Antonucci and Schaumberg (1975) assigned all of the energy in the production of chlorine and caustic soda to chlorine. This difference is insignificant when compared to other energy requirements of the AWT plants.

In order to put the resource consumption due to the operation of Ely's AWT in perspective, one can compare this consumption with a common "baseline", for example, home consumption of energy. On the average, an all-electric home, 111.5 m^2 (1200 sq ft), in Ely, Minnesota, consumes approximately 3240 kWh/mo which is equivalent to 11,065,000 BTU's. The AWT plant at Ely uses 65,000 kWh per month (221,980,000 BTU's) plus another 798 million BTU's in fuel oil. Thus, the direct energy consumption at the AWT facility is equal to the direct energy consumed in 92 all-electric homes. Using another comparison, the 2450 gals of gasoline used in the trucks for hauling sludge would drive an automobile (getting 20 mpg) approximately 49,000 miles, about what four average families would drive in one year.

Based on 1975 emission standards, which are more stringent than the emissions from an average auto, it is possible to compute the number of miles of auto travel that would create the equivalent grams of certain pollutants as does the operation of the AWT at Ely: 1) CO, 337,200 miles; 2) HC, 224,000 miles; and 3) NO_x, 57,950,000 miles. (Table 15 and 16).

Table 15. SUMMARY OF MAJOR ATMOSPHERIC POLLUTANT DISCHARGES PER YEAR DUE TO OPERATION OF AWT AT ELY, MINNESOTA

	(Tons)
Particulates	5.71
SO_x	27.2
CO	5.62
HC	0.45
NO_x	18.9
Cl_2	4.70

Table 16. SUMMARY OF MAJOR POLLUTANT DISCHARGES TO WATER PER YEAR DUE TO OPERATION OF AWT AT ELY, MINNESOTA

	(LBS)
Suspended Solids	740
H_2SO_4	20
Phosphates	20
BOD and COD	10.2×10^3

Other comparisons can be made. However, the purpose of this paper is not to evaluate operation of the Ely AWT facility by comparing its operation to other activities of man. The purpose of this study is to assess what pollutants have been emitted and what resources have been consumed as a result of operating the AWT at Ely. Ideally, it would be desirable to carry this analysis a step further and discuss the effect these pollutants have on human health and natural ecosystems. This is not possible using techniques available today.

Consequently, we are faced with the situation where it is possible to quantify, to some extent, the unquestionable improvement of the Shagawa Lake ecosystem, and compare this improvement to unquantifiable environmental effects that are being borne, not by the users of Shagawa Lake and the residents of Ely, Minnesota, but by others who live in the area of the oil refineries, chlorine plants and other support industries. While we cannot quantify these tradeoffs, it is important to understand that they do exist and, because of this, technology fixes may not necessarily be the solution to all environmental pollution problems.

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Presented December 9, 1976 by ROBERT F. VINING North Pacific Division, Corps of Engineers, Portland, Oregon. This paper is co-authored by NICHOLAS A. DODGE and IVAN J. JONES of the Corps.

The Impact of Irrigation on the Columbia River

ABSTRACT

There presently exists within the Columbia River Basin about 7,000,000 acres of irrigated land. With increasing demands for food and fiber, not only in the United States but also in the whole world, this level of irrigation is expected to increase by over 60% within the next fifty years to about 11,100,000 acres. This increased irrigation will deplete the Columbia River by nearly 9,000,000 acre-feet.

This level of irrigation development will create major economic benefits to the region through the direct sale of agricultural products, the creation of food processing plants, and the establishment of agricultural service industries. This level of irrigation development, however, will also cause major economic and environmental impacts on other river uses, most notably hydroelectric power generation and fish and wildlife.

As part of its ongoing Columbia River planning activities, the Corps of Engineers has recently completed a study which evaluated the economic and environmental impacts that future irrigation developments within the Columbia River Basin would have on the river's operation and use and, consequently, the welfare of the Pacific Northwest Region. Presented here are the results of and experiences gained from this study.

I. BACKGROUND

A. Geographic Setting:

The Columbia River, bounded on the east by the Continental Divide of the Rocky Mountains and on the west by the Pacific Ocean, embraces an area of 259,000 square miles. Eighty-five percent of the basin, or 219,000 square miles, is located in the United States covering portions of Idaho, Montana,

COLUMBIA RIVER BASIN

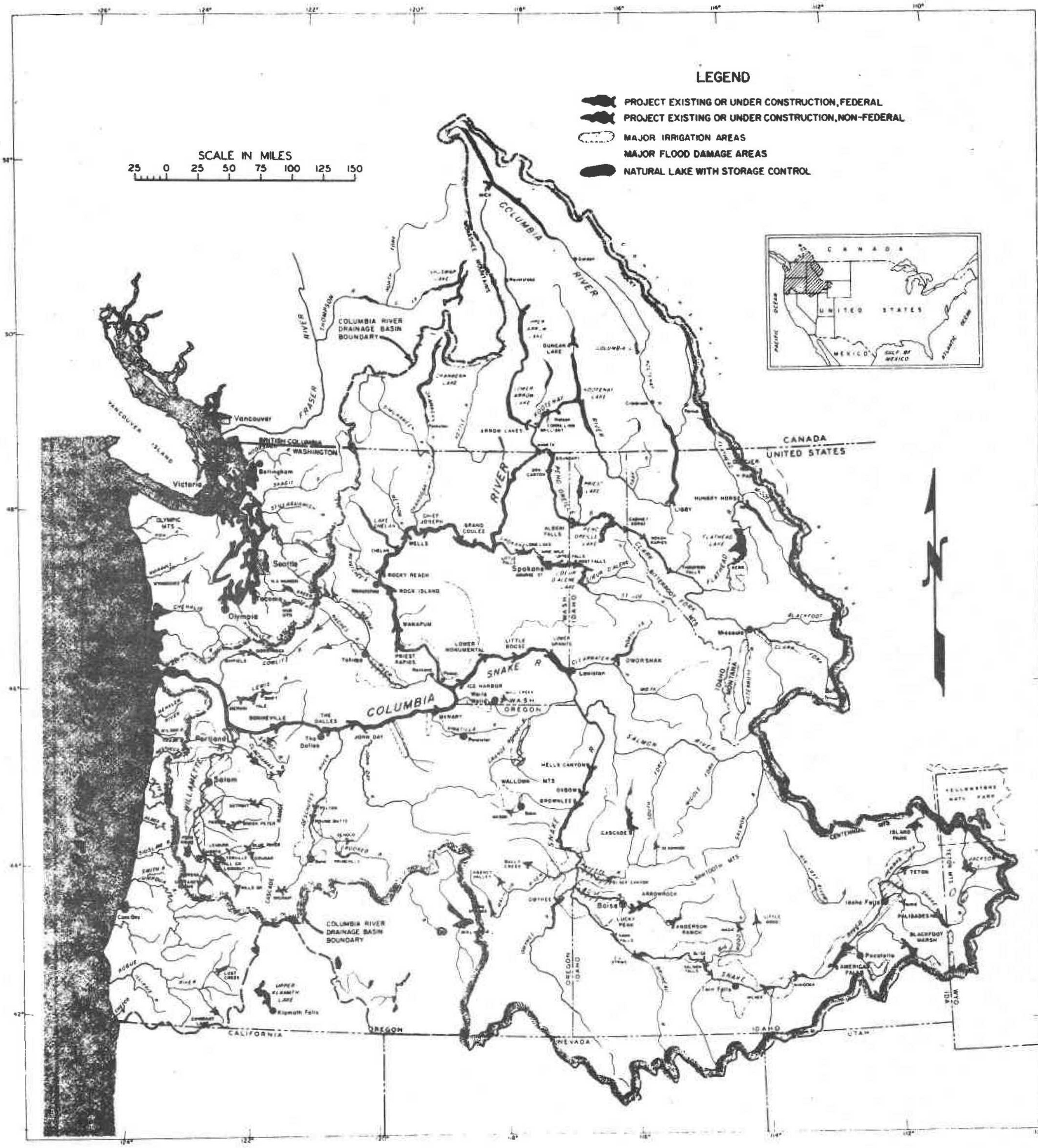

Figure 1

Oregon, Washington, Wyoming, Utah and Nevada. The Columbia River Basin is characterized by its diversity of land forms, climate, settlement patterns, and economic activity. Major tributaries of the Columbia River include: The Kootenai, Pend Oreille, Spokane, Okanogan, Yakima, Snake, John Day, Deschutes, and Willamette Rivers (Figure 1).

Originating in the glacier fields of the Canadian Rockies, the Columbia River drains an area of 39,500 square miles in Canada before entering the United States near the Washington-Idaho border. The Columbia then drains an area of 202,000 square miles of the arid Pacific Northwest interior before reaching the dominant geographic feature of the Columbia River Basin, the Cascade Mountain Range.

Bisecting the States of Oregon and Washington in a north-south direction, this mountain range separates the Columbia River Basin into two rather distinct regions. The western region is characterized by a moist climate with precipitation ranging from 30" to over 120" per year. Populated lowlands with major urban centers, and commerce dominate the economic activity. East of the Cascade range, the region is characterized by a dry climate with average precipitation generally under 12" per year. Settlement is sparse with agriculture the major economic activity. Overall, the Columbia River travels 1,250 miles before joining the sea near Astoria, Oregon.

Most of the annual precipitation in the Columbia River Basin is concentrated in the winter months with the bulk of the precipitation falling in mountainous areas as snow to be stored in deep snow-packs awaiting the warmth of spring for its release. As a result, the winter streamflows are generally low with high sustained runoff flows occurring in the spring and early summer. This runoff pattern of the Columbia River exemplifies a major seasonal maldistribution of flow with about 60% of the natural runoff of the Columbia occurring during the months of May, June and July. The Columbia has an average annual runoff at the mouth of 180,000,000 acre-feet making it second only to the Missouri-Mississippi River System in the United States in average annual runoff.

B. Multiple Uses of the Columbia River System:

The Columbia River is a very complex and heavily utilized resource. No other single resource in the Pacific Northwest influences the character and way of life of people in the region as much as the Columbia River and its major tributaries. The Pacific Northwest is dependent to a large extent upon the Columbia River for its power, food, and fiber through irrigation; transportation through navigation; recreation, fisheries, and to a lesser extent, municipal and industrial water supply.

The 1973 Northwest power shortage, national interest in environmental and conservation issues, and the recent gasoline shortage have contributed to a greater public awareness of the finite nature of the natural resources within the Pacific Northwest Region. Although there have been times in the past when the use that could be made of the Columbia River System appeared to be unlimited, it is becoming evident that with the existing level of development of 43.5 million acre-feet of storage, the system will be unable to continue to completely serve its many diverse uses, such as irrigation, navigation, fish migration, hydropower, recreation, and flood control. These uses have often been and will continue to be in various degrees of competition especially during periods of low water.

The future river system development requires a system-wide analysis to insure that it will continue to provide for the highest possible public benefit. This analysis requires synthesizing several hydrologic models for the Columbia River System. The basic input to these models are modified streamflows derived by the Columbia River Water Management Group for various levels of irigation development.[1] It is recognized that any future commitment of the waters of the Columbia River for a specific use may adversely affect other river uses.

II. IRRIGATION DEPLETIONS/INSTREAM FLOW STUDY:

A. Scope and Objectives:

To provide an estimate of these costs and impacts on future uses of the Columbia River System, the Corps of Engineers has been analyzing the impacts that would be associated with possible future decisions made affecting the allocation of Columbia River water. Called the Irrigation Depletions/ Instream Flow Study[2], its objective is to identify and evaluate the impacts that alternative irrigation depletion levels and minimum instream flow levels would have on the use and operation of the Columbia River System.

B. Conditions Evaluated:

The study has evaluated the impact that three alternative irrigation depletion levels and four alternative minimum instream flow levels would have on the operation and use of the Columbia River System. The alternative irrigation depletion levels evaluated are based on:

a. 1970 level of irrigation development.

b. Year 2020 OBERS (Office of Business Economics - Economic Research Service) level of irrigation development.

c. State-derived year 2020 projected level of irrigation development.

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1. Refer to paper by James A. Anderson, Jack McCloud, John Dillard, and Wilbur Simons entitled "Derivation of Modified Streamflow," October 1976.

2. Study by the Corps of Engineers under the general direction of the Walla Walla District Engineer with cooperation by the States of Idaho, Montana, Oregon, and Washington; The Bureau of Reclamation; Bureau of Outdoor Recreation; Bonneville Power Administration; Pacific Northwest River Basins Commission; Columbia Basin Fisheries Technical Committee; and the Columbia River Water Management Group. The report is currently under review and subject to change.

The alternative minimum instream flow levels evaluated are based on:

1. Zero instream flow level.

2. Existing minimum instream flow level established by Federal Power Commission (FPC) license or operating practice.

3. Mean instream flow levels between Alt. 2. and 4.

4. High minimum instream flow level.

C. Impacts Evaluated

With these three irrigation depletion levels and four minimum instream flow levels, 12 simulation studies were made on the effect that alternative irrigation depletions and minimum instream flows would have on the operation and management of the Columbia River System as it relates to:

a. Power
b. Fish and Wildlife
c. Anadromous Fish
d. Recreation
e. Irrigation
f. M&I Water Supply
g. Navigation
h. Water Quality

D. Impacts of Future Irrigation Development

1. Value of Future Irrigation Development:

The results of the study have shown that projected increases in irrigation depletion levels and minimum instream flow levels do indeed have significant effects both beneficial and adverse on all river uses. Many of these impacts are directly related to the consumptive withdrawal of Columbia River water for future irrigation development in the basin. Irrigation development is presently increasing at some 80,000 acres/year[3] throughout the Columbia River Basin. The 5 Pacific Northwest States have estimated that this rate of irrigation development will continue for the forseeable future, reaching an estimated 11,100,000 acres of development by 2020 from the 1970 level of development of 7,000,000 acres. Major areas receiving pressure for irrigation expansion are the upper and middle Snake River areas of Idaho, central Washington, the Horse Heaven Hills area of Washington, and the Umatilla area of Oregon (Figure 2)

This increased irrigation development will result in major economic benefits to the region. The economic benefit is related to the direct value

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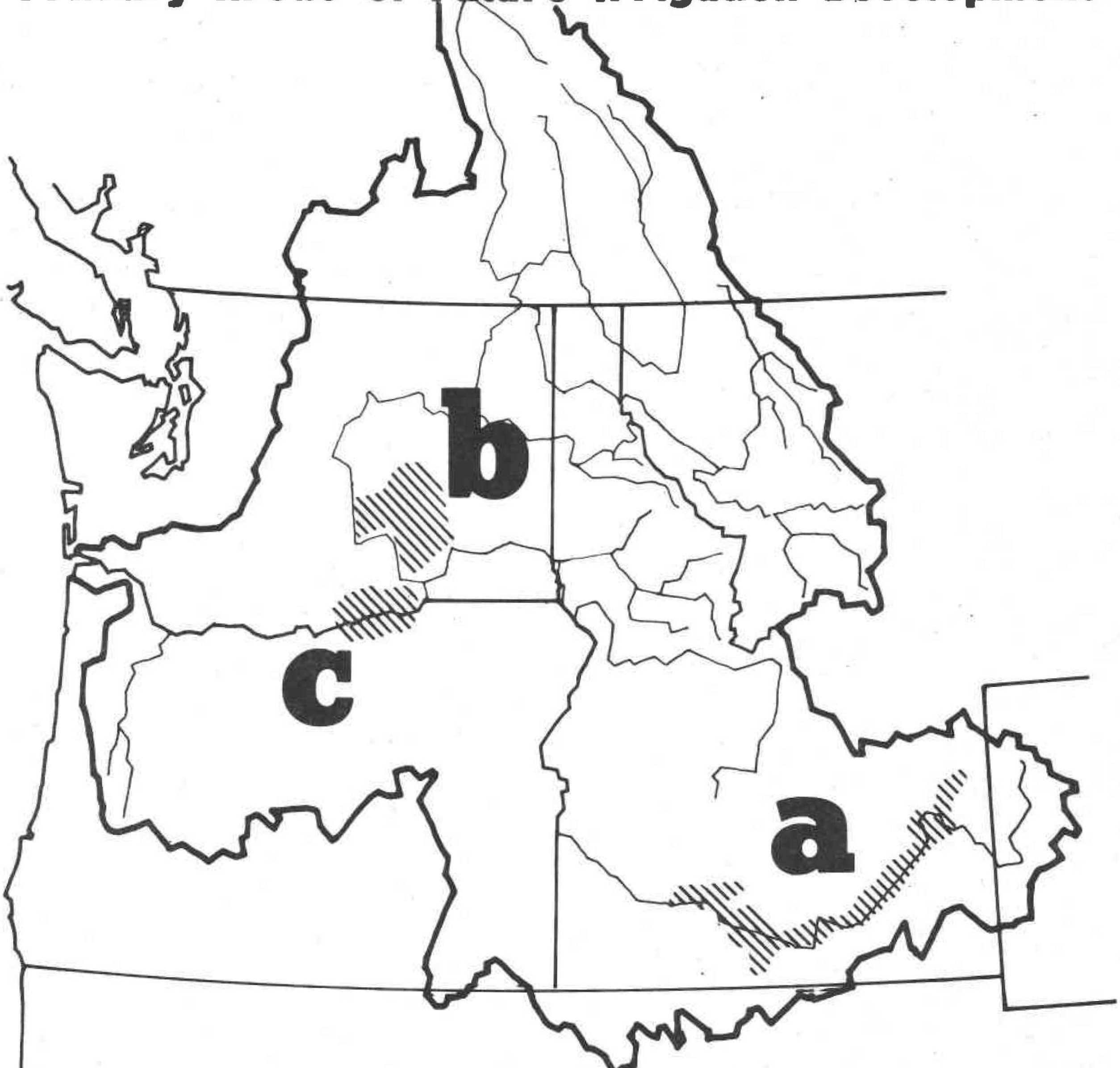
3. U.S. Bureau of Reclamation Technical Report to the Pacific Northwest River Basins Commission on expected irrigation development in the Pacific Northwest, Boise, ID, April 1976.

Columbia River Basin
Primary Areas of Future Irrigation Development



a **Upper & Middle Snake River Basin**

b **Big Bend**

c **Horse Heaven Hill - Umatilla & Boardman**

Figure 2

of agricultural commodities produced and the establishment of agricultural related industries, such as farm equipment distributors and food processing plants. By the year 2020, it is estimated that the annual gross economic value of future irrigation development in the Columbia River Basin at current price level will be about $580/acre.[4] On this basis, if an additional 4,100,000 acres of irrigation development would occur in the Columbia River Basin, the annual gross economic value of this level of development would be 3.9 billion dollars. Future irrigation developments, however, will not occur without major economic costs and possible adverse effects on other river uses. (Figure 3)

2. Impact on Hydropower Generation:

Certainly, one of the major river uses that will be adversely affected by future irrigation development in the region is hydropower generation. Power impacts associated with future irrigation take two forms; the power required for pumping irrigation water from the river to the land, and lost generation due to the removal of water from the river. While power required for pumping is substantial, this paper is limited to discussing the impact of future irrigation development on the power generation capability of the Columbia River hydropower system. As water is removed from the Columbia River System for irrigation, the power generation capability of the Columbia River is reduced. For instance, if the Columbia River Basin's present level of irrigation of around 7,000,000 acres was to increase by some 3,000,000 acres to 10 million acres as projected by the Office of Business Economics and the Economic Research Service (OBERS), the runoff of the Columbia River at The Dalles would annually be reduced by 6,502,000 acre-feet. Associated with this depletion would be an annual energy generation loss of nearly 800MW with an estimated current annual economic value of $92,000,000 (see Figure 4). This level of energy loss would cause an annual loss of industrial output in the Pacific Northwest of $1,500,000,000.[5] (Figure 5)

As has been previously stated, the five Pacific Northwest States have estimated that between 1970 and 2020 irrigation in the Columbia River Basin will increase by 4.1 million acres, reaching a total in the year 2020 of 11,100,000 acres.[6] This level of irrigation development would deplete the Columbia River at The Dalles annually by over 8½ million acre-feet from the 1970 level of development. This depletion is equivalent to about 1½ times the usable storage capacity of Grand Coulee Dam. The annual energy loss will increase at a rate corresponding to the level of irrigation development reaching 966MW at the year 2020 level of irrigation development. The estimated net annual value of the year 2020 level of power loss would be $113,000,000 at the consumer's price for power from the Columbia River System. This is equivalent to the annual generation of one nuclear power plant or equivalent to the energy

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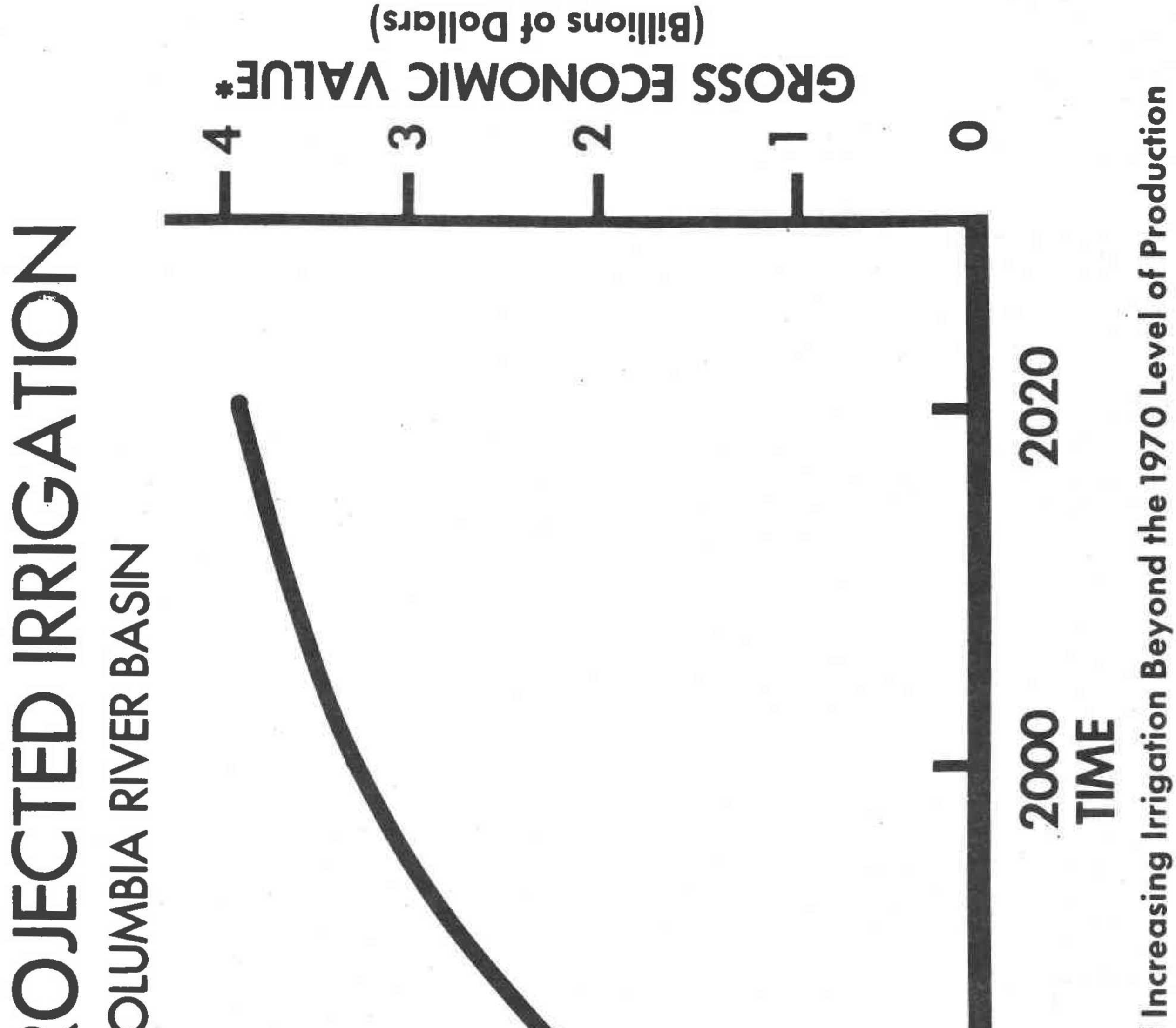
4. U.S. Bureau of Reclamation; Irrigation Impact Assessment Report for inclusion into Corps of Engineers' "Irrigation Depletions/Instream Flow Study," Boise, ID, April 1976.

5. Bonneville Power Administration, Personal Interview, Portland, OR, Sept. 1976.

6. Estimate based on input by the States of Idaho, Montana, Oregon, and Washington to the Corps of Engineers' "Irrigation Depletions/Instream Flow Study."



STATE PROJECTED IRRIGATION
COLUMBIA RIVER BASIN
MILLIONS OF IRRIGATED ACRES
7
8
9
10
11
GROSS ECONOMIC VALUE*
(Billions of Dollars)
0
1
2
3
4
1970
1980
2000
2020
TIME
*Incremental Gross Value of Increasing Irrigation Beyond the 1970 Level of Production

Figure 3

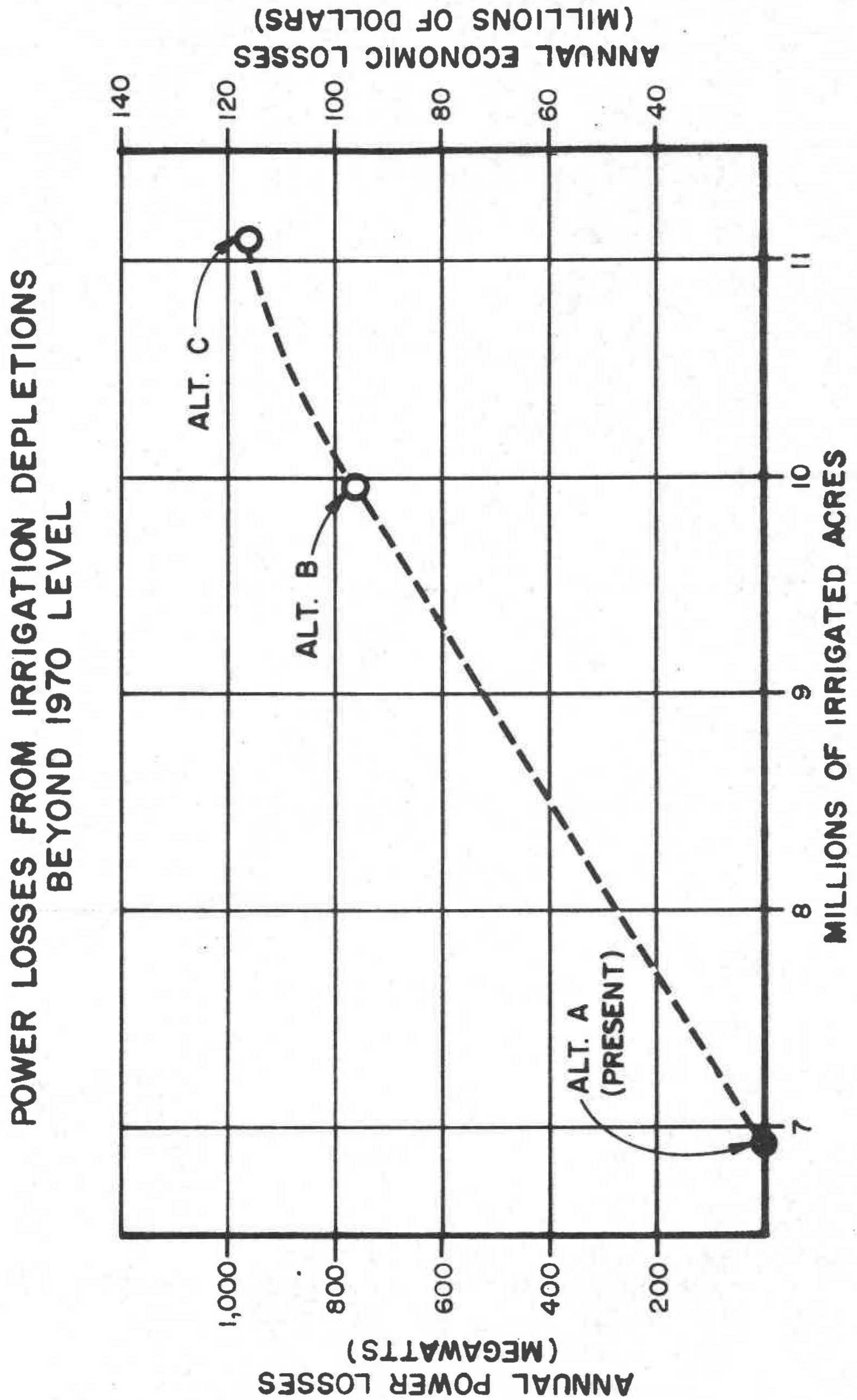

POWER LOSSES FROM IRRIGATION DEPLETIONS
BEYOND 1970 LEVEL
ANNUAL ECONOMIC LOSSES
(MILLIONS OF DOLLARS)
140
120
100
80
60
40
ALT. C
ALT. B
ALT. A
(PRESENT)
1,000
800
600
400
200
ANNUAL POWER LOSSES
(MEGAWATTS)
7
8
9
10
11
MILLIONS OF IRRIGATED ACRES

Figure 4

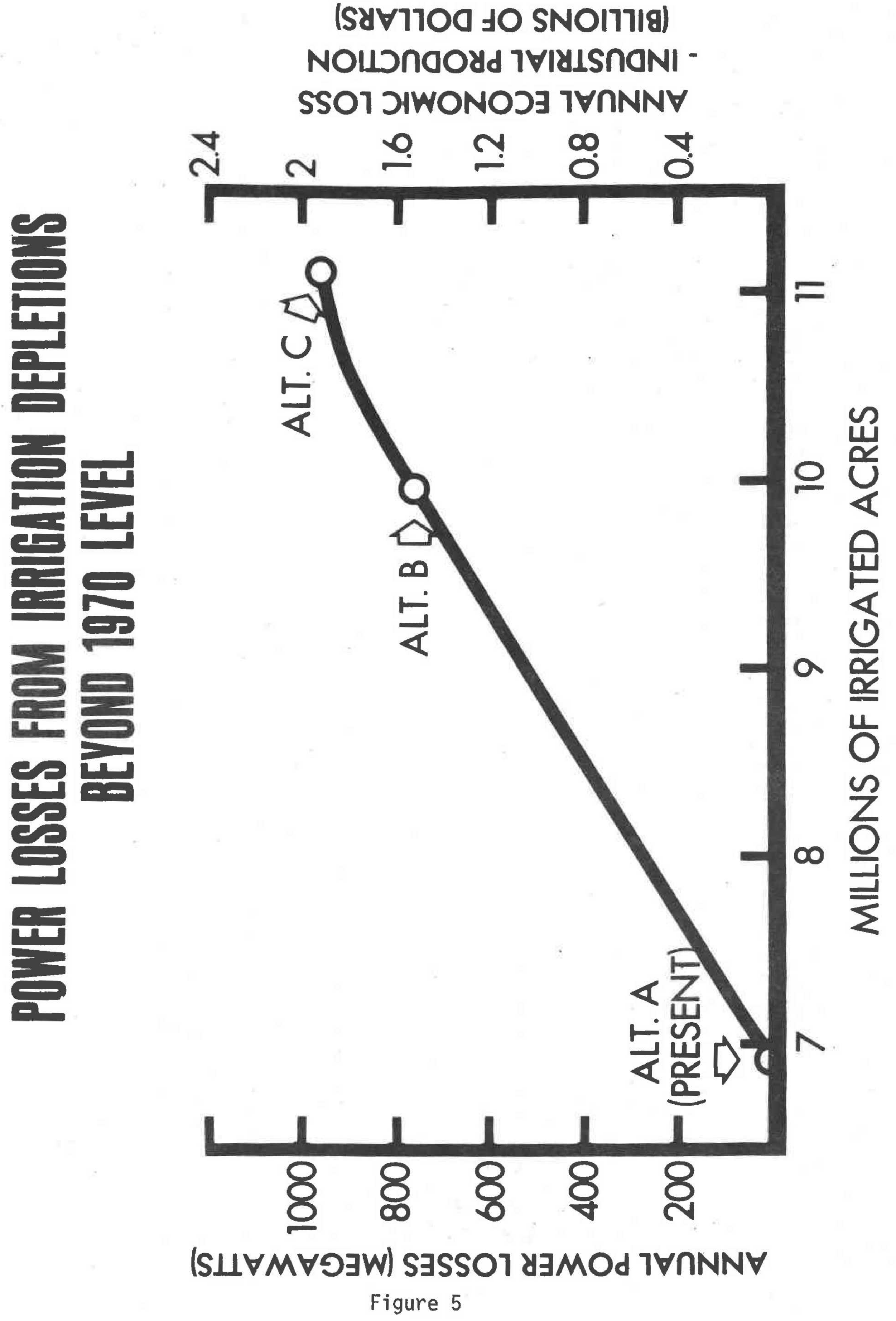

POWER LOSSES FROM IRRIGATION DEPLETIONS
BEYOND 1970 LEVEL
ANNUAL POWER LOSSES (MEGAWATTS)
200
400
600
800
1000
ANNUAL ECONOMIC LOSS
- INDUSTRIAL PRODUCTION
(BILLIONS OF DOLLARS)
0.4
0.8
1.2
1.6
2
2.4
MILLIONS OF IRRIGATED ACRES
7
8
9
10
11
ALT. A
(PRESENT)
ALT. B
ALT. C

Figure 5

of over 13,000,000 barrels of oil annually. The 966MW of energy loss would cause an annual loss of industrial output in the Pacific Northwest of $1,800,000,000.[7] This estimate was computed by comparing available streamflow after projected irrigation depletions with the region's current energy demand. Therefore, during months of high runoff such as May and June which have generally low power demands, power losses associated with future irrigation development would be negligible. During low-flow periods in late summer and early fall, however, water supply for power generation would be seriously impacted by future irrigation development occurring during this time of the year.

3. Impact on Other River Uses:

Future irrigation development will also impact other non-power river uses. As existing storage would be drafted during the summer period to provide for needed irrigation water supply, recreation use of the storage reservoirs could be adversely affected. The recreation impacts would be related to such features as stranding of boat ramps and docks, difficult access to the reservoir's shoreline, and the creation of an aesthetically unattractive appearance to the reservoir. The magnitude of this recreation impact would vary by reservoir due to several factors including reservoir surface area, reservoir cross-section, slope of the beach, range of acceptable operation for established boat ramps, and soil character of the beach. The irrigation impacts on instream river uses, such as navigation and fish migration appear to be minimal. However, the establishment of minimum instream flow levels on the Columbia and lower Snake Rivers would have significant impacts on all river uses.

E. <u>Impacts of Minimum Instream Flows</u>:

1. Impact on Anadromous Fishery:

The establishment of alternative minimum instream flow levels on the Columbia and lower Snake Rivers would cause both beneficial and adverse effects on the use and operation of the Columbia River System. The Irrigation Depletions/Instream Flow Study has shown that as minimum instream flow levels would be increased, instream river uses such as fish migration, navigation, water quality and recreation would be improved. As an example of these benefits, the following Figures 6 and 7 show the impact that increased minimum instream flow levels for the lower Snake River would have on the adult and juvenile anadromous fishery of the lower Snake River, respectively.

This analysis is based on data developed for the study by representatives of the Federal and State fish and wildlife agencies of the Pacific Northwest. The production quotient provides a basis for correlating minimum flows with survival rates of fish. Production quotient 10 is defined as an optimum condition for anadromous fish. A value of 1 identifies the most adverse condition for fish. Looking at flow conditions affecting the survival of adult fish, survival rates increase at an increasing rate with increased flows with the most benefit occurring with flows between 10,000 and 20,000 cfs. This same trend occurs with juvenile fish.

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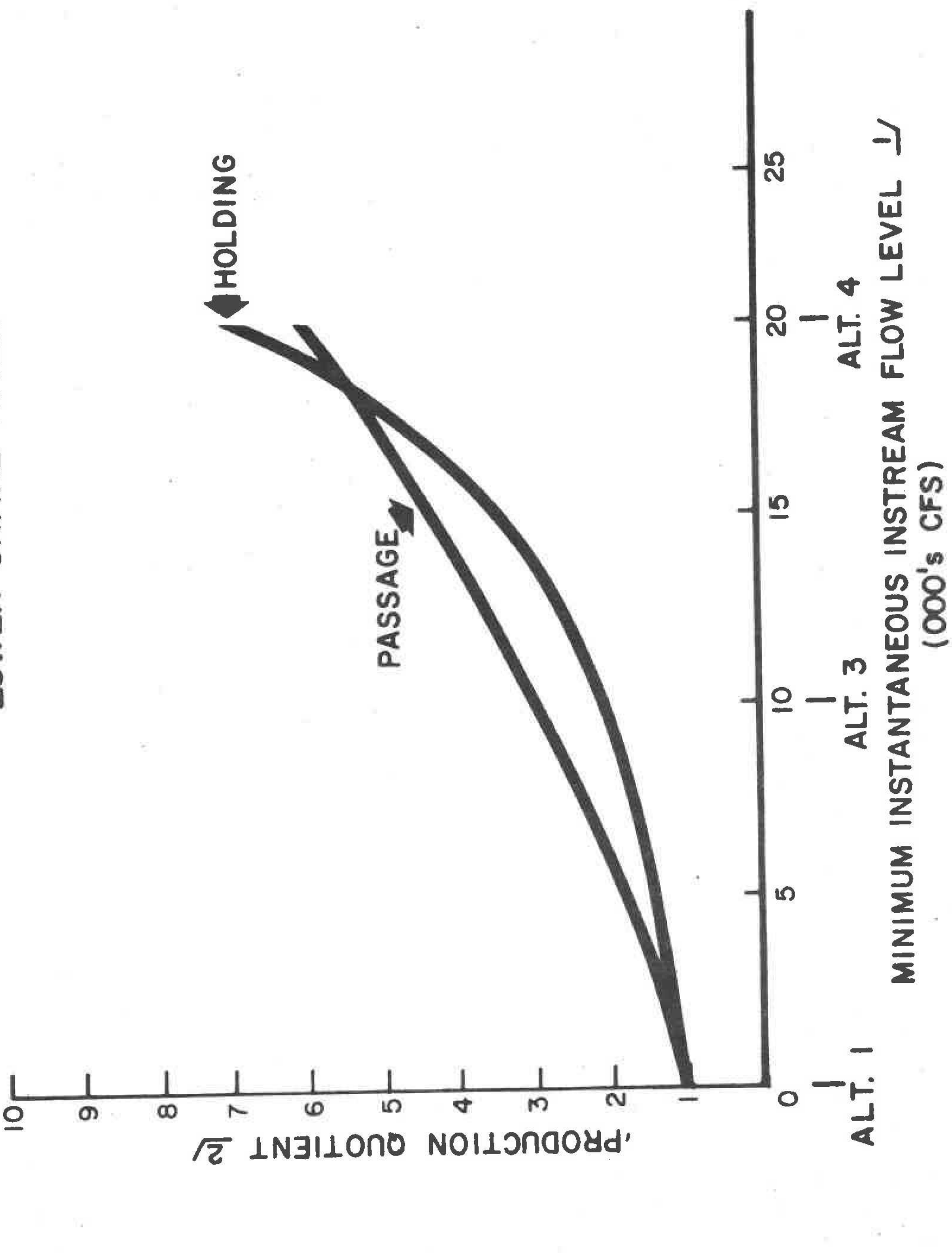
7. Bonneville Power Administration, <u>op</u>. <u>cit</u>., Sept. 1976.

IMPACT OF MINIMUM INSTREAM FLOW LEVELS ON ADULT ANADROMOUS FISH
LOWER SNAKE RIVER

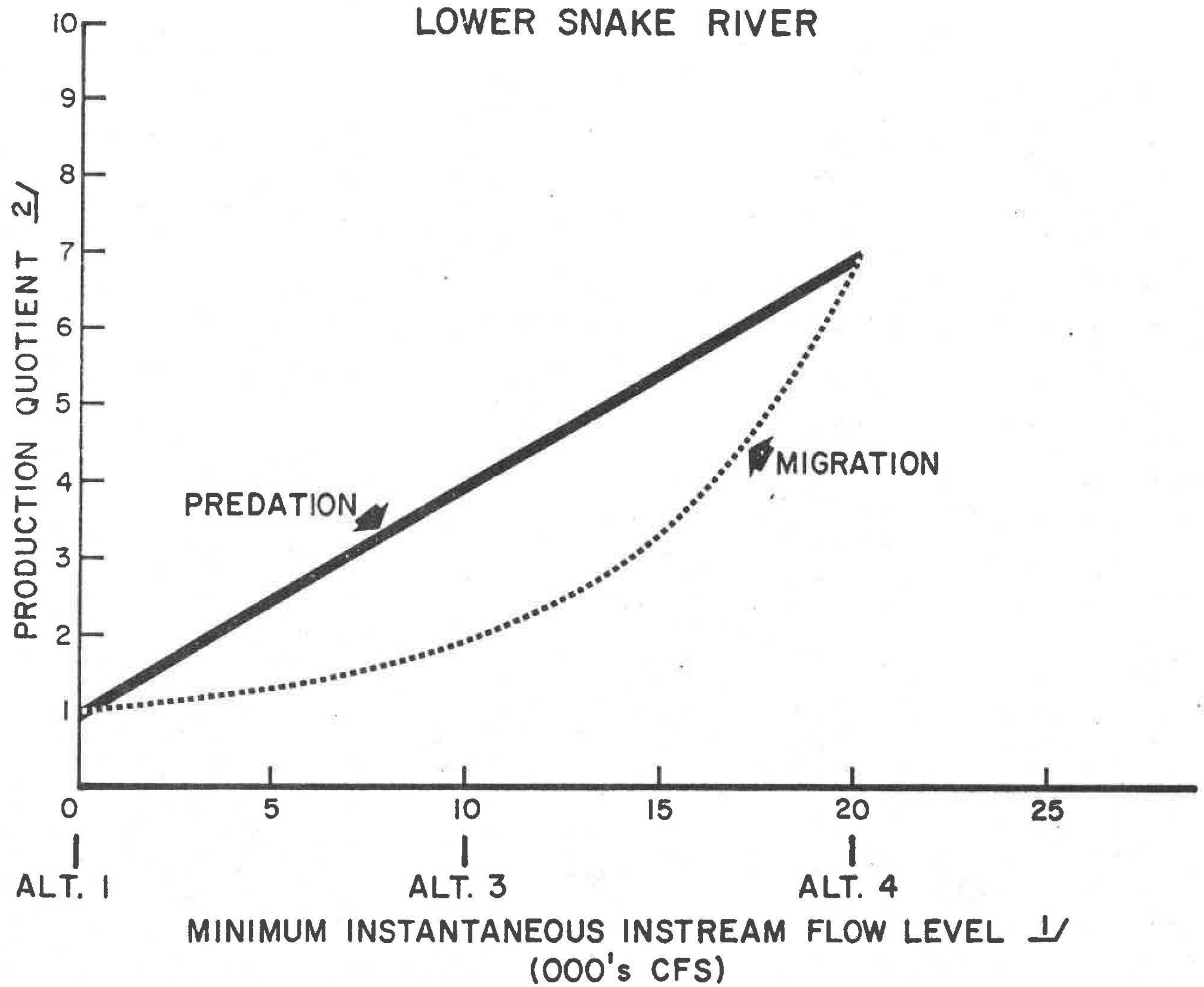


1/ Based on the minimum annual instream flow level

2/ Computed on the basis of the level of adverse effect (1 is the highest adverse effect; 10 is the lowest adverse effect.)

Figure 6

IMPACT OF MINIMUM INSTREAM FLOW LEVELS ON JUVENILE ANADROMOUS FISH LOWER SNAKE RIVER



1/ Based on the minimum annual instream flow level.

2/ Computed on the basis of the level of adverse effect (1 is the highest adverse effect, 10 is the lowest adverse effect.)

NOTE: This analysis is based on empirical data and more detailed studies are required to verify this correlation

Figure 7

2. Impact on Power:

The establishment of alternative minimum instream flows also results in major costs and tradeoffs to other river uses. For instance, the establishment of high minimum instantaneous instream flow levels severely reduces the ability of the Columbia and lower Snake River projects to pond water during off-peak hours for use in generating power during the early morning peak power demand period. The reduced ponding ability leads to significant losses in peak power generation. Figure 8 shows the correlation of minimum instantaneous instream flow levels with the loss of peak power generation capability at the four lower Snake River projects. As shown in Figure 8, the 20,000 cfs minimum instantaneous instream flow level for the lower Snake River would cause a loss of peak power generation at the four lower Snake River projects of nearly 1,800 MW, with an annual economic value of $97,000,000.[8] This represents 85% of the total system power loss of 2,161 MW associated with this minimum instream flow level.

3. Impact on River Uses:

Other impacts associated with alternative minimum instream flow levels would be a reduction in out-of-bank river uses such as irrigation and M&I water supply, and storage reservoir uses such as recreation. Existing storage projects would have to be drafted during low flow periods to augment natural runoff to meet increased or newly-established minimum instream flow levels.

As an example of the magnitude of this required drafting of existing storage to maintain the high minimum instream flow level, during water year 1939, the eighth driest year on record, Dworshak Reservoir would have to be drafted by as much as 109 feet during the late summer period (see Figure 9). This condition would have drastic adverse effects on reservoir uses such as recreation and irrigation. In addition, water normally stored from the spring freshet would not be available to augment the winter stream flows for hydropower generation and other needs. All storage projects in the Columbia River Basin would be likewise affected.

III. CONCLUSIONS:

What the Irrigation Depletions/Instream Flow Study has indicated is that the Columbia River as presently developed is no longer a surplus resource. Any expansion of use of the Columbia River, whether that be instream or out-of-bank use, will involve costs and tradeoffs to other river uses. As an example, the annual economic impact on total power production of the Columbia River System of both alternative irrigation depletions and minimum instream flow levels is shown on Figure 10.

As shown, with the existing system of basin storage, a combination of increasing irrigation by over 4,000,000 acres from the 1970 level of

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8. Corps of Engineers, "Irrigation Depletions/Instream Flow Study," (Walla Walla, WA), July 1976.

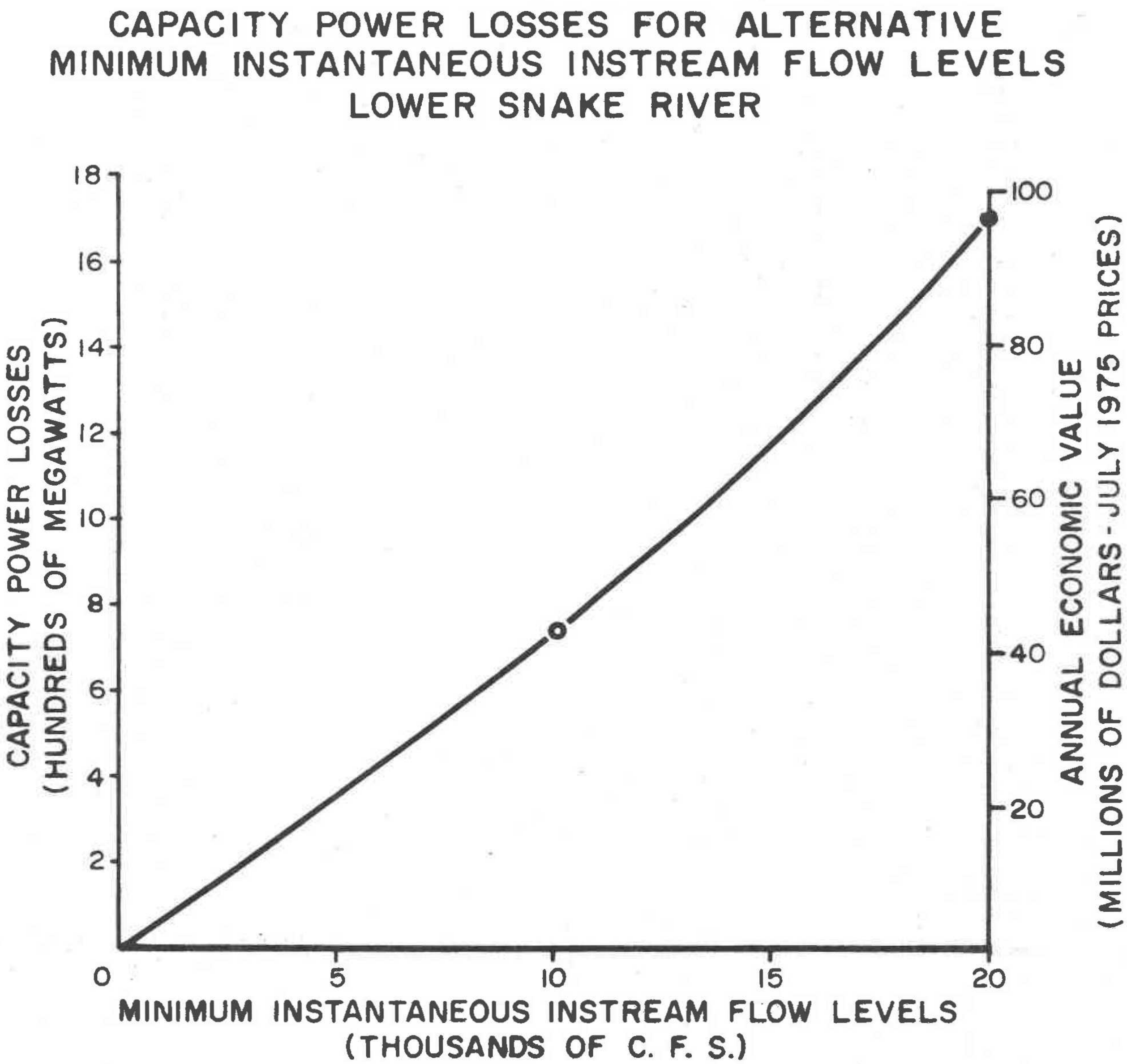
CAPACITY POWER LOSSES FOR ALTERNATIVE
MINIMUM INSTANTANEOUS INSTREAM FLOW LEVELS
LOWER SNAKE RIVER
CAPACITY POWER LOSSES
(HUNDREDS OF MEGAWATTS)
18
16
14
12
10
8
6
4
2
0
5
10
15
20
100
80
60
40
20
ANNUAL ECONOMIC VALUE
(MILLIONS OF DOLLARS - JULY 1975 PRICES)
MINIMUM INSTANTANEOUS INSTREAM FLOW LEVELS
(THOUSANDS OF C. F. S.)

Figure 8

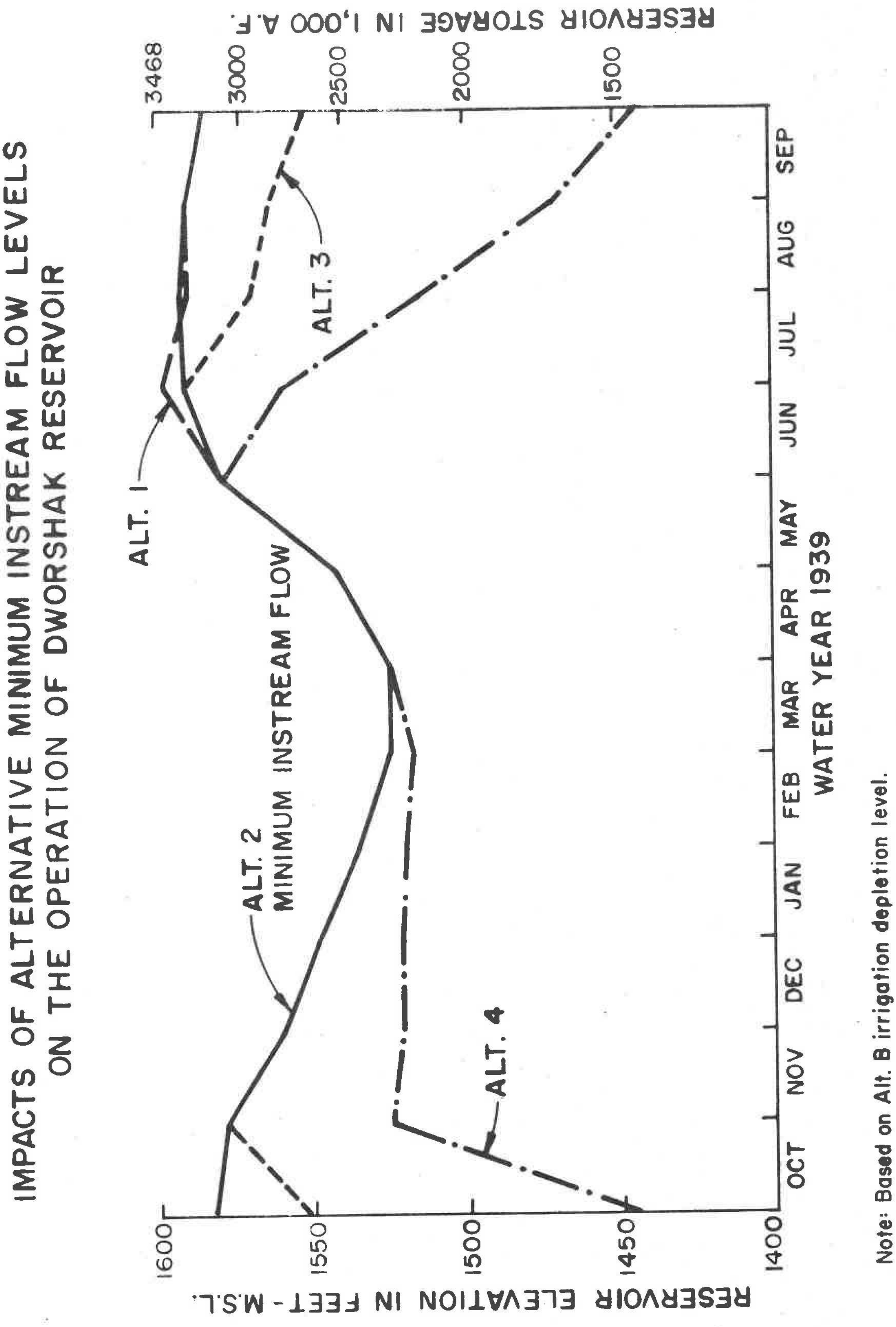
IMPACTS OF ALTERNATIVE MINIMUM INSTREAM FLOW LEVELS
ON THE OPERATION OF DWORSHAK RESERVOIR
RESERVOIR STORAGE IN 1,000 A.F.
3468
3000
2500
2000
1500
RESERVOIR ELEVATION IN FEET - M.S.L.
1600
1550
1500
1450
1400
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
WATER YEAR 1939
ALT. 1
ALT. 2
MINIMUM INSTREAM FLOW
ALT. 3
ALT. 4
Note: Based on Alt. B irrigation depletion level.

Figure 9

ANNUAL ECONOMIC IMPACT OF ALTERNATIVE IRRIGATION DEPLETION AND MINIMUM INSTREAM FLOW LEVELS ON POWER PRODUCTION OF THE COLUMBIA RIVER HYDROPOWER SYSTEM

IRRIGATION DEPLETION ALTERNATIVES / MINIMUM INSTREAM FLOW ALTERNATIVES	A (1970)	B (2020 OBERS)	C (2020 STATE)
1	+ $ 5,700,000	- $ 87,000,000	- $ 107,000,000
2	BASE	- $ 92,000,000	- $ 113,000,000
3	- $ 52,000,000	- $ 152,000,000	- $ 175,000,000
4	- $ 280,000,000	- $ 372,000,000	- $ 399,000,000

Figure 10

irrigation development and establishing optimum minimum instream flow levels on the Columbia and lower Snake Rivers for anadromous fish would cause a $400,000,000 annual economic loss based on the consumer's current price for power from the Columbia River hydropower system.[9] Before decisions are made affecting the future use and allocation of Columbia River water, we all must be fully aware of these costs and trade-offs so that decisions can be made with a full understanding of associated benefits and costs.

Furthermore, the Columbia River is a regional resource that must be planned and managed as such. It is clear that plans and developmental proposals for future irrigation development should include an explicit assessment of the impacts these developments would have on the total management and use of the Columbia River System.

The Irrigation Depletions/Instream Flow Study has demonstrated that unless we augment existing basin storage, we will have to accept lower levels of projected river uses. The Columbia-North Pacific Comprehensive Framework Study prepared in 1971 by the Pacific Northwest River Basins Commission identified over 45 million acre-feet of potential storage still available in the Pacific Northwest. If the region were to develop from 10 to 12 million acre-feet of this storage, the projected river uses, both instream and out-of-bank, could occur without adversely affecting existing river uses such as hydropower generation, navigation, and recreation.

9. Corps of Engineers, op. cit., July 1976.