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DETERMINING THE FEASIBILITY OF INTEGRATING WATER RESOURCE CONSTRAINTS INTO ENERGY MODELS

by

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ABSTRACT

Development of energy sources and generation of electric power require substantial amounts of water. The water is necessary as process water in the production of synthetic fuels, and as cooling water in almost all activities related to the development of energy resources and in thermoelectric power plants. Yet existing energy-economy models do not explicitly take account of the availability of water resources for energy-related activities. The objective of the project was to express, in a general form, the availability of regional water resources and to determine the feasibility of integrating these availabilities into energy models. Following reviews of water resources data bases, of technologies involved in energy development, and of energy models with regional disaggregation, two models were used for the study of this integration: the Regional Energy System Optimization Model (RESOM), currently under development at the Brookhaven National Laboratory, and the Energy Policy Model (EPM), developed at the Lawrence Livermore Laboratory. Water resources constraints were introduced in these models and exploratory computer runs using demonstration scenarios were made. The test scenarios assumed that nonenergy users would make increasing, inelastic demands upon regional water resources, leaving limited amounts of increasingly more expensive water for energy activities. The results of the exploratory runs demonstrate the feasibility of integrating water resources availabilities and water consumption data into energy-economy models.

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CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

The conterminous 48 states of the U.S. have large quantities of energy resources and of surface and groundwater. It is estimated that the average aggregated streamflow* is about 1.9×10^3 million acre-feet/year,** and groundwater within 2500 feet of ground surface amounts to 100×10^3 Maf/yr. However, the distribution of water resources does not parallel that of energy reserves and, in areas where water is relatively scarce or where it is already used by other sectors of the U.S. economy, it may influence appreciably the rate at which energy resources could be developed. Hence, the effects of water availability or scarcity are important and should be reflected in models used in energy R&D planning. Also, the availability of water supplies adequate in quantity and in quality ranks as an important criterion for the siting of thermoelectric power plants, alongside the proximity of fuel supply and load (demand) centers.

The use of water in energy-related activities is consumptive, i.e., water cannot be reused by any other user within the same hydrological unit without some treatment -- if, indeed, it can be treated at all. The consumptive use consists of three major components:

1. process water, such as in the case of synthetic fuels and oil derived from shale, where water contributes to the making of the product;
2. evaporation, which removes excess (waste) heat from energy-related processes;
3. waste water, which removes waste matter.

The use of water by energy-related activities is shown below.

*For a definition of terms, see Appendix A.
**Conversion factors for water-measurement terms are given in Appendix B.

Table S-1

WATER USES IN ENERGY-RELATED ACTIVITIES
(acre-feet per quadrillion Btu of product)

Activity	Process Water	Evaporation	Waste Water	Total	Sources
Nuclear power stations (LWR)	-	537,200	55,600	592,800	(2)[a,b]
Fossil-fueled power stations	-	358,100	37,100	395,200	(4)[c]
Coal gasification, high-Btu gas	32,500	68,100	2,800	103,400	(4)
Oil shale conversion	21,700	32,000	8,000	61,700	(3,4)
Coal gasification, low-Btu gas	1,000	56,000	700	57,700	(1,6)
Coal liquefaction	2,800	36,700	17,500	57,000	(7)
Nuclear fuel processing	-	37,400	3,900	41,300	(2)
Coal slurry pipeline	-	-	-	34,000	(4,9)
Oil refining	-	16,000	6,200	22,200	(2)
Underground coal mining	-	7,700	-	7,700	(5,8)
Strip coal mining, revegetation	-	3,400	-	3,400	(4)
Strip coal mining, no revegetation	-	1,800	-	1,800	(4)

[a]Numbers refer to the bibliography at the end of this summary.

[b]Equivalent to 0.66 gallons/kWh.

[c]Equivalent to 0.44 gallons/kWh.

Water use numbers in this table are representative of ranges of values, reflecting the variability in conditions which exist at different sites.

Hydropower generation, which is not included in this table, may be considered as a user of water, although water flowing through turbines and generating electricity is readily available for other uses a short distance downstream from the hydropower plant. But plants, other than run-of-the-river, are constructed and operated in conjunction with dams, so that part of the water stored behind them evaporates. However, water storage reservoirs often perform other functions in addition to power generation, such as flood control, flow regulation for water supply, recreation, etc., and there is no agreed method for the allocation of evaporative losses among these functions. For this reason, all these losses are combined into one category of water use called "evaporation from man-made lakes" (see Figure A-1, Appendix A).

Table S-1 shows that water plays a key role in the development and operation of the energy sector in the U.S. In order to study the effects of water availability on a growing energy sector, it appears that water-energy-economy models could be very useful. Furthermore, such models could offer guidelines to policy-makers and managers in the energy sector for decisions related to the acquisition, use, treatment, and discharge of water.

Availability of water resources varies both in space (i.e., geographically) and in time (i.e., seasonally): different regions of the U.S. have different amounts of water which can be made available to users; and in the same region, these amounts of water may vary from season to season. Furthermore, the quantity of water flowing past a given point at any specified time varies from year to year. Hence, one may consider the amount of water flowing in a region as a stochastic variable exhibiting certain probabilistic properties. In this study, however, all water quantities are expressed as expected annual volumes, thus restricting the discussion to deterministic terms. It is hoped that future studies of water-energy-economy interactions will consider the stochastic aspects of streamflows.

Information related to water resources and assembled in a number of data bases refers usually to hydrological units called river basins (see Appendix A, glossary). Boundaries of river basins are determined primarily by topography; they seldom coincide with state, country, or other administrative or political boundaries. Although interbasin transfers of water are feasible, they often entail formidable engineering works in order to overcome topographical obstacles. For example, the California aqueduct conveys water from the Sacramento river basin, through the San Joaquin Valley, over the Tehachapi mountains, to southern California. Water resources models should represent availabilities, uses, and transfers on the basis of river basins water balances.

In order to highlight some of the critical problems likely to arise in water-energy interactions, water-energy-economy models have to be regionalized. Two models, each having the capability of emphasizing regional differences yet integrating the regions within the framework of the entire U.S. economy, were used to explore the feasibility of adding water resources constraints: the Regional Energy System

Optimization Model (RESOM), currently under development at the Brookhaven National Laboratory, and the Energy Policy Model (EPM) of the Lawrence Livermore Laboratory, developed on the basis of the Gulf-Stanford Research Institute model.

The RESOM model is a single-period static formulation, and it has two major components:

1. a multiregional interindustry input-output submodel;
2. a multiregional linear programming submodel representing in detail energy-related activities.

In this study, equations representing the water sector were integrated within the I-O submodel, and constraints showing regional availabilities of water resources were added to the LP model. As of this time, only the LP submodel of RESOM has been developed at the Brookhaven National Laboratory; the regional data for the I-O submodel has yet to be produced. Hence, only the LP submodel was used for testing the feasibility of integrating water resources constraints into RESOM, yielding a matrix of more than 1700 rows and some 3000 columns. Computer runs made using 1975 data indicated, as expected, that in 1975 water was not a constraining element in energy-related activities. Other runs used a scenario for the year 2000 in which the following assumptions were made:

- Population growth and increase in the standard of living will more than double the total end-use energy demands, as compared with 1975.
- Water resources available for energy-related activities will be less than 75% of the 1975 quantities, due primarily to the increase in population, increase in the standard of living, increase in food production through irrigated agriculture, and further industrial expansion.

Results of these demonstration of feasibility runs indicate that the incorporation of water availabilities into the model does affect regional energy-related activities, such as considerable reduction in oil-fired steam-electric generation in the central U.S. One should consider these results, however, only as indicative of the possible effects the constraining availabilities of water resources might have on energy-related activities.

The EPM model of the Lawrence Livermore Laboratory uses a general economic equilibrium formulation of the U.S. energy sector in a dynamic framework. Regions are defined separately for energy resource availability and production (supply), and for energy consumption (demand). The integration of water resources into this model requires primarily that regional water availabilities be described by means of supply curves. As an exploratory exercise, this was done in only one energy supply region, namely the Rocky Mountain Region, which contains both the Upper Colorado and the Upper Missouri River Basins. It was necessary to aggregate the two river basins into one region to correspond to the existing energy supply-based regionalization of the EPM model. Since the two river basins were aggregated, a composite supply curve for water was produced, as well as an aggregated projection for nonenergy water use for the entire region. The aggregation of the two river basins is probably one of the more serious distortions of the formulation, since it implies complete mobility of the available water througout the Rocky Mountain Region (and is less constraining than in reality). Even with this far-reaching assumption, the influence of reduced availabilities of water resources, as assumed for this feasibility demonstration, vis-a-vis the increasing energy demands can be detected as early as the year 2000; for example, the amount of power generated by nuclear plants (LWR) (relatively water intensive) begins to drop at the end of this century.

To attain an assessment of the effects of water resources availability on the energy sector, it is proposed to capitalize on the modeling feasibility demonstrated in this study, primarily by developing an improved water-energy-economy model so as to focus on problems arising out of the water-energy interactions. In this way, regions could be identified where water availability may inhibit significantly the rate at which energy resources could be developed and utilized, and these regions could be ranked on a time scale, thus suggesting priorities for further studies in greater subregional detail.

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Section 1

INTRODUCTION

This is an exploratory study of energy-water resources interactions to determine the feasibility of integrating water constraints into energy models. The Continental U.S. has vast quantities of energy resources and large amounts of surface and groundwater. However, the distribution of water resources does not parallel that of energy resources, and in areas where water is relatively scarce it may influence appreciably the rate at which energy resources could be developed. Availability of water supplies adequate in quantity and in quality ranks, alongside the proximity of fuel supply and the load (demand) centers, as an important criterion for the siting of thermal power stations. Similarly, the rate at which oil shale could be developed in the future will probably be conditioned to a great extent by water availability.

The purpose of this study is to clarify the role which water plays in the development and operation of the energy sector in the U.S., so as to identify some of the critical issues which are likely to arise in water-energy interactions. The study is focused on the integration of water resources constraints within energy models, hereby constructing water-energy-economic models. These models should offer guidelines useful to policymakers and managers in the energy sector, emphasizing the acquisition, use, treatment, and discharge of water.

This study consists of five tasks:

1. review of water resources data base (Section 2);
2. review of technologies involved in energy development and their water use requirements (Section 3);
3. review of energy models, with emphasis on regional disaggregation (Section 4);
4. a feasibility study for the incorporation of water resources constraints in energy models (Section 5);
5. preliminary demonstration runs of energy systems models containing water resources constraints and water consumption data associated with energy technologies (Section 6).

The emphasis in task 4 was on clarifying some methodology issues arising when integrating water resources constraints into existing energy models. The title of Section 5, which summarizes this task, was, therefore, modified accordingly.

Two existing energy systems models were selected for the incorporation of water resources constraints: RESOM (Regional Energy System Optimization Model), developed by Brookhaven National Laboratory; and EPM (Energy Policy Model), of the Lawrence Livermore Laboratory. Data reflecting water resource availability and water use by energy-related activities were included in these models.

Section 2

REVIEW OF WATER RESOURCES DATA BASE

INTRODUCTION

A distinction should be made between data and assessments. A data base is probably unique, at least in the sense of "natural data" [Nunamaker and Pingry 1978]: these are streamflow (discharge) measurements and groundwater table elevations, rainfall and snowpack data. In another sense, these are barely raw numbers, which have to be further processed so as to make them useful for planning, design, or any other purpose. An example of processed hydrological data is a list of average monthly discharges at a given point on a stream, including their probabilistic and statistical characteristics, such as frequencies, expected values, variances, and coefficients of skewness.

If to the natural data is added information regarding technologies, economic factors, legal considerations, water quality standards, and so on, a basis is formed for an assessment of the availability of water resources in a given region for a stated purpose. Thus, an assessment will have two sets of components:

1. nature-related, i.e., streamflows (surface and subsurface) and other hydrological and meterological information;
2. man-related, i.e., economics, technologies, laws, traditions, demands, aspirations, etc.

The first set of components of an assessment indicates the physical limits of the natural resources (water, energy) with which we deal; the second set, however, appears to be less immutable than the first. Nevertheless, the degree and the difficulty with which any single man-related component may be changed varies within a wide range. For example, lifestyles may be rather resistant to change, especially in a direction in which standards of living are reduced. Technology, on the other hand, has manifested at times quantum-like jumps. In general, a specific combination of man-related components of an assessment will define a scenario, which may be used in a quantitative evaluation of decisions and policies relevant to the development of energy resources.

THE DATA BASE ASSEMBLED BY THE EPRI SUPPLY PROGRAM

The EPRI Supply Program is currently engaged in an effort for the assembly of a water supply data base [Nunamaker and Pingry 1978]. The thrust of this effort is threefold:

1. to identify pertinent water resources information at national and regional levels;

2. to design a system which will enable EPRI (and others) to make maximum use of this information;

3. to implement this system on a publicly accessible computer.

The result is an information system which has two components, a "macro" data base and a "micro" data base. Both components are computerized.

The "macro" data base is essentially a bibliographic system in which the information is assembled in lists called "records." There are nine such records: ENTRY, ORGANIZATION, DATA-BASE, KEYWORD, REGION, CONFERENCE, PUBLISHER, JOURNAL, AUTHOR.

ENTRY is a set of bibliographic records, each including full bibliographic reference and an abstract. The following are defined: MONOGRAPH, ARTICLE, CHAPTER, UNPUBLISHED REPORT, PAMPHLET, THESIS, CONFERENCE PROCEEDING, CONFERENCE PAPER.

ORGANIZATION is a list of agencies and other institutions which maintain water information of some kind. There are 10 types of organizations: federal, state, local, university, water research center, private, regional, defunct (e.g., Federal Water Pollution Control Administration), international, other.

DATA-BASE contains information of various types. Each type includes a synonym for use with the "micro" data base, where details may be obtained. Ten types of information are defined: data (computerized), data (manual), bibliographic (computerized), bibliographic (manual), legal (computerized), legal (manual), research collection, directory (computerized), directory (manual), other.

KEYWORD is a list of only two types: legal, and data-base-content.

REGION, CONFERENCE, PUBLISHER, JOURNAL and AUTHOR are self-explanatory.

The "micro" data base is a system capable of storing, maintaining, updating, manipulating, and retrieving information in an EPRI Water Supply Data Base; it can also be used to access external data banks (national, regional, and state) for the purpose of acquiring and displaying a desired piece of information. Thus the "micro" system consists of two main subsystems:

1. software for describing and reporting information from sources external to the EPRI Water Supply Data Base;
2. a data base management subsystem for storing these descriptions and reports.

The "micro" data base has two major characteristics:

1. it is capable of handling queries about external water supply data banks;
2. it is capable of storing descriptions of contents of these banks.

The major data banks to which the "micro" data base has access are those assembled by the United States Geological Survey (USGS) and by the Environmental Protection Agency (EPA).

DATA BASES COMPILED BY USGS

The United States Geological Survey is the governmental agency which collects, on a continuous basis, hydrological data and assembles a great deal of other information pertinent to water resources. Much of its work is accomplished through cooperation with other agencies -- regional, state, and local. The information so acquired is accessible through two computerized data banks: NAWDEX and WATSTORE.

NAWDEX (National Water Data Exchange) [Edwards 1977, 1978] is an instrument for identifying sources of hydrological information and for connecting users of this information with those who acquire it. It is a confederation of water-oriented organizations cooperating to provide convenient access to their data located at the USGS National Center in Reston, Virginia. This program performs two major tasks:

1. it maintains a directory of organizations that collect water data;
2. it maintains a master water data index which contains over 80,000 sites at which measurements are made throughout the United States.

In addition, NAWDEX can provide direct access to the daily values file of the National Water Data System of the USGS, so that this minutely detailed information can be retrieved and displayed.

WATSTORE (Water Data Storage and Retrieval) is a large-scale computerized system which is capable, in addition to data processing, storage, and retrieval, of performing statistical analyses of data and displaying their results by means of tables and graphs. It consists of a number of files, which contain the following information:

- quantitative and qualitative measurements of surface and groundwater on a daily or continuous basis;
- annual peak values for streamflow (surface) stations;
- chemical analyses of surface and groundwater;
- geologic information regarding groundwater;
- index of sites for which data are stored in the system;

The daily values file contains currently about 120 million items of information, including streamflow discharges, river stages, reservoir contents, water temperatures, specific electric conductance values, sediment discharges, sediment concentration, and groundwater levels.

The annual peak file contains also computer software for the calculation of flood frequencies and their associated curves.

The water quality file contains results of analyses which describe water quality in terms of chemical, biological, physical, and radiological parameters, as defined by the Environmental Protection Agency.

The groundwater file is cross-referenced to both the daily values and to the water quality files.

DATA BASE COMPILED BY EPA

The Environmental Protection Agency is the governmental body which collects water quality information. This information is handled by STORET (Storage and Retrieval), a computerized data bank which has capabilities for storing and retrieving information, as well as for processing and analyzing the data [U.S. Environmental Protection Agency 1977]. The information handled refers to

- water quality,
- water quality standards,

- point sources of water pollution (municipal and industrial waste discharge),
- fish kills caused by pollution,
- waste abatement needs,
- implementation schedules and costs.

The software may be divided into two main categories:

1. water quality data programs, which include water quality analysis in terms of chemical, physical, and biological parameters (about 2000 in all, 187 of which cover about 85% of the data);
2. waste discharge inventories related to about 24,000 locations.

STORET does not have an explicit effluent discharge file.

WATER RESOURCES ASSESSMENT BY WRC

The Water Resources Planning Act of 1965 (P.L. 89-90) directs the Water Resources Council to maintain a continuing study of the adequacy of the U.S. water resources to meet current and future requirements for these resources. The first assessment was published in 1968. The second assessment uses 1975 as a base year for purposes of analysis and makes projections for 1985 and 2000.

The second national water assessment has undergone a number of revisions [U.S. Water Resources Council 1977] and it is still in draft form [U.S. Water Resources Council 1978a, 1978b]. This assessment involved three major phases:

- Phase one: A nationwide analysis was carried out by the Council's member agencies* reflecting their current and future requirements, their perceptions of problems related to the use of water, and their possible implications.
- Phase two: Specific problems were analyzed in each of the 21 water resources regions (18 in the 48 conterminous states, Alaska, Hawaii, and the Caribbean) reflecting state and regional existing and future water-related problems, conflicts arising out of meeting state and regional objectives, and identifying issues needing resolution.

*Member agencies: U.S. Departments of Agriculture, Army, Commerce, Energy, Housing and Urban Development, Interior, Transportation, and EPA. Observers: Attorney General's Office, Office of Management and Budget, Council on Environmental Quality, Interagency Committees, and River Basin Commissions.

- Phase three: A national problem analysis includes

  --an evaluation of results of the first two phases;

  --identification of the nation's most serious water resources problems;

  --documentation of analysis results.

The second national water assessment will be published as a series of reports and accompanying appendixes. The following is a list of reports currently contemplated.

- Summary -- is an overview of the final report, including a resume of water supply conditions, water use appraisal, identifies critical problems, and draws conclusions of the second assessment.

- Part I, Introduction -- outlines the purpose of the assessment and presents an historical perspective.

- Part II, Water Management Problem Profiles -- identifies 10 most critical issues and their implications.

- Part III, Functional Water Uses -- presents national perspectives regarding existing (1975) and future (1985, 2000) requirements for water to meet offstream, instream, and flow management needs for major functional uses.

- Part IV, Water Supply and Water Quality Considerations -- focuses on the adequacy of freshwater supplies to meet existing and future requirements.

- Part V, Regional Summaries -- analyzes conditions in each of the 21 water resources regions and recommends state-regional scenarios regarding planning, research, data needs, and cooperation with federal agencies.

- Statistical Appendix, A-1 -- presents economic, social, and environmental data for 1975, 1985, and 2000 on which water supply and use projections are based.

- Statistical Appendix, A-2 -- contains streamflow information, reservoir storage capacity, groundwater data, interbasin imports and exports, and instream flow estimates for 1975, 1985, and 2000.

- Statistical Appendix, A-3 -- contains annual streamflow depletion analyses for average and dry years; annual water use-supply analyses for average and dry years; summaries of monthly and annual streamflow depletion analyses for average and dry years; monthly water use-supply analyses for average and dry years; average annual water supply analysis. All these analyses are presented in aggregated form at regional level and in detail for each subregion.

WATER RESOURCES ASSESSMENTS BY THE BUREAU OF RECLAMATION

The Bureau of Reclamation of the U.S. Department of the Interior is charged with the planning of water resources development west of the Mississippi River. One of its major activities is the assembly of relevant information and the assessment of available water resources for specific uses. Traditionally, the Bureau of Reclamation was concerned primarily with the development of irrigated agriculture in the Western United States. Lately, however, it began a series of studies related to future development of energy resources [Water for Energy Management Team 1974, Water for Energy Management Team 1975, Bureau of Reclamation 1975]. This effort still continues, and there appears to be a substantial degree of cooperation with the Water Resources Council [Kauffman 1978, Davenport 1978].

The assessments of the Bureau of Reclamation seem to embody the outlook of the bureau: all future scenarios are oriented heavily toward continuous development of irrigated agriculture in the West at a fairly high rate, without much discussion of the availability of land areas suitable for such intensive cultivation. However, the usefulness of the USBR assessments resides in their estimates of water availability, i.e., water currently not utilized for any purpose (domestic, irrigation, industrial use, energy, recreation, etc.). These estimates have focused primarily on the Upper Colorado River Basin and the Upper Missouri River Basin, where significant energy resources are found (primarily coal and oil shale) and where water resources are limited.

Estimates of the mean annual flow of the Colorado River vary, but most of them are around 15.1 Maf* (million acre-feet) [Wollman and Bonem 1971]. The U.S.-Mexico Treaty of 1944 guarantees Mexico an annual amount of 1.5 Maf, leaving about 13.6 Maf/yr for the United States. The seven states which share the Colorado River Basin -- Wyoming, Utah, Colorado, Nevada, New Mexico, Arizona, and California -- signed in 1922 an agreement known as the Colorado River Compact, which divided the basin into an upper and a lower basin, and which apportioned to each of the two basins in perpetuity 7.5 Maf/yr. Clearly, the Colorado River Compact predated the U.S.-Mexico Water Treaty and could not anticipate obligations of the U.S. towards Mexico. Furthermore, the quantity of 15.1 Maf/yr (average total flow) was based on data accumulated during a period of relatively abundant flows. Therefore, revised estimates of the Bureau of Reclamation [Water for Energy Management Team 1974]

*1 ac-ft = 1233.6 m^3

consider that only 5.8 Maf/yr would be available for consumptive use in the upper basin. Of this amount, the consumptive use in 1974 was in excess of 3.7 Maf/yr, as shown in Table 2-1, leaving 2.1 Maf/yr unused [Buras 1977a].

Table 2-1

CONSUMPTIVE USES OF WATER, UPPER COLORADO RIVER BASIN, 1974

Use	Thousand Acre-feet/Year	Percent of Total
Irrigation	2,154	58.1
Transbasin exports	754	20.3
Evaporation from reservoirs	520	14.0
Livestock ponds	79	2.2
Recreation, fishing, and wildlife	77	2.1
Mining	48	1.3
Municipal and industrial	38	1.0
Thermal power plants	38	1.0
Total	3,708	100.0

Source: Water for Energy Management Team 1974.

The Upper Missouri River Basin is defined by the watershed which contributes to the flow of the Missouri River at Sioux City, Iowa [Water for Energy Management Team 1975]. The estimated mean annual flow at Sioux City is 28.3 Maf/yr. The consumptive use (depletion) in 1970 was 6.5 Maf/yr, as shown in Table 2-2, leaving an availability of 21.8 Maf/yr on the average.

Table 2-2

CONSUMPTIVE USES OF WATER, UPPER MISSOURI RIVER BASIN, 1970

Use	Thousand Acre-feet/Year	Percent of Total
Irrigation	4,200	64.6
Evaporation from reservoirs	1,900	29.2
Other uses	400	6.2
Total	6,500	100.0

Source: Water for Energy Management Team 1975.

The minimum water requirements downstream from Sioux City for hydropower generation and navigation require an annual release into the Lower Missouri River Basin of 11.7 Maf/yr on the average [Buras 1977b]. This leaves in the upper basin an amount of 21.8 - 11.7 = 10.1 Maf/yr available for use.

The state engineer of the state of Utah has recently reviewed the Bureau of Reclamation figures relevant to the Upper Colorado River Basin [Hansen 1976]. His estimate of the amount of water apportioned to the Upper Colorado River Basin is higher than that of the Bureau of Reclamation -- 6.3 Maf/yr. However, the total consumptive use in 1975 was 3,647,000 acre-ft. The amount of unconsumed water in 1975 is, therefore, between 2.153 and 2.653 Maf/yr.

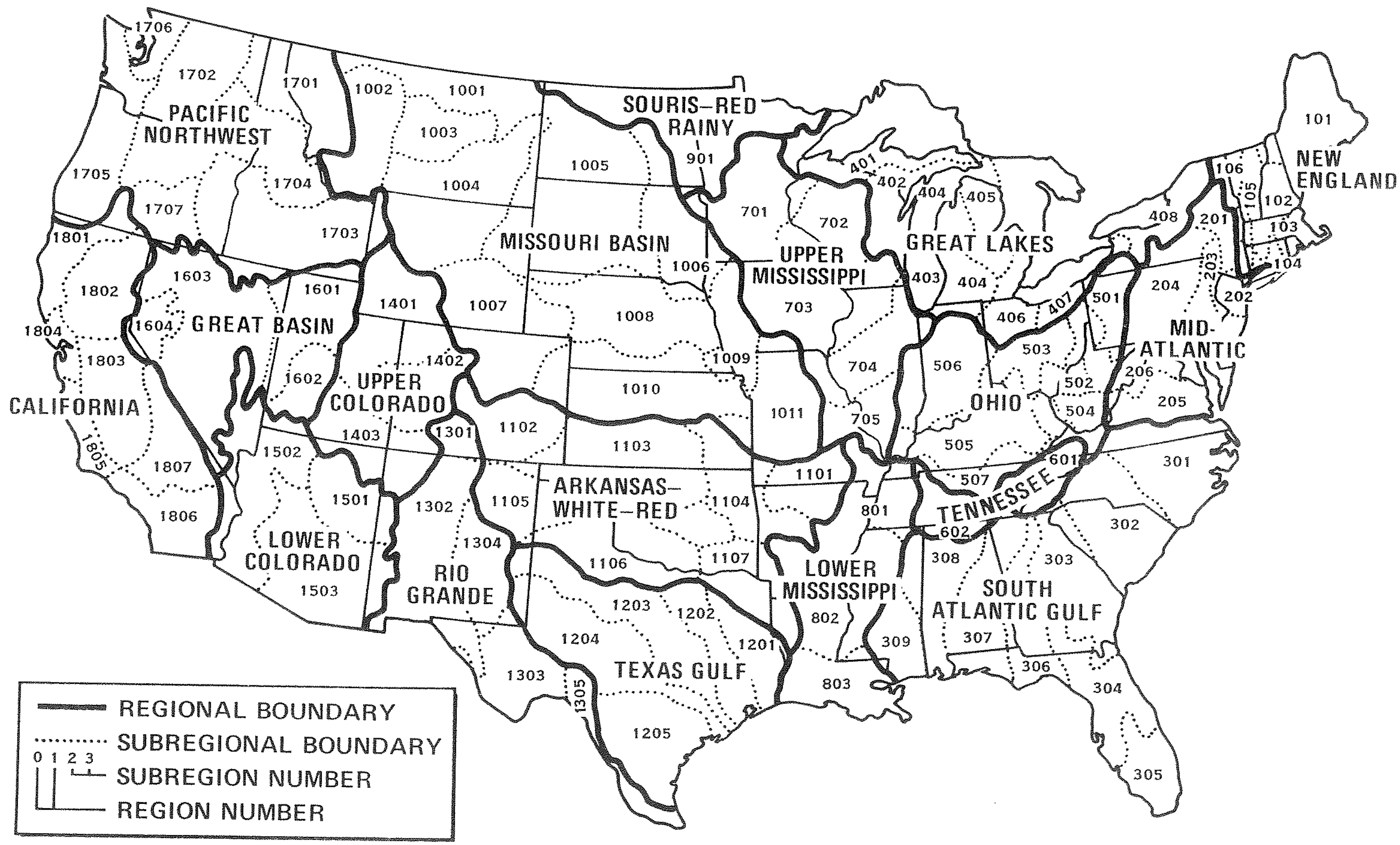
Recently, the water availability in the Upper Missouri River Basin has been estimated at 11.3 Maf/yr [Gibbs 1976].

OTHER ASSESSMENTS

A recent study [Harte and El-Gasseir 1978] shows the mean annual runoff (surface flow) and the 1975 consumptive use of water for each of the regions defined by the Water Resources Council. (See Figure 2-1.) The data relevant to the 48 counterminous states is shown in Table 2-3. The point of this assessment is that, although current consumptive uses of water aggregated over the entire United States appear to be of the order of only 10% of total mean annual runoff, the actual supply and demand for water are highly variable across time and space. Therefore, depending upon the development scenario used, one can estimate at which point in time water availability may become a constraining factor in any given region.

USE OF DATA BASES AND ASSESSMENTS IN WATER-ENERGY MODELS

The usefulness of a water-energy model -- or, for that matter, any model -- is greatly dependent on the reliability of its data base. On the other hand, the usefulness of the details contained in a data base depends upon the level of analysis which uses the information. For example, the detailed information contained in the USGS data base WATSTORE or in the EPA bank STORET would be most useful to planning organizations or even for the detailed design of specific components of water resources systems.



Source: U.S. Water Resources Council 1977

Figure 2-1. Water Resources Regions and Aggregated Subregions of the United States

Table 2-3

REGIONAL RUNOFF AND 1975 CONSUMPTIVE USE OF WATER
(Million acre-feet per year)

Region	Mean Annual Runoff	Consumptive Use
New England	75.4	0.49
Mid-Atlantic	97.3	1.78
South Atlantic Gulf	219.0	4.14
Great Lakes	81.1	1.22
Ohio	137.9	1.38
Tennessee	46.2	0.36
Upper Mississippi	73.0	1.05
Lower Mississippi	81.1	6.16
Souris-Red-Rainy	7.0	0.14
Missouri	60.8	19.46
Arkansas-White-Red	81.1	12.98
Texas-Gulf	35.7	10.54
Rio Grande	5.6	4.87
Upper Colorado	14.6	2.76
Lower Colorado	3.6	8.11
Great Basin	8.1	4.46
Pacific Northwest	235.2	14.60
California	69.7	27.57
Total	1,320.4	122.03

Source: Harte and El-Gasseir 1978.

For the purpose of the present study, because of the regional differences of water availability, the basic information should be regionalized in a meaningful way. An adequate regionalization, with some modifications, would be that of the Water Resources Council. One modification which seems obvious is to separate the Upper Missouri River Basin, because of the important coal deposits found in it.

The regionalization of the data bases and of models should enable the ranking of regions in accordance with the degree at which water may become a constraining element in the development of regional energy resources, including electric power generation. The ranking will then provide a priority scale for the overall research effort. This concept is illustrated graphically in Figure 2-2. Suppose that the entire U.S. is divided into two regions. For each region one can estimate the long-term average of annually available water with a given probability. Considering development scenarios for these regions which translate into monotonically increasing demands for water, the demand function will intersect the availability

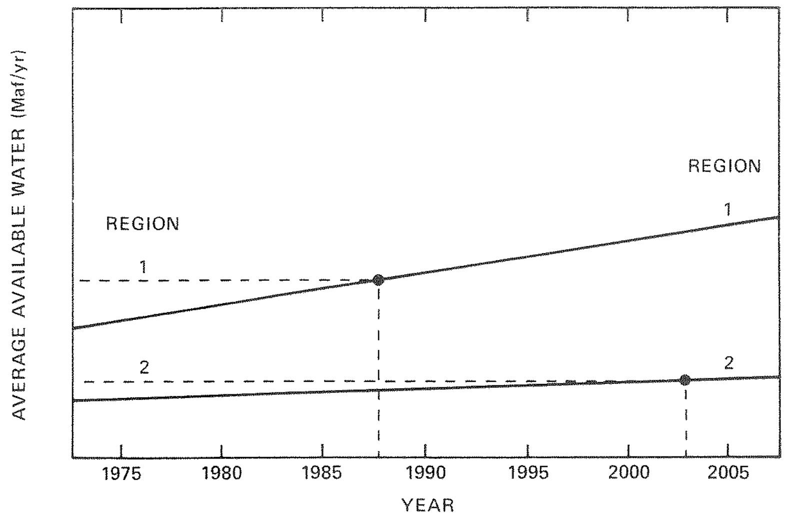


Figure 2-2. A Hypothetical Example of Regional Development Reaching Limits of Water Availability

limit at a certain point in time. In this way, one could forecast the time period when water-related problems will arise in each region, given a development scenario and the technology of water utilization. According to these hypothetical examples, water-related problems will appear around 1987 (Region 1), and 2002 (Region 2).

The various data bases and assessments could also be used to define scenarios to be tested by means of the water-energy models. The importance of evaluating the possible outcomes of different scenarios (also sometimes called "alternative futures") has been stressed in many recent papers [Committee on Water Resources Planning 1976]. To paraphrase Schoeffler [Wismer 1971], optimizing only the energy sector of a national (or regional) economy without regard to the effects of interactions may lead to degraded performances in the other sectors, such as water, land, etc., so that overall process performance is worse than without optimization. A regionalized water-energy model based on regionalized data and assessments will, hopefully, avoid this pitfall.