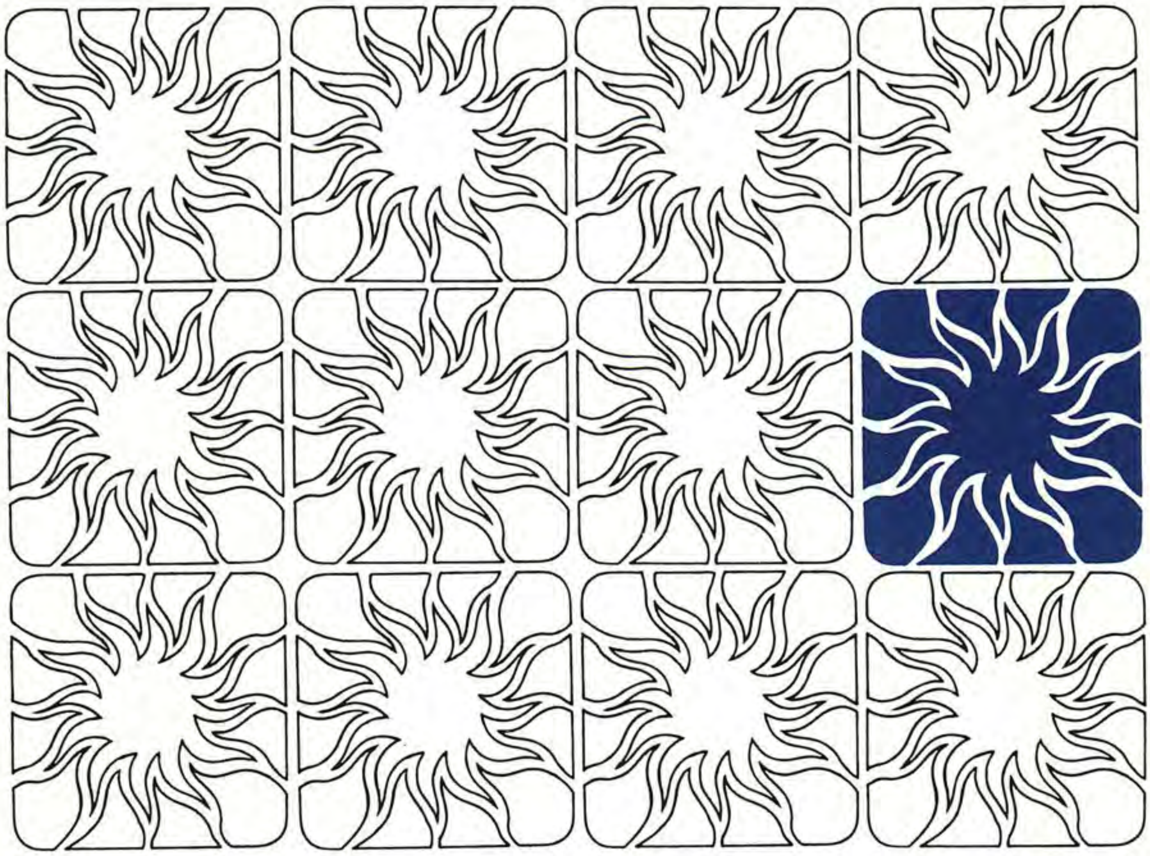
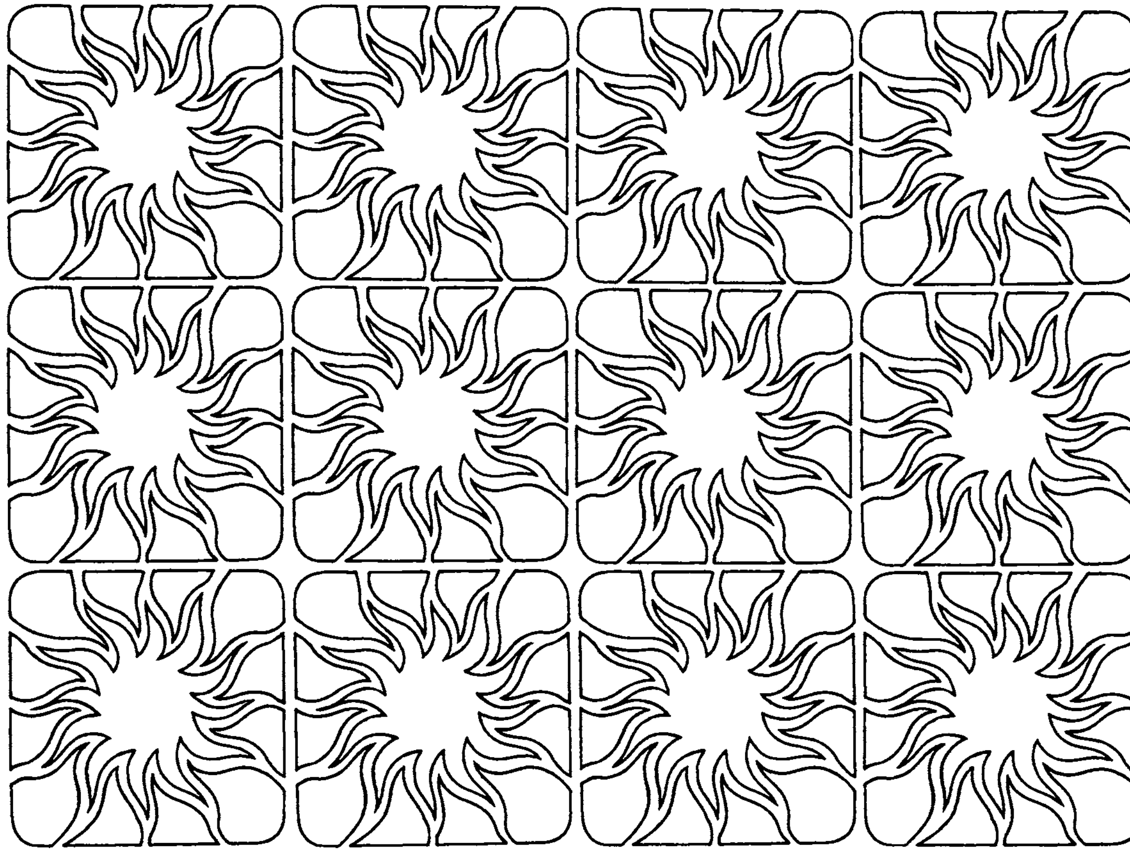


U.S. Energy Outlook

Water Availability

National Petroleum Council



U.S. Energy Outlook

Water Availability

A Report by the
Water Availability Task Group of the
Other Energy Resources Subcommittee
of the National Petroleum Council's Committee
on U.S. Energy Outlook

Chairman - W. B. Oliver
Carter Oil Company

National Petroleum Council

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Industry Advisory Council
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U.S. DEPARTMENT OF THE INTERIOR

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PREFACE

On January 20, 1970, the National Petroleum Council, an officially established industry advisory board to the Secretary of the Interior, was asked to undertake a comprehensive study of the Nation's energy outlook. This request came from the Assistant Secretary-Mineral Resources, Department of the Interior, who asked the Council to project the energy outlook in the Western Hemisphere into the future as near to the end of the century as feasible, with particular reference to the evaluation of future trends and their implications for the United States.

In response to this request, the National Petroleum Council's Committee on U.S. Energy Outlook was established, with a coordinating subcommittee, four supporting subcommittees for oil, gas, other energy forms and government policy, and 14 task groups. An organization chart appears as Appendix B. In July 1971, the Council issued an interim report entitled *U.S. Energy Outlook: An Initial Appraisal 1971-1985* which, along with associated task group reports, provided the groundwork for subsequent investigation of the U.S. energy situation.

Continuing investigation by the Committee and component subcommittees and task groups resulted in the publication in December 1972 of the NPC's summary report, *U.S. Energy Outlook*, as well as an expanded full report of the Committee. Individual task group reports have been prepared to include methodology, data, illustrations and computer program descriptions for the particular area studied by the task group. This report is one of ten such detailed studies. Other fuel task group reports are available as listed on the order form included at the back of this volume.

The findings and recommendations of this report represent the best judgment of the experts from the energy industries. However, it should be noted that the political, economic, social and technological factors bearing upon the long-term U.S. energy outlook are subject to substantial change with the passage of time. Thus future developments will undoubtedly provide additional insights and amend the conclusions to some degree.

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INTRODUCTION

The Water Availability Task Group was created in order to determine whether sufficient water supplies would be available to support the energy production projections provided by the fuel supply task groups of the U.S. Energy Outlook studies. The energy production plants--electrical power, oil shale, synthetic gas and synthetic liquids--which the fuel supply task groups project to be needed in the future, will all require large amounts of water for cooling or processing, or both. A coal liquefaction plant, for example, requires 5.3 barrels of water for each barrel of oil produced. Since the most economically attractive resources are located in the western states, this area is expected to be selected for the bulk of future energy production plants. Unfortunately, much of this area is arid, and water availability is a potential problem. There is sufficient surface water in the overall western states area to supply the needed plants, but it is often locally insufficient within the areas containing the coal and oil shale resources. Moreover, even in areas where sufficient water is physically available, legal restrictions and rights of competing users may preclude its use in energy production.

If availability of water in sufficient quantities is to be ensured, three primary requirements must be satisfied:

- The early establishment of a near billion dollar program of dams and aqueducts in order to meet Case I projections*
- The reconciliation of disputes over water rights and allocations
- The procurement of large amounts of capital for project investments, taking into account the long lead times.

While the primary emphasis of this report is aimed at the western states where most future energy development is expected, other areas of the Nation have been included.

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* Four principal supply cases (designated I through IV) were used in the NPC's U.S. Energy Outlook studies. They can be described generally as follows:

- Case I estimates the possible outcome from a maximum effort to develop domestic fuel sources.
- Cases II and III are intermediate cases, with the former having a higher level of development of domestic energy supplies than the latter.
- Case IV is the lowest supply case.

SUMMARY AND CONCLUSIONS

NATIONAL AND INTERSTATE ISSUES AFFECTING WATER AVAILABILITY

If the water supplies are to be available when needed to develop other energy resources as substitutes for petroleum, several national and interstate issues must be resolved.

- National policies must recognize that large volumes of water are required to convert coal and oil shale into useable electricity or synthetic hydrocarbon form.

- The Federal Government should take actions to encourage energy resource development, including: (1) the construction of reservoirs and aqueducts where needed to provide adequate water, (2) the expedition of the processing of enironmental impact statements for approval as required by the National Environmental Policy Act and (3) the promulgation of reasonably attainable effluent standards and other environmental protection regulations applicable to coal and shale mining and processing facilities.

- Federal, state and interstate policies relating water availability to energy resource development need to be stabilized.

- National energy needs must be weighed against potential environmental impact when any action is to be undertaken by governmental agencies or industry. Such actions must be taken in ways that will not cause substantial detrimental effect on the environment.

- Interstate water allocation compacts and state water resource authorities must recognize that some future energy resource developments will require reallocation of water supplies from other uses, most likely from agriculture.

Western States

Water requirements are based on the levels of energy resource development and unit water needs identified by the National Petroleum Council's Electricity Task Group, Coal Task Group and Oil Shale Task Group.

An estimate of the available supply of water for industrial use has been compiled from studies prepared by federal, state and private agencies. While there are differences of opinion among experts, it is believed that this composite estimate is reasonably accurate. However, two limitations on the reliability of water supply projections should be recognized:

- Physical availabiltiy is estimated from historical records, generally of limited time span and subject to long- and short-term climate trends.

- Legal availability is controlled by a complex body of water law based on interstate compacts, statutes and case law, and is subject to individual property rights created under state law.

For the critical basins of the Upper Colorado River and the Upper Missouri River, the Task Group concludes that there will be an adequate supply of water under present allocations to meet the requirements of Case I (and the lesser requirements of Cases II-IV) in all areas except Arizona and New Mexico. In these two states, the projected level of energy development would create a demand for water substantially greater than the supply allocated for this activity in the *Upper Colorado Region Comprehensive Framework Study* at the 6.5 million acre-feet per year level to the year 2000.*

The combined projected water requirements in Wyoming and Montana (for all supply cases) in the 1980-1985 period require the construction of major transmission facilities for interbasin water transfers as well as the construction of dams and pipelines to develop local supplies. The U.S. Bureau of Reclamation (USBR) has studied several systems to transport the water which will be needed in the 1980-1985 period. They will cost from $300 to $750 million and will require 8 to 10 years for planning and construction. In order to have the water available when needed, the optimum system should be identified and the project moved forward. Dams and pipelines to develop local water sources are estimated to require at least an additional $100 million.

Arizona's projected requirement of 62 thousand acre-feet per year (MAF/Y) exceeds by 80 percent the projected supply allocated for electric power (thermal) generation. New Mexico's Case I projected requirement of 180 MAF/Y (requirement in Case II/III is 168 MAF/Y and in Case IV is 140 MAF/Y) exceeds by about 68 percent the amount the state has allocated for energy and mineral development. The potential shortages in energy production created by these apparent water supply limitations could be eliminated by one or more of the following alternatives:

- Transfer of water presently allocated to other uses. (This could require approval by Congress, as well as the state and water users, if water allocated to Indian use or federally authorized projects were involved)

- Interstate movement of minerals or water

- Stream augmentation programs, such as interbasin diversions and weather modification

- Reallocation of projected plants to states where water would be available.

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* *Upper Colorado Region Comprehensive Framework Study*, Appendix XVIII--General Program and Alternatives (June 1971)--hereinafter referred to as the Upper Colorado Region Study.

These alternatives could apply to other potential water supply limitations as they arise in other locations.

The problem of water quality can be expected to become more important in the arid western states as population, industrialization and energy production continue to grow. Assuming rigorous compliance with plant and municipal effluent standards, problems of stream quality deterioration may develop from diversion of natural flows which have historically diluted the natural "pollutants" (from mineral springs, agriculture return flow, etc.).

Eastern States

No quantitative projections have been made of energy-related growth in water requirements in the eastern states. Nonetheless, the water supply situation in the Appalachian and Illinois coal provinces was considered. It was concluded that at reasonable development rates there would be no serious water availability problems during the period studied. An important consideration in any future energy development in this area will be the costs associated with the standards for mine drainage water and plant effluents designed to prevent stream pollution. In turn, the economics of energy production will be affected by the capital and operating costs required to meet these standards.

Post 1985

While there will be an adequate supply of water in the western states to meet the maximum projected requirements for energy to 1985, subject to solution of local delivery problems, water availability is likely to be a constraint on major growth in production of synthetic fuels and electricity in the Colorado and Missouri Basins after that time.

Chapter One

WATER DEVELOPMENT IN PERSPECTIVE: POLICIES, ISSUES, RESOURCES AND TRENDS

The development of water resources involves diverse problems including the following which are discussed in this chapter:

- The need to formulate national policies
- The role of the Federal Government
- The disputes over environmental protection
- The legal availability of water
- The resources in four selected regions
- The trends beyond 1985.

NATIONAL POLICIES AND MAJOR ISSUES

National policies should be developed to create a balanced economic, social and environmental framework conducive to ensuring the availability of adequate supplies of water for future energy needs and other beneficial uses as well as protecting the environment from unnecessary deterioration. The success of these policies will depend on the public's understanding of the relationship between competing uses of water and the need for maintaining adequate energy supplies.

THE ROLE OF THE FEDERAL GOVERNMENT

The Federal Government and the energy industries must address these issues:

- The Federal Government should provide leadership and guidance for appropriate interstate, state, and local government agencies and for industry, with the purpose of promoting energy resource development in the national interest.
- The Federal Government should extend its good offices to resolve disputes between the states in the administration of water laws and encourage the adoption of appropriate and equitable interstate arrangements dealing with allocation of the available water resources. National well-being should receive consideration in the adoption and adminstration of water laws.
- The Federal Government, following guidelines developed by the Water Resources Council, should assume primary responsibility for planning major multipurpose water development

projects such as main stream dams and aqueducts which are needed to serve dispersed energy resource deposits and related electric power development. Future energy requirements should be considered a part of each river basin or regional water plans. Moreover, the Federal Government should provide adequate data for future water and energy resource assessments.

ENVIRONMENTAL PROTECTION

Any development and use of water for energy production may affect the environment. Potential adverse environmental effects resulting from water development for energy production should be identified during the planning process. These effects can be minimized through research and implementation of new energy technology. As technological progress is reduced to practice, authorities will be able to make intelligent choices, considering both future energy requirements with accompanying water needs and the demands for environmental protection. For this purpose, the energy industries should:

- Provide leadership in development of ecologically sound resource utilization policies and the efficient use of water in the production of energy supplies.

- Strive to develop better industry-government-consuming public communications to expedite compliance with the environmental impact statement requirements of the National Environmental Policy Act in the best interest of the Nation.

- Encourage and cooperate with states' authorities and with the Federal Environmental Protection Agency to adopt economically attainable environmental protection standards. These should include standards for protection and restoration of land surface and facility effluent standards designed to minimize pollution from discharges into public waters. The Federal Water Pollution Control Act Amendments of 1972 require the application of the "best available technology economically achievable" for effluent control to be implemented by July 1, 1983.

THE LEGAL AVAILABILITY OF WATER

Before proceeding to a region-by-region discussion of water availability, three factors relating to the legal availability of water should be noted:

- All of the western states involved here are "appropriation" states. There are two types of appropriation. First, water rights are acquired initially by filing a notice of appropriation in accordance with a procedure established by state statutes, followed by construction of works and application of water to use with reasonable diligence. A second type of appropriation is that for a right to store water for ultimate use. The right to the quantity ultimately put to use (limited by the quantity originally appropriated) "relates back" to the date of filing notices; i.e., the date establishing the priority of the right. Shortages are borne by appropriators in the inverse order of priorities.

A water supply for a particular coal conversion plant may thus be obtained either by an initial appropriation of unappropriated water (if any), or by purchase of an existing appropriation. The fact that the water in a particular stream may be fully appropriated is thus not a conclusively negative answer to the availability of water. There are, however, limitations on the right of transfer, e.g., other appropriators must not be adversely affected by a change in the place of diversion.

- In all of the western states, the Federal Government has constructed large projects to store and convey water, under the Reclamation Act or statutes authorizing construction of works by the Corps of Engineers. In addition, Congress has authorized large projects which have not yet been constructed. In some cases, the Federal Government has acquired water rights for these projects under state laws. In others, it has initially established water rights in its own name in the exercise of federal constitutional power (e.g., the Boulder Canyon Project Act). In all cases, however, obtaining water stored by federal projects is dependent on the execution of contracts with the United States.

- All of the river basins involved are subject to interstate compacts, which impose restrictions on the use of water. Additionally, in the Colorado River Basin, the Mexican Water Treaty imposes an added constraint in the form of a guaranteed delivery to Mexico of 1.5 million acre-feet annually.

RESOURCES IN FOUR REGIONS

In order to develop water resources, it is necessary to examine our water supplies and demands for the conterminous United States for years 1965 through 2000. Our water deficiencies in the southwestern United States are the most critical due to both quantity and quality (see Tables 1-4). Because of these deficiencies and because of the competition for water supplies that will evolve between various users, expanded information is provided for the Upper Colorado, Lower Colorado, Great Basin and California Regions.

Water supply problems in these four regions are quite different (see Figure 1):

- Upper Colorado Region: The Upper Colorado Region has an adequate supply and projected demand less than available supply.

- Lower Colorado Region: The Lower Colorado Region, in

TABLE 1
WATER WITHDRAWALS FOR PUBLIC WATER SUPPLIES
(Millions of Gallons Per Day)

Region Numbers	Names of Regions	Estimates of Actual Withdrawals 1955	1960	1965	1970	Projections 1985	2000
1-2	New England — Middle Atlantic	4,449	4,880	5,300	6,567	8,700	10,000
	New England (North Atlantic)	950	1,000	1,200	1,399	—	—
	Upper Hudson	196	—	—	—	—	—
	Lower Hudson and Coastal Area	1,720	3,000	3,100	—	—	—
	Delaware	720	—	—	—	—	—
	Chesapeake	863	880	1,000	—	—	—
	Middle Atlantic	—	—	—	5,168	—	—
3	South Atlantic — Gulf	1,340	1,790	2,110	2,283	4,600	5,400
	South Atlantic	—	1,300	1,500	—	—	—
	Eastern Gulf	—	490	610	—	—	—
5-6	Ohio — Tennessee	1,861	1,820	2,050	2,741	3,300	3,880
	Ohio	1,620	1,500	1,700	—	—	—
	Ohio and Cumberland	—	—	—	2,441	—	—
	Cumberland and Tennessee	241	320	350	—	—	—
	Tennessee	—	—	—	300	—	—
	Cumberland	—	—	—	—	—	—
9-10	Souris-Red-Rainy-Missouri	800	843	1,005	1,074	1,500	1,563
	Souris-Red-Rainy (Hudson Bay)	—	33	35	48	—	—
	Upper Missouri	—	650	770	—	—	—
	Lower Missouri	—	160	200	(1,026)	—	—
11	Arkansas-White-Red	610	630	680	757	1,400	2,375
	Upper Arkansas-Red	—	350	370	—	—	—
	Lower Arkansas-Red-White	—	280	310	—	—	—
12-13	Texas-Gulf-Rio Grande	1,050	1,200	1,300	1,460	2,600	3,838
	Texas-Gulf	—	—	—	1,144	—	—
	Rio Grande	—	—	—	316	—	—
14-15	Colorado	190	270	410	467	810	1,020
	Upper Colorado	—	—	—	75	—	—
	Lower Colorado	—	—	—	392	—	—

Source: Water Resources Council, *The Nation's Water Resources, The First National Assessment* (Washington, D.C., 1968).

TABLE 2
SUMMARY OF WATER SUPPLIES AND DEMANDS BY MAJOR WATER REGIONS — 1965
(Billions of Gallons Per Day)

Region	Water Supply: Regulated Runoff	Water Supply: Imports-Exports	Water Supply: Basin Inflows	Water Supply: Withdrawal Supply	Water Supply: In-Channel Requirement	Water Supply: Consumptive Use Supply	Water Demand: Total Withdrawal	Water Demand: Total Consumptive Use	Gross Demand/ Supply Ratio (Percent)*	Net Demand/ Supply Ratio (Percent)†
North Atlantic	145.10	—	—	145.10	1.92	143.18	26.07	1.94	18	1
South Atlantic-Gulf	169.30	—	—	169.30	19.70	149.60	16.86	2.68	10	2
Great Lakes	51.80	—	—	51.80	6.32	45.48	25.12	1.20	49	3
Ohio	108.90	—	—	108.90	8.76	100.14	28.26	1.13	26	1
Tennessee	38.60	—	—	38.60	4.15	34.45	5.77	0.33	15	1
Upper Mississippi	49.10	—	—	49.10	6.46	42.64	8.18	0.77	17	2
Lower Mississippi	38.20	—	290.23	328.43	32.84	295.59	5.37	1.47	2	—
Souris-Red-Rainy	4.30	—	—	4.30	0.62	3.68	0.39	0.08	9	2
Missouri	42.20	+0.35	—	42.55	11.00	31.55	19.34	10.55	46	33
Arkansas-White-Red	69.90	+0.06	—	69.96	1.92	68.04	9.41	5.87	14	9
Texas-Gulf	23.90	—	—	23.90	0.78	23.12	16.21	7.29	68	32
Rio Grande	3.30‡	+0.01	—	3.31	0.34	2.97	7.29	4.40	220	148
Upper Colorado	12.00	-0.42	—	11.58	7.37	4.21	4.02	1.98	35	47
Lower Colorado	1.80	-4.25	9.80	7.35	1.86	5.49	6.91	3.45	94	63
Great Basin	4.00	—	—	4.00	0.47	3.53	5.12	2.25	128	64
Columbia-North Pacific	189.00	—	—	189.00	14.70	174.30	29.63	10.52	16	6
California	56.00	+4.25	—	60.25	1.30	58.95	31.70	20.50	53	35
Total	**1,007.40**	**0**	**300.03**	**1,307.43**	**120.51**	**1,186.92**	**245.65**	**76.41**	**19**	**6**

Source: The Water Resources Council, *The Nation's Water Resources, The First National Assessment* (Washington, D.C., 1968).

* Gross Demand/ Supply Ratio = $\frac{\text{Total Withdrawal}}{\text{Withdrawal Supply}}$ (Percent)

† Net Demand/ Supply Ratio = $\frac{\text{Total Consumptive Use}}{\text{Consumptive Use Supply}}$ (Percent)

‡ Of 4.9 bgd mean annual runoff, only 68 percent (3.30 bgd) is estimated as regulated supply which is less than consumptive use. Basin ground water is being depleted to augment surface supply.

TABLE 3
SUMMARY OF WATER SUPPLIES AND DEMANDS BY MAJOR WATER REGIONS — 1980
(Billions of Gallons Per Day)

	Water Supply						Water Demand			
Region	Regulated Runoff	Imports-Exports	Basin Inflows	Withdrawal Supply	In-Channel Reguirement	Consumptive Use Supply	Total Withdrawal	Total Consumptive Use	Gross Demand/Supply Ratio (Percent)*	Net Demand/Supply Ratio (Percent)†
North Atlantic	145.10	—	—	145.10	1.92	143.18	44.02	2.69	30	2
South Atlantic-Gulf	169.30	—	—	169.30	19.70	149.60	41.18	3.32	24	2
Great Lakes	51.80	—	—	51.80	6.32	45.48	47.89	1.88	93	4
Ohio	108.90	—	—	108.90	8.76	100.14	41.75	1.62	38	2
Tennessee	38.60	—	—	38.60	4.15	34.45	12.25	0.57	32	2
Upper Mississippi	49.10	—	—	49.10	6.46	42.64	14.80	1.10	30	3
Lower Mississippi	38.20	—	283.73	321.93	32.84	289.09	12.62	3.01	4	1
Souris-Red-Rainy	4.30	+0.39	—	4.69	0.62	4.07	0.94	0.22	20	5
Missouri	42.20	+0.06‡	—	42.26	11.00	31.26	23.26	13.16	55	42
Arkansas-White-Red	69.90	+0.15	—	70.05	1.92	68.13	17.28	8.48	25	12
Texas-Gulf	23.90	—	—	23.90	0.78	23.12	26.38	9.42	110	41
Rio Grande	3.30	+0.11	—	3.41	0.34	3.07	8.33	4.68	244	152
Upper Colorado	12.00	-0.76	—	11.24	7.37	3.87	5.68	2.70	51	70
Lower Colorado	1.80	-4.18	8.38	6.00	1.86	4.14	8.50	4.08	142	99
Great Basin	4.00	+0.05	—	4.05	0.47	3.58	7.06	3.30	174	92
Columbia-North Pacific	189.00	—	—	189.00	14.70	174.30	41.41	13.58	22	8
California	56.00	+4.18	—	60.18	1.30	58.88	37.99	29.02	63	49
Total	**1,007.40**	**0**	**292.11**	**1,299.51**	**120.51**	**1,179.00**	**391.34**	**102.83**	**30**	**9**

Source: The Water Resources Council, *The Nation's Water Resources, The First National Assessment,* (Washington, D.C., 1968).

* Gross Demand/Supply Ratio = $\frac{\text{Total Withdrawal}}{\text{Withdrawal Supply}}$ (Percent)

† Net Demand/Supply Ratio = $\frac{\text{Total Consumptive Use}}{\text{Consumptive Use Supply}}$ (Percent)

‡ Imports of 0.45 bgd and exports of 0.39 bgd.

TABLE 4
SUMMARY OF WATER SUPPLIES AND DEMANDS BY MAJOR WATER REGIONS — 2000
(Billions of Gallons Per Day)

	Water Supply						Water Demand		Gross	Net
Region	Regulated Runoff	Imports-Exports	Basin Inflows	Withdrawal Supply	In-Channel Requirement	Consumptive Use Supply	Total Withdrawal	Total Consumptive Use	Demand/Supply Ratio (Percent)*	Demand/Supply Ratio (Percent)†
North Atlantic	145.10	—	—	145.10	1.92	143.18	44.96	4.21	31	3
South Atlantic-Gulf	169.30	—	—	169.30	19.70	149.60	59.84	5.44	35	4
Great Lakes	51.80	—	—	51.80	6.32	45.48	96.59	3.18	186	7
Ohio	108.90	—	—	108.90	8.76	100.14	65.11	2.54	60	3
Tennessee	38.60	—	—	38.60	4.15	34.45	13.88	0.83	36	2
Upper Mississippi	49.10	—	—	49.10	6.46	42.64	30.59	1.78	62	4
Lower Mississippi	38.20	—	277.73	315.93	32.84	283.09	25.67	4.38	81	2
Souris-Red-Rainy	4.30	+0.78	—	5.08	0.62	4.46	2.00	0.49	39	11
Missouri	42.20	-0.13‡	—	42.07	11.00	31.07	27.88	14.98	66	48
Arkansas-White-Red	69.90	+0.17	—	70.07	1.92	68.15	25.34	10.59	36	16
Texas-Gulf	23.80	—	—	23.90	0.78	23.12	50.03	10.83	209	47
Rio Grande	3.30	+0.11	—	3.41	0.34	3.07	9.51	4.99	279	163
Upper Colorado	12.00	-0.98	—	11.02	7.37	3.65	6.58	3.10	60	85
Lower Colorado	1.80	-3.93	7.68	5.55	1.86	3.69	8.43	4.65	132	126
Great Basin	4.00	+0.05	—	4.05	0.47	3.58	7.55	3.56	186	99
Columbia-North Pacific	189.00	—	—	189.00	14.70	174.30	70.94	17.15	38	9
California	56.00	+3.93	—	59.93	1.30	58.63	43.11	31.92	72	56
Total	**1,007.40**	**0**	**285.41**	**1,292.81**	**120.51**	**1,172.30**	**588.01**	**124.62**	**45**	**11**

Source: The Water Resources Council, *The Nation's Water Resources, The First National Assessment,* (Washington, D.C., 1968).

* Gross Demand/Supply Ratio = $\frac{\text{Total Withdrawal}}{\text{Withdrawal Supply}}$ (Percent)

† Net Demand/Supply Ratio = $\frac{\text{Total Consumptive Use}}{\text{Consumptive Use Supply}}$ (Percent)

‡ Imports of 0.65 bgd and exports of 0.78 bgd.

contrast, has a small natural supply with a rapidly increasing demand projected to greatly exceed the present supply by the year 2000. This potential deficiency can only be met by augmentation of the natural supply to the Lower Colorado Basin.

- Great Basin Region: The Great Basin Region of western Utah and Nevada is an area of small supply and low demand, even when projected to the year 2000.

- California Region: The California Region represents an area of intensive development--large population with heavy municipal and industrial use and intensive irrigated agriculture--but with natural water supply generally adequate to meet projected demands. Its problems are primarily those of distribution and management of the available supply.

Upper Colorado Region

The Upper Colorado Region has a water surplus which flows at the present time to the Lower Colorado Region, although projected water demands would consume much of this surplus. Its major problems are water quality and sediment production.

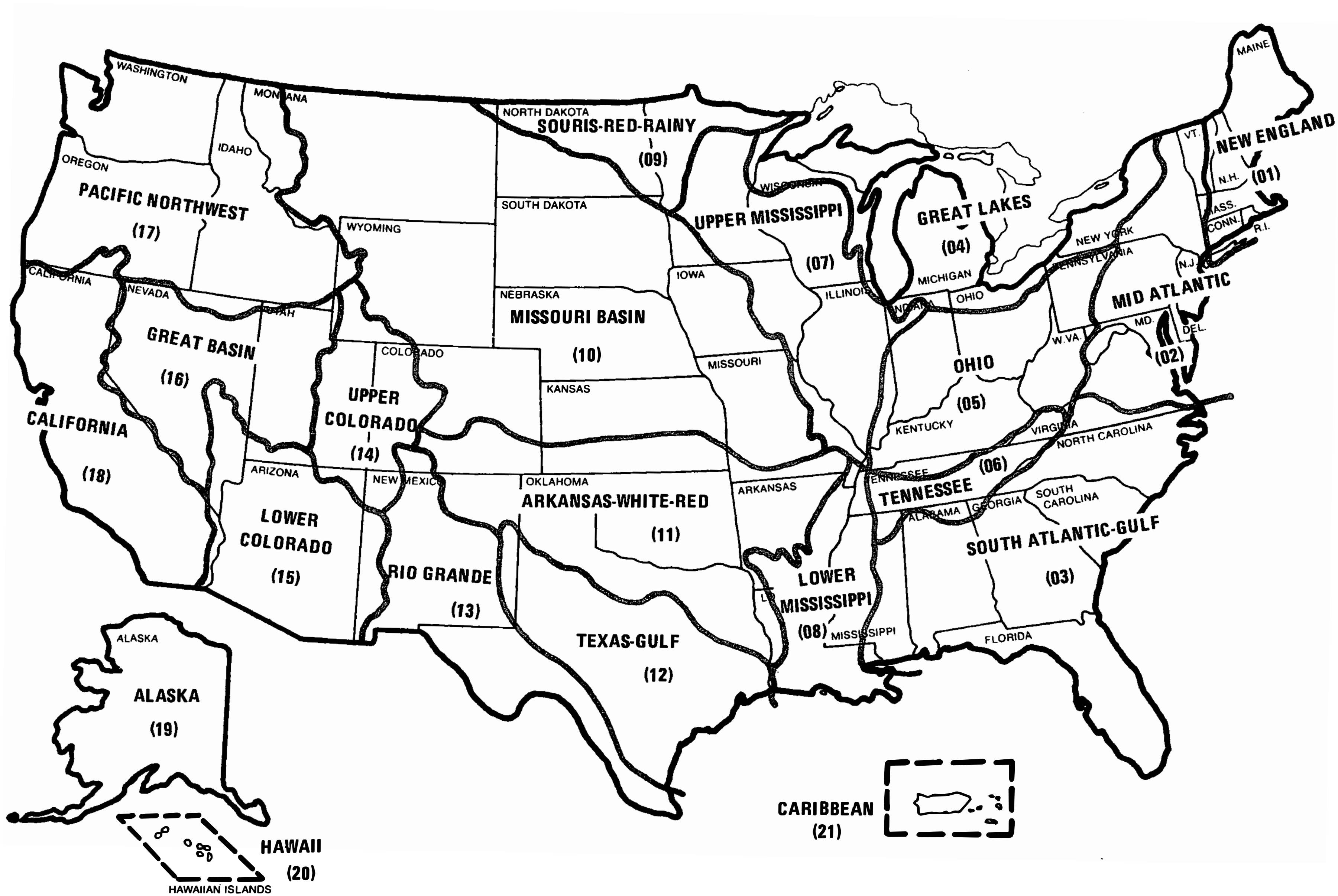
The Region's two large potential users of water are production of minerals and thermal electric power. Projected mineral activity includes four oil shale plants with a total capacity of 400 MB/D by 1985. Coal conversion by hydrogenation is expected. This use, together with coal mined for thermal power production, will amount to an annual increase of approximately 200 million tons of coal. Thermal electric power capacity installed to supply local use and use for export could increase from the present 1,300 to 47,600 megawatts (MW). Uranium production will also increase significantly.

Potential competition for water supplies exists between energy production and irrigation. From these same sources, nearly 7 million acres could be put into production and additionally about one-third of existing irrigated lands could be supplied with needed additional water for best production. Irrigated cropland yields can be increased greatly by providing supplemental water, installing drainage systems, improving irrigation systems and further adopting agricultural management practices.

A watershed management program is planned to reduce the average annual impairment from man-created watershed problems by about 50 percent and natural problems by about 10 percent. It also includes a planned production of 434,000 acre-feet per year of additional water as a result of the vegetal manipulation.

Present sport hunting and fishing demand is projected to nearly double by the year 2000. Recreation demand, of which 97 percent is by nonresidents, will increase fourfold.

Sufficient water is physically available for on-site regional use to meet all needs projected. However, for larger levels, an



SOURCE: U.S. Geological Survey

Figure 1. Water Resources Regions

increase in the Upper Colorado Region's water supply will be required. The amount of increase cannot be determined because of different interpretations of compacts and treaties. More specifically, the Colorado River Compact and Upper Colorado River Compact impose stringent legal constraints on this water development.

Lower Colorado Region

A major problem affecting water availability in the Lower Colorado Region is the heavy load of dissolved salts carried by regional streams. The salinity of surface waters, and in many places ground water, causes major problems to agricultural, municipal and industrial users of water. Substantial future increases in salinity are to be expected, unless significant changes in water quality management are initiated, or unless water supplies are augmented, thereby providing additional water for dilution. The most critical immediate need is to meet withdrawal requirements projected to occur prior to 1985, without increasing the ground water overdraft. To gradually eliminate the ground water overdraft, the long-range program, from 1981 to 2000, would need to provide for an annual increase from new sources of water withdrawals of about 4.7 million acre-feet per year (MMAF/Y).

The most vital needs of the Little Colorado Subregion are to supply additional water to its two major cities--Flagstaff, Arizona, and Gallup, New Mexico. These cities require water to maintain economic stability as well as provide for future growth. Additional water would also provide greater employment opportunities for the Subregion's predominantly rural Indian population through further development of the tourist industry, the attraction of outdoor recreationists, and the encouragement of light industry. Unfortunately, however, the water supply of the Subregion is poorly distributed with respect to the areas of need. Additional water for municipal, industrial and agricultural uses needs to be made available for several areas in the Subregion.

The Gila Subregion is the major water deficient area of the Lower Colorado Region. Even though about 2.5 MMAF of ground water were mined in 1965, the apparent water requirements were not satisfied. By 2000, the annual withdrawal requirement is expected to increase by more than 2.0 MMAF. The increased requirements are due primarily to the needs of an expanding population. Most of the water needs are concentrated in the vicinities of Phoenix and Tucson. In general, existing sources are completely utilized. Therefore, there is a critical need to increase the water supplies of the Subregion to reduce the ground water overdraft and to meet the growing water requirements.

Great Basin Region

The Great Basin is one of the most arid of the water resource regions. Since most of the Region's precipitation occurs in the mountainous areas along the eastern and western boundaries, water is not always available at the point of need. Consequently, construction projects will be required to make water available at the locations where it will be used.

Water withdrawal requirements are projected to increase about 2.6 million acre-feet annually by the year 2000. The largest water use in the Great Basin Region is for irrigation. The largest increase in use, however, will be for municipal and industrial purposes which account for 57 percent of the total increase. Over 70 percent of this projected increase for municipal and industrial purposes is in the Great Salt Lake Subregion, the area of the largest population.

Another use of water is for maintaining the level of water in the three main perennial terminal lakes: Pyramid Lake and Walker Lake in Western Nevada and Great Salt Lake in Utah. These lakes have been receding for many years due to both climatic changes and development in the region. As further development takes place, this problem will become extremely critical unless water imports are available to sustain the lake levels. About 300 MAF/Y would be needed to maintain Pyramid and Walker Lake at their present levels.

California Region

The California Region is an area of intensive development and growing demand for water for municipal, industrial and irrigation needs. The distribution of water is the area's major problem. California's development is concentrated in semi-arid coastal plains and interior valleys in the central and southern parts of the Region. while the natural water supply is centered in the mountainous northern part. To meet projected water needs requires provision for storage of highly variable seasonal runoff and transport facilities to move the water to areas of need. Major projects such as the Bureau of Reclamation's Central Valley Project and the California State Water Plan have been designed to solve this long-recognized problem. An alternative solution is reclamation of waste water now discharged to the sea and desalinization of sea water.

Projects either existing or under construction will provide 10 million acre-feet annually. Other projects currently authorized will provide an additional 1 MMAF. The remaining projected deficiency of 3 to 11 MMAF (depending on planning assumptions) can be met by a variety of alternatives currently under study. Any decisions for these projects will depend upon economic and environmental impacts. Recent considerations in water development planning are improvement of water quality management and greater attention to intangible benefits of water use such as recreation, preservation of fish and wildlife habitats and aesthetic values.

Through the year 2000, the California Region will find its growth relatively unhampered by any lack of land and water resources if it chooses to intensify its use of those resources. However, it will meet its demands for energy only by the allocation of water resource which realistically takes into consideration the competing demands for economic growth and environmental improvement.

As it is one of the major flood-prone areas of the Nation, the California Region must adopt nonstructural, as well as structural, methods of flood control. It may have to advance its schedule for contructing multipurpose reservoirs because of its urgent need to control floods. Its large cities should consolidate waste treatment plants and should supply treated effluent for energy production use. Further, all of its municipalities should provide secondary (and some should provide tertiary) waste treatment.

To meet the wants of anglers and hunters, the California Region will need to supplement existing fish and game programs. To meet the wants of recreation boaters for boating berths, it will need to provide additional dry storage and small craft harbors. In addition, it should develop the full recreation potential of its existing and proposed reservoirs and canals. The closer such developments lie to cities, where the need for recreation is greatest, the more they will satisfy that need. Nevertheless, the development of water for city dwellers, industry and farmers competes strongly with the preservation of water in free-flowing streams for hunters, anglers and other recreation activities.

TRENDS BEYOND 1985

Upper Colorado River Basin

Water to support a continued expansion of energy production will be available in Colorado and Utah, with careful planning and an ordering of priorities. Water supply will come from the sources now allocated for future energy use and, as this allocation is completely utilized, could be augmented by a partial reallocation from agriculture to energy production. Additional supplies may be developed through stream augmentation programs and transbasin diversions. Through these means, water could be made available to support full development of the coal and oil shale resources of these states.

Because of limited water availability, no significant energy production, which requires large amounts of water, can be expected to be sited in Arizona or New Mexico beyond the Initial Appraisal projections.*

Upper Missouri River Basin

An overall supply of water sufficient to support the full utilization of the coal resources of the area is present. Serious legal problems and large capital requirements will be obstacles but they are not likely to be the ultimate constraint on the full realization of the energy potential of the area.

* NPC, *U.S. Energy Outlook, An Interim Report, An Initial Appraisal by the Oil Shale Task Group 1971-1985.* (Washington, D.C., February 25, 1972).

All Areas

With complete development and reallocation of priorities, water could be made available to support full development of the coal and oil shale based energy potential of the western states, with the possible exception of Arizona and New Mexico. However, many unforeseeable factors can change this projection. For example, population growth and the development of other water-using industries may divert the supplies now available for energy production, or climatic trends may decrease the supply below that indicated by the historical record. In addition, environmental protection and legal issues may cause serious problems in attaining a full utilization of the available supply.

Chapter Two

PROJECTED WATER REQUIREMENTS FOR ELECTRICITY AND SYNTHETIC FUEL PRODUCTION

The unit water requirements for electrical generation (thermal) and the manufacture of synthetic pipeline gas and oil have been estimated by the Coal and Oil Shale Task Groups. Their estimates are as follows:

Shale Oil	17.5 MAF/Y for 100 MB/D
Electricity	20.0 MAF/Y for 1,000 MW
Liquids from Coal	25.0 MAF/Y for 100 MB/D
Gas from Coal	20.0 MAF/Y for 500 MMCF/D

These estimates represent actual depletion (consumptive use). And it may be that the actual diversions will be larger than these estimates indicate.

OIL SHALE AND COAL

Total consumptive water requirement for a 50,000 barrels per day oil shale plant is about 8,700 acre-feet per year composed of these elements:

Mining	220 AF/Y
Retorting	2,600 AF/Y
Ash Disposal	1,450 AF/Y
Upgrading	3,600 AF/Y
Power Generation	820 AF/Y
	8,690 AF/Y

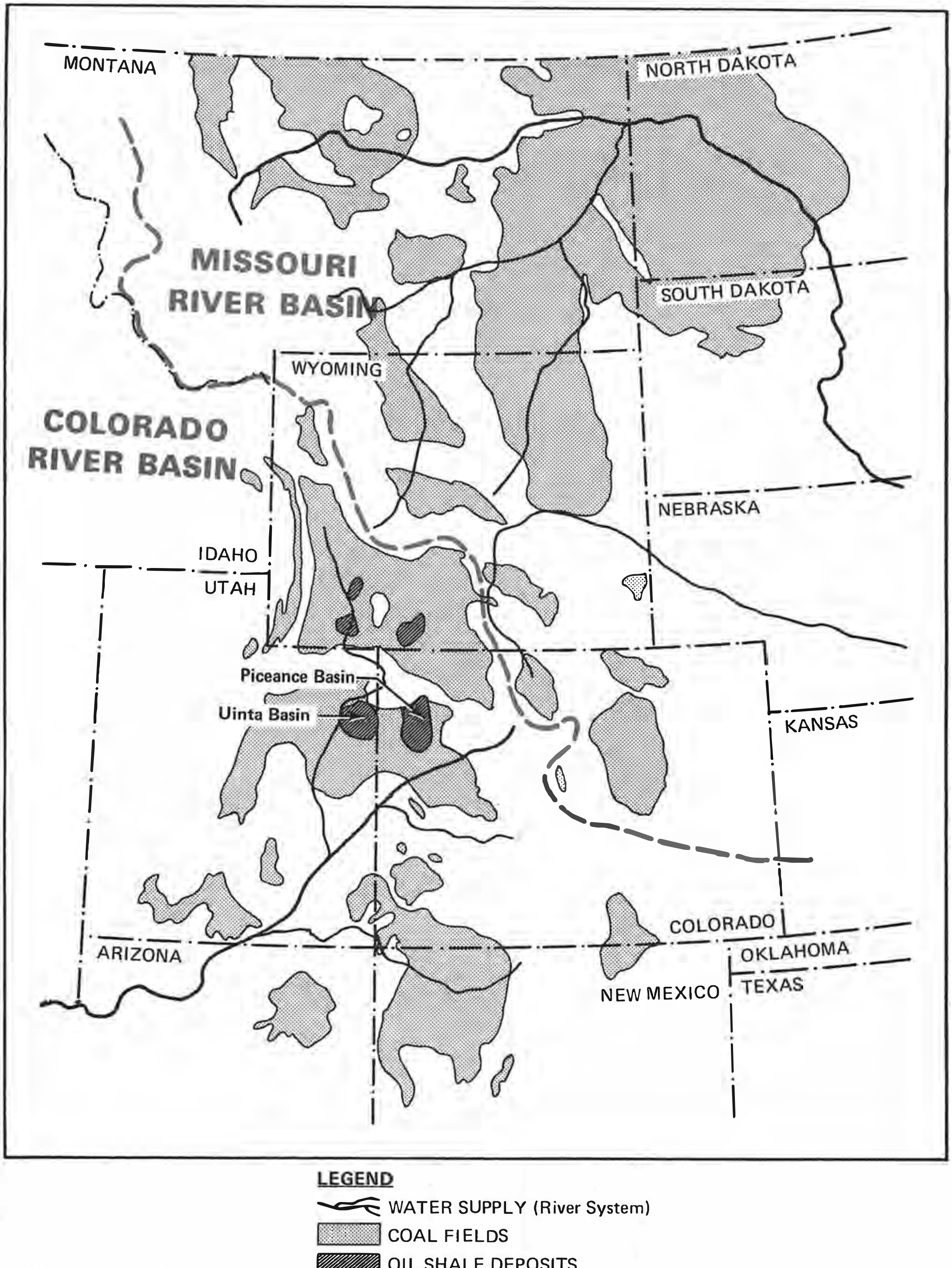
The projected development schedule and accompanying water requirement prepared by the Oil Shale Task Group for Case I is shown in the following tabulation. The figures shown are cumulative.

	Shale Oil Production	Water Required
1976	50 MB/D	8.69 MAF/Y
1979	150 MB/D	26.1 MAF/Y
1981	350 MB/D	60.0 MAF/Y
1983	450 MB/D	78.0 MAF/Y
1984	650 MB/D	113.0 MAF/Y
1985	750 MB/D	130.0 MAF/Y

The oil shale reserves considered by the Oil Shale Task Group supply study were in a selected minable seam located in the Piceance Basin of western Colorado and in the Uinta Basin of Utah. These basins and the Rocky Mountain area coal fields are shown in Figure 2.

The Colorado reserves are in the Colorado River Basin adjacent to both the Colorado River and main stream of the White River, a tributary. The Utah reserves are also in the Colorado River Basin adjacent to the lower reaches of the White River, near its confluence with the Green River.

Tables 5-10 were derived from data received from the Coal and Oil Shale Task Groups. These tables illustrate water requirements for large scale energy production in the western states for Cases I through IV in the pre-1985 period. Tables 5, 6 and 7 show the water requirements by state which would be required to support the coal-fired electricity plants, synthetic gas plants, synthetic liquid plants and oil shale plants projected by the Coal and Oil Shale Task Groups. Tables 8, 9 and 10 show the same water requirements by region. It is significant that the totals indicated in these tables make no allowance for nuclear generating plants which, quite likely, will increase the amount of water needed.



SOURCE: U.S. Geological Survey

Figure 2. Rocky Mountain Area Coal Fields and Shale Deposits.

TABLE 5
CASE I
WATER REQUIREMENTS FOR PROJECTED ELECTRICITY AND SYNTHETIC FUELS DEVELOPMENT TO 1985 FROM WESTERN SURFACE-MINED COALS AND OIL SHALE

	Electricity			Synthetic Gas			Synthetic Liquid		
	Rate (10^6 KW)	Units*	Water (MAF/Y)	Rate (10^9 CF/D)	Units †	Water (MAF/Y)	Rate (MB/D)	Units‡	Water (MAF/Y)
Bituminous Coal									
Arizona	3.1	3.1	62	—	—	—	—	—	—
New Mexico	6.0	6.0	120	0.9	4.0	40	80	1.6	20
Utah	1.2	1.2	24	—	—	—	—	—	—
Colorado	—	—	—	—	—	—	—	—	—
Subtotal	**10.3**	**10.3**	**206**	**0.9**	**4.0**	**40**	**80**	**1.6**	**20**
Subbituminous Coal									
Wyoming	8.0	8.0	160	1.6	7.0	70	500	10.0	125
Montana	4.0	4.0	80	1.5	6.4	64	100	2.0	25
Washington	1.0	1.0	20	—	—	—	—	—	—
Subtotal	**13.0**	**13.0**	**260**	**3.1**	**13.4**	**134**	**600**	**12.0**	**150**
								Units§	
Oil Shale									
Utah	—	—	—	—	—	—	100	2	18
Colorado	—	—	—	—	—	—	650	13	112
Subtotal	—	—	—	—	—	—	750	15	130
Lignite									
Montana	3.4	3.4	68	1.8	8.0	80	—	—	—
North Dakota	4.9	4.9	98	1.0	4.6	46	—	—	—
South Dakota	1.0	1.0	20	—	—	—	—	—	—
Texas and Arkansas	2.2	2.2	44	—	—	—	—	—	—
Subtotal	**11.5**	**11.5**	**230**	**2.8**	**12.6**	**126**	—	—	—
Total	**34.8**	**34.8**	**696**	**6.8**	**30.0**	**300**	**1,430**	**28.6**	**150**

* Unit = 1,000 MW = 10^6 KW = 20 MAF/Y of water required.
† Unit = 250 MM CF/D of synthetic pipeline gas = 91 BCF/Y = 10 MAF/Y of water required.
‡ Unit = 50 MB/D synthetic crude = 12.5 MAF/Y of water required.
§ Unit = 50 MB/D synthetic crude = 8.7 MAF/Y of water required.

TABLE 6
CASE II/III
WATER REQUIREMENTS FOR PROJECTED ELECTRICITY AND SYNTHETIC FUELS DEVELOPMENT TO 1985 FROM WESTERN SURFACE-MINED COALS AND OIL SHALE

	Electricity			Synthetic Gas			Synthetic Liquid		
	Rate (10^6 KW)	Units*	Water (MAF/Y)	Rate (10^9 CF/D)	Units†	Water (MAF/Y)	Rate (MB/D)	Units‡	Water (MAF/Y)
Bituminous Coal									
Arizona	3.1	3.1	62	—	—	—	—	—	—
New Maxico	6.0	6.0	120	0.9	4.0	40	30	0.6	8
Utah	1.2	1.2	24	—	—	—	—	—	—
Colorado	—	—	—	—	—	—	—	—	—
Subtotal	**10.3**	**10.3**	**206**	**0.9**	**4.0**	**40**	**30**	**0.6**	**8**
Subbituminous Coal									
Wyoming	8.0	8.0	160	0.8	3.4	34	50	1.0	13
Montana	4.0	4.0	80	0.7	3.0	30	—	—	—
Washington	1.0	1.0	20	—	—	—	—	—	—
Subtotal	**13.0**	**13.0**	**260**	**1.5**	**6.4**	**64**	**50**	**1.0**	**13**
								Units§	
Oil Shale									
Utah	—	—	—	—	—	—	100	2	18
Colorado	—	—	—	—	—	—	650	13	112
Subtotal	—	—	—	—	—	—	**750**	**15**	**130**
Lignite									
Montana	3.4	3.4	68	0.8	3.6	36	—	—	—
North Dakota	4.9	4.9	98	0.4	2.0	20	—	—	—
South Dakota	1.0	1.0	20	—	—	—	—	—	—
Texas and Arkanas	2.2	2.2	44	—	—	—	—	—	—
Subtotal	**11.5**	**11.5**	**230**	**1.2**	**5.6**	**56**	—	—	—
Total	**34.8**	**34.8**	**696**	**3.6**	**16.0**	**160**	**830**	**16.6**	**151**

* Unit = 1,000 MW = 10^6 KW = 20 MAF/Y of water required.
† Unit = 250 MM CF/D of synthetic pipeline gas = 91 BCF/Y = 10,000 AF/Y of water required.
‡ Unit = 50 MB/D synthetic crude = 12.5 MAF/Y of water required.
§ Unit = 50 MB/D synthetic crude = 8.7 MAF/Y of water required.

TABLE 7
CASE IV
WATER REQUIREMENTS FOR PROJECTED ELECTRICITY AND SYNTHETIC FUELS DEVELOPMENT TO 1985 FROM WESTERN SURFACE-MINED COALS AND OIL SHALE

	Electricity			Synthetic Gas			Synthetic Liquid		
	Rate (10^6 KW)	Units*	Water (MAF/Y)	Rate (10^9 CF/D)	Units†	Water (MAF/Y)	Rate (MB/D)	Units‡	Water (MAF/Y)
Bituminous Coal									
Arizona	3.1	3.1	62	—	—	—	—	—	—
New Mexico	6.0	6.0	120	0.4	2.0	20	—	—	—
Utah	1.2	1.2	24	—	—	—	—	—	—
Colorado	—	—	—	—	—	—	—	—	—
Subtotal	**10.3**	**10.3**	**206**	**0.4**	**2.0**	**20**	**—**	**—**	**—**
Subbituminous Coal									
Wyoming	8.0	8.0	160	0.5	2.1	21	—	—	—
Montana	4.0	4.0	80	0.2	1.0	10	—	—	—
Washington	1.0	1.0	20	—	—	—	—	—	—
Subtotal	**13.0**	**23.0**	**260**	**0.7**	**3.1**	**31**	**—**	**—**	**—**
								Units§	
Oil Shale									
Utah	—	—	—	—	—	—	100	2	18
Colorado	—	—	—	—	—	—	650	13	112
Subtotal	**—**	**—**	**—**	**—**	**—**	**—**	**750**	**15**	**130**
Lignite									
Montana	3.4	3.4	68	—	—	—	—	—	—
North Dakota	4.9	4.9	98	0.3	1.5	15	—	—	—
South Dakota	1.0	1.0	20	—	—	—	—	—	—
Texas and Arkansas	2.2	2.2	44	—	—	—	—	—	—
Subtotal	**11.5**	**11.5**	**230**	**0.3**	**1.5**	**15**	**—**	**—**	**—**
Total	**34.8**	**34.8**	**696**	**1.4**	**6.6**	**66**	**750**	**15**	**130**

* Unit = 1,000 MW = 10^6 KW = 20 MAF/Y of water required.
† Unit = 250 MM CF/D of synthetic pipeline gas = 91 BCF/Y = 10 MAF/Y of water required.
‡ Unit = 50 MB/D synthetic crude = 12.5 MAF/Y of water required.
§ Unit = 50 MB/D synthetic crude = 8.7 MAF/Y water required.

TABLE 8

CASE I

REGIONAL WATER REQUIREMENTS FOR PROJECTED ELECTRICITY AND SYNTHETIC FUELS PRODUCTION TO 1985 FROM WESTERN SURFACE-MINED COAL AND OIL SHALE

(Thousands of Acre-Feet Per Year)

Region	Electricity	Synthetic Gas	Synthetic Liquid	Oil Shale	Total
Upper Colorado River					
Arizona	62	—	—	—	62
New Mexico	120	40	20	—	180
Utah	24	—	—	18	42
Colorado	—	—	—	112	112
Subtotal	**206**	**40**	**20**	**130**	**396**
Upper Missouri River					
Montana	148	144	25	—	317
North Dakota	98	46	—	—	144
South Dakota	20	—	—	—	20
Wyoming	160	70	125	—	355
Subtotal	**426**	**260**	**150**	**—**	**836**
Columbia River					
Washington	20	—	—	—	20
Gulf Coast					
Texas and Arkansas	44	—	—	—	44
Total	**696**	**300**	**170**	**130**	**1,296**

TABLE 9

CASE II/III

REGIONAL WATER REQUIREMENTS FOR PROJECTED ELECTRICITY AND SYNTHETIC FUELS PRODUCTION TO 1985 FROM WESTERN SURFACE-MINED COAL AND OIL SHALE

(Thousands of Acre-Feet Per Year)

Region	Electricity	Synthetic Gas	Synthetic Liquid	Oil Shale	Total
Upper Colorado River					
Arizona	62	—	—	—	62
New Mexico	120	40	8	—	168
Utah	24	—	—	18	42
Colorado	—	—	—	112	112
Subtotal	**206**	**40**	**8**	**130**	**384**
Upper Missouri River					
Montana	148	66	—	—	214
North Dakota	98	20	—	—	118
South Dakota	20	—	—	—	20
Wyoming	160	34	13	—	207
Subtotal	**426**	**120**	**13**	**—**	**559**
Columbia River					
Washington	20	—	—	—	20
Gulf Coast					
Texas and Arkansas	44	—	—	—	44
Total	**696**	**160**	**21**	**130**	**1,007**

TABLE 10
CASE IV
REGIONAL WATER REQUIREMENTS FOR PROJECTED ELECTRICITY AND SYNTHETIC FUELS PRODUCTION TO 1985 FROM WESTERN SURFACE-MINED COAL AND OIL SHALE
(Thousands of Acre-Feet Per Year)

Region	Electricity	Synthetic Gas	Synthetic Liquid	Oil Shale	Total
Upper Colorado River					
Arizona	62	—	—	—	62
New Mexico	120	20	—	—	140
Utah	24	—	—	18	42
Colorado	—	—	—	112	112
Subtotal	**206**	**20**	—	**130**	**356**
Upper Missouri River					
Montana	148	10	—	—	158
North Dakota	98	15	—	—	113
South Dakota	20	—	—	—	20
Wyoming	160	21	—	—	181
Subtotal	**426**	**46**	—	—	**472**
Columbia River					
Washington	20	—	—	—	20
Gulf Coast					
Texas and Arkansas	44	—	—	—	44
Total	**696**	**66**	—	**130**	**892**

Chapter Three

UPPER COLORADO RIVER BASIN WATER AVAILABILITY

The availability of water for energy development in the Upper Colorado River Basin is a complex subject. State law, federal law and regulations, interstate compacts and international treaties are superimposed on the physically available water resource. Further, the monthly and annual variation in the natural supply is large, requiring carry-over storage capacity to develop the resource to its maximum potential.

Of the several published and proprietary analyses of the water supply in the Upper Colorado Region which were available to the Task Group, the Upper Colorado Region Study prepared by the Water Resources Council in 1971 is believed to provide the most detailed and least controversial interpretation. This study was based on a framework plan designed to meet regionally interpreted Office of Business Economics--Economic Research Service requirements modified to fit local conditions in the region. Since the basic framework plan did not fully satisfy the individual states, alternative state plan(s) were developed for inclusion in the report.

The first state alternative is based on a 6.5 MMAF/Y development level for the Upper Colorado Region. It is the identical level used in the basic framework study but with a projected allocation of water to the several classes of uses based on the potential needs of each of the states regarding the development of the state's mineral resources, including electric power generation. The framework study includes projections to years 1980, 2000 and 2020, necessitating some interpolation to arrive at 1985 figures.

Attached as Appendix F is an extract from the Upper Colorado Region Study. Included are Tables 28 and 31 and the text describing the states' alternatives to the Framework Plan at the 6.5 and 8.16 MMAF level of development.

The Task Group's approach has been to consider the indicated framework water availability for the year 2000 in relationship to the 1985 requirements for energy. The normal producing life of plants, which commence operations in the 1980-1985 period, will extend to beyond the year 2000. Further, if the water is considered to be legally and physically available in the year 2000, presumably it can be made available at an earlier date by accelerating construction of storage facilities or otherwise expediting its development.

Chapter Four

UPPER COLORADO RIVER
INDUSTRIAL WATER REQUIREMENTS FOR PROJECTED 1985 ENERGY DEVELOPMENT

SUPPLY

Generally, the potential to meet projected energy plant water requirements for 1985 in this basin is good. In order to avoid temporary deficiencies, however, construction of some major storage projects will be necessary. Moreover, the water quality varies due to the contribution of large concentrations of dissolved solids from natural resources.

Table 8 in Chapter Two shows a Case I water requirement of 396 MAF/Y in all states tributary to the Upper Colorado River, except Wyoming. Of the total, 52 percent will be required for electrical generation, 15 percent for coal conversion and 32 percent for oil shale development.

Wyoming is legally entitled to a large share of Colorado River water and has allocated more that 150 MAF/Y to energy uses. Since many of the state's fuel resources are found in the Missouri River Basin, the state's situation is analyzed in that section of this report. A comparison of these requirements for all cases with the individual state's own proposed allocation of water under the states' alternative plan at the 6.5 MMAF level (Upper Colorado Region Study) is shown in Table 11, 12 and 13.

Arizona's Upper Colorado River total allocation of 50 MAF/Y falls short of the 62 MAF demand by energy projected in the present study even before the assignment of 7.6 MAF to agriculture and 8 MAF to municipal and other uses under the state's alternative plan. This potential shortage of 27.6 MAF/Y could be made up from the state's entitlement of Lower Colorado River water. In the alternative plan, the 1.4 million kilowatts of generating capacity, to which this shortfall was allocated, would have to be transferred in some manner--either by physical movement of coal or by water transfer under interstate compact, or by other development.

New Mexico's alternative plan for the year 2000, under the 6.5 MMAF level, allocated 90 MAF to electrical power and 17.4 MAF to mineral development, about 85 MAF below the requirements of the current NPC projections. This apparent shortfall could be met by a temporary (for the life of the plant) transfer of irrigation water, or by the earlier use of water which the state alternative plan contemplated developing between the year 2000 and 2020. Physical transfer of coal across state lines or transfer of water under future compact terms are also possibilities.

A possible further alternative would be to obtain water from the more than 200 thousand additional acre-feet to which New Mexico would be entitled under the more optimistic 8.16 MMAF level of development. It is concluded that subject to the priorities which

TABLE 11
CASE I
UPPER COLORADO RIVER WATER SUPPLY/DEMAND
(Thousands of Acre-Feet Per Year)

	Ariz.	N. Mex.	Utah	Colo.	Total
Projected Water Requirement for Energy (Consumptive Use)					
Electricity (Coal-fired plants only)	62	120	24	—	206
Coal	—	60	—	—	60
Oil Shale	—	—	18	112	130
Total	**62**	**180**	**42**	**112**	**396**
Apparent Water Availability*					
Electric Power	34.1	90.0	261.8	108.2	494.1
Minerals	.3	17.4	10.3	128.3	156.3
Argiculture	7.6	329.0	660.6	1,778.2	2,775.4
Other	8.0	141.3	314.0	1,004.7	1,468.0
Total	**50.0**	**577.7**	**1,246.7**	**3,019.4**	**4,893.8**

Note: Wyoming's Colorado River entitlement is considered in Chapter Seven of this study.

* From Upper Colorado River Framework Study — States' Alternatives at the 6.5 MMAF level to year 2000.

TABLE 12
CASES II/III
UPPER COLORADO RIVER WATER SUPPLY/DEMAND
(Thousands of Acre-Feet Per Year)

	Ariz.	N. Mex.	Utah	Colo.	Total
Projected Water Requirement for Energy (Consumptive Use)					
Electricity (Coal-fired plants only)	62	120	24	—	206
Coal	—	48	—	—	48
Oil Shale	—	—	18	112	130
Total	**62**	**168**	**42**	**112**	**384**
Apparent Water Availability*					
Electric Power	34.1	90.0	261.8	108.2	494.1
Minerals	.3	17.4	10.3	128.3	156.3
Agriculture	7.6	329.0	660.6	1,778.2	2,775.4
Other	8.0	141.3	314.0	1,004.7	1,468.0
Total	**50.0**	**577.7**	**1,246.7**	**3,019.4**	**4,893.8**

Note: Wyoming's Colorado River entitlement is considered in Chapter Seven of this study.

* From Upper Colorado River Framework Study — States' Alternatives at the 6.5 MMAF level to year 2000.

TABLE 13
CASE IV
UPPER COLORADO RIVER
WATER SUPPLY/DEMAND
(Thousands of Acre-Feet Per Year)

	Ariz.	N. Mex.	Utah	Colo.	Total
Projected Water Requirement for Energy (Consumptive Use)					
Electricity (Coal-fired plants only)	62	120	24	—	206
Coal	—	20	—	—	20
Oil Shale	—	—	18	112	130
Total	**62**	**140**	**42**	**112**	**356**
Apparent Water Availability*					
Electric Power	34.1	90.0	261.8	108.2	494.1
Minerals	.3	17.4	10.3	128.3	156.3
Agriculture	7.6	329.0	660.6	1,778.2	2,775.4
Other	8.0	141.3	314.0	1,004.7	1,468.0
Total	**50.0**	**577.7**	**1,246.7**	**3,019.4**	**4,893.8**

Note: Wyoming's Colorado River entitlement is considered in Chapter Seven of this study.

* From Upper Colorado River Framework Study — States' Alternatives at the 6.5 MMAF level to year 2000.

it may wish to assign its future development, New Mexico can have the water to meet its projected requirements.

Utah, which may require only 42 MAF for electricity and oil shale development, has allocated 261.8 MAF for electrical generation and 10.3 MAF for minerals in the year 2000 under its alternative plan. Availability of this large quantity of water could influence the timing and level of energy development in the state. If the state's mineral resources are insufficient to require all of its available water, then physical importation of minerals (coal) or export of water (under appropriate compact terms and with equitable benefit allocation) will offer a means of meeting required energy development.

Colorado's projected requirements (shown in Table 11) are 112 MAF for oil shale development. In the state's alternative plan, Colorado allocated 108.2 MAF to electrical generation and 128.3 MAF to minerals, for a total of 236.5 MAF for all mineral development. Elsewhere in that report, it is shown that Colorado's specific allocation for oil shale was 97 MAF and 15 MAF for a "coal by-products plan," for a total of 112 MAF. There seems little doubt that water will be legally and physically available in Colorado to meet the level of energy development projected through 1985.

The state-by-state situation is summarized below:

- Arizona--Potential shortage of 28 MAF (1.4 thousand MW) of water. Alternatives exist but are limited.
- New Mexico--Potential shortage of 85 MAF. Conversion of irrigation allocation and other alternatives could meet this requirement.
- Utah--Adequate supply to meet projection.
- Colorado--Adequate supply to meet projection.
- Wyoming--See Upper Missouri River Basin Analysis.

Supply Considerations

Fortunately, most of the oil shale and coal resources of these four states are relatively close to the Colorado River of its principal tributaries. Some limited quantity of water in each of these states is now available for early diversion under direct flow rights or existing storage reservoirs. In most cases, however, major storage projects will be required to provide a dependable day-to-day supply of water to meet the full 1985 projected requirements. Such storage projects will require long lead times (10 or more years) for legal and technical evaluation for construction and for fill-up. These long lead times dictate that the first steps of project planning be initiated in the immediate future if the 1985 projected requirements are to be met.

While specific plant siting is not the intent of this study, it must be pointed out that a significant logistics problem relating to water exists in the area between the diversion works on the streams and the point of physical use at the plant site. In almost every instance, water will need to be moved to mine-mouth plants, or minerals will need to be moved to the water. In either event, the time, capital and materials required for the transportation facility and the energy for its operation can be large and should not be overlooked in evaluating possible constraints on attainable levels of energy development.

The potentially serious problem of a water supply for oil shale development beyond 1985 must command some attention. The level of oil shale development in Colorado projected through 1985 of 650 MB/D will require the commitment of only a small part of Colorado's shale reserves. If the balance of these reserves are to be developed and used effectively, a large volume of additional water will be required. No local source of this water is readily available, however.

WATER QUALITY

Water quality in the Upper Colorado River Basin is quite varied. Of the total amount of dissolved solids in the river systems, very little is contributed by municipal or industrial users and only about 10 percent is contributed by saline springs. Most of the dissolved solids originate from natural sources and from salts dissolved from irrigated lands. Historically, the average amount of dissolved solids measured at Lees Ferry, Arizona, is about 550 milligrams per liter (mg/l).

Water elsewhere in the Basin varies considerably in concentration of dissolved solids from the Main Stem. A major determinant of the chemical quality of the tributary streams is due to the type of rocks underlying the Basin. Headwater streams close to the Continental Divide, underlain by resistant rocks, may contain less than 20 mg/l of dissolved solids. Waters in contact with the more soluble Cretaceous and older rocks of the middle portion of the Colorado River Basin may contain in excess of 2,000 mg/l.

A number of the water quality problems in the Basin have implications for public health. These include disposal of uranium tailings; the high dissolved solids in drinking water and the high levels of fluoride and arsenic in some of the water.

Chapter Five

THE COLORADO RIVER COMPACT

The Colorado River Compact, approved by Congress April 6, 1949 (63 Stat. 31), regulated the use of water in the Colorado River Basin. It encompasses the water rights of Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming. All of the regions' coal reserves are concentrated in the Upper Basin in the portion of the Colorado River drainage area above Lees Ferry, a point in northeastern Arizona upstream from Grand Canyon National Park.

The Colorado River Compact allocates the annual beneficial consumptive use of 7.5 MMAF to the Upper Basin (the area above Lees Ferry) and 8.5 MMAF to the Lower Basin (the area below Lees Ferry). However, it obligates the four states of the "Upper Division" (Colorado, New Mexico, Utah and Wyoming) not to deplete the flow of the Colorado River at Lees Ferry below an aggregate of 75 MMAF in each period of 10 years, calculated in continuing progressive series. It further obligates these states to furnish one-half of the quantity of any international obligation to Mexico undertaken by the United States to the extent that such obligation cannot be supplied from the whole Basin's supply "surplus" to the foregoing allocations of 8.5 plus 7.5 MMAF annually. There is an unresolved legal question as to whether the Lower Basin tributaries should be included in the apportionment of the Mexican obligations.

While avoiding legal interpretations in promulgating regulations for the long-range operation of Lake Powell and Lake Mead (1968), the Department of the Interior has assumed that the regulated releases at Lees Ferry must average 8.3 MMAF, and that the quantity available for consumptive use in the Upper Basin is the residue after subtracting this figure from the average "virgin flow" at Lees Ferry.* The averages for various periods vary greatly, and selection of the base period is a matter of judgment on which experts differ. The upper division states have arrived at a residual quantity of 6,545.5 MAF or, after subtracting main stream reservoir evaporation water losses of 660 MAF, 5,885.4 MAF available annually for use at site. The Lower Basin states arrive at a lesser quantity available for Upper Basin use. This difference would not affect the Task Group's conclusions appreciably because of the very large quantities allocated to agricultural use which are transferable to the relatively small amount required for the supply of projected industrial uses.

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* The average virgin flow is the quantity which, it is estimated, would be flowing at Lees Ferry in any given year if all man-made depletions of the flow had never taken place. These calculated quantities of virgin flow at Lees Ferry are published by the U.S. Geological Survey.

UPPER BASIN

The Upper Colorado Basin Compact concerns water rights among Arizona, Colorado, New Mexico, Utah and Wyoming. It apportions consumptive use of 50 MAF/Y to Arizona and the remainder as follows:

- To Colorado - 51.75 percent
- To New Mexico - 11.25 percent
- To Utah - 23 percent
- To Wyoming - 14 percent

Applying these percentages to 5,885.4 MAF, the quantities available at site of use in each state would be:

- Arizona - 50,000 AF
- Colorado - 3,019,820 AF
- New Mexico - 656,482 AF
- Utah - 1,342,142 AF
- Wyoming - 816,956 AF

Not considered are the possible increases in these allocations resulting from augmentation of the Colorado River by importations from another basin, weather modification, installation of desalination plants, or diminutions which might result from deliveries to Mexico to ameliorate complaints by the Mexican Government over the quality of water reaching the boundary. The possibility of augmentation is provided for in the Colorado River Storage Project Act (82 Stat. 896). The first increase in supply so occasioned is earmarked for relief from the Mexican Treaty obligations. Currently, water is being delivered to Mexico in excess of the 1.5 MMAF treaty guarantee, in recognition of Mexico's water quality problem. (Minute 218, International Boundary and Water Commission, U.S. and Mexico.)

Colorado

Development of the principal oil shale areas in Colorado would utilize waters of the main stream of the Colorado River and of the White River, a tributary of the Green River. These uses would thus be controlled by the Colorado River Compaçt and the Upper Colorado River Compact.

The state has estimated Colorado's "virgin production" of water measured at the state line to be an average of 11,460 MAF. This virgin production is the quantity that would be present in the streams originating in the Colorado River Basin in Colorado as they flowed out of the state in the absence of activities of man.

The effect of the two compacts, as summarized earlier, is to limit Colorado to the consumptive use of a much lesser quantity, estimated by the state to be about 3,019 MAF annually at site of use. Thus, of the quantity of water originating in the Colorado, an average of 8,400 MAF, or about 74 percent, must be allowed to flow out, leaving only 26 percent available for consumptive use in the state.

Colorado has made no allocation of the Compact burden among the five rivers which carry water out of the state enroute to Lees Ferry. These are the Green, White, Colorado, Dolores and San Juan Rivers. The San Juan River, although originating in New Mexico, receives a half-dozen rivers originating in Colorado. It then enters Colorado and flows a short distance across the southwest corner of that state before entering Utah. It has been assumed for this discussion that the Compact burden is apportioned on a pro-rata basis among these five rivers.

New Mexico

It is estimated that 656 MAF of water supply from the Colorado River are available for annual consumptive use at site in New Mexico. It appears that about 600 MAF of this supply have been committed although much of it has not yet been put to use.

The commitments are as follows (in thousands of acre-feet) at site of use:

Navajo Reservoir evaporation losses		30
Federally authorized recreation projects:		
Hammond	10	
San Juan-Chama	110	
Navajo Indians	260	
Animas-LaPlata	35	
	415	415
Industrial contracts authorized by Congress (depletions at site of use)		
Public Service Co. of New Mexico	16,200	
Southern Union Gas Company	50	
Utah Construction Company	34,300	
	50,550	50.6
Non-federal uses		
Existing	100	
Authorized: Town of Farmington	5	
	105	105
Total (rounded)		601

The uncommitted margin is thus, at most, approximately 55 MAF.

Pollution

Water contracts issued by the Secretary of the Interior contain provisions to control water pollution. For example, each electric generation contract provides that the return flow of water, diverted under the contract, may not increase the concentration of dissolved solids in the San Juan River an average of more than 100 parts per million (ppm) when the river flow averages more than 200 cubic feet per second.

In *Jicarilla Indians vs. Morton*, the U.S. District Court of Arizona (Civ. 71-565 PHX-WCF) entered a summary judgment, March 15, 1972, dismissing a suit by a number of parties, including Indians in the Navajo area, who complained of the pollution caused by thermal generating plants in the Four Corners area (New Mexico, Arizona, Utah, Colorado), among other sites. The Court, in its findings and conclusions, found that the increase of salt content of the Colorado River (1 percent at the Mexican border) in consequence of diminution of the flow occasioned by this use of water for cooling was de minimis. The case has been appealed.

Shipment of Coal From New Mexico to Potential Plants in Nevada, Arizona and California

In the event that water cannot be made available in New Mexico in adequate quantities for processing of coal from the Four Corners area, it may be possible to move coal from those sources to plants in Nevada, Arizona and California on the main stream of the Colorado River. Coal is now being moved by slurry pipeline from northeastern Arizona to the Mojave steam power plant in southern Nevada. As discussed in the following section on the Lower Basin, it appears that adequate water supplies can be made available on the main stream in the Lower Basin in Arizona and California, but not in Nevada or in the Upper Basin portion of Arizona. The likely sources of water on the main stream are on or near a main line railroad which traverses the Four Corners area.

Wyoming

The Colorado River Compact provides for the transfer of water from the Colorado River Basin for processing coal in Wyoming because the major coal reserves in Wyoming are so located that the Missouri, rather than the Colorado River Basin, would be the probable source of water for processing. According to the calculation made by the Wyoming state authorities, its entitlement of water from the Colorado River Basin, available in the tributary basin of the Green River, is 816,956 acre-feet. For this reason, the feasibility of exporting 100 MAF to 200 MAF of water is now under consideration.

LOWER BASIN

Arizona

Arizona has three sources of entitlement to waters of the Colorado River System:

- Waters of the tributaries entering the river below Lees Ferry unaffected by the decision in *Arizona vs. California.** All of this is fully committed.

- 50 MAF of consumptive use in the Upper Basin above Lees Ferry (see discussion of the Colorado River Compact at the beginning of this chapter). This is also fully committed.

- 2,800 MAF of consumptive use of waters to be released from Lake Mead under contracts with the Secretary of the Interior pursuant to the decree in *Arizona vs. California*. Most of this supply is unavailable for coal conversion because it is being committed to existing federal reclamation projects on the main stream (Yuma Project, Gila Project, etc.) or to the Central Arizona Project.

However, the Supreme Court decision made a major award to the Colorado River Indian Reservation (adjoining Parker, Arizona). It entailed diversions of 717,148 acre-feet annually or the quantity of mainstream water necessary to supply the consumptive use required for irrigation of 107,588 acres of land "and for the satisfaction of related uses," whichever of the two quantities is less. This quantity, translated from diversion rights into consumptive use, is estimated to be equivalent to about 350 MAF of consumptive use. It is believed that these uses are transferable to industrial uses within the reservation. This water right with decreed priorities of 1864, 1875 and 1915 has priorities that are among the highest on the river, which are the "present perfected rights," free of diligence requirements in putting water to use, as the court decision states. About half of the decreed quantity is estimated to have been committed by agricultural leases, leaving approximately 175 MAF uncommitted. Availability of uncommitted water for industrial use would require contracts with the Tribal Council and the approval of the Secretary of the Interior.

Also included in the 2.8 MMAF is an award to the Fort Mohave Indian Reservation north of Parker. The quantity is 122,648 acre-feet of diversion rights or the quantity necessary to supply the consumptive use required for irrigation of 18,974 acres with priorities of 1890 and 1911. Of this amount, over half is estimated to be uncommitted.

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* *Arizona vs. California, et al.*, 376-U.S.340 (1964).

California

The Sante Fe Railway, which passes through the coal sources in the Four Corners area, crosses the Colorado River at Needles, California (Parker, Arizona). About 20 miles downstream from Needles is the Palo Verde Irrigation District. It has water rights for the irrigation of 104,500 acres, which is equivalent to about 400 MAF of consumptive use. This right is provided by a contract with the Secretary of the Interior and agreements with other California users. Its priority is the highest in California. Water rights of perhaps 100 MAF to 150 MAF could be acquired by purchase from individual landowners confirmed by contract with the District for industrial use within the District.

Nevada

Nevada is not a promising site for additional new power plants dependent on Four Corners coal because the quantity of Colorado River water rendered Nevada by *Arizona vs. California* (an equivalent of 300 MAF annually of consumptive use) is substantially less than the indicated demand. The power plant now using Four Corners coal is supplied by Colorado River water, pursuant to a 30-year contract with the Secretary of the Interior, with no assurance of renewal.

Chapter Six

UPPER MISSOURI RIVER WATER AVAILABILITY

THE NORTH CENTRAL POWER STUDY

Water supplies to support the development of coal and lignite deposits in Montana, North Dakota and Wyoming must come primarily from the Upper Missouri River Basin. However, Wyoming has at least 100 MAF/Y available from the Upper Colorado River for this purpose. About 2,880 MAF/Y are available for municipal and industrial use in the area, of which 2 MMAF are available from existing reservoirs, according to joint research by the U.S. Bureau of Reclamation and a group of electric power companies and municipalities.*

Unfortunately, most of this water is not now available at sites immediately adjacent to the minable deposits of coal. Solving this problem would involve several considerations. First, to move water to the coal operations, either major construction of aqueducts or coal-to-water transportation will be required. In either event, large capital investments and many months of preparation will be necessary. But neither the capital nor the time requirements for water supply development will be large in comparison to requirements for a coal conversion facility.

Second, the allocation of the physically available water will be determined by water rights. Specifically, such an allocation between the states and to sites within the states, or to specific uses at each site, will be controlled by the water laws and regulations of each of the states, the provisions of applicable interstate compacts, and federal laws regarding administration of federally financed and built water projects.

Third, the physical availability of water to any project will also be affected by economic considerations. The combination of legal availability and cost of acquisition and transportation will result in advantages for one coal deposit over another. Therefore, water development will be influenced by competitive pressures. It is beyond the scope of this study to interpret the complex legal and economic factors which will ultimately determine which water source will meet the requirements of particular consuming sites.

TRIAL ALLOCATION OF WATER

The Task Group has made a trial allocation of this water based on assumptions which are believed reasonable. Water, in the quantities reflected in Table 14 for the areas shown in Figure 3, is believed available as a reliable annual supply. However, there are serious problems, discussed previously, regarding the legal availability of some of this water for use in specific localities (i.e., inside or outside the drainage basin of the Yellowstone River) or

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* U.S. Bureau of Reclamation, *North Central Power Study*, Report of Phase I, Volume I (Billings, Montana, October 1971).

TABLE 14
WATER SUPPLY AVAILABLE FOR MUNICIPAL AND INDUSTRIAL USE
(Thousands of Acre-Feet Per Year)

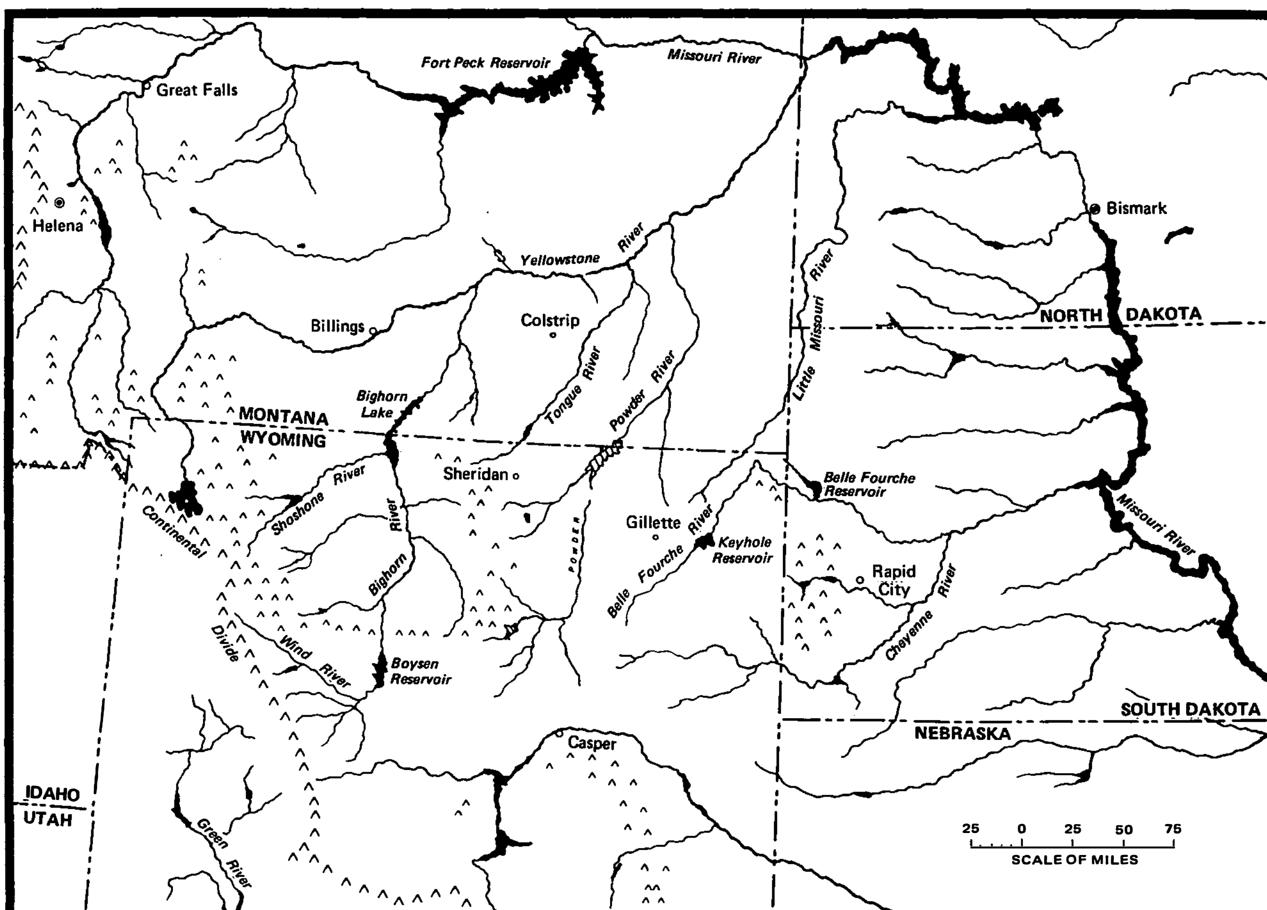
Existing Reservoirs	
Bighorn Basin (Downstream of Hardin, Montana)*	1,000
Missouri Main - Stream (Fort Peck and Garrison Reservoirs)†	1,000
Subtotal	**2,000**
Potential Reservoirs or Water Resources‡	
Powder River and Moorhead Reservoir	100
Tongue River and New Reservoir	60
Little Bighorn River and Reservoir	40
Little Missouri River and Reservoirs†	80
Green River and Aqueduct to Platte River	100
Buffalo Bill Reservoir and Enlargement	50
Yellowstone River surplus flows as firmed by offstream storage reservoirs	450§
Subtotal	**880**
Estimated total water resources available	**2,880**

* Of this amount 775 MAF are annually optioned to industry.

† All sources except these practical for Gillette-Colstrip development.

‡ Water from these reservoirs or sources except from the Little Missouri could be utilized in the Gillette or Colstrip areas.

§ Comparable costs to Hardin-Gillette.



SOURCE: North Central Power Study, Vol. II (October 1971).

Figure 3. Water Availability in the Upper Missouri River Basin.

its allocation between states which advance conflicting claims for its use. Studies by state or federal agencies and private organizations interpret these legal issues differently, leading to a proliferation of estimates which promote confusion. Therefore, for planning purposes, the Task Group has modified Table 15 to show what it believes the most probable allocation of the water to the states. In doing so, there has been no intent to interpret the law or define individual state policies; both litigation and interstate compacts will likely be needed to resolve these issues.

TABLE 15
ALLOCATION OF UPPER MISSOURI RIVER BASIN INDUSTRIAL AND MUNICIPAL WATER AVAILABILITY
(Thousands of Acre-Feet Per Year)

	Montana	N. Dakota	S. Dakota	Wyoming	Total
Missouri River Basin					
Main Stem	500	500	—	—	1,000
Yellowstone River Basin					
Yellowstone River Surplus	450	—	—	—	450
Big Horn River Basin	244	—	—	976	1,220
Little Big Horn River	40	—	—	—	40
Tongue River	60	—	—	30	90
Powder River	20	—	—	100	120
Little Missouri River	—	60	20	—	80
Colorado River Basin					
Import from Green River	—	—	—	100	100
Total	**1,314**	**560**	**20**	**1,206**	**3,100**

Note: Revised from *North Central Power Study* tables by Water Availability Task Group. See U.S. Bureau of Reclamation, *Appraisal Report on Montana-Wyoming Aqueducts* (Washington, D.C., April 1972), and letter dated June 11, 1970 from Harold Aldrich to Lloyd Bishop.

The following excerpt from the *North Central Power Study* discusses annual cost of furnishing water for electric power plant service in North and South Dakota, Colorado, Wyoming and Montana.

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EXTRACT FROM
NORTH CENTRAL POWER STUDY
REPORT OF PHASE I, VOLUME I
OCTOBER 1971

III B-4 WATER

PREFACE

The Water Supply Task Force identified the source and computed the cost of water delivered to potential coal fields which had been located by the Coal and Byproducts Task Force. The estimated costs per acre-foot of water delivered are summarized and are based on October 1970 price levels, including lands, rights, facilities and financing.

WATER RESOURCES

Water supplies which could be used, or developed and utilized, for industrial development of coal in the Gillette-Colstrip geographic area are estimated to be about 2.8 million acre-feet annually. About one million acre-feet of this amount are immediately available from the Wind-Bighorn system and another million acre-feet from Fort Peck or Garrison Reservoir. An additional 280,000 acre-feet can be developed from potential reservoirs on the Powder, Tongue, Little Bighorn and Little Missouri Rivers. It is technically feasible to import 100,000 acre-feet from the Green River. Enlargement of Buffalo Bill Reservoir would produce an additional 50,000 acre-feet. Surplus flows from Yellowstone River would provide at least 450,000 acre-feet if supported by offstream reservoirs to exchange water supplies in periods of low flow. Table III B-4.1 shows the water supply by existing and potential developments. About 1.8 million acre-feet are potentially available for Colstrip-Gillette development.

The Bureau of Reclamation has authorization to annually option 775,000 acre-feet of water to industry from the Wind-Bighorn River system, at Hardin, Montana. Contracts have been executed in the amount of 658,000 acre-feet and requests are pending for 295,000 acre-feet. Interest has been indicated in an additional 200,000 acre-feet or more.

WATER REQUIREMENTS

The annual water delivery requirements were predicated on steam-plants operating at 85 percent load factor. The daily delivery was based on meeting the maximum daily requirement. Wet cooling towers for dissipating heat were considered the most likely choice; however, cooling ponds and flow-through type cooling were investigated.

The water delivery was assumed into a holding reservoir at the steam plantsite from which water could be withdrawn for boiler feed and cooling make-up water to offset evaporation, blow down and other losses.

Table III B-4.2 which permits a comparison of water costs between coal field locations, was based on 17.5 c.f.s. per 1,000 megawatts, which was judged to represent minimum requirements for steam generation, but would enable satisfactory comparisons of water costs between coal sites.

Tables III B-4.3 and -4.4, which compare water costs at the Gillette, Wyoming vicinity and Colstrip Montana area respectively, were based on 28 c.f.s. per 1,000 megawatts as being more liberal

Table III B-4.2

ANNUAL COSTS OF WATER 7/
(Oct. 1970 Price Level)

Plant Location	Plant Size (MW)	Conveyance Investment 1/	Pumping Energy 2/	Replacements 3/	Operation & Maintenance	Assigned Aqueduct or Storage	Total	Per Ac.-Ft. Delivered (Dollars)
		(- - - - - - - -	- - - - - - - -	$1,000	- - - - - - - -	- - - - - - - -	- - -)	
North Dakota								
Bowman #1	5,000	$1,197	$188	$ 48	$141	$1,925	$3,499	$ 64
Bowman #2	5,000	5,562	702	216	288	495	7,263	132
N of Dickinson	3,000	1,267	156	51	178	1,155	2,807	85
Dickinson	3,000	1,894	268	75	265	297	2,799	85
Dickinson and	(3,000)	2,978	600	118	323	792	4,811	55 4/
Bowman	(5,000)	2,950	312	116	257	--	3,635	121 5/
Beulah	5,000	955	112	37	29	495	1,628	30
Center	1,000	346	49	13	117	99	624	57
South Dakota								
Ludlow	1,000	631	72	25	160	385	1,273	116
Colorado								
Watkins	1,000	423	56	17	123	275	894	81
Wyoming								
W of Kemmerer	5,000	1,790	356	70	228	440	2,884	52
NE of Rock Springs	1,000	687	108	27	262	88	1,172	106
N of Wamsutter	5,000	3,153	448	124	331	440	4,496	82
Gillette Vicinity, 10 Plants	10,000 ea.	(- - - - - - - - - St. Xavier to Gillette Aqueduct - - - - - - - - - - -)						(85-101) 6/
Spotted Horse	3,000	" " " " "						(68-80) 6/
Lake DeSmet	10,000	" " " " "						(65-73) 6/
Montana								
NW of Brockway	5,000	1,967	336	77	235	495	3,110	57
Paxton	1,000	672	68	26	157	99	1,022	93
Richey	1,000	733	88	28	213	99	1,161	106
Fort Kipp	1,000	67	12	3	27	99	208	19
Reserve	1,000	643	68	26	188	99	1,024	93
Coal Ridge	1,000	877	96	34	247	99	1,353	123
Wibaux	5,000	1,394	280	56	205	495	2,430	44
W of Savage	1,000	401	60	16	124	99	700	64
Colstrip	5,000	1,401	312	56	189	495	2,453	45
NW of Brandenburg	1,000	292	40	12	89	99	532	48
SE of Ashland	5,000	634	76	25	75	1,870	2,680	49
Birney	1,000	(- - Plant located adjacent to Tongue River - - -)				374	374	34
Birney-PJ	1,000	" " " " " "				374	374	34
S of Birney	10,000	1,041	212	41	88	3,960	5,342	49
Kirby Alt. 1	1,000	475	84	18	154	374	1,105	100
Kirby Alt. 2	1,000	1,200	40	47	94	374	1,755	160
Decker	5,000	(- - Plant located adjacent to Tongue River - - -)				1,870	1,870	34
Volborg	5,000	1,774	304	70	232	495	2,875	52
Camps Pass	10,000	4,476	912	177	374	990	6,929	63
Sonnette	1,000	428	80	17	151	319	995	90
Broadus	3,000	(- - Plant located adjacent to Powder River - - -)				957	957	29
Moorhead	5,000	" " " " " "				1,595	1,595	29

1/ Investment costs amortized over 35 years @ 3.463 percent.
2/ Energy costs computed at 4 mills per kwh.
3/ Combined replacement factor = 0.002674 x field cost.
4/ Unit cost for 88,000 acre-feet of water delivered to Dickinson; 33,000 for Dickinson plant and 55,000 for Bowman plant.
5/ Includes $54 per acre-foot for water delivered to Dickinson for Bowman plant.
6/ Cost range for medium and large size aqueducts, see Table 6A in appendix.
7/ This table is based on 17.5 c.f.s. per 1,000 megawatts of installed capacity, and should be considered as minimum required for boiler make-up water and to offset cooling tower evaporative losses.

Table III B-4.3

UNIT COST OF WATER DELIVERED IN GILLETTE AREA
(Oct. 1970 Price Level)

Aqueduct Water Deliveries and Unit Costs

MW Installed	Water for Generation A.F./Yr. 1/	Cost of Water Per Acre-Foot (Steam Plant Portion of Delivered Water) 100%	67%	50%	33%
3,000	50,000	$170.00	$149.00	$133.00	$114.00
6,000	103,000	133.00	113.00	102.00	91.00
8,000	137,000	118.00	102.00	94.00	85.00
13,000	212,000	101.00	90.00	85.00	79.00
15,000	257,000	96.00	86.00	82.00	78.00
20,000	342,000	89.00	82.00	79.00	77.00
23,000	394,000	86.00	80.00	78.00	76.50
25,000	427,000	84.00	79.00	77.00	76.00
30,000	510,000	82.00	78.00	76.50	76.00
40,000	685,000	79.00	76.50	76.00	76.00
50,000	855,000	77.00	76.00	76.00	76.00

1/ Based on 28 c.f.s. per 1,000 MW installed capacity as suggested in Chapter X of National Power Survey.

Table III B-4.4

UNIT COST OF WATER DELIVERED IN COLSTRIP AREA
(Oct. 1970 Price Level)

Aqueduct Water Deliveries and Unit Costs

MW Installed	Water for Generation A.F./Yr. 1/	Cost of Water Per Acre-Foot (Steam Plant Portion of Delivered Water) 100%	67%	50%	33%
3,000	50,000	$45.00	$41.00	$37.00	$32.00
6,000	103,000	37.00	31.00	28.00	23.00
8,000	137,000	33.00	28.00	24.00	20.00
13,000	212,000	27.00	22.00	20.00	18.00
15,000	257,000	25.00	21.00	19.00	16.50
20,000	342,000	22.00	19.00	17.00	16.00
23,000	394,000	21.00	18.00	16.00	15.50
25,000	427,000	20.00	17.00	15.50	15.00
30,000	510,000	19.00	16.00	15.00	15.00
40,000	685,000	17.00	15.50	15.00	15.00
50,000	855,000	16.00	15.00	15.00	15.00

1/ Based on 28 c.f.s. per 1,000 MW installed capacity as suggested in Chapter X of National Power Survey.

and to be used for the NCPS. These water rates were judged to be adequate for steam generation and were used to determine costs of various generating capacities in terms of water deliveries solely for generation and in combination with water needs for other types of coal processing.

INVESTMENT AND ANNUAL COSTS

The cost of water delivered was based on quantities relating to installed generation capacity. Pipeline sizing was based on studies of economical size pipe for various flows, hydraulic head, and structural safety. The number of pumping lifts was determined from total lift but each lift was limited to 250 feet wherever possible. Flow control structures were used at each 150-foot drop in elevation along any line. Each conveyance facility was estimated as a modern system which would automatically sense and adjust to varying demand.

The field costs of conveyance facilities to deliver water to each of the potential coal fields, and all engineering, supervision, administration and related indirect costs including financing and interest during construction are summarized on Table III B-4.2. Operation, maintenance, and replacement costs were estimated for a system operating almost continually during the 35-year project life.

* * * (End of Extract) * * *

Any steamplant that could be located adjacent to its water supply would not require an expensive or complex conveyance system. Assigned costs as shown in Table III B-4.2 represent the costs of developing or acquiring a firm water supply from existing reservoirs, of constructing new reservoirs or of purchasing irrigated land to obtain a water right.

A consumptive use, including boiler make-up water, of 28 cubic feet per second per 1,000 megawatt installed capacity greatly increases the water requirements of a plant but decreases the unit cost per acre-foot of water delivered. The increased water requirements and unit cost of water delivered to Gillette, Wyoming, are tabulated on Table III B-4.3 of the foregoing extract. The last three columns of the tabulation indicate the unit cost of water when sharing the use of a pipeline system with other coal processors. It should be noted that the unit cost of water becomes less when the portion of water delivered for generation becomes less. Table III B-4.4 indicates similar cost conditions for water delivered from the Yellowstone River to Colstrip, Montana.

Chapter Seven

UPPER MISSOURI RIVER
INDUSTRIAL WATER REQUIREMENTS FOR
PROJECTED 1985 ENERGY DEVELOPMENT

Availability of sufficient water to support projected energy plant development appears certain in the Upper Missouri River Basin. Table 8 shows a maximum (Case I) projected water requirement of 836 MAF/Y in the states of the Upper Missouri River Basin. Of this total, 51 percent was assumed allocated (by the NPC's Coal Task Group) to electrical generation, with the other 49 percent assumed allocated for conversion of coal and lignite to synthetic liquids and gas.

A comparison of these requirements and a projection of the available supply is shown in Table 16. The estimate of available supply has been prepared by the Water Availability Task Group based on a modification of Table 3, Volume I, of the *North Central Power Study* cited in the preceding chapter. While this Task Group has confidence in the total water availability from the sources listed, it is less certain concerning allocation of these totals to individual states. Where such allocations have been made without some indication of a consensus on the part of the states, a question mark has been added to emphasize the uncertainty. It must be recognized that the actual rights of each state to a portion of the total supply available will be controlled by interstate compacts and that availability within a state of any part of an individual state's entitlement will be controlled by the laws of that state. However arbitrary the allocations flagged by question marks may be, the other allocations are sufficiently firm as to lead to the conclusion that available supplies can readily meet the requirements shown. Of course, meeting the Case II/III and Case IV requirements (shown in Table 16) would be even less taxing.

MONTANA

Montana's indicated requirement of 317 MAF of water per year can be met from her partially developed Wind-Big Horn River and undeveloped Yellowstone entitlements. Other smaller sources are available to the state for development of individual projects and these may actually offer the most attractive alternative for the first plants during the initial slow buildup of capacity (see Table 17). In addition to these sources, the state can take from the main stem of the Missouri River, including the existing Fort Peck reservoir, great quantities of water. While this source is somewhat more remote from most of Montana's coal than the sources earlier mentioned, it would not be economically or physically impractical to use this water.

TABLE 16
CASE I
UPPER MISSOURI RIVER
WATER SUPPLY / DEMAND
(Thousands of Acre-Feet Per Year)

	Mont.	N. Dak.	S. Dak.	Wyo.	Total
Projected Water Requirement for Energy (Consumptive Use)					
Electricity	148	98	20	160	426
Coal	169	46	—	195	410
Oil Shale	—	—	—	—	—
Total	**317**	**144**	**20**	**355**	**836**
Apparent Water Availability*					
Existing Reservoirs					
Wind-Big Horn River† (Yellowtail, Bighorn Lake and Boysen)	244.1	—	—	976.6	1,220.7
Missouri River (Fort Peck and Garrison)	500(?)	500(?)	—	—	1,000.0
Subtotal	**744.1**	**500**	**—**	**976.6**	**2,220.7**
Projects to be Developed					
Little Missouri	—	60	20	—	80.0
Yellowstone Surplus	450(?)	—	—	—	450.0
Other	120(?)	—	—	230(?)	350.0
Subtotal	**570**	**60**	**20**	**230**	**880.0**
Total	**1,314.1**	**560**	**20**	**1,206.6**	**3,100.7**

* Modified from U.S. Bureau of Reclamation, *North Central Power Study,* Vol. I, Table III, (Billings, Montana, 1971).

† Letter 6-11-71 Aldrich (USBR) to Bishop.

NORTH DAKOTA

North Dakota has access to huge quantities of water from the Missouri River and some of its tributaries. The 144 MAF (Case I) requirement indicated in Table 16 is small in comparison with the available supply. While some of North Dakota's coal resources are adjacent to the river, other deposits are more remote. On balance, however, the situation is comparable to that in Montana and Wyoming.

SOUTH DAKOTA

South Dakota's modest requirement of 20 MAF may be met by diversions from the Little Missouri or Grand River basins.

TABLE 17

CASE I—MONTANA
PROJECTED SCHEDULE OF ENERGY DEVELOPMENT AND WATER CONSUMPTIVE USE REQUIREMENTS

	1970	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Synthetic Gas													
Plant (250 MMCF/D) Units													
Incremental		–	–	–	–	–	1	2	2	2	3	2	2.4
Cumulative		–	–	–	–	–	1	3	5	7	10	12	14.4
Water Requirements (MAF/Y)*													
Cumulative							10	30	50	70	100	120	145
Synthetic Oil													
Plant (50 MB/D) Units													
Incremental		–	–	–	–	–	–	–	–	–	1	–	1
Cumulative		–	–	–	–	–	–	–	–	–	1	1	2
Water Requirements (MAF/Y)													
Cumulative		–	–	–	–	–	–	–	–	–	15	15	25
Electric Generation													
Plant (1,000 MW) Units													
Incremental		–	.4	–	1	–	1	–	1	1	–	1	1
Cumulative		–	.4	.4	1.4	1.4	2.4	3.4	4.4	5.4	5.4	6.4	7.4
Water Requirements (MAF/Y)													
Cumulative		–	10	10	30	30	50	70	90	110	110	130	150
Total Water Requirement (MAF/Y)		–	10	10	30	30	60	100	140	180	225	265	320

* Thousand acre-feet per year.

WYOMING

Wyoming will have more than enough water to meet the projected Case I requirements of 355 MAF (shown in Table 16). Her entitlement from the developed reservoirs on the Wind and Big Horn Rivers would provide 976.6 MAF/Y if these reservoirs were operated at near optimum efficiency. Her "other" sources (shown in Table 16) include 100 MAF from the Colorado River Basin and an estimate of supplies from streams within the Powder River Basin of northeastern Wyoming where most of the state's coal reserves are concentrated.

Wyoming is entitled to some 817 MAF/Y from the Colorado River Basin at the 6.5 MMAF level of development of the Upper Colorado River (Appendix F, Table 26). Under the state's alternative to the Upper Colorado Region Study, Wyoming has allocated 170.8 MAF to electrical generation and mineral development in the year 2000 and 170.2 MAF in 2020. Table 16 includes only about 100 MAF of this quantity. Studies have been made by the state to demonstrate the feasibility of physically transferring all of the Colorado River water to which the state is entitled, and which may not be required for in-basin development, to the Powder River Basin coal fields.

The Task Group anticipates that the more limited local sources of water may be developed to supply the earliest plants (see Table

18) and assist in meeting early demand while the major transbasin diversion projects are being built. It should be emphasized that as much as 8 to 10 years of lead time must be allowed to permit planning and orderly construction of projects of the magnitude required.

WATER QUALITY

In general, the surface and ground water available in the Northern Rocky Mountain region is of fair quality. On some streams and in some sources of ground water, the concentrations of dissolved solids are relatively high and may at points exceed 2,000 mg/l.

In the headwaters, most streams contain from 100 to 300 mg/l of dissolved solids. However, as the water flows toward the junction with the Missouri River, the concentration increases markedly receiving soluble salts from irrigation return flows and dissolving the soluble fraction in soils and rocks. The Yellowstone River below the junction with the Powder River contains between 350 and 700 mg/l. The lower reach of the Big Horn River contains between 700 and 1,200 mg/l of dissolved solids. The concentration of dissolved solids in the lower reach of the Powder River may often exceed 2,000 mg/l.

TABLE 18

CASE I—WYOMING
PROJECTED SCHEDULE OF ENERGY DEVELOPMENT AND WATER CONSUMPTIVE USE REQUIREMENTS

	1970	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Synthetic Gas													
Plant (250 MMCF/D) Units													
Incremental		–	–	–	–	1	1	–	1	1	1	1	1
Cumulative		–	–	–	–	1	2	2	3	4	5	6	7
Water Requirements (MAF/Y)*													
Cumulative		–	–	–	–	10	20	20	30	40	50	60	70
Synthetic Oil													
Plant (50 MB/D) Units													
Incremental		–	–	–	–	–	–	1	1	–	1	4	3
Cumulative		–	–	–	–	–	–	1	2	2	3	7	10
Water Requirements (MAF/Y)													
Cumulative		–	–	–	–	–	–	15	25	25	40	90	125
Electric Generation													
Plant (1,000 MW) Units													
Incremental		1	–	1	–	1	–	1	1	–	1	1	1
Cumulative		1	1	2	2	3	3	4	5	5	6	7	8
Water Requirements (MAF/Y)													
Cumulative		20	20	40	40	60	60	80	100	100	120	140	160
Total Water Requirement (MAF/Y)		**20**	**20**	**40**	**40**	**70**	**80**	**115**	**155**	**165**	**210**	**290**	**355**

* Thousand acre-feet per year.

Sediment concentrations are relatively high in many streams. Although land treatment programs have been effective in reducing sediment loads in some areas, more extensive watershed treatment and management will be required to effectively reduce sediment loads throughout a large part of the area.

The average sediment concentration may exceed 5,000 mg/l in streams in the northern part of the basin and may exceed 20,000 mg/l in the Powder River. Extensive surface mining activities may aggravate the sediment problem in the Powder River Basin, and any plans for mining should contain provision for retention of sediment in the mining area.

Chapter Eight

OTHER BASINS

COLUMBIA RIVER INDUSTRIAL WATER REQUIREMENTS FOR PROJECTED 1985 ENERGY DEVELOPMENT

Table 8 shows a projected requirement of 20 MAF in the State of Washington (Pacific Northwest Basin) for electrical (thermal) power generation. Because this quantity is insignificantly small as compared to the water physically present in the Columbia River and other sources in the state, the Task Group has assumed, without further investigation, that this requirement can be met.

GULF COAST INDUSTRIAL WATER REQUIREMENTS FOR PROJECTED 1985 ENERGY DEVELOPMENT

A projected requirement of 44 MAF of water for electrical generation and coal gasification in the States of Texas and Arkansas is shown in Table 8.

The lignite deposits in these states are located in an area of high precipitation near the Gulf of Mexico. Since lignite is found in these states in a large number of river basins, it will be necessary to identify specific deposits before water availability tests can be intelligently applied. The Task Group has assumed, without further inquiry, that the 44 MAF of water will be available.

ILLINOIS BASIN

Water supplies in the Illinois Basin are considered adequate for all uses until 1980. Beyond this date, supplies from some local areas may become scarce and intra-region diversion may be necessary.

The Illinois Basin is drained by two principal river and three tributary drainage systems. The Wabash River drains the major coal field of southern Indiana and the Kentucky-Green River system drains the coal fields of central and western Kentucky. Both rivers are tributary to the Ohio River and are shown in the Ohio Basin in Figure 1. The major coal fields of southern Illinois are drained by the Illinois and Kaskaskia Rivers, both tributary to the Mississippi River.

Availability of Surface Water

The average runoff from the Illinois Basin is 57 billion gallons per day (bgd). Runoffs from the individual basins vary from 15 bgd in the Illinois River Basin to 23 bgd in the Kentucky-Green River Basins. The Wabash River has an average runoff of 19 bgd. In addition to the natural runoff, the Illinois River system receives an export from the Great Lakes Basin--about 2 bgd of waste water from the Chicago metropolitan area.

Extremely low flows generally occur in mid-winter and mid-summer, and extremely high flows normally occur in the spring. Smaller watersheds produce extremely high runoffs of short duration following summer rainstorms. Runoff is generally lowest in the Illinois River Basin.

Droughts occur in varying intensity, duration and geographic location. For example, the drought of 1931, one of the most severe, affected the water supply conditions throughout the area. Streamflow averaged only 12 percent of normal in the western portion of the Illinois Basin.

The existing surface water supply and water use by steam-electric power plants are summarized in Table 19.

TABLE 19
NATURAL RUNOFF, ILLINOIS BASIN
(Billions of Gallons Per Day)

	Average Runoff	Electric Power	
		Water Use	Consumed
Wabash River Basin	19.2	1.4	0.01
Kentucky-Green Basin	23.2	5.3	0.04
Illinois River Basin	15.4	2.6	0.03

Availability of Ground Water

Ground water is available throughout the Illinois Basin. The best aquifers are in the alluvial material along the Ohio River and in the low reaches of the major tributaries. The glacial sediments north of the Ohio River are a mixture of clay, silt, sand and gravel and many of the gravel train (buried river valleys) aquifers contain large volumes of water. The bedrock aquifers, sandstone and limestone produce good yields from wells, but there are large areas of shale through the center of the region where ground water supplies are difficult to develop. Approximately 1 bgd are withdrawn from ground water sources in the Basin for municipal and industrial uses.

Water Quality

In general, surface waters in the Basin are of good chemical quality. Dissolved solids vary from less than 100 mg/l to over 1,000 mg/l. Principal water quality problems are associated with residual organics and nutrients, sediment loads and acid-mine drainage from coal producing areas. Heat from steam-electric plants creates localized water quality problems in some areas. The chemical content of ground water is generally higher than that of surface water and tends to be constant in composition.

Water Supply

Water supplies, both surface and ground, are considered adequate under present conditions. However, future demands for energy in the Basin may strain the available water supplies by the year 2000. At present, about 2.6 bgd (8 MAF) out of an average supply of 15 bgd (46 MAF) are used for steam-electric power in the Illinois River Basin. By 2000 it is projected that 12 bgd (37 MAF) will be necessary to sustain the steam-electric generating capacity. The use of this volume of water may require extensive pollution controls to decrease thermal loading of the streams while at the same time reducing evaporative losses in the system.

APPALACHIAN BASIN

An excellent supply of water is one of the factors favoring as well as hindering further mining development in the Appalachian Basin. Sufficient water of good quality is available for the expansion of the coal mining industry and the development of energy reserves although a high degree of management skill will be required to resolve existing environmental pollution problems and to forestall the development of new problems.

As surface streams generally will supply large future demands for industrial water, areas where major transportation systems and streams coincide may offer the best potential sites for expansion of mining activities. Water problems are now present at some of these sites--Pittsburgh and Birmingham for example--and may continue to arise at other points with future development of the Basin. Stream pollution is a major concern, particularly in the lower reaches of streams where industries tend to congregate. Acid mine drainage is a problem throughout much of the coal-bearing part of the Basin. Other local problems in the Basin include the natural hardness of water from limestone areas and the presence of other undesirable minerals. Problems in water quality management in the Basin undoubtedly will increase as further development occurs.

Availability of Surface Water

An average of 150 billion gallons of water (460 MAF) leaves the Appalachian Basin daily. About two-thirds of this flow is carried in four major streams: the Tennessee, Susquehanna, Ohio, and Alabama Rivers. Table 20 lists the average flow of all streams flowing from the Basin, as measured at the gaging site nearest the boundary of the Basin. The Basin, with an average runoff of 20 inches (and more than 30 inches in some areas), ranks among the highest in the country for regions of comparable size.

The pattern of average annual runoff for the Basin follows closely the pattern of average annual precipitation. There are two distinct areas of high runoff. One occurs in the southern part of the Blue Ridge province in North Carolina and the other

TABLE 20

AVERAGE FLOW FOR SELECTED STREAMS ENTERING OR LEAVING THE APPALACHIAN REGION

Streams	Location		Drainage Area in sq. Miles	Years of Record	Average Flow	
	Lat.	Long.			Cubic Feet Per Sec.	Inches Per Year
Streams entering Region:						
Chemung River at Chemung, New York	42°59′	76°38′	2,530*	56	2,514	13.4
Mahoning River at Lowellville, Ohio	41°02′	80°32′	1,076	20	1,078	13.6
Hocking River at Enterprise, Ohio	39°34′	82°28′	460	32	435	12.8
Muskingum River at Dresden, Ohio	40°07′	82°00′	5,982	41	6,137	13.9
Paint Creek near Greenfield, Ohio	39°23′	83°22′	251	26	219	11.9
Pymatuning Creek near Orangeville, Pennsylvania	41°19′	80°29′	169	49	205	16.4
Scioto River at Chillicothe, Ohio	39°21′	82°58′	3,847	42	3,294	11.6
Susquehanna River at Waverly, New York	41°59′	76°30′	4,780*	25	7,549	21.5
Streams leaving Region:						
Alabama River near Montgomery, Alabama	32°25′	86°25′	15,100*	35	23,250	20.9
Big Sandy River at Louisa, Kentucky	38°10′	82°38′	3,892	24	4,228	14.8
Black Warrior River at Tuscaloosa, Alabama	33°13′	87°34′	4,828	42	7,723	21.7
Broad River near Gaffney, South Carolina	35°06′	81°35′	1,490*	24	2,420	22.0
Cahaba River at Sprott, Alabama	32°40′	87°14′	1,378	24	2,077	20.5
Catawba River at Catawba, North Carolina	35°43′	81°04′	1,535	30	2,337	20.6
Chattahoochee River near Norcross, Georgia	34°00′	84°12′	1,170*	50	2,241	20.6
Cumberland River at Carthage, Tennessee	36°15′	85°57′	10,700*	40	17,220	21.9
James River at Buchanan, Virginia	37°32′	79°41′	2,084	64	2,488	16.2
Kanawha River at Charleston, West Virginia	38°22′	81°42′	10,419	23	14,466†	18.9
Kentucky River at Lock 6, near Salvisa, Kentucky	37°56′	84°49′	5,102	37	6,664	17.8
Little Kanawha River at Palestine, West Virginia	39°04′	81°23′	1,515	23	2,119	19.0
Middle Island Creek at Little, West Virginia	39°29′	81°00′	458	34	617	18.3
Ohio River at Cincinnati, Ohio	39°06′	84°31′	76,580*	23	96,810‡	17.2
Potomac River at Point of Rocks, Maryland	39°16′	77°33′	9,651	67	9,246	13.0
Shenandoah River at Millville, West Virginia	39°17′	77°47′	3,040	47	2,694	12.1
Sipsey River near Elrod, Alabama	33°15′	87°46′	518	26	760	20.0
Susquehanna River at Harrisburg, Pennsylvania	40°15′	76°53′	24,100*	72	34,420	19.4
Tennessee River at Savannah, Tennessee	35°13′	88°16′	33,140*	32	53,000	21.7
Wheeling Creek at Elm Grove, West Virginia	40°03′	80°40′	282	22	328	15.8
Yadkin River at Yadkin College, North Carolina	35°51′	80°23′	2,280	34	2,916	17.4

Note: Flow is measured at gauging site nearest the Region boundary.

Source: Department of the Interior, U.S. Geological Survey, *Hydrological Investigations Atlas #199,* (Washington. D.C., 1965).

* Approximate

† Adjusted for storage since 1938

‡ Adjusted for storage

along the western face of the Valley and Ridge province in West Virginia and Pennsylvania.

Annual runoff in the Basin varies widely from year to year. In many places, annual runoff ranges from nearly double the average to less than half the average. Annual runoff for three selected streams is shown in Figure 4. The Susquehanna River at Harrisburg, Pennsylvania ranged from 11.35 inches in 1931 to 29.64 inches in 1891. The Greenbrier River at Alderson, West Virginia draining 1,357 square miles, ranged from 9.83 inches in 1941 to 33.83 inches in 1906, with an average of 20.0 inches. The Black Warrior River at Tuscaloosa, Alabama also for the period of record shown in Figure 4 ranged from 11.59 inches in 1941 to 39.13 inches in 1900. These ranges in annual runoff are typical of those for other streams in the Basin.

The 1931 water year is noted for large deficiencies in runoff over most of the Basin. Runoff at most gaging sites was about half the average. This deficient streamflow resulted from below-normal precipitation, compounded by below-normal ground-water storage and soil moisture as a result of below-normal precipitation in the preceding year. It should be noted, however, that years of deficient streamflow do not necessarily mean droughts, which occur as a result of extended periods of deficient precipitation during the growing season. Occasionally, even in years of extremely deficient streamflow, precipitation during the summer will be ideally distributed to give maximum benefit to crop growth with little or no contribution to streamflow.

In addition to the year-to-year variations in total runoff, there is also a within-year cyclical variation. Streams throughout the Basin experience high flows during spring and low flows during fall. Flooding, particularly on streams draining over 100 square miles, occurs mostly during the spring period of high runoff, followed by a general recession of flow to a minimum usually in September or October. A typical cyclical variation in daily flow is shown in Figure 5.

Availability of Ground Water

Small to moderate quantities of ground water are available nearly everywhere in the Appalachian Basin, and abundant ground water is available in some areas, as shown on the map of ground-water availability in Figure 6. The map covers parts of six physiographic provinces, each having distinctive features of ground-water occurrence related to precipitation, topography and geology. The provinces are the Piedmont, Blue Ridge, Valley and Ridge, Appalachian Plateaus and small parts of the Interior Low Plateaus and Central Lowland.

Throughout the Basin, the ground-water aquifers serve the dual function of providing water supply via wells and springs and of furnishing a perennial base of streamflow by seepage and spring

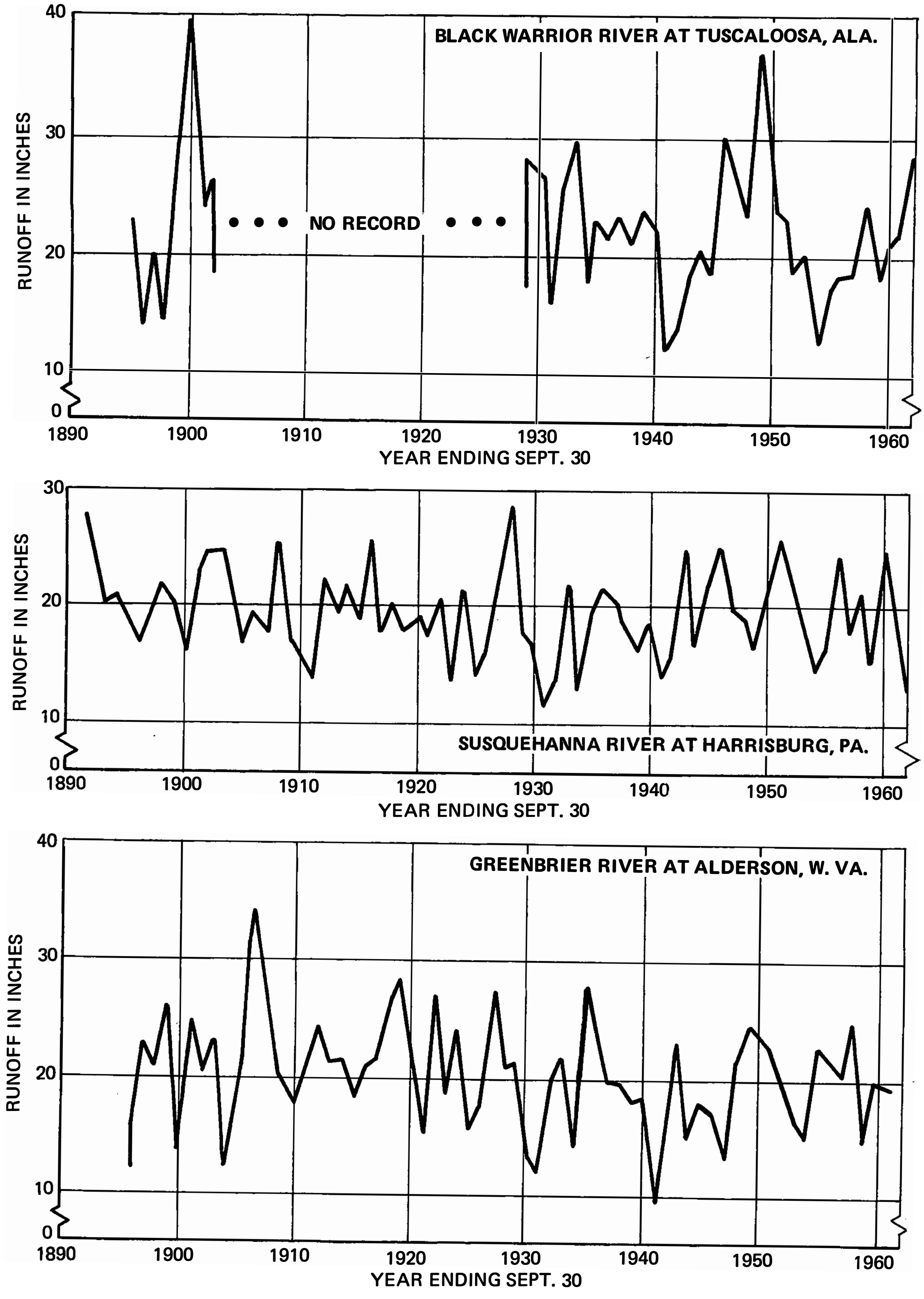

Figure 4. Variability of annual runoff.

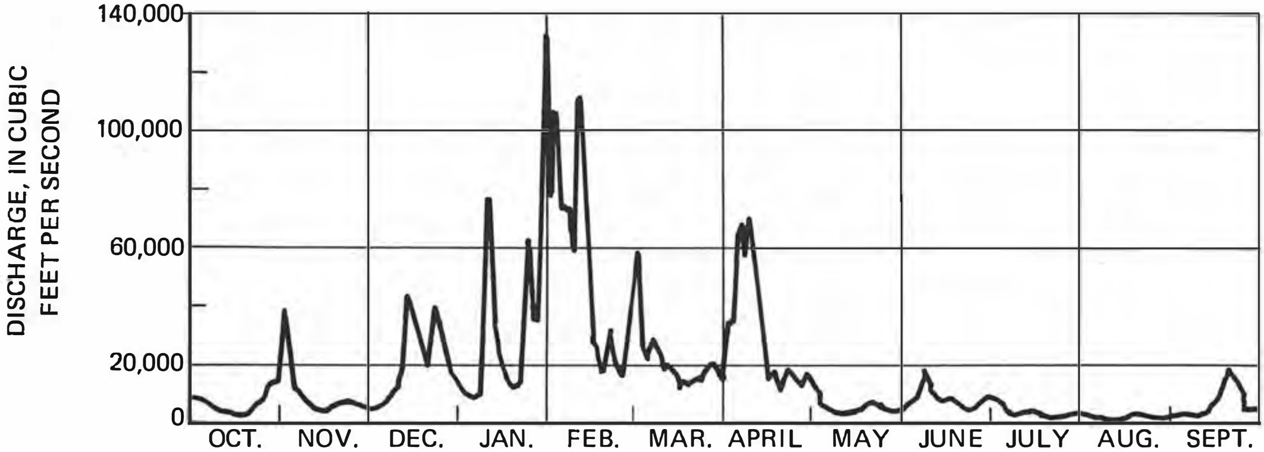

Figure 5. Daily streamflow, Kanawha River at Winfield, West Virginia, 1936-37.

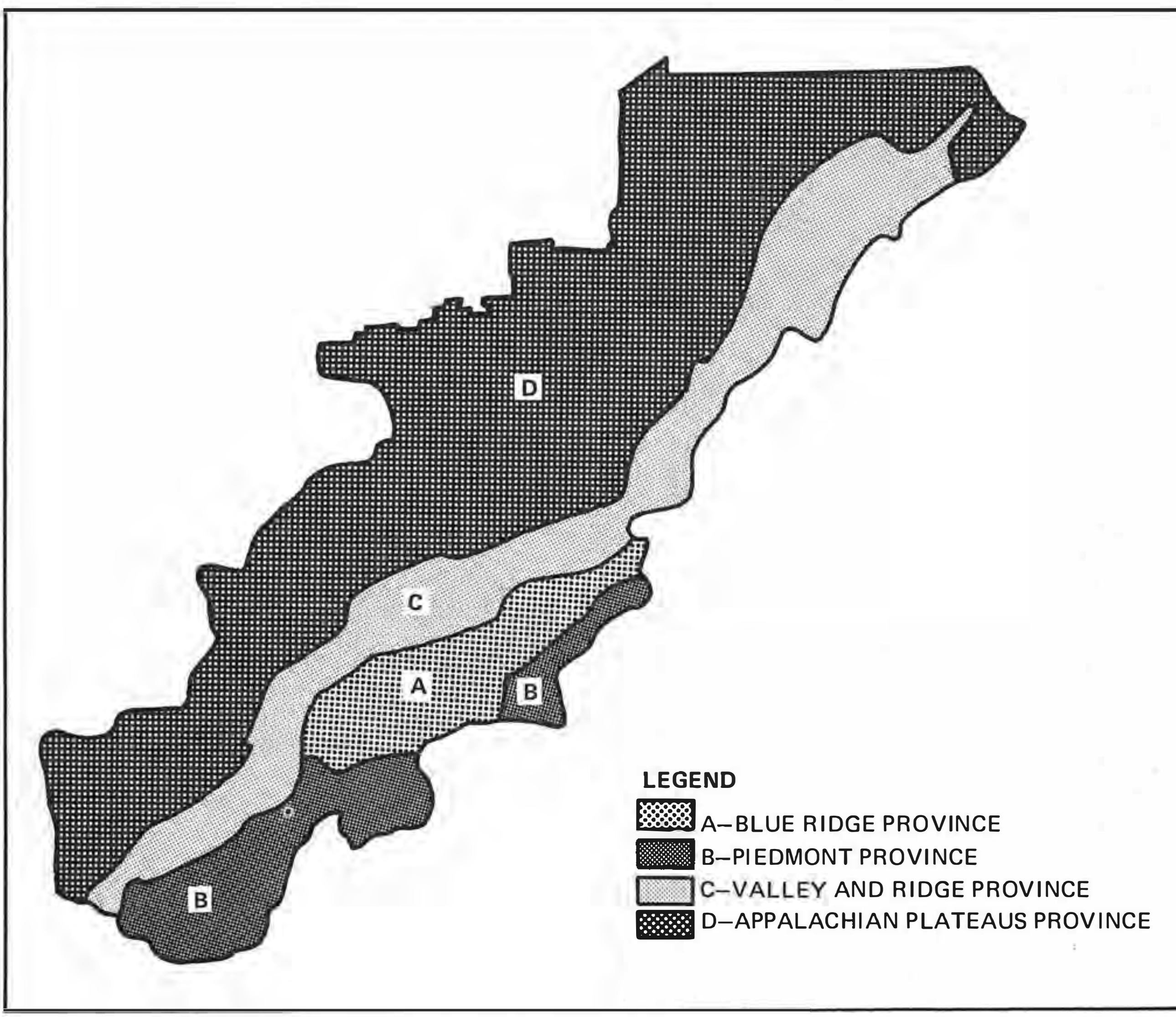

Figure 6. Ground water zones in the Appalachian Region.

discharge. The rates of discharge from the ground-water reservoirs to the streams generally are greatest immediately after rainfall. During lengthy rainless periods, the discharge from ground-water reservoirs reaches its lowest rate, ranging from zero to more than 1.0 cubic foot per second from each square mile of territory.

The least productive ground-water province in the Basin is the Blue Ridge (Figure 6, Zone A), which is underlain by dense, sparsely fractured, poorly permeable crystalline rocks that yield little water to wells. Development of supplies in excess of domestic or small commercial requirements is unlikely; well yields in excess of about 15 gallons per minute (gpm) generally are not expected.

The Piedmont province within the Basin (Figure 6, Zone B) is underlain by rocks similar to those of the Blue Ridge but is more favorable to the occurrence of ground water. Highly calcareous metamorphic rocks, particularly the narrow belts of marble, limestone and other carbonate rocks, are the best aquifers; however, they are not widespread. At shallow depths, these rocks yield readily to solutional attack and the enlarged crevices provide space for the storage and movement of ground water. Wells that penetrate cavernous water-filled carbonate rocks yield several hundred to several thousand gallons per minute, but, because of the narrowness and shallowness of the aquifers, they may show a progressive decrease of yield with continued heavy pumping. The extensive quartzite rocks of the Piedmont also contain good aquifers where optimum conditions such as deep weathering, open fractures and a valley or lowland topographic situation exists, but as a whole, they yield only a small to moderate supply. Few wells encounter water-bearing fractures at depths greater than 200 to 300 feet.

The Appalachian Plateaus province generally includes the western half of the Appalachian Basin (Figure 6, Zone D). For convenience, small segments of the Interior Low Plateaus and Central Lowland in central Tennessee and Kentucky and eastern Ohio are treated as part of this province because of similar ground-water conditions. Though ground water is sufficient nearly everywhere for domestic, commercial, and farm needs, the Appalachian Plateaus province is an area of only moderate well and spring supplies--with two important exceptions.

Locally, large well yields of several hundred gallons per minute, adequate for industrial and municipal needs, are obtainable. Many of these are in the belt of coarse clastic rocks of Pennsylvanian age in the eastern part of the province. It is reasonable to expect that other areas of above-average water-bearing capacity exist in untested parts of this belt of rocks.

Glacial outwash deposits in the valleys in northern Pennsylvania and along the Allegheny and Ohio Rivers provide large supplies of ground water to municipalities and industries. Present withdrawals are only a small fraction of the supply available. Only one or two localities have serious problems from overpumpage. The glacial outwash is recharged mainly from precipitation and from adjacent streams. Heavy pumping of wells lowers the water level in the outwash below river level, and river water is induced to move through the stream bed, into the outwash deposits, and to the pumping wells. Inasmuch as the river stage of the Ohio River is upheld by navigation dams and by flow augmentation from surface reservoirs, the ground-water supply available by induced infiltration is limited only by the permeability of the river bed and of the outwash deposits. In the stretch of outwash along the Ohio River in West Virginia the quantity of ground-water available per mile of river length ranges from as much as 42 million gallons (129 acre-feet) to as little as 6 million gallons (18 acre-feet) per day. New, higher dams will raise the river level and, in turn, may be expected to increase ground-water supplies in the adjacent and subjacent outwash appreciably.

The chemical quality and physical characteristics of the ground water for domestic and most other uses are generally satisfactory with certain qualification. Throughout much of the region the iron content of the water may be troublesome, and hardness must be reckoned with in areas underlain by limestone and marble. However, modern water-treatment techniques alleviate these objectionable features, and new advances in water-treatment technology promise additional aid. Saline ground water occurring naturally at depths of several hundred feet throughout much of the western Appalachian Plateaus tends to limit the availability of fresh water to shallow depths.

In some old oil fields, leaking oil- and gas-well casings, brine disposal pits, and the discharge of oil-separator wastes at the land surface have in the past contaminated the shallow groundwater. Liquid and solid chemical wastes and mine gob deposited on the land surface yield contaminants that infiltrate to the ground water reservoirs. Some ground-water pollution is associated with acid-mine water generated in active and abandoned coal mines, both surface and deep mines. Corrective action at both the state and federal levels includes strengthening and enforcement of pollution laws and further field and laboratory research into methods for waste disposal and pollution abatement.

Water Quality Problems

The Appalachian Basin encompasses a total land area of 164,113 square miles with a population of approximately 15,610,000. Drainage from old mines pollutes surface and ground water in large areas in the coal mining region of the Appalachian Basin.

In the region many streams draining mining areas are acid. They contain hard calcium sulfate type waters and often require extensive treatment for domestic and industrial uses. These waters range in dissolved solids concentrations from 500 mg/l or more in the larger streams and often exceed 2,000 mg/l in the smaller streams.

These streams drain 13 percent of the region and are located in the coal mining areas of Pennsylvania, West Virginia, Kentucky, Ohio, and Tennessee. About 6 million people are directly affected by acid-mine drainage and related environmental problems caused by coal mining.

Many small and medium size cities in the region withdraw water from streams affected by mine drainage. The largest towns are located in West Virginia and include Clarksburg (30,000), Fairmont (27,000), and Morgantown (23,000).

Any increase in water demands in the region through the year 2000 depends on the development of coal and petroleum resources. In 1970, just under 600 million tons of coal were mined in the United States. Approximately 60 percent of the coal was mined in the Appalachian Basin. It has been estimated that by the year 2000, 900 million tons of coal will be required to meet the energy demands at that time. Significant coal reserves are located in the region, but unless steps are taken now to control the mine-draining problems, the development of additional reserves in this area may meet with public and legislative resistance.

Current costs for treating acid-mine waters are shown in Table 21. The flow of acid-mine discharge (AMD) waters amounts to some 1,400 million gallons per day alone. This amounts to an equipment market of $250 to $500 million. The annual lime market would amount to 1 to 2 million tons per year.

TABLE 21
CURRENT COSTS FOR TREATING ACID-MINE WATERS

Process	Water	Operating Costs ($/1,000 gals)	Capital Costs ($/1,000 gals/yr)
Distillation	*	2.36-0.49	13.00-3.15
Crystallization	*	3.10-0.85	12.00-3.60
Membrane (ED, RO)	*	2.57-0.68	6.90-2.45
Neutralization-Oxidation	†	1.09	4.00
Neutralization-Oxidation	‡	0.72	3.60
Neutralization-Oxidation	§	0.087	0.50
Neutralization-Oxidation	‖	0.226	0.50
Ion Exchange	**	0.537	1.30
	*	0.43-0.49	n.a.

* Acidity 600 mg/1, Sulfate 750 mg/1, Fe 120 mg/1, DS 1,085 mg/1
† Acidity 4040 mg/1, Sulfate 10,000 mg/1, Fe 815 mg/1, DS 18,300 mg/1
‡ Acidity 770 mg/1, Sulfate 1,360 mg/1, Fe 225 mg/1, DS 1,920 mg/1
§ Acidity 190 mg/1, Sulfate 290 mg/1, Fe 5.8 mg/1, DS 560 mg/1
‖ Acidity 560 mg/1, Sulfate 3,430 mg/1, Fe 360 mg/1, DS 6,100 mg/1
** Acidity 1250 mg/1, Sulfate 5,656 mg/1, Fe 712 mg/1, DS 9,080 mg/1

Chapter Nine

WATER REQUIREMENTS FOR NUCLEAR, OIL, AND GAS-FIRED ELECTRICAL GENERATION IN INLAND WESTERN STATES

Water requirements for nuclear and oil and gas-fired electrical generation will impose additional demands for water beyond those projected for coal and oil shale development. The Task Group considered the magnitude of this additional demand and its consequences.

The projections from the "1970 National Power Survey of Thermal Generation Resources for the West Region, Served by Inland Cooling Water Sources" were adopted as the primary reference.* The capacity additions projected in that study were estimated for the time periods 1971 to 1980 and 1981 to 1990. These projections were recast into the 1985 time frame by interpolation; the results are shown in Table 22 for the maximum buildup, Case I.

TABLE 22
CASE I
WATER REQUIREMENTS FOR NUCLEAR AND OIL AND GAS-FIRED ELECTRICAL GENERATION ADDITIONS IN SELECTED WESTERN STATES — 1971-1985
(Millions of Acre-Feet of Water Per Year)

	Nuclear	Oil and Gas-Fired	Total
Upper Colorado River States			
Arizona	8	15	23
Colorado	24	0	24
New Mexico	8	7	15
Utah	60	0	60
Upper Missouri River States			
Montana	24	0	24

Water to meet the projected Case I coal and oil shale energy development, as well as the above projected nuclear and oil- and gas-fired electrical generation requirements can probably be made available. However, in Arizona, Colorado and New Mexico serious shortages may develop unless water is diverted from irrigation or other non-energy use.

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* Federal Power Commission, *The 1970 National Power Survey* (Washington, D.C., 1970).

Nuclear and oil- and gas-fired generating plants can be located near load (population) centers and away from competitive low-cost fuel deposits. Therefore, it is likely that nuclear and oil- and gas-fired plants will not compete directly for the same water supplies which would be required for coal and oil shale development. For example, such plants might be located on the eastern slope of Colorado, along the Rio Grande River in New Mexico or near Phoenix in Arizona. In these locations, these plants would not necessarily compete for water supplies with energy plants located near the oil shale deposits in western Colorado or the coal fields in northern New Mexico and Arizona.

Chapter Ten

ESTIMATES OF CAPITAL AND TIME REQUIREMENTS TO DEVELOP WATER SUPPLIES FOR ENERGY PRODUCTION

The development of firm supplies of water for energy producing plants will require varying levels of capital and construction time. The requirements vary depending upon the size and location of impounding or diversion structures which may be required and the capacity and length of aqueducts. The estimates of new capital requirements are shown in Tables 23 and 24. Of course, these estimates were not intended and should not be used as a substitute for competent engineering studies in connection with any one specific situation.

TABLE 23
CASE I
NEW CAPITAL REQUIREMENTS— UPPER COLORADO RIVER BASIN
(Millions of Dollars)

Water Demand	Dam	Aqueducts	Total
Arizona — 62 MAF/Y			15-30
Glen Canyon (about 35 MAF available)	Existing	15-30	
New Mexico — 180 MAF/Y			50-75
Navajo Reservoir (about 100 MAF available)	Existing	50-75	
Other Projects	?	?	
Utah — 42 MAF/Y			15
Oil Shale Supply — 18 MAF/Y (White River)	5	5	
Coal Supply — 24 MAF/Y (Green and Colorado Rivers)	Existing	5	
Colorado — 112 MAF/Y			20-25
Green Mountain and Reudi Reservoirs (plus direct flow diversions)	Existing	20-25	
Total	**5**	**95-140**	**100-145**

TABLE 24
CASE I
NEW CAPITAL REQUIREMENTS
UPPER MISSOURI RIVER BASIN
(Millions of Dollars)

Water Demand	Dam	Aqueduct	Total
Montana — 317 MAF/Y			
Tongue River — 60 MAF/Y	40	5	45
Powder River — 20 MAF/Y	10	5	15
Big Horn River — 244 MAF/Y (Montana-Wyoming Aqueduct)	Existing	400	400*
Subtotal	**50**	**410**	**460**
Wyoming — 355 MAF/Y			
Powder River — 100 MAF/Y	30	30	60
Tongue River — 30 MAF/Y	15	5	20
Big Horn River — 382 MAF/Y (Montana-Wyoming Aqueduct)	Existing	310	310*
Subtotal	**45**	**345**	**390**
North Dakota — 144 MAF/Y			
Missouri River — 144 MAF/Y	Existing	100	100
South Dakota — 20 MAF/Y			
Little Missouri — 20 MAF/Y	5	5	10
Total	**100**	**860**	**960**

*Assumes that an integrated aqueduct system to serve the requirements of both Montana and Wyoming (for example, the USBR Montana-Wyoming aqueduct) will be constructed. The division of costs here shown is based on physical location of system elements and does not attempt to allocate costs on a service-rendered basis.

CAPITAL REQUIREMENTS

The estimates of capital requirements for dam construction have been taken either from published information on dams which have been planned for the development of the identified water source or are extrapolated from estimates for other dams which should be comparable to those required. Capital cost estimates for pipelines are more nebulous, except in the case of the Montana-Wyoming Aqueduct where the source of water and the coal deposits to be developed are known and where the U.S. Bureau of Reclamation (USBR) has completed an appraisal report on the project.

Capital requirements for dams and aqueducts, to serve Case I energy plants in the Colorado and Missouri River Basins, are indicated in the following sections.

To develop a supply for some 22 plant units projected through 1985 for the Upper Colorado River Basin, the new capital investment will be about $6 million for each plant. This low capital requirement reflects the present existence of a number of major dams and reservoirs on the Colorado River and its tributaries, and the proximity of the oil shale and coal deposits to these reservoirs or to the river below such reservoirs. Hence, only limited dam construction and short aqueduct facilities will be required.

In addition to the costs reflected above, there will be an additional capital requirement for distribution facilities from pipeline terminals or turnouts to supply individual plants. In the absence of specific siting projections, it is only possible to estimate that these facilities for individual plants would require investment of less than $5 million.

These estimates indicate that new capital requirements for the development of water supplies for energy producing plants (shown in Table 24) in the Upper Missouri River Basin could require $960 million for major demand aqueduct facilities, plus up to $300 million for distribution lines, or an average for each plant of just over $20 million. It should be noted that the development of "local" sources for the first plants will probably require less than this average. The investment for the Montana-Wyoming Aqueduct will provide a capacity above the projected requirements of some 50 MMAF/Y in Wyoming. Therefore, there would be substantial carry-in water capacity to the post-1985 period if the system were built as now conceived by the USBR. Optimization of the scale and time of such a project will be required if it is to make its maximum contribution to the energy supply situation.

The new capital requirements for water development are large but are only a minor element in the total capital which will be demanded by mine, plant and product transmission facilities for projected energy production levels.

TIME REQUIREMENTS

Time requirements for project construction are expected to be less than those for governmental approvals and permits. Dam and aqueduct construction of water supply facilities for energy developments in the Upper Colorado River Basin are minimal. A potential time problem does appear imminent, however, in that the necessary dam and pipeline construction will, in most cases, involve federally owned land. Since much of this geographic area is noted for its aesthetic assets, it is expected that public opposition to construction will develop and severe limitations designed to protect the environment may be imposed. Recent experience shows that delays occasioned by the requirements of adminstrative and judicial bodies can cause serious delays in the construction and operation of facilities of the type and in the locations required. Laws and regulations which detail the rights and obligations of entities who engage in the development of these water resources will be needed. Furthermore, the public will need to be informed of the trade-offs required between energy availability and cost as compared to the preservation of the environment. Energy level projections cannot be met unless governments adopt regulations which are supported by the public, defensible before the courts and economically tolerable to industry. The cost of delay will be measured not only in increased energy prices but also in decreased energy availability. The attainment of energy supply capability at the projected levels will not permit the luxury of prolonged hearings and litigation in advance of construction activities.

The completion of the Montana-Wyoming Aqueduct by 1981 will be necessary if the projected schedule of energy supply growth of NPC Case I is to be met. But, for this aqueduct, the more significant problems may be the potential limitation imposed by time requirements for planning, engineering and construction. The "local" water supplies, which can be expected to serve the earliest plants, are estimated to require engineering and construction periods of 3 to 4 years--comparable to the engineering and construction time for the plants to be served. The time requirement becomes more alarming when major aqueduct facilities are considered. The USBR estimated that the Montana-Wyoming Aqueduct (a system to transport water from the Big Horn-Yellowstone Rivers into the coal-bearing areas of Montana and Wyoming's Powder River coal fields) could be in service by 1981, if (1) planning, engineering and construction were pursued in an aggressive manner from 1972 forward; (2) the Congress authorized the USBR to proceed on that timetable; (3) industry indicated support for the project; and (4) industry was willing to enter into water service contracts as early as 1976. Completion of the Montana-Wyoming Aqueduct, or other projects of comparable magnitude, will be required if the large energy developments projected in Wyoming are to be satisfied. Smaller projects requiring less time for completion could serve the projected requirements in Montana, North Dakota and South Dakota. Figure 7 and Tables 17 and 18 show the time frame for the growth of the Case I energy industry in Montana and Wyoming, and Figures 7 and 8 show the critical relationship between the energy-industry water requirements in these states and the time requirements for development of the necessary water supply.

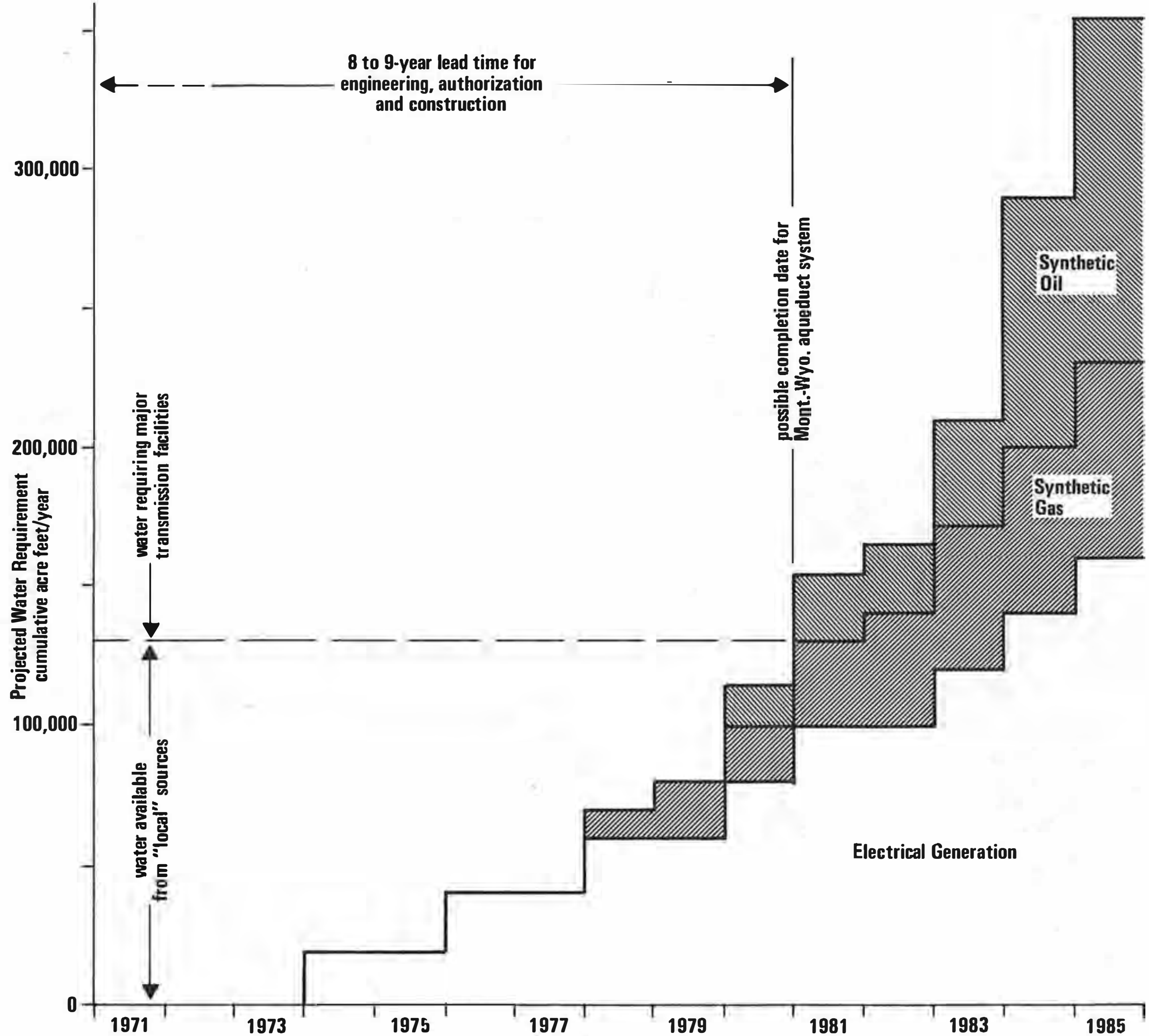

Figure 7. Projected Water Requirements in Wyoming
Case I Energy Development.

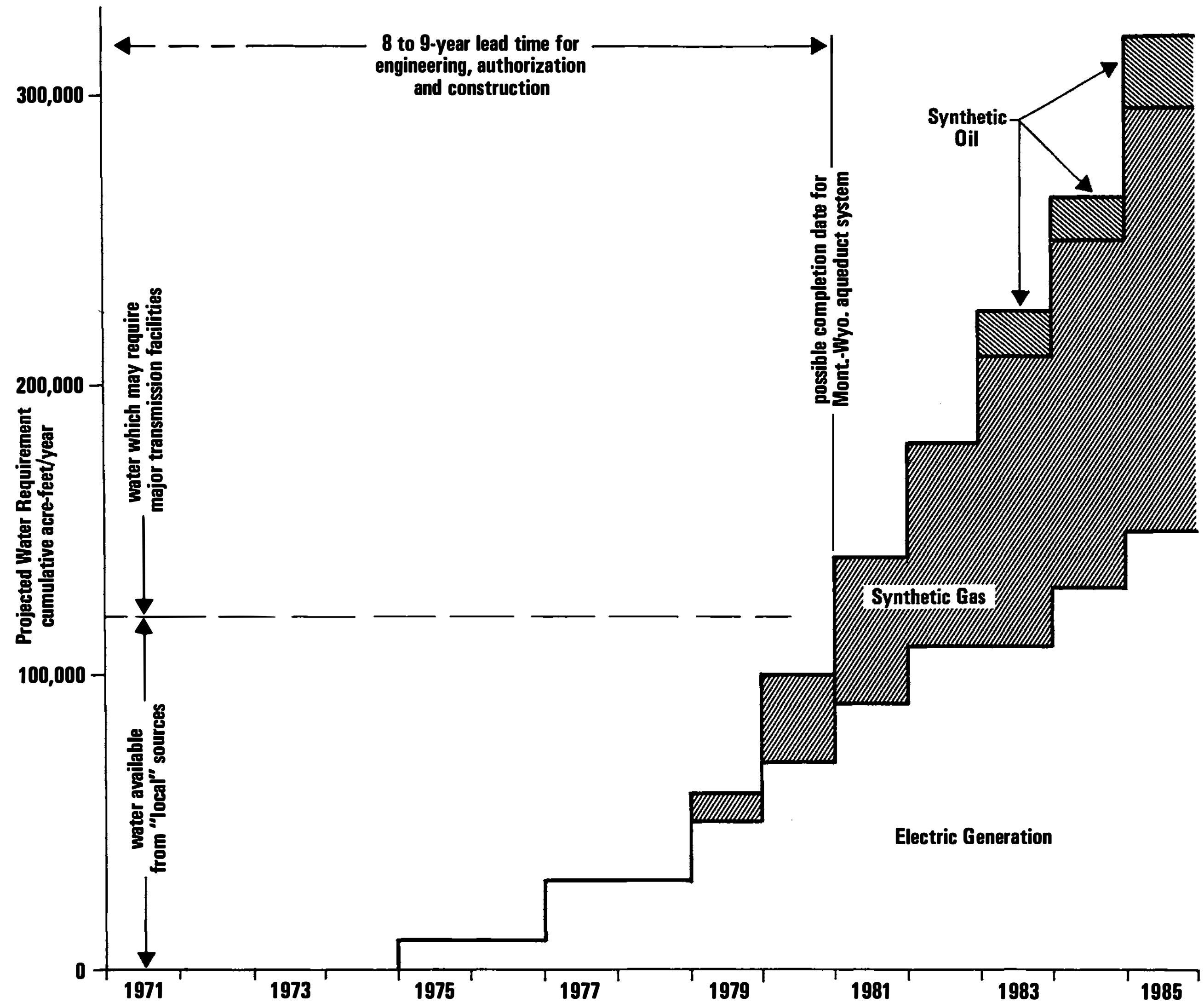

Figure 8. Projected Water Requirements in Montana Case I Energy Development.

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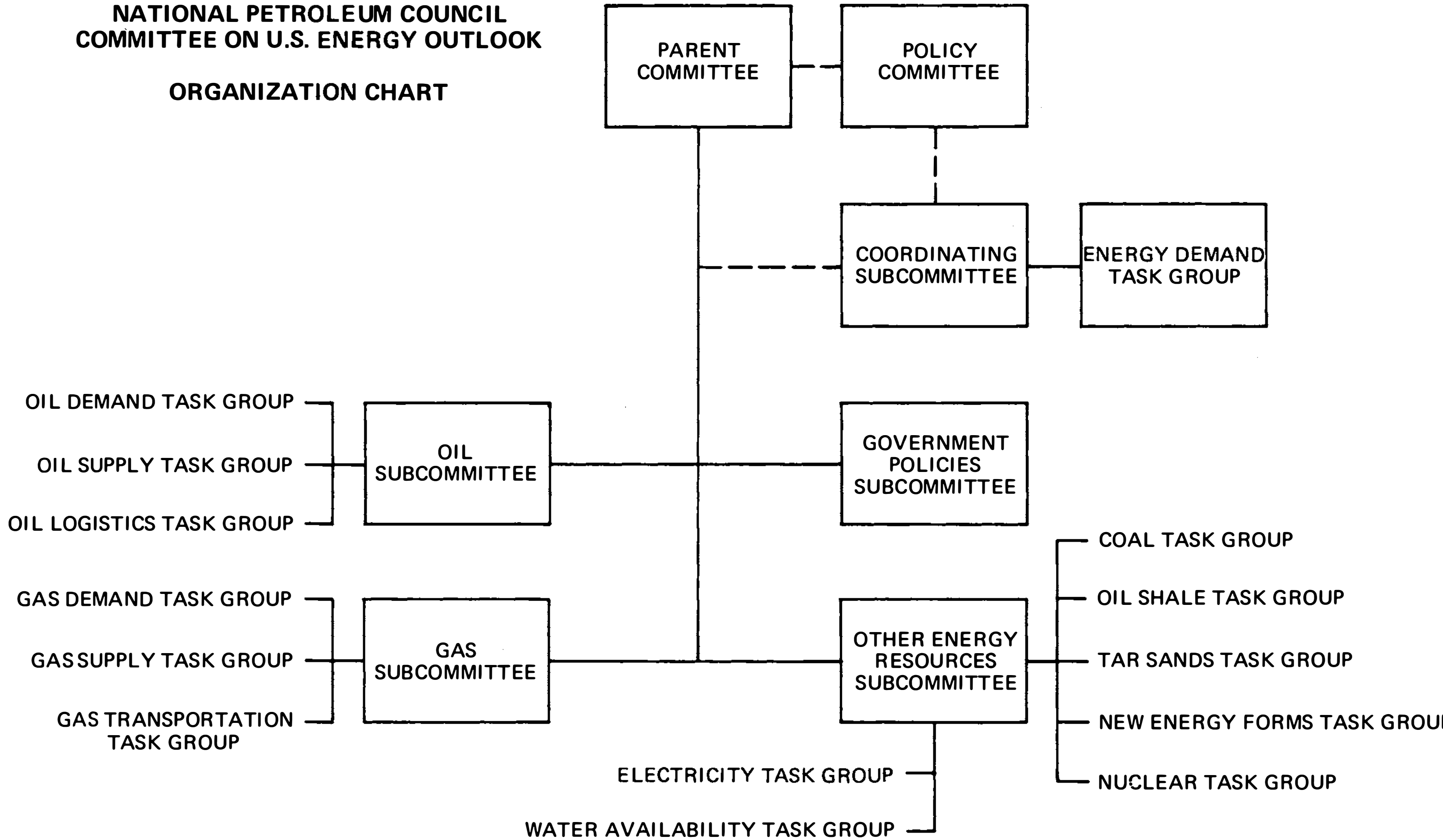
APPENDIX B

NATIONAL PETROLEUM COUNCIL
COMMITTEE ON U.S. ENERGY OUTLOOK

ORGANIZATION CHART



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WATER RIGHTS: ITS IMPLICATION FOR THE COAL GASIFICATION PROGRAM

In much of the United States, and particularly in the semi-arid western states, much, if not all, of the available water is already committed to other uses. But large amounts of water will be required for the coal gasification program. Therefore, water rights will have direct and pronounced effects on the availability of a water supply for this purpose. This appendix briefly describes water rights in several areas and how they could affect coal gasification.*

Water rights laws have developed and changed to meet the needs of the area. Where the amount of water is ample they are aimed toward making it available to all. Where the supplies are not ample, the aim is to put the available supply to the best use.

The law changes with the needs of the people. If the law creates a serious obstacle to a desired development that cannot be overcome by economic or cooperative means, there is always the possibility of solution by judicial or legislative action.

Water rights laws are complex and vary from state to state and there are two general types: riparian rights and rights by prior appropriation. They are mixed to varying extents in some states.

RIPARIAN RIGHTS

Riparian rights give equal rights to the water of a stream to all the lands that touch the stream. The water cannot be used outside the basin of the stream, however, even though a tract of land bordering the stream extends beyond the watershed boundary. Some states limit the right to the tract of land to which the right first applied. In those states, a riparian right to a tract of land not contiguous to the stream cannot be obtained by purchasing the land between it and the stream.

Since the right is appurtenant to the land, it exists whether or not it actually is utilized and it may be exercised at any time. It is not forfeited by non-use.

The riparian rights doctrine developed in England and the humid eastern states. It is basic water law of the tier of states extending from Louisiana through Minnesota and states to the east of this tier, with the exception of Iowa and Mississippi.

* This section is based on Treslease, Frank J., *Applied Hydrology*, Chapter 27, New York: McGraw-Hill (1964).

In general, riparian rights are restricted to a reasonable use and quantity, which often must be defined for specific cases by the courts. In some states, non-riparian owners can purchase the rights of riparian owners and use the water for reasonable purposes and in reasonable amount of non-riparian lands. The test of reasonableness is subject to determination by the courts in doubtful cases.

A public or semi-public body generally has the power to take riparian water rights for a public purpose by condemnation with payment of a just compensation. Governmental agencies and corporations performing a public service, such as utilities, have this right of eminent domain.

The fact that a non-riparian use will be detrimental to a riparian right does not necessarily mean that the non-riparian use is forestalled. The owner of the superior right may be willing to relinquish his right upon payment, or, if the damage is not obvious, he may make no objection. The latter possibility is most likely to occur where the water in question is a small part of the total flow of a river.

Since the doctrine of riparian rights is based on the assumption that there is water enough for all who are entitled to its use, the doctrine is inadequate for the arid and semi-arid lands of the western states. In those states the basic water right is based on the doctrine of prior appropriation.

APPROPRIATED RIGHTS--COLORADO DOCTRINE

Appropriation is the only method of obtaining water rights in Alaska, Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Wyoming. These states follow what is termed the "Colorado Doctrine." In the Pacific Coast States and the Great Plains States, both appropriation rights and riparian rights are recognized to some extent, but the latter usually only in the case of old rights. These states follow what is generally referred to as the "California Doctrine."

Beneficial Use and Priority of Use

The general features of appropriation rights under the Colorado Doctrine are that the rights are based on beneficial use and not ownership of land. In case of a shortage, priority of use rather than equality of rights is the criterion for distribution.

In general, any legal entity can appropriate water. Appropriation consists of filing an application with the prescribed authority, physically diverting the water and putting the water to beneficial use. The term "beneficial use" usually is interpreted broadly, but it must be reasonable and economic in view of other demands for the water.

Prior Right Has Precedence Over Junior Rights

The appropriation of water always must be for a definite quantity. If, at a later date, additional water is appropriated, the earlier appropriation will have a higher priority than the incremental priority.

Usually, direct flow appropriation rights are expressed as a maximum flow, but it cannot exceed the amount that is beneficially used at any time. Storage rights are expressed in terms of volume of storage for future beneficial use. Because of variations in annual runoff, usually it is permissible to store more than one year's needs as a protection against dry years. However, water cannot be stored if it interferes with prior direct flow rights.

An appropriation permits use of water wherever it is needed, except that in some states there are restrictions on exporting water across a state line. The location of a water right on a stream is immaterial; use of a junior right must be curtailed if it interferes with a prior right farther downstream.

The owner of an upstream junior right can make substantial changes in the regime of a stream as long as he observes the prior rights of a downstream user. He can even take the direct flow of a river if he replaces it with stored water or water imported from an outside source.

All appropriated water rights must have a date to permit assignment of priorities. Although a right is not complete until beneficial use has been made of the water, the priority date usually is the date of the first significant action in connection with the appropriation, provided there have not been undue delays in completion of the action.

Appropriated rights sometimes are for a specific season of the year; otherwise they can be exercised at any time the appropriator can put the water to beneficial use. In some cases courts have held that early patterns of use establish seasonal limitations.

Preferential Use

The principle of preference has a very important direct impact on the coal gasification program. A higher use is given preference over a lower use even though its priority date may be later than that of the lower use. There is general agreement that man's personal needs rank first. Therefore, domestic and municipal use have a high preference, while power and navigation usually have a low preference. Irrigation, manufacturing and mining are given some preference in some the the states, usually between the high and low preferences mentioned above. Generally, the junior preferred user is merely given the power to condemn the water supply of a senior user with a lower preference upon the payment of compensation, resulting in a permanent change of water rights from the inferior to the preferred user.

In most states, the pertinent administrative official can deny a permit if he deems that it is not in the public interest, such as where issuing the permit would interfere with a larger and more desirable project.

Another important feature of appropriated rights that affects the coal gasification program is that appropriated water rights are private property. As such, they can be bought and sold. Changes can be made in place of use, point of diversion, type and time of use, or place of storage provided the changes do not interfere with prior rights of other users. Agencies and courts can approve or forbid these changes on the basis of such interference. Some states have adopted restrictions on changes of use or changes of place of use.

Appropriated water rights for irrigation pertain to the land and go with the land if it is sold, but are forfeited if not used for a specified period of time.

An important feature of the law of appropriation is the doctrine of "relation back." If an appropriation, having initiated a right by compliance with the laws respective notice of appropriation of a specified quantity (or rate of flow) puts the appropriated water to use with reasonable diligence, the right "relates back" to the full extent of the quantity, thus ultimately put to use (within the quantity originally appropriated) so that the original priority attaches to the quantity ultimately used, even though a period of many years may elaspe between the two dates. Thus the priority of a project, once established, cannot be cut off by the more rapid completion of a competitive project initiated later but completed sooner than that of the first appropriation.

APPROPRIATED RIGHTS--CALIFORNIA DOCTRINE

The general feature of the California Doctrine is some mixture of riparian rights and appropriated rights. The most common situation is that of a state formerly having riparian rights, but later adopting the appropriation method. Generally, such states recognize the older riparian rights, but subsequent to the changeover, new rights can be acquired only by appropriation. This situation exists in the western states of Kansas, Nebraska, Oregon and South Dakota.

Under certain conditions new riparian rights can be started in California, North Dakota, Oklahoma, and to some extent, in Washington. These states permit appropriations that are not injurious to riparian rights. In Texas, riparian rights apply to the ordinary flow while surplus and flood waters are subject to appropriation. Some eastern states have granted certain priorities to favored industries, including certain mining enterprises, while still generally maintaining riparian rights.

POLLUTION

Generally speaking, water rights do not give the user the right to seriously interfere with the quality of the water in the river. This includes a significant rise in the temperature of the water. Now, both pollution laws and their enforcement are undergoing rapid change. It is reasonable to anticipate water quality standards and their enforcement in the future are likely to be much higher than in the past.

INTERSTATE STREAMS

The U.S. Supreme Court has jurisdiction in cases involving controversy between states over rivers crossing state lines or forming a boundary between the states. Congress has authority to apportion the waters of navigable interstate streams. With the consent of Congress, the states can enter into an interstate compact for the distribution of the water without resorting to litigation.

FEDERAL LAW

The Federal Government has specific, important powers over rivers where national interests are involved. Because of its jurisdiction over interstate commerce, ownership of land adjacent to the river, flood control and general welfare, the Federal Government has further expanded its power over the rivers and streams.

GROUND-WATER LAWS

Ground-water law tends to be less specific than surface water law, largely because it is based on less understood hydrological principles.

Early law divided ground water into percolating water and underground rivers--an illogical classification. "Underground rivers" are very infrequent, and "percolating waters" are not significant as a ground-water source until they reach the water table. The water table is the top of the zone of saturation, which has more of the characteristics of a reservoir than of a river. If large supplies are removed from this ground-water reservoir, it lowers the water table, causing water to flow slowly to the area from surrounding areas, possibly damaging the adjacent land.

The purpose of ground-water law is to permit a landowner to remove a reasonable amount of water for a beneficial use, but still keep damages to others at a low level. Reasonable use generally is considered to be on the overlying land, including use for manufacturing, mining and agriculture. Unreasonable uses have been held to include wasteful or malicious extraction and transportation of water away from the land for use elsewhere.

Idaho, Kansas, Nevada, New Mexico, Oklahoma, Oregon, Utah, Washington and Wyoming apply the principle of appropriation to ground water as well as surface water with beneficial use being the basis of the right rather than ownership of the overlying land. These laws cover all ground water in most of these states and only underground streams, channels and basins with reasonably determinable boundaries in others. Generally, the states having appropriation laws can deny permits if there is no unappropriated water available and also may specify minimum spacing of wells. In areas of ground-water mining (pumping exceeding recharge) safe yield sometimes is construed to be the rate that can be maintained for a sufficient time to permit amortization of investment in land and facilities.

In Colorado, ground-water tributary to a stream is subject to appropriation under the same laws that are applicable to the surface water of the stream.

A table of hydraulic conversion factors and abbreviations are attached as Table 25 .

TABLE 25

TABLE OF HYDRAULIC CONVERSION FACTORS AND ABBREVIATIONS

Acre-foot (AF)	= 43,560 cubic feet (cf)
	= 325,851 gallons (gal)
	= 7,758 barrels (42 gal)
1000 acre-feet per year (MAF/Y)	= 1.37 cubic feet per second (cfs)
	= 885,000 gallons per day (gpd)
	= 615 gallons per minute (gpm)
	= 21,071 barrels (42 gal) per day
Gallons per minute (gpm)	= 192.5 cubic feet per day
	= 1.63 acre feet per year
	= 34.29 barrel (42 gal) per day
	= 1,440 gallons per day

UPPER COLORADO REGION
COMPREHENSIVE FRAMEWORK STUDY
General Program and Alternatives (June 1971)

This report of the Upper Colorado Region State-Federal Interagency Group, prepared at field level, presents a framework program for the development and management of the water and related land resources of the Upper Colorado Region. This report is subject to review by federal agencies at the departmental level, by the Governors of the states concerned and by the Water Resources Council prior to its transmittal to the Congress for its consideration.

States' Alternative to the Framework Plan 6.5 Million Acre-Feet Level of Development

For comparative purposes and to express states' desires, the states proposed an alternative to the framework plan at the 6.5 MMAF level of development. Data on proposed water uses for this alternative are shown in Table 26.

In the framework plan, there is need to service a large electric power market from potential fuel-burning electric powerplants in the Upper Colorado Region. Each of the states of Colorado, New Mexico, Utah and Wyoming anticipated that a part of their coal and water resources will be used for the production of such energy. Previously, the states had agreed to maintain proportionate levels of water development very close to their respective percentage allotments in the Upper Colorado River Compact. Without upsetting a multitude of water uses set forth in the framework plan, the approximate state percentages could be maintained only by an arbitrary assignment to each state of portions of the needed thermal-electric power installations as necessary to bring each state's total water uses to amounts approximating the compact percentages. Although this assignment depicted a reasonable satisfaction, on a regionwide basis, of the requirements for the framework plan, there were certain features objectionable to Colorado and Utah.

Changes in uses from those contained in the framework plan are described in the following narrative. Tables 27 and 28 provide further details on proposed thermal-electric and irrigated land development.

Arizona retained its exact allotment of 50 MAF/Y in the revised year 2020 distribution with no change in types of use.

Colorado varied its water depletions for full and supplemental irrigated land by 88 MAF less in 1980, 145 MAF more in 2000 and 31.5 MAF more in 2020. Irrigated land acreage varied by 18,000 less acres in 1980, 80,000 more acres in 2000 and 6,500 more acres in 2020.

Oil shale industry in the Green and Upper Main Stem Subregions totalling 1 MMB/D capacity, with a support population of 78,000 depleting 97 MAF/Y, was added by the year 2020. A coal by-products plant, using 15 MAF, and a potash plant, capacity 1.5 million tons annually, using 9.5 MAF/Y, are projected. Exports are increased by 2.4 MAF and fish and wildlife by 600 AF/Y.

It appears that Colorado would deplete its 51.75-percent allotment by the year 2000. Thermal-electric power installed capacity is lessened by 9,690 MW from the framework plan, depleting 146.4 MAF/Y less. In addition, 22.1 MAF of irrigation water would be transferred between 2001 and 2020 to meet municipal and industrial requirements.

New Mexico, in order to stay within its 11.25-percent apportionment of the 6.5 MMAF level of development, changed its uses involving a net decrease of 9.5 MAF/Y. A large reduction (51.2 MAF) resulted from an arbitrary programmed reduction in installed generating capacity. However, mineral production would materially increase, and an additional municipal and industrial use of 11.8 MAF/Y was projected owing to a population increase of 64,500.

Utah desired that a much greater portion of its potential thermal-electric power production be included and projected an additional 11,700 MW to be installed. This required a support population of 26,000 people. Utah also added an oil shale industry with a capacity of 500 MB/D, with a support population of 39,000 people. In order to stay within its 23-percent allotment, Utah revised downward its irrigation acreage (-10,500 acres) and likewise revised downward (-200,000 acre-feet annually) its export to the Bonneville Basin.

Wyoming also suggested no changes in its type of uses but revised its irrigation depletions downward 900 AF/Y to stay exactly within its 14-percent allotment.

States' Alternative at the 8.16 Million Acre-Feet Level of Development

This is an alternate plan of development which reflects 8.16 MMAF of man-made depletions in the Upper Basin. It includes the amounts of water evaporated from Main Stem reservoirs. This plan assumes the Colorado River water supply would be firmed to meet the division of water by the Colorado River Compact. Proposed depletion distribution among the states in 2020 equals their percentage shares under the Upper Colorado River Compact.

Development of some resources would not be limited by present water availability. The states have assumed that a market for the increased production associated with this level of development would readily be absorbed within national and increasing western markets. This is especially true since the added increment is a small part of the national market and would accordingly have a small impact.

Arizona retained its allotment of 50 MAF for 2020 with no changes in types of uses previously described for the framework plan.

Colorado plans to irrigate 1,256,300 acres in 2020, which is 104,400 acres more than the framework plan, with a depletion of 1,941,500 acre-feet. Oil shale complexes, in the Upper Main Stem and in the Green River, each having a capacity of 1 MMB/D, would deplete 194 MAF/Y by 2020. A coal by-products plant, using 15 MAF in the San Juan-Colorado area, and a potash plant, with a capacity of 1.5 million tons annually, using 9.5 MAF, are projected. Fish and wildlife uses would total 71.4 AF, a substantial increase over the framework plan. Thermal-electric power capacity of approximately 10,000 MW would deplete 153.2 MAF/Y. Export would increase to 1.36 MMAF/Y. This plan would meet regionally interpreted OBERS requirements for all sectors except power, which would be met by Utah.*

New Mexico plans no changes in agriculture, fish and wildlife, or recreation from the framework plan. Population by 2020 is estimated at 189,500 and the minerals industry is projected to increase as a result of available reserves and national needs. Thermal-electric powerplant installed capacity would be 5,623 MW. Export to the Rio Grande Basin via the San Juan-Chama Project would be increased 125 MAF for a total export of 243 MAF.

Utah would increase its use by irrigated crops 10.7 MAF over the framework plan and irrigate about 401,200 acres by 2020. There are no changes in fish and wildlife, recreation, or stockpond evaporation and livestock use. Export to the Great Basin by 2020 would increase to 447 MAF, which is 20 MAF less. Major changes are in increased thermal-electric power to 19,500 MW installed capacity and increased mineral activity, including mining coal for powerplants, a million barrel-per-day shale output, processing oil-impregnated sandstone and conversion of coal.

Wyoming's development includes a substantial increase in the mineral industry, including a million barrel-per-day shale oil production, depleting 97 MAF of water, and conversion of coal. Trona plant capacity would continue to increase. Population would increase to 148,000 by the year 2020. The agricultural base of irrigated land would increase to 513,000 acres by year 2020. Thermal-electric power installed capacity is estimated at almost 10,000 MW. Transbasin diversions to the North Platte River are estimated at 153 MAF which is a 32 MAF reduction.

Table 29 enumerates water uses for this alternative and Tables 30 and 31 summarize projected thermal-electric and irrigation developments.

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* OBERS requirements are set and issued periodically by the Office of Business Economics, Department of Commerce, and the Economic Research Service, Department of Agriculture.

TABLE 26

WATER USE FOR THE STATES' ALTERNATIVE TO THE FRAMEWORK PLAN (6.5 MAF LEVEL OF DEVELOPMENT) TO 1980, 2000, AND 2020, UPPER COLORADO REGION

	On-site depletions (acre-feet per year)								
Type of use	Arizona	Colorado	New Mexico	Utah	Wyoming	Region	Green River	Upper Main Stem	San Juan-Colorado
					1980				
Municipal and industrial	2,900	22,100	7,200	10,100	4,300	46,600	12,200	16,200	18,200
Electric power (thermal)	34,100	10,700	90,000	125,400	33,200	293,400	56,700	1,600	235,100
Minerals	400	19,500	11,800	10,300	19,000	61,000	31,500	13,700	15,800
Fish and wildlife	1,200	38,800	6,800	22,200	18,800	87,800	49,400	7,900	30,500
Recreation	100	700	100	1,000	200	2,100	800	700	600
Stock-pond evaporation and livestock use	1,400	25,000	2,900	7,300	4,800	41,400	15,300	13,700	12,400
Subtotal	40,100	116,800	118,800	176,300	80,300	532,300	165,900	53,800	312,600
Irrigation: consumptive use, incidental use, and reservoir evaporation	7,000	1,391,100	245,000	576,600	334,000	2,553,700	935,400	1,007,800	610,500
Export		663,400	117,500	190,000	65,000	1,035,900	255,000	660,900	120,000
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	47,100	2,171,300	481,300	940,300	479,300	4,119,300	1,356,300	1,722,500	1,040,500
Main-stem reservoir evaporation						660,000	67,000	17,000	576,000
Total for 1980						4,779,300	1,423,300	1,739,500	1,616,500
					2000				
Municipal and industrial	4,800	48,300	13,600	16,800	5,900	89,400	19,100	38,900	31,400
Electric power (thermal)	34,100	108,200	90,000	261,800	148,700	642,800	331,100	16,600	295,100
Minerals	300	128,300	17,400	10,300	22,100	178,400	32,900	109,200	36,300
Fish and wildlife	1,200	39,400	6,800	22,200	18,800	88,400	49,500	8,400	30,500
Recreation	300	1,100	100	1,600	200	3,300	1,400	900	1,000
Stock-pond evaporation and livestock use	1,700	30,500	3,300	9,000	5,800	50,300	18,200	17,100	15,000
Subtotal	42,400	355,800	131,200	321,700	201,500	1,052,600	452,200	191,100	409,300
Irrigation: consumptive use, incidental use, and reservoir evaporation	7,600	1,778,200	329,000	660,600	407,000	3,182,400	1,197,500	1,184,500	800,400
Export		885,400	117,500	267,000	150,000	1,419,900	417,000	882,900	120,000
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,019,400	577,700	1,246,700	758,500	5,652,300	2,066,700	2,258,500	1,327,100
Main-stem reservoir evaporation						660,000	67,000	17,000	576,000
Total for 2000						6,312,300	2,133,700	2,275,500	1,903,100
					2020				
Municipal and industrial	7,200	70,000	29,100	32,100	9,200	147,600	35,600	54,400	57,600
Electric power (thermal)	30,100	108,200	55,600	261,800	148,700	604,400	331,100	16,600	256,700
Minerals	300	124,500	32,500	52,900	21,500	231,700	67,900	113,300	50,500
Fish and wildlife	1,200	39,400	6,800	22,200	18,800	88,400	49,500	8,400	30,500
Recreation	400	1,600	200	2,600	400	5,200	2,200	1,300	1,700
Stock-pond evaporation and livestock use	1,800	35,800	4,000	10,700	6,700	59,000	21,200	20,600	17,200
Subtotal	41,000	379,500	128,200	382,300	205,300	1,136,300	507,500	214,600	414,200
Irrigation: consumptive use, incidental use, and reservoir evaporation	9,000	1,754,500	411,000	695,200	427,100	3,296,800	1,253,300	1,166,500	877,000
Export		885,400	117,500	267,000	185,000	1,454,900	452,000	882,900	120,000
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,019,400	656,700	1,341,900	817,400	5,885,400	2,212,800	2,264,000	1,408,600
Main-stem reservoir evaporation						660,000	67,000	17,000	576
Total for 2020						6,545,400	2,279,800	2,281,000	1,984

TABLE 27

PROJECTED INSTALLED CAPACITY AND WATER DEPLETIONS FOR THERMAL-ELECTRIC POWER GENERATION FOR THE STATES' ALTERNATIVE TO THE FRAMEWORK PLAN (6.5 MAF LEVEL OF DEVELOPMENT) UPPER COLORADO REGION

Subregion and state	Installed capacity and consumptive use					
	1980		2000		2020	
	Megawatts	1,000 acre-feet	Megawatts	1,000 acre-feet	Megawatts	1,000 acre-feet
Green River						
Colorado	663	9.1	4,663	69.1	4,663	69.1
Utah	959	14.4	7,559	113.3	7,559	113.3
Wyoming	2,213	33.2	9,913	148.7	9,913	148.7
Subregion total	3,835	56.7	22,135	331.1	22,135	331.1
Upper Main Stem						
Colorado	123	1.6	1,123	16.6	1,123	16.6
Subregion total	123	1.6	1,123	16.6	1,123	16.6
San Juan-Colorado						
Arizona	2,310	34.1	2,310	34.1	2,310	30.1
Colorado	0	0	1,500	22.5	1,500	22.5
New Mexico	5,623	90.0	5,623	90.0	5,623	55.6
Utah	7,400	111.0	9,900	148.5	9,900	148.5
Subregion total	15,333	235.1	19,333	295.1	19,333	256.7
Arizona	2,310	34.1	2,310	34.1	2,310	30.1
Colorado	786	10.7	7,286	108.2	7,286	108.2
New Mexico	5,623	90.0	5,623	90.0	5,623	55.6
Utah	8,359	125.4	17,459	261.8	17,459	261.8
Wyoming	2,213	33.2	9,913	148.7	9,913	148.7
Region total	19,291	293.4	42,591	642.8	42,591	604.4

TABLE 28

PROJECTED ON-SITE WATER DEPLETIONS BY IRRIGATED LAND (NEW AND SUPPLEMENTAL), INCIDENTAL USE, AND IRRIGATION RESERVOIR EVAPORATION FOR THE STATES' ALTERNATIVE TO THE FRAMEWORK PLAN (6.5 MAF LEVEL OF DEVELOPMENT)
UPPER COLORADO REGION

Hydrologic subregion and state	1980 Irrigated land (1,000 acres) Total	1980 Irrigated land (1,000 acres) Supplemental 1/	1980 Water depletions (1,000 acre-feet)	2000 Irrigated land (1,000 acres) Total	2000 Irrigated land (1,000 acres) Supplemental 1/	2000 Water depletions (1,000 acre-feet)	2020 Irrigated land (1,000 acres) Total	2020 Irrigated land (1,000 acres) Supplemental 1/	2020 Water depletions (1,000 acre-feet)
Green River									
Colorado	129.3	6.1	124.8	192.2	17.1	257.9	193.2	17.1	258.6
Utah	286.8	31.0	476.6	295.7	102.6	532.6	314.8	102.6	567.6
Wyoming	341.5	59.0	334.0	379.5	85.0	407.0	392.5	95.0	427.1
Subtotal	757.6	96.1	935.4	867.4	204.7	1,197.5	900.5	214.7	1,253.3
Upper Main Stem									
Colorado	646.4	25.7	991.1	727.2	99.3	1,167.3	718.2	99.3	1,149.3
Utah	9.6	2.0	16.7	9.7	2.0	17.2	9.7	2.0	17.2
Subtotal	656.0	27.7	1,007.8	736.9	101.3	1,184.5	727.9	101.3	1,166.5
San Juan-Colorado									
Arizona	10.0	0	7.0	9.4	1.0	7.6	9.4	2.0	9.0
Colorado	209.7	28.7	275.2	248.0	53.8	353.0	247.0	53.8	346.6
New Mexico	104.2	5.5	245.0	174.2	5.5	411.0	174.2	5.5	411.0
Utah	54.4	0	83.3	65.7	7.0	110.8	59.1	14.6	110.4
Subtotal	378.3	34.2	610.5	497.3	67.3	882.4	489.7	75.9	877.0
Region									
Arizona	10.0	0	7.0	9.4	1.0	7.6	9.4	2.0	9.0
Colorado	985.4	60.5	1,391.1	1,167.4	170.2	1,778.2	1,158.4	170.2	1,754.5
New Mexico	104.2	5.5	245.0	174.2	5.5	411.0	174.2	5.5	411.0
Utah	350.8	33.0	576.6	371.1	111.6	660.6	383.6	119.2	695.2
Wyoming	341.5	59.0	334.0	379.5	85.0	407.0	392.5	95.0	427.1
Total	1,791.9	158.0	2,553.7	2,101.6	373.3	3,264.8	2,118.1	391.9	3,296.8

1/ Supplemental acreage included in total.

TABLE 29

WATER USE FOR THE STATES' ALTERNATIVE AT THE 8.16 MAF LEVEL OF DEVELOPMENT, 1980, 2000, AND 2020, UPPER COLORADO REGION

Type of use	On-site depletions (acre-feet per year) Arizona	Colorado	New Mexico	Utah	Wyoming	Region	Green River	Upper Main Stem	San Juan-Colorado
				- - 1980 - -					
Municipal and industrial	2,900	22,100	7,200	10,100	5,500	47,800	13,400	16,200	18,200
Electric power (thermal)	34,100	10,700	90,000	125,400	22,000	282,200	45,500	1,600	235,100
Minerals	400	19,500	19,800	10,300	23,900	73,900	36,400	13,700	23,800
Fish and wildlife	1,200	38,800	6,800	22,200	20,100	89,100	50,700	7,900	30,500
Recreation	100	700	100	1,000	200	2,100	800	700	600
Stockpond evaporation and livestock use	1,400	25,000	2,900	7,300	4,800	41,400	15,300	13,700	12,400
Subtotal	40,100	116,800	126,800	176,300	76,500	536,500	162,100	53,800	320,600
Irrigation: consumptive use, incidental and reservoir evaporation	7,000	1,391,100	245,000	576,600	431,500	2,651,200	1,032,900	1,007,800	610,500
Export		663,400	117,500	190,000	65,000	1,035,900	255,000	660,900	120,000
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	47,100	2,171,300	489,300	940,300	573,000	4,221,000	1,450,000	1,722,500	1,048,500
Main-stem reservoir evaporation						660,000	67,000	17,000	576,000
Total for 1980						4,881,000	1,517,000	1,739,500	1,624,500
				- - 2000 - -					
Municipal and industrial	4,800	50,000	13,600	20,200	7,300	95,900	29,500	31,900	34,500
Electric power (thermal)	34,100	153,200	90,000	291,800	37,000	606,100	234,400	61,600	310,100
Minerals	300	128,300	38,800	10,700	47,100	225,200	99,600	67,700	57,900
Fish and wildlife	1,200	39,400	6,800	22,200	20,100	89,700	50,800	8,400	30,500
Recreation	300	1,100	100	1,600	200	3,300	1,400	900	1,000
Stockpond evaporation and livestock use	1,700	30,500	3,300	9,000	5,800	50,300	18,200	17,100	15,000
Subtotal	42,400	402,500	152,600	355,500	117,500	1,070,500	433,900	187,600	449,000
Irrigation: consumptive use, incidental and reservoir evaporation	7,600	1,792,500	411,000	660,600	534,500	3,406,200	1,325,000	1,198,800	882,400
Export		925,400	243,000	437,000	125,000	1,730,400	602,000	882,900	245,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,120,400	806,600	1,450,500	777,000	6,204,500	2,360,900	2,269,300	1,574,300
Main-stem reservoir evaporation						660,000	67,000	17,000	576,000
Total for 2000						6,864,500	2,427,900	2,286,300	2,150,300
				- - 2020 - -					
Municipal and industrial	7,200	84,100	29,100	42,500	28,900	191,800	78,300	54,400	59,100
Electric power (thermal)	30,100	153,200	90,000	291,800	148,700	713,800	346,100	61,600	306,100
Minerals	300	207,500	54,000	165,600	122,700	550,100	364,600	113,300	72,200
Fish and wildlife	1,200	71,400	6,800	22,200	20,100	121,700	50,800	40,400	30,500
Recreation	400	1,600	200	2,600	400	5,200	2,200	1,300	1,700
Stockpond evaporation and livestock use	1,800	35,800	4,000	10,700	6,700	59,000	21,200	20,600	17,200
Subtotal	41,000	553,600	184,100	535,400	327,500	1,641,600	863,200	291,600	486,800
Irrigation: consumptive use, incidental and reservoir evaporation	9,000	1,941,500	411,000	733,700	562,500	3,657,700	1,470,100	1,262,600	925,000
Export		1,360,300	243,000	447,000	153,000	2,203,300	640,000	1,305,800	257,500
Less import				(-)2,600		(-)2,600			(-)2,600
Subtotal of all above	50,000	3,855,400	838,100	1,713,500	1,043,000	7,500,000	2,973,300	2,860,000	1,666,700
Main-stem reservoir evaporation						660,000	67,000	17,000	576,000
Total for 2020						8,160,000	3,040,300	2,877,000	2,242,700

TABLE 30

PROJECTED INSTALLED CAPACITY AND WATER DEPLETIONS FOR THERMAL-ELECTRIC POWER GENERATION FOR STATES' ALTERNATIVE AT THE 8.16 MAF LEVEL OF DEVELOPMENT, UPPER COLORADO REGION

	Installed capacity and consumptive use					
	1980		2000		2020	
Subregion and state	Megawatts	1,000 acre-feet	Megawatts	1,000 acre-feet	Megawatts	1,000 acre-feet
Green River						
Colorado	663	9.1	4,663	69.1	4,663	69.1
Utah	959	14.4	8,559	128.3	8,559	128.3
Wyoming	1,463	22.0	2,463	37.0	9,913	148.7
Subregion total	3,085	45.5	15,685	234.4	23,135	346.1
Upper Main Stem						
Colorado	123	1.6	4,123	61.6	4,123	61.6
Subregion total	123	1.6	4,123	61.6	4,123	61.6
San Juan-Colorado						
Arizona	2,310	34.1	2,310	34.1	2,310	30.1
Colorado	0	0	1,500	22.5	1,500	22.5
New Mexico	5,623	90.0	5,623	90.0	5,623	90.0
Utah	7,400	111.0	10,900	163.5	10,900	163.5
Subregion total	15,333	235.1	20,333	310.1	20,333	306.1
Arizona	2,310	34.1	2,310	34.1	2,310	30.1
Colorado	786	10.7	10,286	153.2	10,286	153.2
New Mexico	5,623	90.0	5,623	90.0	5,623	90.0
Utah	8,359	125.4	19,459	291.8	19,459	291.8
Wyoming	1,463	22.0	2,463	37.0	9,913	148.7
Region total	18,541	282.2	40,141	606.1	47,591	713.8

TABLE 31

PROJECTED IRRIGATED ACREAGE FOR STATES' ALTERNATIVE AT THE 8.16 MAF LEVEL OF DEVELOPMENT, UPPER COLORADO REGION

Hydrologic Subregion and State	Irrigated land (1,000 acres)		
	1980	2000	2020
Green River			
Colorado	129.3	192.2	217.4
Utah	286.8	295.7	312.9
Wyoming	421.3	494.8	513.3
Subtotal	837.4	982.7	1,043.6
Upper Main Stem			
Colorado	646.4	727.2	771.8
Utah	9.6	9.7	8.0
Subtotal	656.0	736.9	779.8
San Juan-Colorado			
Arizona	10.0	9.4	9.4
Colorado	209.7	255.0	267.1
New Mexico	104.2	174.2	174.2
Utah	54.4	65.7	80.3
Subtotal	378.3	504.3	531.0
Region			
Arizona	10.0	9.4	9.4
Colorado	985.4	1,174.4	1,256.3
New Mexico	104.2	174.2	174.2
Utah	350.8	371.1	401.2
Wyoming	421.3	494.8	513.3
Total	1,871.7	2,223.9	2,354.4

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