ENERGY AND WATER RESOURCES INTERACTIONS IN ARIZONA

Nathan Buras, Ph.D.
Department of Hydrology and Water Resources
University of Arizona, Tucson, AZ 85721

Abstract

Water and energy interact strongly in Arizona. The Arizona State Water Plan mentions that under 1970 normalized conditions 60% of total use in the State was from groundwater aquifers, a proportion which may have increased in the last decade. The utilization of groundwater resources requires substantial amounts of power. In addition, the Central Arizona Project is an energy-intensive project: its Granite Reef aqueduct will require a pumping lift of 1,084 ft (352 m) using about 1.665 x 10^9 kwh/year. The Tucson aqueduct component will have an additional lift of 997 ft (304 m). The hydropower installations planned within the CAP will have only limited generating capacities: Agua Fria 3 Mw, Granite Reef 3.5 Mw, and Maxwell 11 Mw. The remainder of the load will have to be picked up by thermal power plants and by pumped storage schemes which, by the year 2000, may need over 100,000 acre-feet per year to make up evaporative losses. Thus, energy is required to make water available to users, and water is a necessary ingredient in energy-related activities. These and other water-energy interactions in the Lower Colorado Basin are discussed.

Introduction

By and large, the United States has substantial quantities of energy resources and considerable amounts of surface and groundwater. However, in the Southwest and especially in Arizona, water is scarce and most of it is already allocated to various sectors of the economy, the most notable being agriculture and mining. The availability of water resources in reliable quantities and of adequate quality ranks as an important criterion for the siting of thermoelectric power plants.

Water and energy interact in two ways (Buras, 1982). On the one hand, energy is an input to many water resources systems, from pumping of groundwater to treatment of liquid wastes. On the other hand, almost all energy-related activities use water, either as process water in the production of synthetic fuels or as a transport medium for the removal of waste heat and/or waste matter. Water-energy interactions are shown diagramatically in Figure 1.

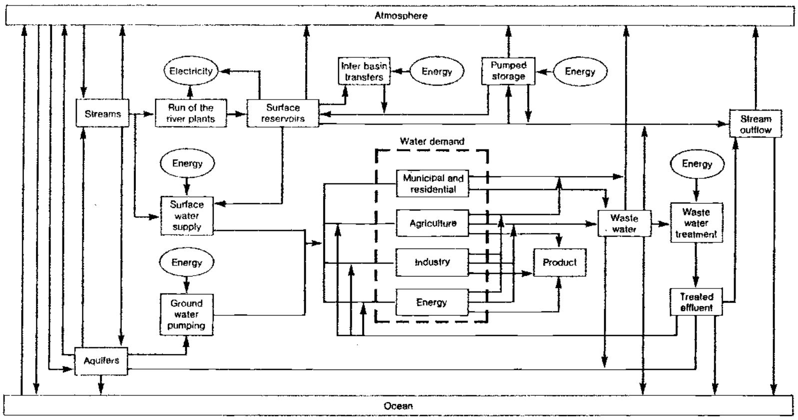

Figure 1. Water-energy interactions.

Water Requirements for Energy-Related Activities

The use of water in energy-related activities is consumptive and it consists of three major components:

1. Process water, such as in the case of synthetic fuels 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 in Table 1.

Table 1. Estimated Water Use in Energy-Related Activities (Acre-feet/10^{15}BTU).

Activity	Process Water	Evaporation	Waste Water	Total	References
Light-Water Reactors	-	537,200	55,600	592,800[a]	Davis and Wood, 1974
Fossil Fuel Thermal Power Stations (No scrubbing)	-	358,100	37,100	395,200[b]	Gold et al, 1977
Coal Gasification, HBTU	32,500	68,100	2,800	103,400	Gold et al, 1977
Oil Shale Conversion	21,700	32,000	8,000	61,700	Gold et al, 1977
Coal Gasification, LBTU	1,000	56,000	700	57,700	Chandra et al, 1978
Coal Liquefaction	2,800	36,700	17,500	57,000	McNamee et al, 1978
Nuclear Fuel Processing	-	37,400	3,900	41,300	Davis and Wood, 1974
Coal Slurry Pipeline	-	-	-	34,000	
Oil Refining	-	16,000	6,200	22,200	Davis and Wood, 1974
Coal Mining, Underground	-	7,700	-	7,700	James and Steele, 1977
Coal Mining, Strip, Revegetation	-	3,380	-	3,380	Gold et al, 1977
Coal Mining, Strip, No Revegetation	-	1,800	-	1,800	Gold et al, 1977

a. 0.66 gal/kwh
b. 0.44 gal/kwh

Development of Groundwater

Much of the water currently used in Arizona in energy-related activities is pumped from aquifers, and it is quite possible that this situation will continue in the foreseeable future. It is also conceivable that as the demands for water will continue to rise, the different economic sectors in the State will increase their competition for the limited water resources to the point of conflict. It is important, therefore, to develop strategies for the management of the groundwater basins so as to meet the competition and avoid the conflict. The groundwater management issue is shown schematically in Figure 2 (Domenico, 1972).

The crucial question is whether to exploit the aquifer within safe-yield limits or to mine the groundwater. An optimal management policy seems to be found between two extreme positions: unregulated mining of groundwater will definitely lead toward the exhaustion of the aquifer within a finite time period, while infinite preservation based on a safe-yield policy may waste groundwater due to the

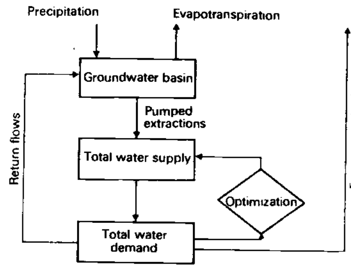

Figure 2. Schematic representation of a groundwater basin.

natural aquifer outflow (Mandel and Shiftan, 1981). Thus the safe-yield concept, based on the natural recharge, should be substituted by the principle of sustained yield. Sustained yield is defined as the maximum rate of groundwater abstraction that can be maintained over a long period of time (e.g., more than a century) without causing consequences unacceptable from an economic, political or environmental point of view. Examples of undesirable effects are lower water levels and reduced well discharges, deterioration of water quality due to intrusion of saline waters, and land subsidence. The "undesirable effects" may be expressed quantitatively by ranges of values, so that their limits can be used as constraining conditions in mathematical programming models of groundwater systems.

The development of regional groundwater resources should be planned in conjunction with the surface waters. In Arizona in particular, aquifers need to be integrated within the State Water Plan.

The Arizona State Water Plan

The major components of an Arizona Water System could be the following:

surface water:
- the Salt River Valley Project
- the Central Arizona Project
- other surface water projects

groundwater:
- Tucson Active Management Area
- Phoenix Active Management Area
- Prescott Active Management Area
- Pinal Active Management Area
- other groundwater basins

The integration of the major (and other) components into a comprehensive system, including its legal framework required for the development, utilization, and management of state's water resources, is a time-consuming process. So far, an inventory of water resources was completed (Arizona Water Commission, 1975), some alternative futures were explored (Arizona Water Commission, 1977), and a number of important water uses were analyzed (Arizona Water Commission, 1978). Currently, the state water planning efforts are concentrated on the groundwater components of the state water resources system (Arizona Water Commission 1980). These efforts should continue so that an integrative plan should emerge in the near future, according to which groundwater aquifers and surface subsystems would be operated conjunctively.

The Arizona State Water Plan should include provisions for establishing water quality standards and guidelines for water quality management. Water quantity and water quality are inseparable issues: they influence each other and are integral parts of the natural hydrological processes. Even if it may seem economically attractive and politically acceptable in the immediate or short range to deal with water quality separately from water quantity, the irreversibility of most policy decisions based on this separation may generate considerable social costs in the medium and long time horizon. This becomes particularly obvious when considering that the reclamation of marginal waters (e.g., brackish groundwater, effluent from wastewater treatment plants) is an energy-intensive activity.

The Central Arizona Project

The Central Arizona Project will divert from the Colorado river about 1.2 Maf/year on the average (U.S. Bureau of Reclamation, 1962). Roughly two-thirds of this amount is allocated to irrigated agriculture and the remainder to the municipal and industrial sectors including electric power generation. The contribution of the CAP to the Arizona state water system will be considerable less than the current groundwater overdraft which is in excess of 2.2 Maf/year.

Energy considerations overshadowed the CAP in the last decade. It was suspected that energy-related development in the Upper Colorado Basin (such as coal-based synthetic fuels, or oil shale exploitation) will deplete all remaining water supplies so that none will be left for CAP. Subsequent studies (Steiner, 1975) refuted these suspicions. Nevertheless, the CAP is an energy-intensive component of the Arizona water resources system. Its Granite Reef aqueduct (capacity, 3,000 cfs; 219 miles long) involves a pumping lift of 1,084 ft. The Tucson aqueduct, which will deliver about 100,000 af/year (capacity, 150 cfs; 56 miles long), will need a pumping lift of 997 ft. The annual pumping power requirements for the Granite Reef aqueduct are estimated at 1.665×10^9 kwh. The projected power plants included in the CAP--Agua Fria, 3 Mw; Granite Reef, 3.5 Mw; Maxwell, 11 Mw--will contribute only marginally to satisfy these requirements. Hence, most of the load needed by the CAP will have to be picked up by power plants outside the project.

Water-Energy Interactions

The Central Arizona Project, one of the most energy-intensive components of the State Water System, is located in a region where electric power requirements are projected to increase more than four-fold during the last two decades of this century: from 6,617 Mw of peak demand in 1980 to 28,532 Mw in year 2000 (Arizona Water Commission, 1971). By the year 2000, it is estimated that the annual consumptive use of water for pumped-storage and thermal power plants in the CAP service area may exceed 100,000 af/year.

A second component where water and energy interact strongly is the desalination plant for the Colorado River International Salinity Control Project. This desalination plant, with a projected output of 101,000 af/year, will require all the power generated by a plant of about 35 Mw capacity (Jacoby, 1975).

Finally, the groundwater basins which supply the bulk of the water currently used in the state use considerable amounts of power for pumping. The increased demand for water increases pumping rate, which lowers the water table, so that the amount of energy required to lift one unit of water is steadily increasing. It is estimated that each foot of increased pumping head in the southern half of Arizona requires the equivalent of about 6 million kWh of electric energy (U.S. Water Resources Council, 1978).

Summary

The water-energy interaction highlights a very important question: to what extent are water problems in Arizona a barrier to development within the State? Apparently, an answer to this question must take into account four unresolved water issues (Brown and Kneese, 1978): the equity issue, the efficiency issue, the environmental quality issue, and the water development issue. In many cases solutions exist, some of which were already tested, accepted, and are being implemented; others are still in the theortical-conceptual stage.

Water is an essential ingredient in almost all energy-related activities, primarily for the removal of excess heat. Energy is a major component of the Arizona State Water Plan, especially when considering that about 60% of the water is pumped from the aquifers and that the major surface water system (the CAP) is energy-intensive. The necessity of studying, planning, designing, and operating the water and energy sectors of the State cannot be overemphasized.

References

Arizona Water Commission. 1971. Lower Colorado Region Comprehensive Framework Study, Appendix XIV: Electric Power. Phoenix, AZ.

Arizona Water Commission. 1975. Arizona State Water Plan, Phase I. Inventory of Resources and Uses. Phoenix, AZ.

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

Arizona Water Commission. 1978. Arizona State Water Plan, Phase III - Part 1. Water Conservation. Phoenix, AZ.

Arizona Water Commission. 1980. Tenth Annual Report, 1979-1980. Phoenix, AZ.

Brown, Lee and Allen V. Kneese. 1978. The Southwest: a region under stress. The American Economic Review. 68(2):105-109.

Buras, Nathan. 1982. Modeling water supply for the energy sector. Electric Power Research Institute report EA-2259. EPRI. Palo Alto, CA.

Chandra, K., B. McElmurry, E. W. Neben and G. E. Pack. 1978. Economic studies of coal Gasification combined cycle systems for electric power generation. Electric Power Research Institute report AF-642. EPRI. Palo Alto, CA.

Davis, G. H. and L. A. Wood. 1974. Water demands for expanding energy development. U.S. Geological Survey circular 703. Reston, VA.

Domencio, Patrick A. 1972. Concepts and Models in Groundwater Hydrology. New York: McGraw-Hill.

Gold, H., D. J. Goldstein, R. F. Probstein, J. S. Shen and D. Yung. 1977. Water requirements for steam-electric power generation and synethic fuel plants in the Western United States. Environmental Protection Agency report no. 600/7-77-037. EPA. Washington, D.C.

Jacoby, Jr., G. C. 1975. Overview of water requirements for electric power generation. In: Proceedings of the Conference on Water Requirements for Lower Colorado Basin Energy Needs. The University of Arizona. Tucson, AZ.

James, I. C., II and T. D. Steele. 1977. Application of residuals management for assessing the impacts of coal-development plans on regional water resources. Third Internation Symposium in Hydrology. Colorado State University. Ft. Collins, CO.

Mandel, Samuel and Z. L. Shiftan. 1981. Groundwater Resources. New York: Academic Press.

McNamee, G. P., N. K. Patel, T. R. Roszkowski and G. A. White. 1978. Process engineering evaluations of alternative coal liquefaction concepts. Electric Power Research Institute report AF-741. vol. 1. EPRI. Palo Alto, CA.

Steiner, W. E. 1975. Water for energy as related to water rights in the Colorado River Basin. In: Proceedings of the Conference on Water Requirements for Lower Colorado Basin Energy Needs. The University of Arizona. Tucson, AZ.

U.S. Bureau of Reclamation. 1962. Appraisal Report. Central Arizona Project. Boulder City, NV.

U.S. Water Resources Council. 1978. The Nation's Water Resources 1975-2000. Washington, D.C.: U.S. Government Printing Office.