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GROUND WATER OCCURRENCE AND UTILIZATION IN THE ARIZONA-SONORA BORDER REGION

by

Michael D. Bradley, Ph.D.*

and

Kenneth J. DeCook, Ph.D.**

This article discusses ground-water resources along the Arizona-Sonora border from Yuma, Arizona to the Douglas-Río Yaqui region in Eastern Arizona. Transfrontier physiography and geology are reviewed to understand the physical occurrence of ground water, its storage, movement, depth, and availability. The border region is divided into five zones or basins for ground-water supply; then the utilization of ground-water resources is detailed, including kinds of development and production water quality considerations, and present and future resource supply problems. Particular attention is paid to the extensive pumping proposals at San Luis, Sonora near the Colorado River. The need for better institutional

arrangements to plan and manage the conjunctive use of both surface and ground-water supplies is discussed as a summary conclusion.

INTRODUCTION

All permanent streams along the Arizona-Sonora border originate outside the desert region itself. Under natural conditions the major river, The Colorado, discharged to the Gulf of California, but it no longer flows regularly to the sea. Other border streams between Arizona and Sonora are intermittent, that is, they flow for only part of the year. Ephemeral streams are the most common type of stream, originating in the desert and flowing only during or after a rain. Large ephemeral streams rise on steep slopes of desert mountains or on high alluvial plains, forming continuous drainage channels that are often as long as 50 miles. Short-term supply from ephemeral sources is important for livestock grazing, but as streams dry, cattle are moved back to areas of more certain supply.[1]

Ground-water resources are irregularly distributed throughout the Sonoran Desert region and Sonora border. Rainfall sinking into the ground after running some distance in a stream bed is the source of most ground water. But since rainfall is sparse and uneven, it usually only wets the upper soil and evaporates immediately. Of the remaining water, a large share is lost by plant evapotranspiration; each desert plant helps reduce the supply available for underground storage.[2] Thus rainfall, streams, natural vegetation, and other factors affect the distribution of water to underground aquifers. What little water remains percolates unevenly into the alluvial basins of the desert.

The general physiography and geology along the Arizona-Sonora border is typical of the Basin and Range Province, with thick alluvial plains between highlands and rock pediments. The alluvial material holds uneven amounts of ground water; valley materials have variable porosities from region to region.

In addition, molecular attraction and other adhesive forces causing the retention of ground water vary from one aquifer to another. But where deep alluvium overlies impermeable rock, ground water may be found in significant amounts throughout saturated zones in the subsurface.

Before the present century the underground water along the Arizona-Sonora border was in dynamic hydrologic balance over large areas. Since that time man, by diverting surface and ground water from the system, has upset the balance by heavily drawing upon both surface and underground resources. Today, throughout most of the border region, outflow exceeds inflow as man uses water from storage. Present depletions of underground reserves on a steady basis can depress the water table to an extent that recovery would be difficult. For now, ground water must be visualized as a body of ore, being mined to eventual depletion. For this reason, the planned management of aquifers is of considerable economic importance.[3]

The development of ground-water resources has a peculiar history along the Arizona-Sonora border. Surface waters were rapidly and intensively developed, with little or no consideration given to the physical conjunctions between surface, underground, and atmospheric resources.[4] This is partly a consequence of history (modern large-scale development with enormous water demand occurred only since the end of World War II); partly a matter of technology (dams and reservoirs provided enough water for past seasonal fluctuations); and partly the result of institutional inertia (public officials responded to immediate supply needs rather than to long-term alternatives for a limited resource). Recently these perceptions have been broadened by the realization of the finiteness of planetary resources. Indeed, water management is now understood as more than an exercise in engineering economics; instead it is a purposeful environmental, social, legal, and political process to grapple with the entire complex of water related problems and values.[5]

Economic development continues to press upon limited water supplies, and ground-water allocation is becoming increasingly important. Recent technological developments have made large-scale exploitation of ground water more economically efficient, but a planned appreciation of the direct and secondary consequences of ground-water use is still often missing altogether or misleading when provided. Ground water is no longer mysterious; divining and witching rods are no longer necessary for its discovery. What is important to realize is that the technology for ground-water exploitation is rapidly outdistancing society's capability for rational ground-water planning and management. Many problems are jurisdictional; the boundaries of states and other political institutions rarely coincide with the natural boundaries of a water resources system. Other problems are organizational; often water supply or water quality agencies are administratively separate, with clearly defined and clearly limited functions that usually stress engineering. The most difficult problems are perceptual; the concepts of the hydrologic cycle and of the catchment or watershed have developed with little or no appreciation for ground water. Legal doctrines and management theories allocated surface water as if the only important resource was the one most easily seen. What is now needed is a recognition of the interdependence of surface and ground waters not only as a matter of physical supply but also as a matter of regional management and international water law. More specifically, the international drainage basin concept, which focuses upon the surface runoff of water, needs to be expanded to the idea of the international water resource system, including all surface and ground waters which flow in, stand on, are present within, or pass over the territory of more than one state.[6] This is particularly true along the Arizona-Sonora border where ground water forms such an important part of total supplies, and where the responsibility for rational planning and management has been submerged and hidden by intense upper and lower basin political conflicts over a limited resource.[7]

THE UTILIZATION OF GROUND WATER: DEVELOPMENT AND PRODUCTION

Ground water has two major historic uses and one important potential use along the Arizona-Sonora border; the first two are irrigated agriculture and municipal-industrial uses, which have developed as the border region grew into a major population and agriculture area. The important future use is regulation of pumpage from the ground-water reservoir underlying the lower Colorado River region, including Yuma Mesa, lands in Mexico south of the border, and land west of the Colorado River separating Arizona from Baja

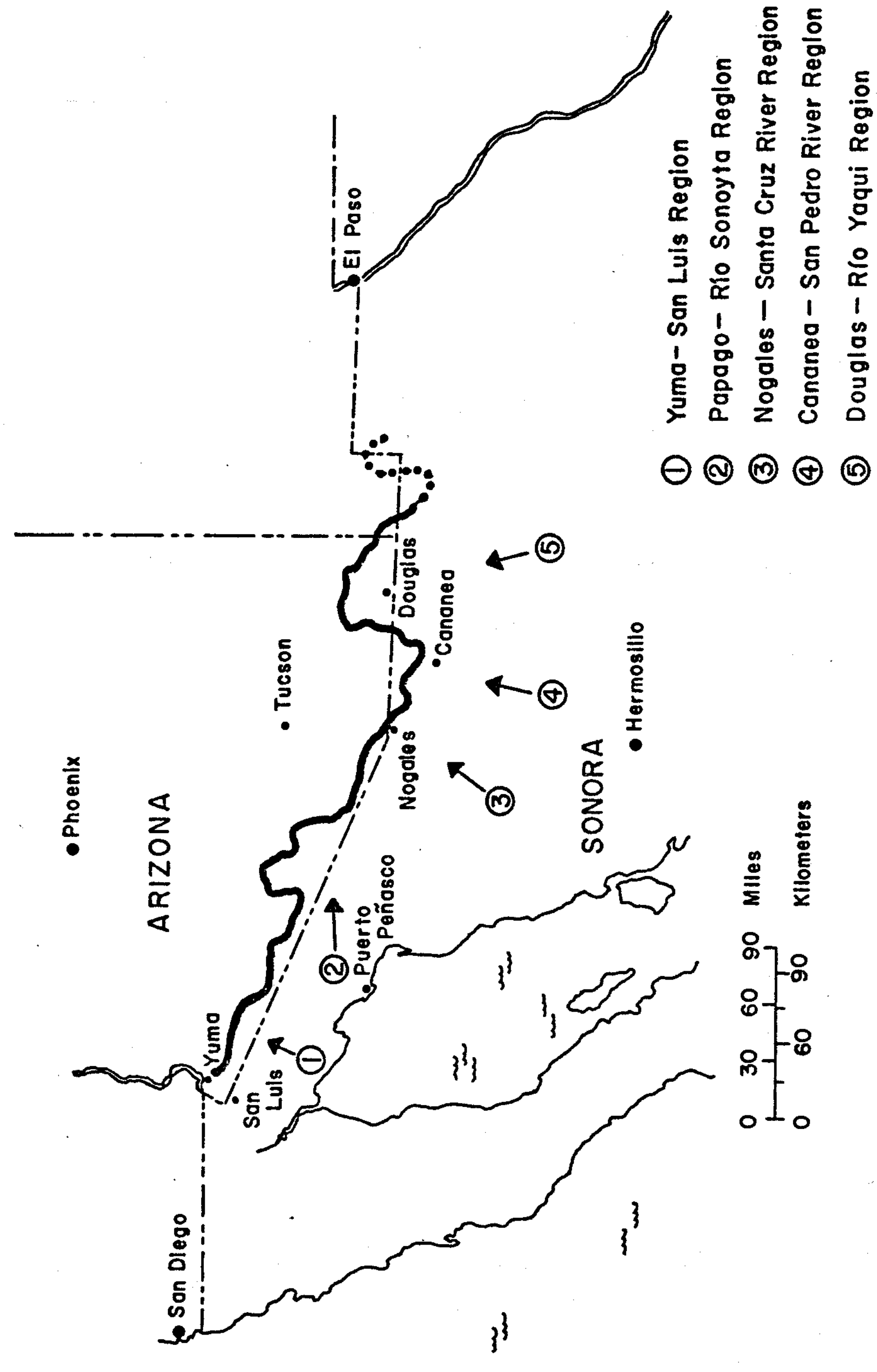
California, Mexico. The ground-water study regions along the Arizona-Sonora border are presented in Figure 1.

Irrigation first began in Yuma Valley about 1897, and by 1902, four private canals were operating. In 1904, the first Federal irrigation project on the main stem of the Colorado River, the Yuma Project, was authorized by Congress. The project pumped and diverted 10,000 acre-feet of water annually, but the supply was undependable due to fluctuations in stage of the river.

Between 1904 and 1912 about 50,000 acre-feet a year was being pumped for irrigation; in 1912 the Colorado River siphon began diverting water at Laguna Dam where it flowed by gravity to the Valley Division of the Yuma Project. A rise in ground-water levels led to drainage ditches being built. The Main Drain channels drainage to the border where the boundary pumping plant lifts it 12 to 15 feet for discharge to Mexico.

A shift in diversion from Laguna dam to Imperial Dam began in 1940 and was completed in 1945. Water flows from the Imperial Dam desilting works to the All-American Canal and the Yuma Main Canal, a delivery route presently used.

FIGURE I



Groundwater Study Regions Along the Arizona-Sonora Border

University of Arizona
1976

Yuma Mesa was not heavily irrigated before 1923, when the Yuma Auxiliary Project began lifting and distributing Colorado River water at the B-lift pumping plant. The project increased irrigated acreage from 650 acres in 1923 to 16,200 acres in 1953 and was abandoned when water became available to the project from an extended Gila Project. The Yuma Mesa Division of the Gila Project substantially increased irrigated acreage by diverting Imperial Dam water into the Gila Gravity Main Canal and pumping it to the mesa 9 miles east of Yuma. The irrigated acreage increased from 1,000 acres in 1944 to about 17,000 acres in 1959, a reasonably stable amount.

When development began, Mesa lands were about 90 feet above the underground water table, and drainage was not a problem. However, drainage concerned irrigators in the Valley Division, who feared that existing drainage facilities would be overtaxed by an increase in flows from the Mesa. Consequently, they began to improve their drainage system by drilling wells near the foot of the Mesa escarpment to control the water level and to prevent waterlogging. Studies of the effects of mesa development on valley lands have been inconclusive, but about two-thirds to three-fourths of the 5 million acre-feet used for irrigating mesa land between 1922 and 1966 either percolated into ground-water storage to build a widespread ground-water mound or induced ground-water movement in the valley lands west and north of the mesa.[8]

Other lands with changed hydrologic regimens due to development are the Reservation Division, the North Gila Valley Unit of the Yuma Project, and South Gila Valley Unit of the Gila Project. The Reservation Division of the Yuma Project is in the Colorado River flood plain north of Yuma and on the right side of the river. About 9,000 - 10,000 acres are irrigated here. A drainage system, begun in 1912, keeps the lands from becoming waterlogged. The North Valley Unit of the Gila Project is on the left side of the Colorado River north of its confluence with the Gila River. The 6,000 irrigated acres has also been irrigated by Colorado River water, before 1955 from Laguna Dam, since then from the Gila Gravity Main Canal.

South Gila Valley lies between Yuma and the Gila River, bounded on the north by the Colorado and Gila Rivers, and on the south by the Yuma Mesa escarpmemt. The South Gila Valley Unit, part of the Yuma Mesa Division of the Gila Project, used ground water for irrigation until 1965, when surface water from the Colorado River became available. The first irrigation well in the valley was drilled in 1915. By 1925 about 1,000 acres was irrigated with ground water; by 1943 the acreage had increased to 4,500, and by 1948, to nearly 9,000 acres. Substantial quantities of ground water continue to be pumped for irrigation. Ground-water levels declined in the valley by about 10-15 feet by 1947, then began to rise again due to recharge from the Gila Gravity Main Canal and lessened outflow to Yuma Mesa because of the rising ground-water mound.

As the ground water mound rose, the historic southward gradient in South Gila Valley reversed northward and waterlogged lands near the Mesa. In 1961 and 1962, nine large-capacity wells were drilled near the mesa to reclaim land and to prevent waterlogging. Three supply wells also provide water of better quality than the surface supply.

In the Mexicali Valley, irrigation from the Colorado River began in 1901. By 1915, 40,000 acres were irrigated; by 1925, 200,000 acres were irrigated; by 1949, 330,000 acres were irrigated; and by 1955, 540,000 acres were irrigated. This much irrigation requires more water than the 1.5 million acre-feet of Colorado River water guaranteed to Mexico annually by the treaty of February 3, 1944.[9] In late 1955, the Mexican Government authorized 281 deep wells to augment the surface-water supply, and in 1957, an additional 100 irrigation wells. These were in addition to 230 privately owned irrigation wells at that time.

The early history of irrigation pumping is not well documented for the Mexicali Valley. Most early wells were drilled by United States interests to furnish supplemental water to land irrigated from the Colorado River. Some pumpage records exist for the private wells, and they roughly show an increase in the amount pumped from 300,000 acre-feet in 1956, to 865,000 acre-feet in 1961, to 940,000 acre-feet in 1965.[10] Records from the Secretaría de Recursos Hidráulicos in Mexico also indicate the magnitude of increased distribution of pumped irrigation waters in both the Mexacali and San Luis Valley, from 49,074 hectares in 1957; to 40,194 hectares in 1961; to 67,558 hectares in 1965; to 73,584 hectares in 1972.[11]

Other ground-water use for irrigation along the Arizona-Sonora border is small compared with the Yuma-San Luis region uses. In the Papago-Río Sonoyta region, ground water supplies small irrigation wells in Papago villages and near Sonoyta, Sonora. The amounts pumped have not been determined with accuracy, although one well reportedly can pump 2,000 gallons per minute. The Nogales-Santa Cruz River region has irrigation on both sides of the border, but the amount so used in Sonora is unknown. The Santa Cruz river is a major recharge source for the copper mines and the irrigated areas south and west of Tucson, Arizona, but this has little, if any, transfrontier effect on Mexico. In the Cananea-San Pedro region, present pumpage for irrigation is also small, although new wells will probably be developed for ejidos in the future. Finally, the Douglas-Río Yaqui region is one of the largest basins shared across the border with Mexico. Irrigation pumpage by Mexico remains unknown, but on the United States side, 100,000 acre-feet a year are pumped for use on 50,000 acres of land.

MUNICIPAL AND INDUSTRIAL USES OF GROUND WATER

Municipal and industrial uses of ground water along the border are also small compared with irrigated agriculture in the Yuma-San Luis region. In the Papago-Rio Sonoyta region small wells provide the domestic needs of Papago villages, and at Lukeville wells provide the town supply although the yield is small and the quality of water is poor. In Mexico, much the same situation exists, and wells also supply the needs of the city of Sonoyta. The Nogales-Santa Crùz River region supplies more municipal and industrial ground water. At Ambos Nogales on the Mexican side, infiltration galleries and well fields along the Santa Cruz supply the city of Nogales, although the exact quantity is unknown. On the Arizona side, five wells supply the city of Nogales. In 1975 the pumpage was 883 million gallons, or about 2,700 acre-feet per year. These wells show immediate response to river flows in the Santa Cruz, so that the depth of water in the wells fluctuates from 30 to 80 feet. Any heavy upstream use in Mexico is rapidly seen in water levels in the wells of Nogales, Arizona. The city of Nogales is acquiring new pumping areas to the north in watersheds tributary to the Santa Cruz River, in Potrero and Mariposa Canyons, to help moderate the summer peak demands upon the city supply. Both cities discharge wastewater into the international treatment plant Nogales, Arizona discharges 3,400 acre-feet into the plant a year; therefore, it is possible to infer a discharge from Nogales, Sonora of about 4,000 acre-feet a year. In 1975, 3 million gallons per day was treated at the international plant before discharge into the Santa Cruz River.[12]

The Cananea-San Pedro River region is another jointly shared water system which headwaters 25 miles south of the border before flowing northward to the United States. Wells in the river's floodplain produce about 1,000 to 2,000 gallons per minute. The City of Cananea, Sonora is supplied with a well field in the San Pedro River Headwaters, as in the nearby copper mine and mill. Ground-water quality in this system is questionable, with high fluoride and sulfate levels, making the water marginal as a drinking supply but sufficient for irrigation and industrial use. Finally, the Douglas-Río Yaqui region supplies some water for the city of Douglas and the copper smelter, but not a significantly large supply.

WATER QUALITY CONSIDERATIONS

The Salinity Problem. One of the most important water quality problems along the Arizona-Sonora border is the heavy concentration of salt delivered to Mexico in its share of Colorado River water. The salinity issue has been the subject of many studies in both nations, by public agencies, universities, and private consultants, and that work will not be reviewed here.[13] The salinity issue is important as a precipitating factor for ground-water exploitation. During negotiation to resolve the salinity problem, the United States pointed out to Mexico that ground water underlying the Yuma Valley was being withdrawn by Mexican pumping. The cause and effect relationship between increased salinity in the surface water deliveries from the Colorado to Mexico can be clearly seen. In 1961, drainage wells were drilled to discharge saline drainage from the Wellton-Mohawk project to the Colorado River below the last United States diversion, but above Mexico's Morelos Dam No quality stipulation was written into the 1944 treaty with Mexico, and the two nations still disagree about the justifiability of sending highly saline water to Mexico. The controversy over saline deliveries has been carefully analyzed elsewhere.[14] The ground-water withdrawals by Mexico were due to the operation of a well field between one and five miles south of the border near San Luis, Sonora, which began significant pumping in 1972. The field has 63 wells with pumps and concrete lined laterals. Water is collected in a canal westerly to San Luis for irrigation. Mexico's pumping from the underground reservoir will deplete ground water underlying both the United States and Mexico. Mexico uses this water at no charge to the 1944 Colorado River Water Treaty since underground flow across the border is not considered as "deliveries in satisfaction of the Treaty."[15]

Yuma Valley agricultural drainage and irrigation return flows have historically been credited to the 1,500,000 acre-feet annual delivery to Mexico, amounting to about 125,000 acre-feet of drain flow and 15,000 acre-feet of wasteway flow annually. Mexican pumping may lower ground-water elevations and reduce the drainage flows from the Yuma Valley, from the present 105,000 acre-feet of canal wasteway flow. Under the Treaty terms, reduced deliveries at the Southern International Boundary must be balanced by increased deliveries from other sources. Presently the only other source is river storage not now committed to Mexico.[16]

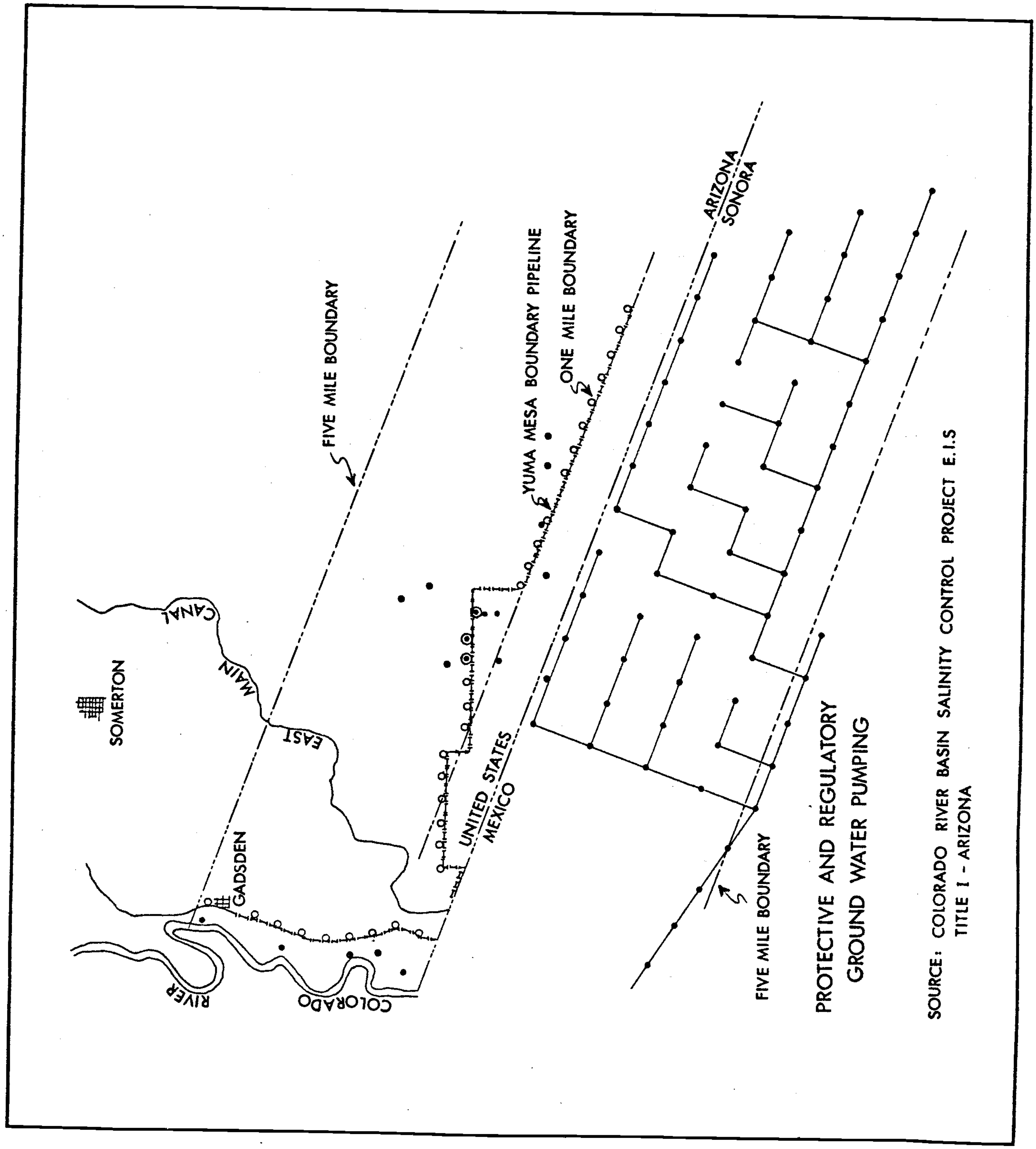
The Ground-Water Problem. The U.S. Geological Survey, the United States Section of the International Boundary and Water Commission, and the U.S. Bureau of Reclamation have extensively studied the geology and ground-water hydrology of the Yuma area, and have indicated that the irrigation of mesa lands has built a ground-water storage mound beneath the mesa of about 1.5 million acre-feet. In addition, another larger quantity of ground water is in storage under the Yuma area. The ground-water reservoir under Yuma hydraulically connects with the reservoir underneath lands south of the border in Sonora, Mexico and west of the Colorado River separating Arizona from Baja California, Mexico. Approximately 2,800 square miles of reservoir is in the system, about one-third in the United States and two-thirds in Mexico. Available data indicate that more than 300 million acre-feet of recoverable and usable ground water are in the subterranean reservoir, approximately 200 million acre-feet in

Mexico, and 100 million acre-feet in the United States. These studies also indicate that pumping on the Sonora Mesa in Mexico, in addition to withdrawing ground water from the Mexican reservoir, will draw ground water from the Yuma Mesa and Yuma Valley in the United States. In 10 years, 465,000 acre-feet would be withdrawn from the ground-water basin in the United States, and in 50 years, the quantity withdrawn would be about 2,610,000 acre-feet.[17]

To answer the Mexican pumping near San Luis, Sonora the U.S. Bureau of Reclamation and the United States Section, International Boundary and Water Commission, are proposing a protective and regulatory ground-water pumping scheme. Well fields capable of pumping 160,000 acre-feet a year will be located on the South Yuma Mesa and the southwestern part of Yuma Valley: the Yuma Mesa Boundary well field and the Yuma Valley Boundary well field.[18] The Yuma Valley Boundary well field includes 25 wells located one mile north of the International Border and spaced at 1/2 mile intervals (see Figure 2). Each well would be 500 feet deep with the lower 200 feet screened to pump water from the underlying ground-water reservoir at the rate of 7.5 cubic feet per second. The wells will be connected by a 15.3 mile underground pipeline which will carry water west to the afterbay of the Boundary Pumping Plant where it will flow by gravity across the International Border.[19] The Yuma Valley Boundary Well Field will have 10 wells in the west Yuma Valley along the east side of the Yuma Valley Levee next to the West Main Canal. Each Well will be 400 feet deep with the lower 200 feet screened to draw water from the underground reservoir at the rate of 7.5 cubic feet per second. A 5.3 mile connecting underground pipeline will carry water south to the afterbay of the Boundary Pumping Plant. A four-foot earth cover over the pipeline will allow farming (see Figure 2). The well fields will be powered by a 35-mile, 34.5 - kv transmission line from the desalting plant switchyard answering a peak demand of 7 megawatts (MW) and an electrical energy requirement of 52,000,000 kilowatt-hours per year (kWh/yr). These figures are based on an 85 percent plant factor.[20]

The pumped water will be used for delivery to Mexico as part of

FIGURE II


FIVE MILE BOUNDARY
YUMA MESA BOUNDARY PIPELINE
ONE MILE BOUNDARY
ARIZONA
SONORA
SOMERTON
EAST MAIN CANAL
GADSDEN
UNITED STATES
MEXICO
COLORADO RIVER
FIVE MILE BOUNDARY
PROTECTIVE AND REGULATORY GROUND WATER PUMPING
SOURCE: COLORADO RIVER BASIN SALINITY CONTROL PROJECT E.I.S
TITLE I - ARIZONA

the commitment under Minute 242 and for agricultural and other users. In the United States, 35,000 acre-feet per year is scheduled for agricultural and other uses while 125,000 acre-feet per year is to be delivered to Mexico at the border, a total of 160,000 acre-feet of pumped water; another 15,000 acre-feet of canal wasteway water will be delivered to Mexico, a total of 140,000 acre-feet. The salinity of the pumped water is 1,000 to 1,100 parts per million (ppm) of Total Dissolved Solids (TDS) in the Yuma Mesa Boundary Well Field and 1,000 to 1,500 ppm TDS in the Yuma Mesa Boundary Well Field. Present drainage and wasteway flows have salinity concentrations from 1,400 to 1,600 ppm TDS; therefore, deliveries from the protective and regulatory ground-water scheme are expected to be of better quality than present deliveries.[21]

FUTURE WATER PROBLEMS

Ground Water Resources. Ground-water pumping on both sides of the border has short and long-range policy implications. The immediate effect of Mexican pumping, a drawdown of groundwater from the U.S. side, is a matter of justifiable concern to policymakers at both the state and federal levels. But an answer in the form of a regulatory and protective pumping scheme may create more future problems than it presently solves. A permanent and just solution to the competition for water between the U.S. and Mexico will require more than short-range structural projects or technical fixes. Instead, a long-range scheme of water management and resources planning is more likely to present a worthwhile and equitable resolution to the conflict building among two co-riparian river basin nations.

It is important to maintain a system-wide perspective of the entire Colorado River in order to reach solutions that are realistic. In the historic development of the Colorado River, controversy has raged between both the Upper and Lower Basin States and the upstream and downstream nations of the entire watershed. As economic development continues in both countries, and as the demand for limited water accelerates, it is more important than ever to let reasoned and planned management instead of prior claims or greed guide water allocation. Furthermore, a regional water policy needs an understanding of the entire interactive system between water, on the one hand, and agriculture, industry, urban growth, and the natural ecosystem, on the other.

The Colorado River is an international water resources system, regardless of which nation developed first or in which nation the most rainfall and runoff occurs. A rational planning and management scheme for this system would of necessity be a joint arrangement based upon the principles of mutual cooperation and shared responsibility for the resource. Whether such a system is feasible remains an open question, but the societal costs of other arrangements, in damages, conflict, and distrust, are rapidly becoming apparent.[22] Even more apparent are the purely internal costs of the recent salinity agreement to taxpayers north of the border. In order to avoid disturbing established and inefficient economic relationships in the lower basin, the United States has agreed to absorb the costs of mitigating an externality caused by irrigators. The extent of public subsidy to this industry has only recently been appreciated; a continued subsidy has been called by some wildly uneconomic, not only as a net economic cost but also as a loss in the ability to rationally organize for managing an international water resources system.[23]

Ground-water resources are being exploited by both the United States and Mexico in a modern version of the historic conflict for surface water in the Colorado River, and ground water is now being exploited as surface water was previously. Although ground water may occur with no apparent surface connection in a watershed and may flow underground to appear in another state or nation, it nevertheless joins the states sharing the resource into an international water resources system. Most of the accepted international law and organizational arrangements that have developed for the last fifty years address only the problems of co-riparians on a shared stream. Nations have been reluctant to surrender territorial integrity or to share political sovereignty over the national portion of a water course. But, ground water is a finite resource that is easily overexpolited with a loss of uses and economic benefits to other parts of the water resources system. What is important now is the recognition of the full costs of overexploitation of resources and the recognition of higher net benefits from coordinated and cooperative development by the partners in an international water resources system.

International Water Law. Concurrently, the international law of water resources is evolving to address the realities of an interdependent world, a noticeable shift toward shared resources and equitable utilization. Early international law accepted the proposition that a state had absolute rights to all waters within its territory. This concept, even when authoritatively voiced by the U.S., gave way to the principle that no state could use the water of a communal river in a manner which substantially affects other states without their prior consent. The prior consent principle was supported by treaties and conventions, national and international cases, U.S. federal practice, and many major publicists.[24] It was a stepping stone in the evolution of international water law to the more recent principle of equitable utilization, which declares that the water of a shared system must be equitably apportioned according to a number of relevant considerations. This principle does not mean that all basin states should have an identical share in the use of the waters; instead of a mathematical division, the economic and social needs of all co-basin states are to be taken into consideration.[25]

But the development of international water law is still incomplete. The river, long the focus of international treaties among nations, is not the only important resource in a water system. More recently the broader concept of the drainage basin has been recognized as a more logical unit for analysis and management.[26] The 1966 Helsinki Conference of the International Law Association embraced the drainage basin concept as the only effective basis for international regulation, and agreed that a system of rivers and lakes in a drainage basin whould be treated as an integrated whole, not piecemeal. An international drainage basin was defined as "a geographical area extending over two or more states determined by the watershed limits of the system of waters, including surface and underground waters, flowing into a common terminus."[27] Integrating ground water more completely and realistically into international law is an important part of the evolutionary growth of rational water management, especially when for nearly one third of the arid or semi-arid earth, future developments depend primarily upon groundwater supplies.

The Need for Institution-Building. In addition to changes in international law, the rational management of international water resource systems will require institution-building on a scale appropriate to future problems and needs. In past years, it was implicitly assumed that institutional design happened by chance or by some hidden hand that would allow men to allocate valuable resources with minimal administration. Today, this assumption is no longer taken seriously, for the goals of cooperation and integrated management are now understood as complex human relationships, and the outcome of carefully balanced decision-making and planned processes. The design of an institution to carry out appropriate functions of international collaboration in water resources administration is the most important task facing nations sharing the resources of an international water system.

Realizing how complex the task of water resources administration in international water systems is likely to be is the first step in the realistic design of appropriate institutional arrangements. Organizational structure can respond to a variety of purposes and expected duties ranging from the less elaborate and the less authoritative to the more complex forms of planning and development. In general, international water management can be implemented by various institutions designed to provide some or all of the following functions:

(a) consultation and coordination (including policy determination, cost-benefit analysis, and joint-use coordination);

(b) information gathering and exchanges (including data system design, collection, and dissemination);

(c) project planning (including master plan preparation, systems analysis, and program recommendation);

(d) joint project design, construction, and operation;

(e) basin-wide regulation and development of the water system;

(f) regional distribution of water supplies and disposal of wastewaters.

These six stages of water management are progressive in extent of responsibility and the degree of governmental intervention in the use of water resources. Each stage is more complex than the last, requiring more sophisticated activity. For example, information gathering and exchange may progress from simple collection of hydrologic data to the development and analysis of social indicators and economic indices relevant to water use and development, and then merge into the project planning stage. Also, the stages are largely devoted to creating an information network or policy from more appropriately limited, national programs and goals, while the more advanced stages are transnational and more appropriately system-wide functions. Although built upon earlier stages, the advanced functions integrate resources and policies for an entire physiographic region, regardless of political borders.[28]

Although integrated water management is an ideal, experience also suggests that co-system states will wish to consider their common undertaking with care. Initial institutional development is usually on a more limited scale, and caution is understandable where there is little systematic knowledge about the shared water system or about the possibilities of financial or technical assistance.[29] Most basin states reach the stage of complex, full-time administration of water resources in a slow or incremental transformation, from simple, irregular consultation to more advanced, serious administrative undertakings tailored to the perceived needs and problems of the regions. Usually the scheme provides for an overall coordinating organ with engineering and technical expertise provided in support of the hydrological, practical engineering, and ongoing management functions of the agency. More sophisticated institutional arrangements provide for policy review at the diplomatic level and higher, and a system for dispute resolution and adjudication, often using commissions, arbitrational arguments, or the international courts. But, as impressive as this experience has been, the design of international water management still can be much improved. The choice of institutional design is more than an evolution from small-scale to large-scale water resources management.

CHOICE AND WATER INSTITUTIONS

There are many serious implications in the choice of water institutions. Simple coordinating institutions may prove too weak and too slow-acting to implement needed programs. A more authoritative international agency may meet resistance from old-line or local agencies, generating more friction than tangible results. Authorized uses of an international resource may not sufficiently weigh a broader public interest in environmental protection (including aesthetics) or may be addressed to the special needs of only a sector of the regional economy (such as irrigated agriculture). An international water management organization must be adequately designed, or cooperation and collaboration will be all to easily reduced to ineffective discussions and reports or plans that gather dust on a bookshelf. The spirit of joint operation and shared responsibility can be all to easily thwarted by bureaucratic or political rivalries or financial inability.[30] Institutional design will be effective only if it is sophisticated enough to deal realistically with political factors and administrative problems, instead of concentrating solely upon the technical and engineering aspects of water resources development.

Thus, institutional design must provide a water management agency with specific competencies to act and with a structure that links internal variables with external demands by transactions of decisions, goods, and services. Specific competencies are those powers conferred upon an agency for the purpose of international cooperation and collaborative management of an international water resources system. Examples of specific powers are: the authority to determine rules of procedure; to visit and inspect national and joint projects; to hold hearings and conduct investigations, with the power to compel appearance and the production of records; to acquire, own, and dispose of property; to contract for services and materials; to plan for the conjunctive use of all waters in the system and to publish the findings and plans; to buy and sell water and power; to operate and maintain works and water control structures; to draw up and administer a budget; to make water allocations, confer rights to use, require abatement of pollution or siltation, determine equitable compensation, and set conservation standards; to license and to set rates; to borrow money and issue debentures; and to adjudicate disputes or to seek resolution by existing international machinery.[31]

Establishing specific duties is only a first step in the institutional design process, and should proceed in conjunction with the design of an enabling mechanism that transforms demands into water goods and services. The institutional design perspective allows an understanding of how internal variables in agency operation, such as leadership, doctrine, program elements, financial and technical resources, and internal structure are related by transactions with the external environment of an agency, those linkages that are enabling, functional, normative, and diffuse. The institutional building model provides a framework for understanding the dynamic operation of a water resources agency with the clients and constituencies, suppliers and consumers, and the authoritative allocation of the water resources goods and services subject to its administration.[32] More importantly, the model provides a realization of the crucial role that leadership and doctrine play in water resources management. Although often unrecognized, the factors of directing an institutions policy-making process and of explaining the purposes of an organization by the development of an expressed doctrine are slowly gaining prominence in the realistic analysis of institutional behavior. The doctrines of economic efficiency and of supply engineering are strongly implicit in traditional water management, and any attempt at institutional change or policy reform will need to more fully appreciate the operation of these variables.[33]

The analysis of the nature of international water management provides a basis for suggesting essential characteristics of present institutions. These are not rigorous evaluative criteria, but they can serve to direct attention to needed changes in present arrangements or to develop alternative institutions for more effectively addressing the accelerating demands being placed upon limited and finite water resources. By comparing current institutional arrangements, such as the International Boundary and Water Commission, with the possibilities of a well designed institution, an evaluation can be made as to the ability of the IBWC to answer certain key questions.[34] For instance, can present arrangements apply to the total range of governmental interventions for influencing surface and ground water use and development? What is the current ability to consider and adjust or adapt to externalities stemming from the hydrologic interdependency across the border? Can externalities be effectively internalized or can adjustments or exhanges be made in accordance with spillover damages incurred or spillover benefits received? How flexible is the institution in adapting water management actions to different circumstances of time and place with protection against arbitrary and capricious actions? And finally, to what extent is water resources management recognized and built into the international agreement as a continuing function and a joint responsibility?[35] There remains much to be done in the field of coordinated international water resources use, conservation, and development. The reasoned application of administrative reform to established regimes and the design of flexible and responsive institutions to meet future problems is being recognized as one of the most crucial duties of international water resources administration.

SUMMARY AND CONCLUSION

Increasing demands for the water resources of the Arizona-Sonora border region have increased the conflicts in use of a finite water resources system. Population growth and the need for expanded agricultural production have been precipitants for water conflict throughout the entire Colorado River system. Along the Mexican border, increased pressure upon water resources is represented in demands to further exploit and use all available supplies, both surface and underground waters. As the intensity of use accelerates, the need for adequate planning and management institutions at an international scale will increase also. Ground water, recognized late as an important resource, is being utilized as a new supply, as a single-purpose bonanza. Little consideration is being given to the conjunction between surface and ground waters and, therefore, little appreciation is being developed of the joint benefits that can be realized on both sides of the border from the planning and management for conjunctive use of a common pool resource system.

Therefore, the development of an adequate institutional arrangement to effectively allocate the international waters of the Colorado River is a fundamental task for future resources management. Such an institution would probably include as a minimum:

(a) An agreement between the U.S. and Mexico to plan and manage surface and ground waters for optimal conjunctive benefits across the border, that is, a new minute to the existing treaty or a new treaty.[36]

(b) An international institution with sufficient resources, authority, and expertise to perform joint water planning and management, probably created by the minute or treaty.

(c) An appreciation of shared water resources, not as river basins or drainage basins because these are surface-water concepts calling attention only to the resources most easily seen; but as international water resource systems, including atmospheric, surface, and ground waters, their physical interactions, and the multiple benefits derived from a holistic approach to shared water management.

Of all natural resources, water deserves the most imaginative planning and the most careful management. Water is vital for all life, especially in desert regions where rainfall is scarce and an adequate supply requires man's interventions into the hydrologic cycle. Without water, lands go uncultivated and towns are small; with water, crops grow nearly year-round and civilization flourishes. The joint management of an international water resources system is the highest expression of man's international public purpose.

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* Associate Professor of Hydrology and Water Resources, University of Arizona, Tucson, Arizona 85721.

** Associate Hydrologist, Water Resources Research Center, and Associate Professor of Geosciences, University of Arizona, Tucson, Arizona 85721.

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