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Systematic Analysis of Priority Water Resources Problems to Develop a Comprehensive Research Program for the Southern Plains River Basins Region

R.E. Babcock
J.W. Clark
E.J. Dantin
M.T. Edmison
N.A. Evans
W.L. Power
J.R. Runkles

Texas Water Resources Institute

Texas A&M University

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SYSTEMATIC ANALYSIS OF PRIORITY WATER RESOURCES PROBLEMS TO DEVELOP A COMPREHENSIVE RESEARCH PROGRAM FOR THE SOUTHERN PLAINS RIVER BASINS REGION

Principal Investigators

Robert E. Babcock
John W. Clark
Elvin J. Dantin
Marvin T. Edmison
William L. Powers
Jack R. Runkles

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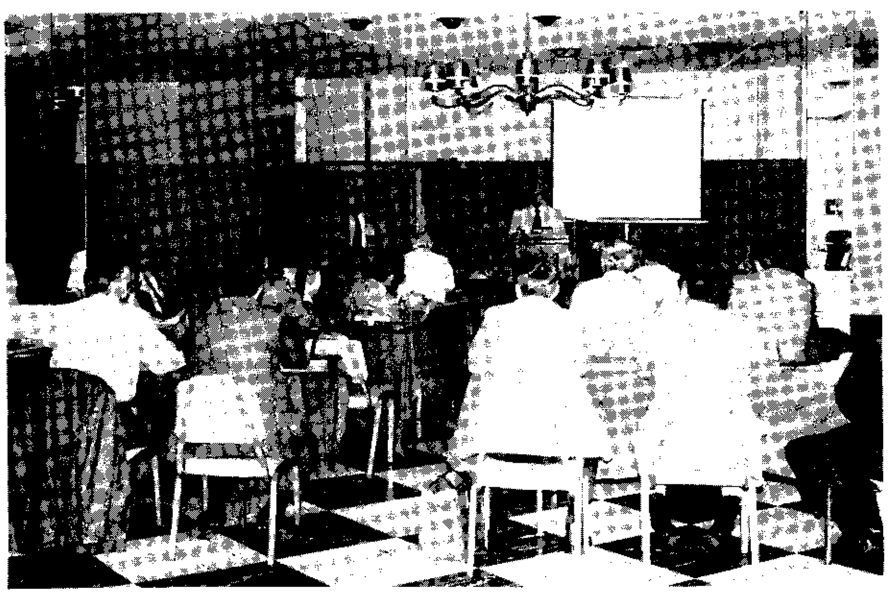
REGIONAL PROBLEM ANALYSIS--(from left to right) John Clark, Howard Gerald, Elvin Dantin, Jack Runkles, William Powers, George Clausen, Marvin Edmison, and Robert Babcock.



LEONARD BROWN, Office of Water Research and Technology--addressing workshop participants.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

During the past twenty years, there have been several evaluations of national water resources research requirements. Many states have made similar analyses of their water resources research needs. Funding for water resources research generally has not been directed to these identified requirements; also, the level of funding has not been commensurated with the magnitude of the water resources problems. The Office of Water Research and Technology and the associated state water resources research institutes (or centers) initiated a regional problem analysis program to improve the effectiveness of research programs on major regional and national water resources problems.

Today no single university or water resource agency possesses the competence to adequately analyze our major water resources problems and to conduct the research necessary to solve these problems, thus the regional problem analysis program was conducted in close cooperation between the universities and the state and federal water resource agencies in the region. The state institutes (or centers) in the Southern Plains River Basins Region joined together and developed a series of workshops to analyze some of the major regional water resources problems. The water resources research institutes in the Southern Plains River Basins Region have made significant contributions to water resources knowledge in their respective states. In spite of this, the Institutes are striving to improve the effectiveness of their research programs. A potential area for improving the effectiveness of the Institutes is through the inter-institute cooperative problem analysis program to identify research needs for urgent regional water resources problems. This approach provides an opportunity to examine the "total" problem, all alternative solutions, and the probable impact of research on solution of these problems. Upon completion of the systematic analysis of these problems, the Institutes should be able to provide more effective leadership in the state water resources research programs.

The objectives of the systematic problem analysis program for the region was as follows:

1. To develop a detailed description of each regional priority problem and sub-problems.
2. To identify and describe the alternatives and sub-alternatives of each priority problem and sub-problems.
3. To identify and describe the knowledge essential to implementation of the complete alternatives sets.
4. To develop a comprehensive research program for the Southern Plains River Basins Region based on the research needs and feasible alternatives identified in the systematic analysis.

The objectives at the problem analysis program was accomplished through a series of workshops. Prior to the workshops, considerable discussion was held in each state on important water resource problems. The water resources research institute directors in each state had input on the problem from state and federal agencies in each state as well as faculty knowledge in the area of the particular problem. Thus, the institute directors had input into the problem analysis process from the water resources profession on each problem and sub-problems being conducted by the region.

IDENTIFICATION OF PRIORITY WATER RESOURCE PROBLEMS IN THE REGION

While there is a great diversity of water supply and utilization in the Southern Plains River Basins Region, several problems are of common interest to the states making up this region. In developing the priority problems which were analyzed at the workshops, each SPRBR director, with inputs from water resources agencies, analyzed the major problem facing his state. Some of the important water resource problems facing the individual states in the region are given in the following section.

After analyzing each individual state problems and discussing the water resource problems of common interest, the SPRBR directors identified the priority water resource problem to be analyzed by the workshops. The directors identified three high priority problems which were subject to systematic problem analysis and these are as follows:

1. Ground water depletion, ground water pollution, and land surface subsidence;
2. Allocation of water resources, conservation and environmental impact, and;
3. Conflicting interests and synergistic effects between energy production and water resources management.

Important Water Resource Problems in Arkansas

Robert E. Babcock

Arkansas covers an area of approximately 53,100 square miles. On the basis of physiography, the state can be divided into two areas of nearly equal size. The northwestern half is known as the Interior Highlands and the southeastern part is within the Gulf Coastal Plain Physiographic Province.

The Gulf Coastal Plain is nearly flat to gently rolling with elevations from about 100 to 700 feet above sea level. The Coastal Plain is composed mainly of poorly consolidated sand, gravel, clay, marl, and limestone.

Coastal Plain

Problems of water quality are especially critical in the Coastal Plain Province. To cope with the most pressing problems, the USGS and Arkansas Geologic Commission have initiated an extensive well monitoring program. The most important water-level measurements will be derived from a network of 600 wells. These measurements will be used to demonstrate long-term trends of water-level fluctuations, using water-level contour maps and hydrographs. The measurements are made in the spring, before irrigation starts, so as to measure water levels at as close to static conditions as possible. This "spring" network covers:

1. Cretaceous aquifers in southwest Arkansas.
2. Nacatoch Sand in northeast Arkansas.
3. Wilcox Group in northeast Arkansas.

4. Carrizo Sand in central Arkansas; only two observation wells; very little water from this aquifer is used.

5. Cane River Formation; 4 or 5 wells in south-central Arkansas.

6. Sparta Sand and Memphis aquifer in east and south Arkansas.

7. The Cockfield Formation in southeast Arkansas.

8. Quaternary deposits throughout the Coastal Plain.

Intensive-use Areas

The intensive-use areas are those where use of water is so great that withdrawals far exceed recharge and thus, stored ground water has greatly decreased. The networks in these areas are virtually complete. The aquifers used in these areas are: The Sparta Sand in the Pine Bluff area, the Sparta Sand in the El Dorado-Magnolia area, and the Sparta Sand in the Helena-West Helena area. In these areas, one measurement a year does not provide sufficient advance notice of ground water depletion. Water levels are read in the spring and in the fall. At least one recorder is, or will be, operated in each area.

Pine Bluff

Pine Bluff is Arkansas' principal industrial water-use area. The Sparta Sand is the principal aquifer; in it water levels have been declining rapidly since 1956 due primarily to heavy pumpage by papermills. Situation is considered to be critical.

El Dorado-Magnolia Area

This is a petrochemical, oil refinery, and oil-producing area where more than 90 percent of the water used is pumped from the Sparta Sand. Although less water is pumped in this area than is pumped in Pine Bluff, the Sparta Sand has a much lower transmissivity in the El Dorado-Magnolia area and large declines of the potentiometric surface have resulted. The water-level contour map shows cones of depression in the surface at both cities. At El Dorado, the apex of the cone is 130 to 150 feet below sea level; at Magnolia, the apex is slightly below sea level, and is very close to the top of the aquifer. The two cones appear to be about to coalesce. Any increase in pumpage at either area will probably affect the supply at both.

Grand Prairie Area

Grand Prairie, the "rice basket" of Arkansas, is an area where rice has been grown since 1904 and ground water storage has been declining since 1915. Water levels can be expected to continue their decline due to irrigation and fish-farming withdrawals. In the heart of the Prairie, the supply in the Quaternary deposits is effectively exhausted. In this area, it is no longer economically feasible to pump much water from Quaternary deposits and wells that tap the Sparta Sand are being installed. The supply in the Sparta Sand is now being depleted at an ever acclerating rate by increased pumpage for irrigation. More than 100 of the 4,000 irrigation wells in the Grand Prairie tap the Sparta Sand; most of them have been drilled since 1960. The spring-measurement network has been considered adequate to define long-term trends in both aquifers.

Interior Highlands

The Interior Highlands are hilly and mountainous with elevations from about 250 to 2,800 feet above sea level. The Interior Highlands are comprised mainly of consolidated limestone, dolomite, shale, sandstone and some chert, novaculite, and igneous rocks. Ground water within the Ozark Plateaus is relatively scarce, and water yield characteristics are related directly to the lithology of each respective aquifer. The Cotter and Boone formations are carbonates which crop out over a large area in northwest Arkansas (Benton, Boone, Carroll, Madison, Marion, Searcy, Stone, and Washington Counties).

The movement of ground water in fractured rocks makes them especially susceptible to pollution, and contamination from surface waters can take place with little or no natural treatment. Environmental implications related to fractured rocks and spring water quality are probably greatest in carbonate terrain where extensive interconnected solution zones can exist within or near the water table. During times of heavy rainfall, natural recharge can sometimes occur as a direct injection into the ground water system. As an area is urbanized, it is possible that as the water table is lowered certain fracture zones can become potential sites for recharge, providing pathways by which pollutants move. Many limestone and dolomite aquifers throughout the nation have been contaminated in this manner.

Northwestern Arkansas, an area underlain by carbonate rocks, is destined to become increasingly urbanized within the next few decades. Associated with this urban sprawl will be the increasing use of septic tanks, many of which will be improperly installed. In advance of the anticipated urban sprawl, ground water studies should be made to provide an understanding of the hydraulic behavior of the complex geohydraulic systems. Land use planning information becomes an essential feature of any zoning program which considers the location of waste disposal sites, sites for storm sewer discharge, and septic tank installation.

While the shallow carbonate aquifers are important to the rural population, most communities in north Arkansas needing large quantities of ground water utilize the much deeper aquifers; the Gunter Sandstone member of the Van Buren Formation, and the Roubidoux Formation. Little data exist on these aquifers, although several inventory or monitoring programs have been initiated by state agencies and the USGS.

The Socio-Economic System Involved (North Arkansas)

The climate of the Ozark Plateaus is humid. The average annual precipitation ranges from 40 inches in the northern part to about 56 inches in the southern part. The precipitation is fairly well distributed throughout the year, but the seasonal maximum generally occurs in the months of April, May, and June. Only a small part of the average annual precipitation occurs as snow, and it is during the winter months that the seasonal minimum precipitation occurs. Temperature extremes normally range from about 0°F (-18°C) to 100°F (38°C), and the average annual temperature is about 60°F (16°C).

The plateaus are sparsely populated. Although the plateaus make up about 23 percent of the area of the state, the 1960 census shows that they contain only 226,000 inhabitants--about 13 percent of the state's population. The population is largely rural. In 1960 only five cities in the plateaus had populations that exceeded 5,000. These were Fayetteville (20,274) in Washington County, Springdale (10,076) in Washington County, Harrison (6,580) in Boone County, Batesville (6,270) in Independence County, and Rogers (5,700) in Benton County. In recent years however, the trend has been toward urban development, and the populations of these and other urban centers have increased.

The economy of the plateaus is based largely on agriculture and to a lesser extent on industry. Poultry and cattle are the chief agricultural products. Locally, apples, peaches, and grapes are commercially important. Industry largely involves the processing and distribution of farm products, however the tourist industry has grown considerably in recent years and is rapidly becoming a valuable part of the overall economy. Water is a basic resource necessary for economic development of the Ozark Plateaus province.

The management of water resources and the assessment of the benefits of such management are dependent upon the timely availability of accurate data concerning resource distribution and concentration. At the same time, the increasing water demands for urban, agricultural, and esthetic uses point to the need for resource development on a larger scale to more efficiently allocate the available resources for maximum benefit to all users. As the demand-supply balance becomes critical, the need increases for extremely rapid and broad-coverage data with which to evaluate the ecological impact of reducing availability to different sectors of the management area. The intelligent development of ground water resources in this region should be based on sound geologic and hydrologic studies of an area.

Arkansas Water Problems and Alternative Actions Summary

Water Quantity Problems

Management of Excess Water

Salvage and conservation of excess water in future years may provide a solution to Arkansas' seasonal water shortages due to drouth conditions.

Supply Availability Problems

Seasonally Deficient Supplies - Unless research is undertaken to determine the effect of watershed use on water supply availability, we will be constantly investigating corrective actions for existing problems. Factual information is needed to anticipate water supply availability problems.

Ground Recharge - Especially in areas of extensive agriculture, the problem of ground distribution and ground recharge is becoming a major water resource problem in Arkansas. The accurate measurement of water levels in fine grained materials is a special problem. If corrective action is not taken, future agricultural programs will suffer considerable reduction.

Water Utilization Problems

Industrial Use Efficiency - May provide a solution to localized water availability problems in Arkansas. Without reclamation and reuse, seasonal water shortages due to drouth conditions will become especially critical.

Quantity-Quality Interactions - Most significant of the problem areas developing within the next few years is the contamination of both ground and surface water resources in the rapidly expanding metropolitan areas of the state. The effect of disposal systems on ground and surface water quantity and quality must be determined.

Water Quality Problems

Ground Water Quality Protection

Toxic Trace Substances - Especially in the rapidly expanding Ozarks region of Arkansas, Missouri, Kansas, and Oklahoma shallow ground water aquifers are becoming increasingly contaminated. Without corrective action, the entire northwestern part of

Arkansas' shallow ground water supply will become unfit for human consumption.

Upland Watershed Quality Degradation

Diffuse Sources of Contaminants
Land Use Patterns - Pollution of surface and ground water resources are directly related to land use, especially agricultural wastes. Without adequate upland watershed land use monitoring, the problem will, in the future, become economically and socially disastrous.

Point Source Contaminants

Industrial Waste
Urban and Domestic Waste - Problems of industrial and urban waste pollution of both surface and ground water resources is becoming serious in the rapidly expanding metropolitan areas of the state. Without corrective action, maintaining adequate water quality will be a severe problem.

Lake and Reservoir Quality Degradation

Recreational Development
Eutrophication - Extensive lake and reservoir development in Arkansas has contributed significantly to the state's economy. Recreational development requires adequate water quality, yet some of our reservoirs are presently being degraded because of inadequate land use planning.

Urban Water Problems

Urban Land Development Impacts - Simulative capacities of streams relative to urban land development are not fully understood or analyzed. Data collection programs to provide factual inputs are needed.

Planning and Management Problems

Planning Methodologies

Trade-off Analysis - Developing, initiating, and monitoring data collection programs necessitates an input of accurate water resources information. These data are required to solve water resource problems long before the problems become severe and thus providing a possible means to avoid precipitous reactions that may later prove to be unsound.

Regional Management

Legal Requirements and Constraints - Problems related to regional management include the development of philosophies, policies, and water laws acceptable beyond local, county, and state boundaries. In northern Arkansas, for example, the future development of ground water resources will necessitate using deep ground water aquifers. The recharge area is in Missouri and the future planning and management problems will be complex. The future economic development of rural northern Arkansas will be dependent upon adequate acceptance of regional management of water resources.

Important Water Resource Problems in Colorado

Norman A. Evans

1. Measurement of vertical permeability in field (methods).
2. Evaluation of water quality efforts on flora/fauna.
3. Political/social/economic implications of present ground water development practices.
4. Better evapotranspiration data for hydrologic models and water salvage practices.
5. Transpiration rate for various crops as a function of age, size, soil type, moisture stress, etc.
6. Subsurface waste disposal, couple transport equations with diffusion equations.
7. Recharge--problems due to chemical interaction of water with rock.
8. Better hydrologic models of small watersheds--infiltration, soil moisture, geometry, roughness.
9. Water pollution contribution from small watersheds.
10. Sources of pollution in heavily used aquifers, e.g., the Denver basin.
11. Reclamation of aquifers polluted with: a) oil and gas, b) nitrates, and c) other chemicals.
12. Water use efficiency--"real need" per capita and trends.
13. Regional cost/benefit analysis on ground water development.
14. Operating criteria for wells in alluvium in conjunction with river rights.
15. Forecast models for various ground water basins.
16. Inventory studies on lesser known aquifers.
17. Identification of potential recharge areas for Ogallala aquifer.
18. Better estimates of natural regional flux of ground water, especially in the Ogallala.
19. Amount of water salvagable by phreatophyte control.

Consultors and Collaborators

United States Geological Survey: Ted Moulder, John Ficke, Jim Biesecker, John Moore, Bob Stallman.

Colorado State Engineer: C. Kuiper, W. Smith, J. Danielson, H. Erker.

United States Bureau of Reclamation, Lower Missouri Region: Jim Engles, Jesse Hannold, Richard Eggen, Henry Hoff, Samuel Kennedy, Morris Droskin, James Bowman.

Colorado Geological Survey: John Rold, Dick Pearl.

Important Water Problems in Kansas

Hyde S. Jacobs

Ground Water Resources

Ground water storage in Kansas is estimated at 428 million acre feet (maf), whereas annual recharge is only about 3.5 maf.[1]* Extensive sand and gravel deposits, such as the Ogallala and other formations in western Kansas, sand dunes and Equus Beds in central Kansas, and alluvium along major stream valleys form aquifers of high yield. Ground water resources are normally diffused over large areas. In Kansas, the total irrigable area overlying aquifers capable of well yields over 500 gpm is estimated to be 10,900,000 acres. For well yields over 100 gpm, the acreage is estimated to be 15,600,000.[2] Water depth in aquifers with sufficient quantity and quality for irrigation is usually under 200 feet, so pumping depth is not a major deterrent to water use. Consequently, large acreages are irrigated using ground water.

Water bearing aquifers of substantial volume are not nearly as prevalent in eastern as in western Kansas.

Use and Depletion

Municipalities, industry, and agriculture all utilize ground water, but irrigation is by far the largest user of ground water in Kansas. The resource is spread under millions of acres of agricultural land and a combination of ground and surface water was used to irrigate 1,227,000

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* Numbers refer to literature cited.

acres in 1965. By 2000, irrigated acreage is predicted to be increased to 4,750,000 acres.[1]

Ground water use in predicted to rise from 2.4 maf in 1965 to 8.0 maf in 2000 with agriculture utilizing 90 percent of the withdrawal. During this same period, municipal and industrial use of ground water is expected to grow 270 percent from 0.3 to 0.8 maf and agricultural use 340 percent from 2.1 to 7.2 maf annually. In this interval surface water withdrawals will change from 1.1 to 6.2 maf annually.[1]

In many areas, pumpage already exceeds recharge. In 1966, it was estimated that withdrawal exceeded recharge by 100,000 acre feet per year in five counties. By 2000, that condition might prevail in a total of 19 counties. Depletion of ground water reserves results directly from over pumpage and ground water reserves may be essentially depleted in four counties by 2000 and in 19 counties by 2050.[2]

Appropriation of Water

Under existing water appropriation statutes,[3] all water in Kansas, both ground and surface water, is dedicated to the use of the people, subject to control and regulation by the state. Subject to vested rights, water may be appropriated by anyone desiring to use it beneficially.

For other than domestic purposes, a person can aquire an appropriation right to the use of water only by filing an application and obtaining approval of the chief engineer of the State Board of Agriculture. The chief engineer may limit the amount of water appropriated.

A water right is severable from the land and is transferable and inheritable.

Reasonable lowering or raising of the static water table is to be tolerated so long as holders of existing rights can obtain the water to which they are entitled.

An appropriation right that is first in time is first in right. Since anyone, subject to state regulations, can appropriate water in Kansas, the chief means of water allocation is in the market place. Likewise, the holder of an appropriation right can use that water up to the limit of his water right. However, enabling legislation has been passed for the organization of ground water management districts so water users therein can determine their own fate with respect to water use within the district.

Economic Benefits of Water

Water is an essential ingredient in many economic activities. Dr. Jarmin Emerson recently provided forecasts of population, employment, income, and industry for Kansas as part of a statewide study conducted cooperatively with the Bureau of Reclamation and the Kansas Water Board.[5] Later the economic projections were translated into requirements for water by the Kansas Water Resources Board as partially summarized in Table 1.[4]

Agricluture in the year 2020 is predicted to use <u>88</u> percent of the water to produce \$5.3 billion in income. Industry including mining, manufacturing, and utilities will utilize 9 percent of the water to produce \$29.7 billion in income. The people in both rural and urban centers will require about 4 percent of the water.

The income derived from water is uniquely related to use but an example in the agricultural sector is instructive. In a six county area in southwestern Kansas, it was estimated in 1966 that 768,000 acre feet of water were used to irrigate 379,000 acres. Each acre foot of water used developed about $33 of increased income or $26 million in the six county area. Increased taxes accruing to the state were estimated at $10 per acre foot or $8 million.[6] Irrigation is an important economic asset in the area and loss of the irrigation industry would have far reaching state and regional implications.

Ground Water Problems

Numerous problems associated with ground water are presented in outline form below. The list is not exhaustive but illustrates variety of general problems that could be studied profitably and presents a starting point for determining research priorities.

Research Priority*	I. Resource Characterization
5	A. Geology, location, and depth of ground water aquifers
5	B. Amount of ground water reserves
5	C. Quality of ground water
3	D. Rate of use and rate of recharge

Resource characterization provides the basic data for making ground water management decisions and is essential to sound water resources planning. Conducting of ground water surveys and associated studies is the responsibility of state and federal agencies and are not an appropriate activity of the Kansas Water Resources Research Institute (KWRRI).

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* Rated on a 1 to 5 scale, with 1 representing the highest priority.

Table 1. Comparison of Selected Economics Indicators with Water Requirement Projections - Kansas

	1965	1980	2000	2020
Agriculture, Crops				
Output in $1000	763,112	1,107,541	1,665,765	2,405,963
Employment, People	44,600	29,800	23,200	24,500
Water, AF	2,263,004	6,461,800	10,707,700	13,557,800
Agriculture, Livestock				
Output in $1000	792,936	1,196,791	1,905,751	2,893,486
Employment, People	45,200	36,700	28,600	23,600
Water, AF	91,924	138,826	221,078	335,643
Mining				
Output in $1000	608,238	913,441	617,199	840,630
Employment, People	30,600	29,900	17,100	11,800
Water, AF	67,599	87,692	162,324	322,800
Manufacturing				
Output in $1000	4,185,518	7,026,639	13,581,512	26,011,790
Employment, People	117,000	149,600	190,800	237,900
Water, AF	151,538	225,239	433,965	843,937
Utilities (Electric, Gas, and Sanitary Services)				
Output in $1000	284,973	602,611	1,367,724	2,942,657
Employment, People	9,800	12,700	17,200	23,700
Water, AF	461,661	323,333	484,808	266,080
Energy, Billion KWHRS	10.5	29.3	90.6	255.2

Research to determine new methods by which ground water reserves can be more effectively described or determined could properly be undertaken by KWRRI.

Research Priority	II. Resource Development
5	A. Future water rights
	B. Organizing ground water management districts
4	1. Regulating rate of use by water right holders
4	2. Policies on granting water rights as ground water supplies diminish
	C. Water resources planning
5	1. Future water requirements
5	2. Economic projections
	3. Environmental impact
4	a. Critical environmental areas
4	b. Water quality
3	4. Development of models of ground water aquifers responsive to both physical and economic conditions
	a. Optimal resource use
	b. Alternative social and economic strategies in areas where water resources are diminishing
3	5. Land use planning

The Water Resources Division, State Board of Agriculture, has ultimate responsibility for granting water rights. Once organized, ground water management districts will no doubt play significant roles in future decision regarding rate of water use and the granting of new water rights. Research needs in those areas are not critical.

Water resources planning is the responsibility of the Kansas Water Resources Board. Preliminary studies on future water requirements and economic projection have been completed. The development of models of ground water aquifers would be useful in planning efforts. The model could be used to predict optimal resource use and to develop alternative social and economic strategies. Care must be taken to insure that an adequate data base is available for model development and testing.

Research Priority	III. Water Conservation
1	A. Water use efficiency
	1. Irrigation
5	a. Measurement of water applied
1	b. Irrigation scheduling
1	c. Crop and soil management system
4	d. Water conveyance
3	e. Water application and system design
	2. Industry and municipalities
1	B. Evapotranspiration
3	C. Ground water recharge
3	D. Legal, social, and economic implications

Efficient utilization of irrigation water is basic to any ground water conservation plan in Kansas because irrigation is predicted to use 90 percent of the ground water withdrawn. Evapotranspiration research will continue in importance because irrigation is a consumptive water use. Three general processes are required to conserve water including (1) education--using knowledge already known; (2) research--finding better methods; and (3) passage of wise laws.

Research Priority	IV. Alternative Water Sources
4	A. Water importation and inter-basin diversion
4	B. Weather modification

Research in these important areas are largely the responsibility of other agencies although KWRRI researchers may contribute to methodology.

Research Priority	V. Water Quality and Environment
4	A. Irrigation water quality

B. Ground water pollution

2 1. Feedlot
2 2. Fertilizer, herbicides, pesticides

5 C. Irrigation return flows

5 D. Oil and gas drilling--brine disposal

Practical techniques to adequately measure the pollution potential from feedlots, fertilizer, and pesticides from run off and infiltration are needed.

Research Priority VI. Socio-Economic Problems

2 A. Optimal utilization of a diminishing resource

2 B. Alternative economic and social strategies

The need for imaginative water resources research in the social science disciplines is well recognized. The difficulty has been in providing an adequate data base for obtaining meaningful judgements.

5 VII. Land Subsidence

Types of Participants

The type and number of participants in workshops on ground water problems will vary, dependent on the problems under consideration, the resources available for travel, and the objectives adopted for the workshop. In Kansas, representatives of groups listed below would all have interest in ground water problems.

State and Federal Agencies

1. Kansas Water Resource Board
2. U. S. Geologic Survey
3. Kansas Geologic Survey
4. State Board of Agriculture
5. Kansas State Board of Health
6. Environmental Protection Agency

7. Bureau of Reclamation
8. Soil Conservation Service
9. Kansas Conservation Commission

University Representatives

1. Kansas Water Resources Research Institute
2. Kansas Agricultural Experiment Station
3. Kansas Evapotranspiration Laboratory
4. Department of Geology
5. Departments of Civil and Agricultural Engineering
6. Department of Agricultural Economics
7. College of Law

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6. Economic Implications of Irrigation, Bulletin 9, Kansas Water Resources, 1968.

Important Water Resource Problems in Louisiana

Elvin J. Dantin

Salt Water Encroachment in Water-bearing Formations Containing Fresh Water

Salt water encroachment in aquifers has been observed in the 700 foot sand under the Lake Charles, Louisiana, industrial area and, mysteriously, in the 500 foot sand in the same area. Similar aquifer degradation has been observed due to coning in the rice area of southwestern Louisiana; the shallow aquifers south of Baton Rouge in the Gonzales and Gramercy areas also report salt water contamination; it is also a problem in the New Orleans area. Studies leading to remedial action are needed.

Land Subsidence Due to Ground Water Offtake

Land subsidence due to ground water offtake has been observed in Baton Rouge and New Orleans. Similar subsidence has undoubtedly occurred in the Lake Charles area. Again, definitive studies are needed to determine rates of subsidence, and the type and costs of measures to halt subsidence.

Changing of Water Quality in the Mississippi River Due to Operation of Upstream Power Generating Plants and Irrigation Projects

The water quality (mineralization) and temperature of the Mississippi River are being altered by upstream developments. Benchmark studies are needed to establish water quality changes (by analyzing of data collected at water treatment plants up and down the river), and the impact of leakage from nuclear plants should be evaluated on the basis of measurements of alpha, beta, and gamma radiation in water samples. Such studies have not been made and data is not available. The future decreases in low flow due to upstream diversion for irrigation and power production should also be taken into account although, at present, we don't know how.

Impact of Proposed Development on the Mississippi River

Impact of proposed development of deep-draft navigation in the Mississippi River on its water quality: The Corps of Engineers proposes a 50 foot channel through the Southwest Pass and a 40 foot channel to Baton Rouge. This will increase the probability of saline water at industrial and municipal intakes.

Rehabilitation of Fresh Water and Brackish Lakes

New regulations on weedicides (and pesticides) have resulted in lake eutrophication, since 2,4-D may not be used. The water quality has been impaired; recreation and navigation have been hampered due to the masses of water vegetation. Research is needed on the impact of these practices on water quality and the possibilities of restoring the lakes to a less eutrophied condition: Lake Pontchartrain, Lac des Allemands, Lake Boeuf.

Atchafalaya River

The aggradation of the Lower Atchafalaya River and the active subsidence of land at Morgan City has increased the danger of flooding there. In addition, the Wax Lake Outlet is taking a greater fraction of the Atchafalaya flow. During very low water, the salt wedge reaches Morgan City, endangering its water supply and the water supply of Houma and cities and settlements in between. Methods of alleviating the upcoming water shortages should be explored.

The deposition in the Atchafalaya is raising flood heights and making the levee system increasingly inadequate. A new evaluation of the flood control capacity is needed.

Spreading Cone of Depression in the Monroe-Ruston Area and the Effect of Reclamation of Land for Irrigation, on Ground Water Levels

Increased prices of agricultural products have made land reclamation in the Monroe-Ruston area economically attractive. If rice is to be grown, the least expensive water supply will be the establishment of well fields. The impact of rice irrigation on water levels throughout the Sparta Sand merits an intensive study.

Improved Efficiency in Energy Use by Cyclic Storage and Retrieval of Heat in Aquifers.

The storage of waste heat in aquifers for later use is a theoretically attractive method for reducing thermal pollution and improving the overall efficiency of fuel utilization. Present laboratory and digital studies of the cyclic storage of fresh water in saline aquifers can serve as the basis for new research on heat storage by use of well fields. The additional parameters involved include large differences in viscosity and heat flow from the stored water. Preliminary estimates, already published by others, indicate that despite heat losses due to mixing and thermal leakage, the overall thermodynamic efficiency of a steam-electric generating plant could be increased from 40 percent to 50 or 55 percent if the project were feasible at the selected site. Laboratory and digital studies followed by a semi-scale field test should be accomplished.

Important Ground Water Problems in New Mexico

John W. Clark

The High Plains of New Mexico--Union, Harding, Quay, Curry, Roosevelt, and Lea counties in eastern New Mexico--contain productive ground water irrigated agricultural areas. These counties are rapidly depleting their irrigation water supply--ground water sources which have little or no recharge. The Portales Valley in northern Roosevelt County, with irrigation experience predating statehood, has already felt the pinch of a declining water supply and some irrigated cropland has been abandoned. Irrigation development has been more recent in the other counties. For example, there was no irrigation in Curry County in 1940 but by 1970 about 190,000 acres had been developed; Lea County increased from 3,200 to 113,500 acres; Roosevelt County from 11,300 to 103,700 acres; Quay County from 200 to 48,000 acres; Harding County from 0 to 6,300 acres; and Union County from 5,800 (which was primarily surface right) to 35,000 acres.

The ground water irrigated acreage of the High Plains region represents about 35 percent of the irrigated acreage in New Mexico and it is estimated that in 50 years the irrigated acreage in the area will drop significantly.

Essentially all water problems of the High Plains are concerned with ground water supplies with very little natural recharge. As early as 1937, C. V. Theis estimated the ground water recharge of the southern High Plains to be less than 0.5 inch into the Ogallala formation, the primary aquifer of the study area. Since then, large scale pumping of ground water for irrigation of the rapidly increasing acreage and industrial, municipal, domestic, stock, power production, and recreational uses has resulted in a lowering of the water table. Agriculture accounts for approximately 97 percent of these uses.

Ground water levels declined as much as 30 feet over the period 1961-1965 in the Clovis area and as much as 9 feet from 1967 to 1968.

The Lea County underground water basin was declared in 1931 and extended in 1952. The largest water level declines in the Lea County area occurred southeast of Lovington, where the decline was about 13 feet, over the five-year period 1961-1965; the decline for the 1967-1968 period was about 3 feet. This area is one of New Mexico's major petroleum producing areas, and in recent years demand for use in oil field waterflooding operations has been increasing. Projections indicate that the demands will continue to increase. Contamination of the ground water by surface disposal of oil field brines and from leaky oil well casing has been partially corrected in recent years by subsurface disposal of brine and periodic testing of oil well casing.

The use of ground water for irrigation in Quay, Harding, and Union counties is of recent development and water level declines have been minor. Ground water yields are often limited and considerable expenditures are often required for development.

In a recent study supported by the Office of Water Resources, Bittinger and Associates (1970) recognized the eastern High Plains of New Mexico as an interstate ground water problem between New Mexico and Texas. It involves a severe depletion situation in conjunction with widely varying legal doctrines. New Mexico's ground water law is based on public ownership (prior appropriation) with controlled development. Texas water law is based on riparian doctrine with little regulation of ground water development. As a consequence there is disparity between irrigated agricultural development in the High Plains region of New Mexico and Texas.

The Ogallala Formation, the common source of water for the High Plains, taps a common water source. Any hydrologic analysis of the High Plains area should disregard state boundaries.

Important Water-Related Problems in Oklahoma

Marvin T. Edmison

Geographically, Oklahoma is a transitional state. The coastal plains, which includes most of eastern Texas, most of Louisiana, and parts of Arkansas, also extend well into the southeastern corner of Oklahoma where rainfall may locally average 60 inches per year. From there to the Oklahoma panhandle the general geographic trend is to higher, cooler, and more arid climatological regimen. Elevation varies from a low of less than 500 feet above sea level in the Red River Basin southeast of Idabel, to nearly 5,000 feet in the Black Mesa of the western panhandle. The decrease in precipitation in the state is striking, averaging 1 inch decreased precipitation for each 25 miles from southeast to the northwest. Oklahoma's vegetation directly reflects the westerly decrease in annual precipitation. Mixed forests of the southeast provide the basis of an increasingly intense forest products industry. A transitional zone, the crosstimbers area, includes many open tall grass prairies interspersed with heavily wooded water courses. Further to the west, the tall grass prairies yield to the short grasses of western Oklahoma which in turn give way to sage brush, sand sage, shinery, and bunch grasses of the panhandle. The 14 inches of annual precipitation of the western panhandle is inadequate for cultivated agriculture without supplemental irrigation.

As Oklahoma is a transitional state geographically, its land-use is also in transition. By the time of statehood, most of Oklahoma had been divided into 160-acre family farms. Over 80 percent of the state's total population lived on the farms or in small towns where their livelihood was related directly to agriculture. Today, in a process which was rapidly accelerated after World War II, Oklahoma agriculture had shifted to a large extent from the family farm and row cropping to a grassland economy of cattle grazing and calf production. The original 160-acre farms have been consolidated into a much smaller number of significantly larger ranches and wheat farms.

While erosion and siltation are still locally serious, the problem is significantly less than prior to World War II. Oklahoma has been a leader in the implementation of soil conservation practices, particularly in the organization of soil conservation districts and in the construction of small upstream impoundments which now average over 3,000 per county. These small impoundments, plus the large number of major multi-purpose reservoirs which have been constructed, have greatly alleviated the periodic scourge of floods but has also significantly increased the problem of low stream flow during dry periods.

Most of Oklahoma's major water problems involve distribution of water, water quality protection, and local depletion of ground water resources. These are problems shared with most of the other states of the Southern Plains River Basins Region. Generally these problems fall within three major categories: (1) ground water depletion and pollution, (2) allocation, conservation and environmental protection of our water resources, and (3) conflicting interests between energy production and water resources management. The ground water depletion is a major problem in five counties of the far northwestern part of the state and in several southwestern counties where there is an intensive and rapidly growing feed grain cultivation which supports inportant beef production. This problem is common to southwestern Kansas, the Texas panhandle, northeastern New Mexico and southwestern Colorado where the highly productive Ogallala Aquifer is being pumped at a rate exceeding its natural recharge. Other ground water depletion problems are locally important and locally severe. These particularly involve terrace aquifers along the various water courses of western Oklahoma. While many terrace aquifers are periodically recharged during periods of plentiful rainfull, the general trend is downward with municipal and industrial pumpage exceeding natural recharge. Other aquifers in the central part of the state are being depleted due to an increasing demand; however, alternative surface waters are generally available and can supplement ground water resources.

Ground water pollution occurs both naturally from the extensive saline and sulfate beds in the western one-third of the state and from the injection of brines into the oil bearing stratas for oil recovery operations. Though locally severe, ground water pollution from brine injections is as yet only a potentially-major problem.

Allocation of water resources is currently undergoing intensive examination with the major emphasis on a water distribution system which can economically transport surface water from eastern Oklahoma to the western two-thirds of the state where demand is presently outstripping the supply. While the need for additional water in the west is universally recognized, the cost of lifting the water 2,000 feet or more greatly compounds the economic problem. The Oklahoma Water Resources Board, the Corps of Engineers, and the Bureau of Reclamation are jointly engaged in the development of feasible plans and alternatives for the Red River drainage area. Their efforts will be expanded to cover the Arkansas Basin as well in the next fiscal year.

Eastern Oklahoma has rich coal beds which have been little exploited because of the more cheaply produced and previously abundant supply of crude oil and natural gas. As energy demands increase and as the production of oil and gas decrease, it is anticipated that extensive coal mining will become a major industry. While adequate water appears to be available to support extensive strip mining and to properly reclaim the mined land, research is needed to insure that local water quality is not adversely affected.

Water pollution from the refining of oil is still significant but continuing pollution abatement efforts by the industry have prevented the development of other than locally critical problems. Of growing concern is the allocation of water resources between competitive nonconsumptive users. Real estate development interests are in direct confrontation with scenic river groups; fish and wildlife interests are in conflict with thermal power plant operators and aesthetically oriented recreationists are concerned with potential and actual environmental degradation caused by sewage disposal. Extensive research is urgently needed to assist planners in equitably allocating uses of natural resources.

In summation, Oklahoma has few water problems of an immediate critical nature. The potential, however, is great in several important areas. In the near future, several important decisions must be made if Oklahoma is to be able to satisfy the many water demands which exist and which will become crucial as the population and industrial base expands. Important ground water problems existing in Oklahoma with possible solutions and identified water resources needs are tabulated in the Appendix. Other critical problems which are identified in conjunction with the regional survey of research needs are listed in Table 2 on the following page.

Table 2. Important Ground Water Problems in Oklahoma

Where Occurring	Primary Use of Water	Possible Solutions	What is Being Done	Research Needs
Oklahoma Panhandle "Ogallala"	1. Agricultural 2. Domestic	1. Restrict withdrawals 2. Restrict acreage 3. Import water 4. Impound surface water 5. Utilize lower aquifers for dilution 6. Restrict crop types or practice	1. "Okla. Water Plan" OWRB 2. Test wells--USGS 3. Aquifer characteristics. OSU--Kent & DeVries 4. Kerr Lab 5. Corporation Commission	1a-Socio-economic evaluation of water transport plan 1b-Ecological impact of OWP 1c-Ground water law 1d-Underground storage and withdrawal 3a-Movement of water in Ogallala 3b-Recharge coefficients 3c-Effect of recharge on aquifer-quality-permanent recoverability 6a-Suppression of evaporation and transpiration 6b-Drought resistant species
Central & Western Oklahoma--Terrace Dep.	1. Domestic & Industrial 2. Agricultural	1. Convert to surface water use 1. Seek new aquifers 2. Impound surface water 2. Import water 1. Use lower quality water for industry & agriculture	1. Okla. Water Plan 2. Demineralization of surface water	1. Definition & potential yield of aquifers 2. Water law
Central & NE Oklahoma Localized Aquifers	1. Domestic	Convert to surface water use	Spot surveys USGS--O.G.S.	Definition & potential yield of local aquifers

Important Water Resource Problems in Texas

Jack R. Runkles

Ground Water Pollution

Natural Pollution

Mineralization due to leaching is the most common type of natural pollution. Natural leaching may take place within a water-bearing aquifer or within the soils and rocks of the watershed area. Natural accumulation of soluble minerals is greatest in areas of low precipitation, especially where ground water is near the surface and evaporation and transpiration combine to concentrate the minerals in the waters left behind. Precipitation percolating through the salt laden soils or ground water movement takes some of the minerals in solution and carries them into the aquifer. Where hydrogeology permits, the resulting highly mineralized water may even return to the surface as springs and contaminate surface water. Natural pollution undoubtedly affects the quality of more ground water in Texas than all other sources of contamination combined.

The source of much highly mineralized water in Texas is an area known as the Permian Basin (Figure 1) which underlies large sections of Oklahoma, New Mexico, and Texas. Rock formations of Permian Age are composed of red and gray gypsiferous shale, siltstone, sandstone, gypsum, anhydrite, dolomite, and sometimes halite. Halite usually occurs as lenses in relatively impervious shales, but thick massive beds are not uncommon. Leaching of the salt is generally accomplished by small

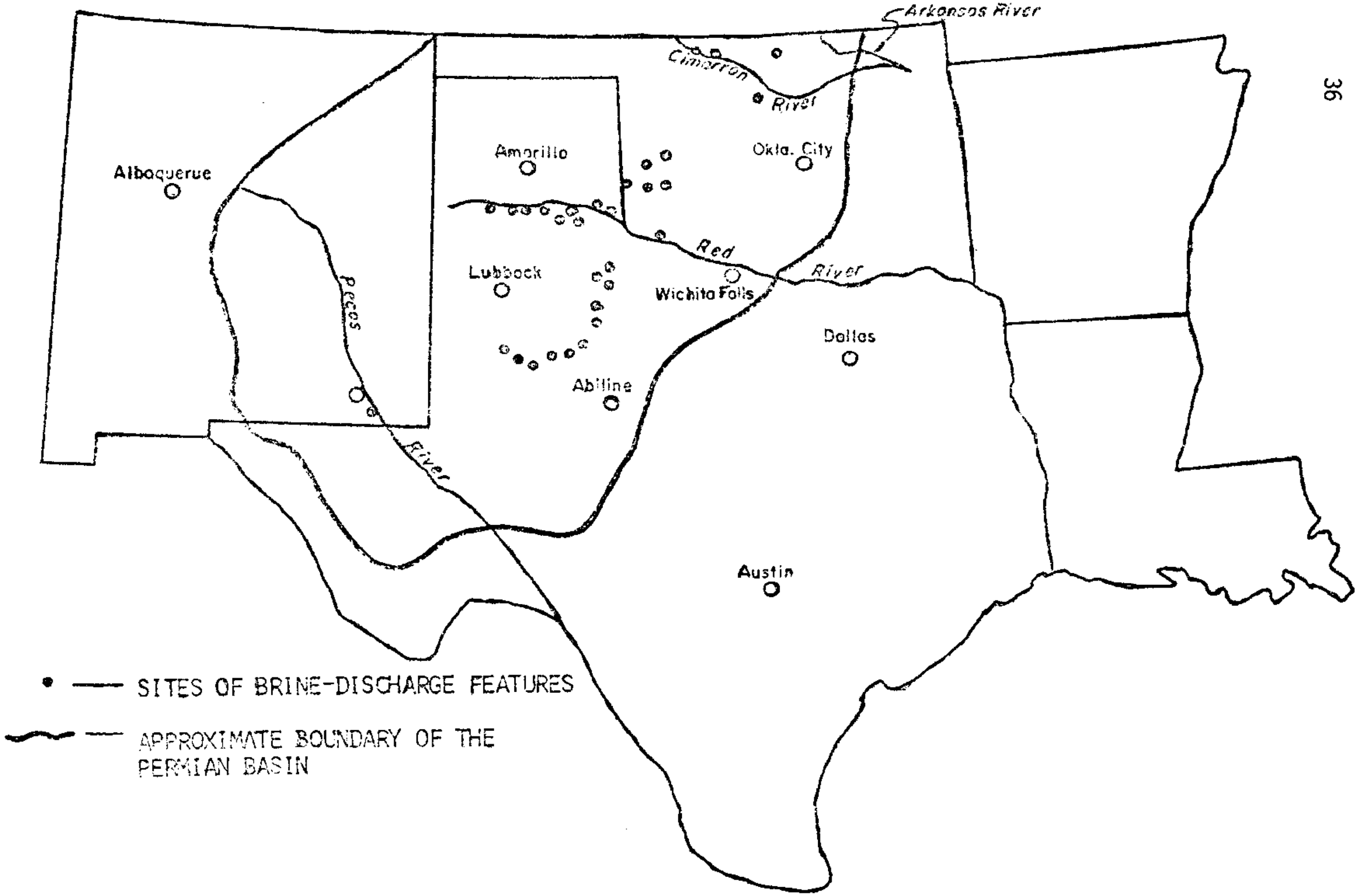


Figure 1--APPROXIMATE BOUNDARY OF THE PERMIAN BASIN

quantities of water which pass through small joints and fractures.

In the Permian Basin, salt water occurs at depths of less than 100 feet to more than 1,000 feet. In much of the area, leaching of salt-bearing formations near the surface and regional circulation of water from outcrop areas in the east result in springs and seeps which contaminate much of the surface water of the Pecos, Arkansas, Red, and Brazos Rivers. Although flow from these springs is small, chloride concentrations in the water range up to 190,000 mg/l depending on the dilution by fresh water. Alluvium near these springs is saturated with high chloride, high sulfate waters and evaporation from the surface causes the formation of salt crust during dry weather. These springs are estimated to contribute over 20,000 tons of sodium chloride per day to the waters of the Arkansas, Red, Brazos, and Pecos Rivers.

Although not as obvious at the surface as in the Permian Basin, natural leaching of minerals into the ground water affects tremendous volumes of ground water in other parts of the state.

In Runnels County, Texas, nitrates in extremely high concentrations in ground water are believed the result of leaching of natural deposits. Over 80 percent of 800 wells sampled in the area have nitrate concentrations above the Public Health Service recommended limit of 45 mg/l. Many wells contain nitrate concentrations of over 500 mg/l, and some are more than 1,000 mg/l. These extremely high concentrations are much higher than can be attributed to man-related sources of the area.

Other minerals are found in localized parts of the project area. Fluorides in excess of Public Health Service recommended limits are common in parts of western Texas. Radioactivity is a natural contaminant around uranium mining areas such as Karnes City, Texas.

Organic pollutants from natural sources are also problems in some areas. Nitrogen gas, methane, hydrogen sulfide, and carbon dioxide gases are found in many shallow aquifers in northeast Texas. The source of the these gases is believed to be the decay of lignitic or carbonaceous material naturally occurring in the aquifer. In 1970, three well drillers in Cass County, Texas, died from breathing gases escaping from such a source.

Because of the immense and unknown hydrological patterns associated with natural pollution in ground water, there appears to be little opportunity of preventing such contamination. For instance, it is theoretically possible to prevent recharge to salt-bearing formations and prevent further leaching of brines to the surface; however, the practical problems of finding and sealing thousands of square miles of recharge areas preclude serious consideration except in very unique small areas.

Alternative Actions

While this is the greatest single problem in the study area affecting both surface and subsurface waters, it is also one of the most difficult to attack. It is a natural phenomena extending in most cases over broad geographical areas. Some work is being done by the U. S. Corps of Engineers particularly as the problem affects surface water. The problems are probably of more concern to surface supplies than ground water because once the subsurface flows emerge at the surface, the damage becomes much more widespread. The phenomena is, nonetheless, subsurface in origin and should be addressed here in terms of alleviating predominantly surface pollution.

1. Technology associated with demineralization has been advanced to a considerable degree. Work remains to be done on the application of these techniques to waters of this chemical composition so that the economics of providing at least small quantities of water can be established.

2. The development of technology to collect small heavily mineralized alluvial flows should be pursued along with ways to lower alluvial water tables in order to prevent surface accumulation of brine crystals which are washed into streams during periods of runoff.

3. Opportunities for secondary oil recovery by waterflooding exist in many of the areas where natural brines are present. Since the need for water for waterflood greatly exceeds that available from natural brines, the possibility of using these natural brines for this purpose should be investigated. Collection facilities and incompatibility due to high sulfate concentration in the natural brines may present obstacles that will have to be resolved.

4. Deep well disposal of natural brines is being studied by the U. S. Corps of Engineers. This work should be encouraged particularly in view of the disposal of brines into formations which naturally discharge into the sea.

5. In situ evaporation rates should be established for the various natural brines encountered in the study area. This would allow for optimizing systems of disposal or use which are a function of volume.

Oil Field Brine

Since oil was discovered in 1902, Texas alone has produced over 31 billion barrels of crude oil--36 percent of the total U. S. production. Each oil well is a potential or actual source of pollution to aquifers because of improper control of gas, oil, salt water, or the many chemicals used in drilling and production operations. Production of crude oil is usually accompanied by the production of waste water of variable but usually high chloride content. The amount of this salt water produced is also quite variable and may range from zero to as much as 15 barrels to one barrel of oil.

Until about the last decade, the common methods of oil field brine disposal consisted of discharge to streams or to "evaporation" ponds. In both cases, brine-contaminated aquifers became commonplace in most or all areas of oil production as infiltration from the streams and ponds moved to the ground water. Thousands of unlined brine pits were in use in the five state area until only a few years ago when they were prohibited by the oil regulatory agencies of the respective states. Texas was one of the first states to enact a statewide ban on unlined pits in January 1969, and other states have adopted similar regulations. Despite this ban and the fact that few of the brine contaminated areas have been mapped, enough have been located to indicate a serious ground water pollution problem for many years to come. Because of the slow movement of ground water, brine-contaminated ground water is only now being discovered in many areas of oil development abandoned 20 or 30 or more years ago. It is probable that such discoveries will continue for many years. It is also apparent that, even if no more brine contamination occurs, the slow ground water movement will require many years and even centuries for natural cleansing and rehabilitation of the aquifers.

With the ban on unlined evaporation pits, oil companies were forced to construct pits lined with an impervious material. Brines theoretically must now be evaporated or injected back into the subsurface, either into the oil-bearing formation or into another formation far enough removed from fresh water aquifers to prevent contamination. Nevertheless, there are numerous reported and suspected violations of these regulations, primarily by economically marginal oil producers. Such violations may be in the form of bypassing brine pits, by accidental or deliberate rupture of pit liners, by overflowing waste pits, or by leakage from broken lines.

Another problem has been the inadequate design of brine disposal wells. It has been common practice in the past to use abandoned production wells for brine disposal. Since the wells were not designed, cased, or cemented for brine injection, there have been numerous instances of injected brine seepage from undetected ruptures beneath the surface. This seepage into fresh water aquifers has gone on for many years before detection. Some state regulatory agencies have somewhat alleviated this problem by requiring injection tubing inside a casing filled with an inhibited fluid under pressure. Ruptures can be detected by changes in the fluid pressure.

Currently, most oil field brines are returned to subsurface formations either for waterflooding--increasing the pressure in an oil producing formation--or just as a disposal method. However, even with properly designed and constructed injection wells, brine disposal is not without real or potential problems. Much of the problem results from the nature of early oil exploration and to abandoned and inadequately plugged oil, gas, and injection wells. Thousands of such wells are scattered throughout much of the project area. For many years of oil exploration, it was a common practice to abandon test holes without proper plugging, thereby leaving a vertical pathway of contact between the various subsurface formations.

The contamination problems inherent in such a ground water environment are apparent. Whether the source of the brine is injection from the surface or natural brines in a subsurface formation, unplugged wells offer a connection to the fresh water aquifer. In some cases, artesian pressure alone may be adequate to force salt water up the well and into the fresh-water aquifer. In other cases, injection of brine into the formation may increase the pressure sufficiently to move formation salt water up the well.

Some idea of the magnitude and location of oil field brine problems can be obtained by looking at the crude oil production. Of the estimated 74,000 salt water injection wells in the United States in 1970, about one-half of these were in Texas.

Examples of ground water pollution from oil field brines are legion in many parts of the five-state area, especially Texas and Oklahoma. Many cases are documented in published and open-file reports of the respective state regulatory agencies. Brine pits, both active and abandoned, have been implicated as sources of ground water pollution in Baylor, Cochran, Colorado, Comanche, Cook, Dawson, Ector, Gaines, Glasscock, Harris, Karnes, Knox, Montague, Pecos, Matagorda, Runnels, Rusk, Victoria, Wilbarger, Wilson, and Winkler counties in Texas, just to name a few.

Brine injection wells, both waterflood and disposal wells, have also demonstrated their capacity for pollution in Coleman County, Texas, where salt water from a waterflooding operation has moved through inadequately plugged oil test wells and into the Trinity Formation. Similar problems from brine disposal wells have been noted in Karnes, Victoria, and Wilbarger counties, Texas and Garvin County, Oklahoma. In Wood County, Texas, brine and gas were found to leak through fault zones into fresh water. In Shackelford County, Texas, salt water seeps at the ground surface resulted from brine disposal wells.

Alternative Actions

The practice of disposing of oil field brines has changed over the last decade. The use of evaporation pits has almost been abandoned in favor of subsurface injection either for waterflood or disposal. The protracted use of pits has resulted in the discharge of large volumes of brines to both the saturated and unsaturated subsurface environment and is likely to remain a problem for many years even though the use of pits is generally abandoned. Technology for brine injection either for disposal or waterflooding is generally available, but the consequences of these types of brine disposal on ground water resources has not been fully evaluated.

1. Techniques for locating areas of subsurface brine pollution should be developed so that these areas can be investigated. Remote sensing and resistivity techniques show promise.

2. Aquifer restoration should be demonstrated and encouraged particularly in areas where polluted ground water can be used for waterflooding.

3. The geologic and hydraulic relationship between fresh water aquifers and brine disposal formations must be evaluated in order to establish sound disposal criteria in forms of disposal volume and pressure. Economic techniques for making these appraisals should be improved and demonstrated so that regulatory agencies could regulate disposal activities more soundly and in individual fields, if necessary.

4. Existing inspection and monitoring techniques should be evaluated and, if necessary, modified to assure that the pollution potential to ground water is minimized.

5. A conceptual appraisal of the pollutional hazards of using oil field drilling fluids and chemicals should be made. The results of such an appraisal would dictate future studies, if required.

6. A handbook should be developed by a firm with exceptional expertise in the field of design, construction, and operation of disposal or waterflood wells. The handbook should dwell on techniques, materials, treatment, operation, monitoring, and training.

Land Subsidence

The Gulf Coast area of Texas is being affected in an "alarming" way by the withdrawal of ground water resulting in the subsidence of land. Land subsidence can be caused by one or more of several things including: (1) loading of the surface; (2) compaction due to ground water withdrawal; (3) drying and shrinkage of deposits; and (4) oxidation of organic aquifers. In the Houston-Galveston area of Texas where the sinking of the land is critical, the principle cause of subsidence is the lowering of pressure heads due to the removal of water and oil.

The Houston-Galveston region is underlain by a thick section of unconsolidated lenticular deposits of sand and clay. Pertinent geologic formations in this section are, from oldest to youngest--Fleming Formation of Miocene age, Goliad Sand of Pliocene age, Willis Sand of Pliocene age, and Lissie Formation and Beaumont Clay of Pleistocene age. The formations crop out in bands roughly parallel to the coast and dip toward the coast at an angle greater than the slope of the land surface.

The geologic formations compose the principal aquifers of the region, commonly grouped with other formations along the Gulf Coast as a unit and called the Gulf Coast Aquifer. Within the aquifer, the interbedded sands and clays are saturated with water almost to the land surface, but the clays retard the vertical movement of water, creating artesian conditions.

Withdrawal of water from the artesian aquifers results in an immediate decrease in hydraulic pressure, which partially supports the weight of the overburden. With reduction in pressure, an additional load is transferred to the skeleton of the aquifers, and a pressure difference between the sands and clays causes water to move from the clays to the sands. Most of this process of the sediment compaction takes place in the clays. Because the clays are mostly inelastic, the compaction is permanent.

Subsidence of as much as 5 feet occurred in the Houston-Galveston region between 1943 and 1964, and as much as 200 feet of water level decline has occurred during the same period. The rate of subsidence increased from about 0.2 foot per year during the 1954-1959 period to about 0.24 foot per year during the 1959-1964 period. The decline in water levels increased from about 4 feet per year to about 7 feet per year in those same two periods.

The detrimental effects of land-subsidence are: (1) structural damage, probably due to faulting that has cracked buildings and disrupted pavements; (2) damage to well casings; and (3) submergence of coastal lowlands.

The Socio-Economic System Involved

Subsidence has been greatest in the area of the Houston Ship Channel--as much as 7 feet since 1943. Engineers say the San Jacinto Monument is roughly the epicenter for an affected area which extends outward for 30 miles. Other areas hard-hit by subsidence include Baytown, LaPorte, Seabrook-Kemah, and Clear Lake. This is the industrial area of Houston, an area which draws heavily on the ground water for its needs. Daily pumpage in the Pasadena area in 1971 averaged 120 million gallons per day. For all the Houston district, 516 million gallons per day were pumped in 1971. And as long as the pumpage of wells remains unregulated, the Houston-Galveston area will sink at an increasing rate.

In many of the communities facing Galveston Bay, the reach of the tides creeps higher each year. Serious problems for property owners and municipal officials are created. Sometimes property is abandoned. Frequent inundation or immersion renders it virtually useless for residences, commercial buildings, or similar uses. Attempts to resist flooding via construction of retaining walls and filling of lower areas have been costly but necessary to salvage investments in homes and businesses. Municipalities in the area must often raise the elevations of roads, repair damaged utilities, and construct bridges, dikes, and drainage works. Expenditures for protection, repair, salvage, etc. increase each year.

Alternative Actions

1. Water importation

   Surface water is available from Lake Livingston and the Neches and Sabine River Basins. This surface water could be used to replace ground water in a controlled pumpage program. The surface water would cost more than ground water since it would require canals to bring the water to the Houston-Galveston area. Costs associated with this alternative need to be developed.

2. Control pumpage

   Under Texas law, as interpreted by courts in the state, surface land owners may take for use or sale all of the percolating water, as defined in the statutes, captured beneath their land although there are certain prohibitions against waste. Under these laws, as consistently interpreted by the courts, Texas follows the English rule on ground water conservation and development of absolute ownership rather than the "American rule" of reasonable use and correlative rights.

With the present system of private ownership, a state ground water law would be required to control pumpage from the aquifer in Texas. Also, a complete aquifer ground water management program would have to be developed for the region and should include control pumpage and/or dispersing wells.

3. Dispersing the well field

   It is generally agreed that land subsidence in the Houston-Galveston area results from the high density of wells. Dispersing the well over larger areas would provide the water for industries and municipalities, but would minimize subsidence. Obviously water from the dispersed well fields would cost more because of new well construction and transport cost to the Houston-Galveston area.

4. Desalination of sea water or saline ground water

   Both saline ground water and sea water are relatively close to the region for desalination; however, the desalted water would have a high cost.

5. Recharge of regional surface water

   Regional surface water is available in Lake Livingston and the Neches and Sabine River Basins for recharge. Recharging the aquifer would be very expensive since the water would have to be recharged at a high pressure. The process of subsidence is probably irreversible for all practical purposes.

6. Do nothing

   If ground water depletion is not controlled, damage to the highly industrialized Houston-Galveston area is going to be very severe.

7. Research the systems for ideas for action

Ground Water Depletion

<u>Ogallala Aquifer</u>

The Ogallala Aquifer has been described and correlated throughout a region in the Great Plains which extends from southern South Dakota to central west Texas, a distance of 800 miles. It has a maximum east-west width of 300 miles. Throughout the region it is either exposed at the surface or is covered by deposits, eolian sands and silts, or by shallow pond deposits. Clearly, the Ogallala Aquifer constitutes the largest ground water reservoir in the Great Plains region.

In Texas, the Ogallala Aquifer underlays about 35,000 square miles with an average saturated reservoir thickness of 140 feet, an average porosity of 30 percent and a specific yield of 15 percent. The total storage capacity of the aquifer is estimated at 360 million acre-feet of which 75 million acre-feet have already been withdrawn. In 1968, the Ogallala Aquifer provided 9.8 million acre-feet of water, equal to over 70 percent of all the ground water withdrawals in the state. The aquifer is the most intensely developed in the state with over 65,000 wells withdrawing water. Irrigation takes most of the present withdrawal; municipal and industrial uses take about 22 percent; and a small percentage is used in waterflooding of oil fields for secondary recovery. Ground water in the Ogallala Aquifer generally contains between 300 and 1,000 milligrams per liter of dissolved solids, of which calcium, magnesium, and bicarbonate are the principal constituents. The water is hard, but suitable for most uses.

Depletion of the ground water in the Ogallala Formation in Texas is well recognized and has received considerable state and national attention. The Texas Water Development Board has maintained an extensive program of water level records on a number of wells in the region over the past 35-40 years. In general, this data indicates a variable rate of depletion, depending upon the saturated thickness and the density of wells within the area. The yearly decline of water well levels averages from around 1 foot per year to 5 feet per year. A recent survey of the water table decline for the northern-most area of the Texas panhandle indicates a little over 2 feet per year during the past 10 years. Further evidence of the declining water reservoir supply is indicated by a substantial drop in individual well capacity in much of the southern portion of the aquifer.

A recent irrigation survey for the region indicates that there were about 5 1/2 million acres under irrigation in 1969. This acreage is expected to increase to about 6 million acres, perhaps by the year 1980 and then decrease rapidly beyond 1980. Estimates of the life of the aquifer depend on many factors, but most indicate that under present development conditions, the number of acres of irrigation will be substantially reduced within the next 25 years.

The Socio-Economic System Involved

The land resources in Texas overlying the Ogallala Aquifer are of high natural fertility and are highly suitable for crop production. These land resources, in conjunction with availability of water, resulted in a rapid development of an intensive irrigation economy in the region during the past 25 years.

Since the Texas High Plains is a semi-arid region (average annual rainfall is about 18 inches), irrigation water drawn from the Ogallala has been an important input. Per acre yields with irrigation, as compared to dryland production, are doubled for cotton, increased two to five-fold for grain sorghum, wheat, and corn. Commodities such as soybeans, castor beans, and vegetables are considered as feasible crop alternatives only with irrigation.

Farm operations have shifted from reliance on migratory labor to farm economy based on large capital investments. The region is flat to mildly rolling; hence, the typical operator uses six to eight row machinery for row crop production.

Farm operators in the area are very progressive and quick to incorporate new technology into their farm operations. For example, at the beginning of irrigation in the area, open ditches or canals were used to deliver water to the field. Due to a concern for efficiency, thousands of miles of underground tile was installed with gated pipe used above ground to distribute water on the field. For sandy and mixed soils, sprinkler systems are used to distribute the water.

Currently, the average farm size in this area is about 1,000 acres with gross returns of about $80,000. The average age of the farm operator is 47. Farms are principally owner-operator or "family" farms. With a shift from irrigated to dryland production the average size farm will, for economic survival, have to increase in size three to four times. This means that by 2015, three out of four farm families currently in the Southern High Plains will be displaced.

The desire to efficiently use the water from the Ogallala is emphasized in the formation, by farmers, of Underground Water Conservation Districts (UWCD). These UWCDs issue permits for new wells, assuring a minimum distance between wells. Efficiency of water use is assured by a continual patrolling of the area to locate farmers who are needlessly allowing irrigation water to run out the end of the field and into nearby playa lakes. If a farmer refuses to stop "wasting" water, the UWCD has the authority to seal the farmer's well.

The 1970 population of the counties covered by the Ogallala Aquifer in Texas was 893,000. There are four Standard Metropolitan Statistical Areas represented in the region--Amarillo in the northern part, Lubbock in the central portion, and Midland and Odessa in the extreme southern part.

Studies of the importance of irrigation to the economy of this region have shown that in 1959 the total benefits of irrigation was $89.06 per composite irrigation acre. A recent input-output economic study was completed for the region. The total value of all agricultural products sold in 1967 was $1,115 million. Of the total sales, 67 percent resulted from the sale of crops. Livestock represented 33 percent of the value of agricultural sales of the study area in 1967. The advent of cattle feeding operations in the region has greatly expanded this type of agriculture. In 1969, the number of cattle marketed from feedlots was 1,792,000 head. Recent data indicates that in 1972, the number of fed cattle from this region was 3.2 million head. The total benefits to the region from the net increase in crop production from irrigation was estimated to be $1,561.1 million in 1967.

For the Southern High Plains of Texas (south of Amarillo), some estimated effects of the declining water supply are (1) a 65 percent reduction in cotton production, (2) a 91 percent reduction in grain sorghum, and (3) a 22 percent increase in wheat production in 2015 compared to 1966. It is expected that wheat will replace much of the grain sorghum as the shift from irrigation to dry land occurs. With total agricultural output declining as indicated above, significantly less inputs and labor will be required. Therefore, related agribusiness firms will be affected in a similar manner. The implications for rural communities in this area are clear.

A last point relative to agricultural production in the High Plains of Texas is socio-environmental in character. The latest research indicates insects are not a major problem in this area. This has significance for cotton (a crop on which a majority of all insecticides used in the U. S. is applied). This means cotton and grain sorghum can be produced in this area with little or no use of insecticides. In this day of environmental awareness, this is an important production characteristic.

Alternative Actions

1. Water importation

   The U. S. Bureau of Reclamation, the Corps of Engineers, and the Texas Water Development Board have an extensive study in progress to examine this alternative for water from the Mississippi River Basin. Water importation from Canada has been given preliminary study by various plans--such as NAWAPA and the Beck Plan.

2. Control pumpage

   Under Texas law, as interpreted by courts in the state, surface land owners may take for use or sale all of the percolating water, as defined in the statutes, captured beneath their land although there are certain prohibitions against waste. Under these laws, as consistently interpreted by the courts, Texas follows the English rule on ground water conservation and development of absolute ownership rather than the "American rule" of "reasonable use" and correlative rights.

With the present system of private ownership, a state ground water law would be required to control pumpage from the aquifer in Texas. Also, a complete aquifer ground water management program would have to be developed, including annual allocations, water measurement, institutions, taxation, etc.

3. Improved efficiency of use by irrigation

   New technology in the form of trickle irrigation and sub-irrigation is developing rapidly and indications are that it will substantially improve the efficiency of irrigation water use.

   This alternative would reduce the water use per acre of irrigation; however, to be effective it would have to be combined with a control of irrigation acres in order to affect a reduction in water depletion from the aquifer.

4. Desalination of saline ground water aquifers

   There are several saline ground water aquifers below the Ogallala Formation. Saline ground water could be extracted and desalted at a relatively high cost for some uses in the region. The saline aquifers are mostly deep and have low permeabilities.

5. Recharge of regional surface water

   In the 36 thousand square miles of the High Plains region of Texas, there are approximately 16,700 shallow, undrained depressions which collect surface runoff. During periods of precipitation, runoff accumulates in the depressions and forms playa lakes. These lakes range in size from less than one acre to more than 100 acres. Estimates of the volume of water in the playa lakes are extremely valuable, but most consider it to be around 1.4 million acre-feet annually. During wet years, estimates range as high as two times this amount and about one-fourth this amount in dry years.

6. Weather modification

   The region has a program of cloud seeding for hail suppression. A program of cloud seeding might increase precipitation either in the cold or warm seasons.

7. Increased efficiency of precipitation

   New technology in the form of water harvesting has developed. The principle involved is to reduce the infiltration at the soil surface, thus increasing the runoff. The harvested water usually is stored for future use. Materials can be applied to the soil surface to produce 80-100 percent runoff. The cost of water harvesting is still high, but may be considered for municipal and industrial use.

8. Do nothing

   If nothing is done on a state of national basis to solve the ground water depletion problem, the region will probably experience most of the projected economic and social changes. Opinions differ as to the severity and timing of the socio-economic adjustments; however, research can make positive contributions to minimize the severity of the adjustments.

   All of the above alternatives, except water importation, are designed to extend the economic life of the water supply. Therefore, an important need for the entire region (assuming no water importation) is to develop other strategies to minimize adverse impacts of shifting from irrigated to dryland production. This means the social and economic adjustments need to be identified and appropriate plans, social programs, and assistance mechanisms designed to minimize individual and regional costs (disutility) of the adjustments.

9. Research the systems for ideas for action

Edwards Aquifer

The Edwards Aquifer arcs across south central Texas from near Bracketville in Kinney County, east through Uvalde, Medina, and Bexar counties, then northeast through Comal and Hays counties. It consists of the cavernous and honeycomb limestone which permit the movement and storage of vast quantities of water. It is unique in terms of its exceptional capacity of rapid movement and replenishments. The primary recharge zone for the Edwards Aquifer is the Balcones Fault Zone, an area of porous limestone through which the surface water enters the underground reservoir. Rivers and streams which cross in the fault zone lose a large part of the water into the aquifer. Approximately three-fifths of the water entering the reservoir comes from the streams in the western counties of Medina, Uvalde, and Kinney which includes the Nueces, San Antonio, Gaudalupe, Blanco, and Frio rivers. The Edwards Aquifer supplies municipal and industrial water to numerous cities and towns, including the total municipal water supply for the city of San Antonio. Some of the largest springs in the state result from the natural discharge of ground water from the aquifer. These include Leona Springs at Uvalde, San Pedro and San Antonio Springs at San Marcos, Comal Springs at New Braunfels, and Barton Springs at Austin.

Ground water is discharged from the Edwards Aquifer by both springs and wells. Prior to 1954, most of the discharge was from springs, although the discharge from wells showed an annual increase. By 1956, approximately 80 percent of the discharge was from wells, and in 1964, the discharge from wells exceeded that from springs. This trend has continued although the discharge from wells was only 54.6 percent in 1970. The three principal springs--San Antonio, San Pedro, and Leona--ceased flowing between 1955-1956. Comal Springs ceased flowing in 1956 for the first time on record.

The safe yield of the Edwards Aquifer is estimated to be between 235-300 million gallons per day. The pumping rate during the year 1970 was 285 million gallons per day, which is in the vicinity of the maximum probable safe yield of the Edwards Aquifer. With the continued growth of the water demand in the San Antonio area and increasing irrigation in the western portion, depletion of the aquifer will be a serious problem. During 1969, the aquifer discharge showed a decrease in 18 percent of flow from springs; an increase of 19 percent withdrawals in municipal and military use; irrigation use was increased 74 percent;

industry use decreased 9 percent; and domestic and miscellaneous supplies were relatively unaffected. Continued increased withdrawal from the aquifer will result in further decreases in spring flow and eventually a trade-off between irrigation, municipal, and spring flow will have to be made to meet future water demands.

The Socio-Economic System Involved

The Edwards Aquifer provides the total public water supply for the cities of San Antonio, New Braunfels, and San Marcos which have an estimated population of about 950,000 people. The major city in the region is San Antonio, a standard SMSA which in 1970 had a total population of 864,014. San Antonio increased about 20 percent in population during the 1960-1970 period. The natural springs at San Marcos and New Braunfels are an important tourist attraction and are visited by several hundred thousand people annually.

San Antonio, the fifteenth largest city in population in the U. S., has the greatest concentration of people and economic activity related to the Edwards Aquifer. There are five separately incorporated cities, which are enclaves within the city of San Antonio, and seven military installations within or adjacent to the city. San Antonio is an active business community, and the region is well-developed with both agricultural and commercial enterprises. There is comparatively little basic industrial activity within the region, thus the economy heavily depends upon the military complexes in the area and upon tourism.

The 1967 Census of Business for the San Antonio area reports that there were 6,301 retail establishments within the Standard Metropolitan

Statistical Areas with total sales of $1.1 billion and a payroll of $132 million annually. In 1967, there were over 1,300 financial institutions in the region including banking, insurance, and real estate. Of these, 51 were commercial banks and there is a local Federal Reserve Branch Bank located in San Antonio, In 1967, total deposits of the region's banks were $1.4 billion.

Alternative Actions

1. Water importation

   The Texas Water Development Board has a rather extensive plan to provide surface water to the San Antonio area to replenish the depleting ground water sources by importation from the Guadalupe and San Antonio river basins. In the Texas Water Plan, reservoirs (Cuero 1 and Cuero 2) were planned in the Guadalupe River Basin Cibolo Reservoir in the San Antonio River Basin. A canal system is to be used to pump this water to the San Antonio area.

2. Control pumpage

   Under Texas law, as interpreted by courts in the state, surface land owners may take for use or sale all of the percolating water, as defined in the statutes, captured beneath their land although there are certain prohibitions against waste. Under these laws, as consistently interpreted by the courts, Texas follows the English rule on ground water conservation and development of absolute ownership rather than the "American rule" of "reasonable use" and correlative rights. With the present system of private ownership, a state ground water law would be required to control pumpage from the aquifer. Since the Edwards Aquifer is a renewable aquifer, pumpage control may perhaps be the best alternative to a sustained water supply for the region. This alternative would require a complete aquifer ground water management program, including annual allocations, water measurement, institutions, taxation, etc. Also, trade-offs would have to be made with regard to irrigation water, municipal water largely for the San Antonio area, and the natural flowing springs at San Marcos and New Braunfels.

3. Improved efficiency of use by irrigation

   New technology in the form of trickle irrigation and subirrigation is developing rapidly and indications are that it will substantially improve the efficiency of irrigation water use.

This alternative would reduce the water use per acre of irrigation; however, to be effective it would have to be combined with a control of irrigation acres in order to affect a reduction in water depletion from the aquifer.

4. Desalination of saline ground water aquifers

   There are several saline ground water aquifers between the Edwards Aquifer and the Gulf Coast. Saline ground water could be extracted and desalted at a relatively high cost for some uses in the region. The saline aquifers are mostly deep and have low permeabilities.

5. Recharge of regional surface water

   During the 1934-1970 period, the annual recharge of the aquifer ranged between a minimum of approximately 44,000 acre-feet in 1956 to a maximum of 1,700,000 acre-feet in 1958. The average annual recharge was estimated at 519,000 acre-feet. There is very little opportunity to recharge any additional surface waters in the vicinity of the aquifer without importation from other river basins.

6. Weather modification

   The region had a cloud seeding program during the drought of 1970. The program was short-termed and was not continued. A program of cloud seeding might increase precipitation either in the cold or warm seasons.

7. Increased efficiency of precipitation

   New technology in the form of water harvesting has developed. The principle involved is to reduce the infiltration at the soil surface, thus increasing the runoff, and concentrating on storing the water for a high priority use. Materials can be applied to the soil surface to produce 80-100 percent runoff. The cost of water harvesting is still high, but may be considered for municipal and industrial use.

8. Do nothing

   If the depletion of ground water from this aquifer is not brought under some control mechanism, municipal, industrial, and irrigation water withdrawals will stop the natural spring flow in the near future.

9. Research the systems for ideas for action

DEVELOPMENT OF WORKSHOP PROCEDURES

Jack R. Runkles

In order to conduct the systematic problem analysis workshops with efficient utilization of time at the workshop, a procedure was developed to provide the necessary background prior to the workshops. Tests of the procedure at the first workshop proved to be successful. Three workshops were held during the course of the project. Also, numerous meetings of the SPRBR Directors were held to provide the input to develop the research needs for the region. The following workshop procedure was developed.

I. Identify important water resource problems for the region.

This was accomplished by the SPRBR Directors with inputs from various state and federal agencies in the region and the highest priority problems are given below:

A. Ground water depletion, ground water pollution, and land subsidence.

B. Allocation of water resources, conservation, and environmental impacts.

C. Conflicting interests and synergistic effects between energy production and water resource management.

II. Identify the relevant sub-problems for each priority problem.

A. Identify the important sub-problems at the state level. Each state director in consultation with state agencies, federal agencies, and others should identify the important sub-problems, alternatives, and sub-alternatives and users (or potential users). The reason for identifying the users or potential users is to provide the basis for information dissemination when the research is completed. This step can be accomplished by mail or by state meetings.

B. The identified sub-problems and associated material should be transmitted to the SPRBR Director responsible for developing the workshop on the particular problem.

C. The SPRBR Directors will select the highest priority sub-problems for analysis. One or more sub-problems may be selected depending on the nature of the priority problems. The sub-problems should be narrow enough in scope so that they can be analyzed by the "Hall Procedure." This step can be accomplished by mail or by meetings of the two SPRBR Directors coordinating each priority problem.

Example: Under the priority problem "Ground water depletion" the sub-problem "Ground water depletion from the Ogallala formation" was selected for workshop analysis (See Example Below).

III. Develop background material for SPRBR workshops and a list of expected participants. The SPRBR Director responsible for the priority problem will develop the background material and a list of invited participants for the problem analysis workshop. This background material will contain the following:

A. Introduction describing the nature of each sub-problem. The discussion should include enough detail to enable the participants to understand the sub-problem and its relevance.

B. Itemized list of all alternatives and sub-alternatives.

C. Preliminary research needs analysis -- This will include selection of the most feasible alternatives, identification of knowledge gaps, and a list of research needs for each feasible alternative and sub-alternative.

These steps can be accomplished by mail between the two SPRBR Directors responsible for the priority problem and all SPRBR Directors. The example background material for the sub-problem "Ground water depletion from the Ogallala formation" follows no. IV. With the background material available prior to the workshop, the participants can come to the meeting prepared for an "in-depth" analysis of the sub-problem.

IV. The workshop will assemble a small group of people knowledgeable in the disciplinary spectrum of each sub-problem. At the workshop, the group will subject each sub-problem to the "Hall Procedure." The workshop should begin with a discussion of each sub-problem by knowledgeable scientists. During the workshop the participants will complete and refine (1) the alternatives and sub-alternatives; (2) the research needs analysis for each alternative and sub-alternative; and (3) establish preliminary priorities of research needs for each sub-problem.

Example: Ground Water Depletion from the Ogallala Formation

Definition: Ground water withdrawals are greatly exceeding natural recharge in many major aquifers.

Ground water resources are being depleted at a rapid rate throughout most of the Southern Plains River Basins Region. The major aquifer in the region is the Ogallala. Other important ground water sources are the Glorietta Aquifer in Oklahoma; the Edwards, Gulf Coast, and Carrizo-Wilcox aquifers in Texas; the Quaternary Aquifer in Arkansas; sand dunes and Equus Beds in Kansas; and numerous alluvial aquifers along the major stream valleys in the region.

The Ogallala Aquifer has been described and correlated throughout a region in the Great Plains which extends from southern South Dakota to central West Texas, a distance of 800 miles. It has a maximum east-west width of 300 miles. Throughout the region it is either exposed at the surface or is covered by deposits, eolian sands and silts, or by shallow pond deposits. Clearly, the Ogallala Aquifer constitutes the largest ground water reservoir in the Southern Plains River Basins Region.

In general, the land resources overlying the Ogallala Aquifer are of high natural fertility and are highly suitable for crop production. These land resources, in conjunction with availability of water, resulted in a rapid development of an intensive irrigation economy in the region during the past 25 years.

Irrigation began on the Texas High Plains with the completion of the first successful irrigation well on the J. H. Slaton farm, four miles west of Plainview, in 1911. Development of the vast ground water resources of the High Plains progressed very slowly until 1935. Drought and the improved efficiency of pumps and power units stimulated increased interest in irrigation about 1936. After World War II, irrigation acres increased at a phenomenal rate in the region. A recent irrigation survey indicated that there are about 5.5 million acres under irrigation. Irrigation development of the New Mexico High Plains followed a similar pattern. In 1940 there was no irrigation in Curry County, but by 1970 there were 190,000 acres under irrigation. Lea County increased from 3,200 acres in 1940 to 113,500 acres by 1970; Quay County from 200 to 48,000 acres; and Union County from 5,800 to 35,000 acres.

The ground water irrigation acreage of the High Plains region represents about 35 percent of the irrigation acreage in New Mexico and it is estimated that in 50 years the irrigation acreage will drop significantly. Ground water irrigation in the High Plains region of Texas represents about 67 percent of the state's total and it is expected to decrease substantially over the next 30-40 years because of the fast rate of depletion.

Depletion of the ground water in the Ogallala Formation is well-recognized and has received considerable regional and national attention. Data from water well level records indicates a variable rate of depletion, depending upon the saturated thickness and the density of wells within the area. The yearly decline of water well levels in the Texas High Plains averages from around 1 foot per year to 5 feet per year. A recent survey of the water table decline for the northern-most area of the Texas High Plains indicates a little over 2 feet per year during the past 10 years. Ground water levels declined as much as 30 feet over the period 1961-1965 in the Clovis, New Mexico area and as much as 9 feet from 1967-1968. Further evidence of the declining water reservoir supply is indicated by a substantial drop in individual well capacity in much of the extreme portion of the aquifer.

Since the Texas High Plains is a semi-arid region (average annual rainfall is about 18 inches), irrigation water drawn from the Ogallala has been an important input to the agricultural economy. Per acre yields with irrigation, as compared to dry land production, are doubled for cotton and increased two-to-five-fold for grain sorghum, wheat, and corn. Commodities such as soybeans, castor beans, and vegetables are considered as feasible crop alternatives only with irrigation.

Studies of the importance of irrigation to the economy of the Texas High Plains region have shown that in 1959 the total benefits of irrigation was $89.06 per composite irrigation acre. A recent input-output economic study was completed for the region. The total value of all agricultural products sold in 1967 was $1,115 million. Of the total sales, 67 percent resulted from the sale of crops. Livestock represented 33 percent of the value of agricultural sales of the study area in 1967. The advent of cattle feeding operations in the region has greatly expanded this type of agriculture. In 1969, the number of cattle marketed from feedlots was 1,792,000 head. Recent data indicates that in 1972, the number of fed cattle from this region was 3.2 million head. The total benefits to the region from the net increase in crop production from irrigation was estimated to be $1,561.1 million in 1967.

For the Southern High Plains of Texas (south of Amarillo), some estimated effects of the declining water supply are (1) a 65 percent reduction in cotton production, (2) a 91 percent reduction in grain sorghum, and (3) a 22 percent increase in wheat production in 2015 compared to 1966. It is expected that wheat will replace much of the grain sorghum as the shift from irrigation to dry land occurs. With total agricultural output declining as indicated above, significantly less inputs and labor will be required. Therefore, related agribusiness firms will be affected in a similar manner. The implications for rural communities in this area are clear.

Ground water depletion is an important water resource problem affecting the Southern Plains River Basins Region. The depletion problem is most critical in the western part of the region because of lower precipitation. The socio-economic system which has developed in the western portion of the region depends greatly on vast ground water resources in the Ogallala formation. The problems associated with ground water depletion are somewhat similar for all aquifers. However, the most important ground water depletion sub-problem for the Southern Plains River Basins Region was determined to be "Ground Water Depletion in the Ogallala Aquifer."

Alternatives

1. Regulate withdrawals

   a. Local water districts to regulate
   b. State regulation
   c. Regional institutions to regulate
   d. National regulation
   e. Metering - pricing

2. Obtain additional supplies

   a. Interbasin transfer within region
   b. Water importation from outside region
   c. Desalination of regional saline ground water aquifers
   d. Weather modification
   e. Substitute other fluids for some uses

3. Recycle - reuse

   a. Tail water recycle
   b. Sewage effluent utilization
   c. Return flow utilization
   d. Conjunctive use of surface (playa lakes) and ground water

4. Recharge

   a. Playa lake water
   b. Sewage effluent
   c. Tail water
   d. Other surface water sources

5. Reduce delivery losses

   a. Improved transport system
   b. Irrigation canal linings
   c. Drip irrigation systems
   d. Automated distribution systems
   e. Evaporation suppression

6. Reduce application losses

   a. Land preparation
   b. Increase infiltration rates
   c. Tail water recovery systems
   d. Control irrigation scheduling
   e. Drip irrigation systems
   f. Metering - pricing - taxing - legal penalties
   g. Public awareness programs
   h. Maximize efficiency of precipitation in crop production systems

7. Reduce evapotranspiration

   a. Evaporation suppression
   b. Transpiration suppression
   c. Weed control
   d. Plant-water stress control
   e. Replacement by crops of lower transpiration
   f. Modify microclimate
   g. Water harvesting microridges
   h. Drip irrigation systems

8. Do nothing

   a. Develop knowledge to minimize adverse impacts of shifting from irrigation to dry land production
   b. Develop alternatives for region to adjust to declining ground water supply

9. Research the system - new technology

   a. Examine influence of water pricing on introducing improved (new or existing) technology into the system
   b. Increase recoverable water from aquifer
   c. Control water cycle of food production systems
   d. Examine effects of alternative type of development on characteristics and yield of formation

Research Needs Analysis (Preliminary)

Alternative 1 - "Regulate withdrawals"

The withdrawal of ground water is not uniformly regulated throughout the region. Water districts and state agencies are some of the institutions which have the authority to regulate withdrawals in the region. The experimental evidence that this is a feasible alternative is found in the fact that New Mexico laws provide for state wide control of ground water withdrawal. The institution which regulates the withdrawals and the metering procedures has been established and functioning for several years. In theory, this principle could be extended to the aquifer-wide regulation of ground water withdrawals.

1. Will it work? Maybe.
2. Why not?
   a. Each individual state utilizing the ground water from the Ogallala has its own unique political structure. The fact that few states have passed laws to regulate ground water withdrawals indicates that such laws may be politically unfeasible without new knowledge and/or an expanded public information system. Research is needed to identify the type of institutional structure best suited for regulation of ground water withdrawals from regional aquifers. The research should also identify the control mechanisms such as laws, metering, pricing, penalties, public awareness, and/or other legal, social and economic means.

   b. The Ogallala Aquifer is a non-renewable water resource and any withdrawals will result in ground water depletion. The desired optimum rate of ground water depletion for the aquifer has not been clearly established. Research is needed on the impact of the declining water supply on the socio-economic systems involved. This would increase our knowledge about the importance of regulating withdrawals.

Research is also needed on the impact of different rates of withdrawals on these socio-economic systems. If the research establishes that an optimum depletion rate does exist, then the regulating institution could use the information for establishing guidelines.

Alternative 2 - "Obtain additional supplies"

Other water sources are available for use in the region and these could be substituted for ground water use. At the present time, these supplies are not available for use in the region because of economic or political reasons. In some cases, the basic science and technology has not proven the availability and use of these sources.

1. Will it work? Maybe.

2. Why not?

   a. Interbasin transfer of water from the eastern part of the region or other river basins outside the region is under study by various state and federal agencies. The political and economic constraints make this alternative of questionable feasibility at this time.

   b. There are known saline ground water aquifers in the region, but the hydraulic characteristics of these aquifers are relatively unknown. The economics of desalination make the alternative favorable only for high value uses -- industries and municipalities.

   c. Weather modification has been found to increase precipitation in mountain areas during cold seasons. The feasibility of weather modification for warm season clouds, typical of most of the region, has not been determined. An extensive regional research program is needed to test the possibility of providing additional water to the region through weather modification.

   d. For some uses of water, it may be possible to substitute other fluids and conserve the water for high priority uses. For example, other fluids can be used as coolants.

Example concludes but would continue as Alternative 3, etc.

SUMMARY OF PROBLEM ANALYSIS WORKSHOPS

During the course of the project, three problem analysis workshops were held in:

(1) New Orleans, Louisiana, June 5-6, 1973

(2) Arlington, Texas, August 22-23, 1974

(3) Las Cruces, New Mexico, January 6-7, 1975

The systematic problem analysis workshops focused on the three major priority problems for the region which were as follows:

(1) Ground water depletion, ground water pollution, and land surface subsidence

(2) Allocation of water resources, conservation, and environmental impact

(3) Conflicting interests and synergistic effects between energy production and water resources management

A summary of the workshops on each priority problem is provided in the following sections.

Ground Water Depletion

Raphael G. Kazmann

The chairman of the session, R. G. Kazmann of Louisiana State University, started the analysis by deploring the tendency to exhaustively research trivial problems resulting in the pollution of the technical literature. No one ever seems to ask, "How would anyone be able to use the results of this study, if we are successful in finding an answer?"

In the discussion of ground water depletion, four major problem formulations came to mind.

1. Effective life of an aquifer as an economic water supply under conditions of depletion (ground water mining)
2. The increasing mineralization of the water by the encroachment of mineralized water as the supply is depleted
3. Institutional barriers to prolonging the life of the supply--necessity for ground water compacts
4. Defining the physical and hydrologic constants and boundaries of the aquifer in detail to serve as a basis for a mathematical model and later to interface this model with a socio-economic-legal one

The goals and objectives of a study of ground water depletion might be:

1. To establish, in the long term, a steady-state water supply with the use of aquifer storage, i.e., bring withdrawals and all types of recharge (natural and artificial) into balance, or
2. To maximize or optimize the use of the water so as to obtain the most social and economic benefits from the stock of water, or
3. To find out where present trends in withdrawal and use will bring us if no action is taken. The following areas of research might be investigated:
    a. Future water levels and yields under various assumptions of crops and prices

b. Social implications deriving from the results in (a) such as:

(1) Land use patterns
(2) Tax base changes
(3) Population trends
(4) Changes in water use
(5) Trade-offs between economic activity, agricultural production, water use, unemployment, etc.

c. The optimum solution must be physically possible and politically feasible

As applied to the Ogallala aquifer which underlies parts of Texas, New Mexico, Oklahoma, Kansas, and Colorado, there is research to be accomplished in associating the different legal doctrines in use on the distribution and rate of ground water withdrawals. A separate research project might be useful to find out how interstate conflicts could be resolved when one group of irrigators are operating under an assumed economic life of 40 years of water mining while just across the border others are operating on an assumed annual yield basis.

The next question is whether the relevant system and its parameters are known. Is it physically possible to define water use and needs? It would seem that, for the Ogallala Aquifer, even the physical parameters are not adequately known and research is needed to determine the social and political feasibility of any physical solution to the ground water depletion problem.

The research needed, if events take their course, might answer the questions:

1. In interstate aquifers is it worthwhile to try to bring the legal regulations of all neighboring states into uniformity? Should controls on water withdrawal (and priorities of use) be set?

2. What are the economic impacts of depletion?

   a. Water mining (some people will still have an ample economic supply when their neighbors are dry)

b. Economic model depends on an adequate physical model

c. Well completion practices may have an impact on depletion rates

Identification Research in Ogallala

1. How, and to what extent, can costs be expected to rise as water levels fall? Research is needed on:

    a. Thickness and transmissivity of beds

    b. Water thickness remaining

    c. Power available

    d. Value of product

2. What will happen if we do nothing? Some possibilities are:

    a. Poorest land abandoned

    b. Potential new crops identified and grown

    c. Recreational use of area emphasized

    d. Improve efficiency of water use

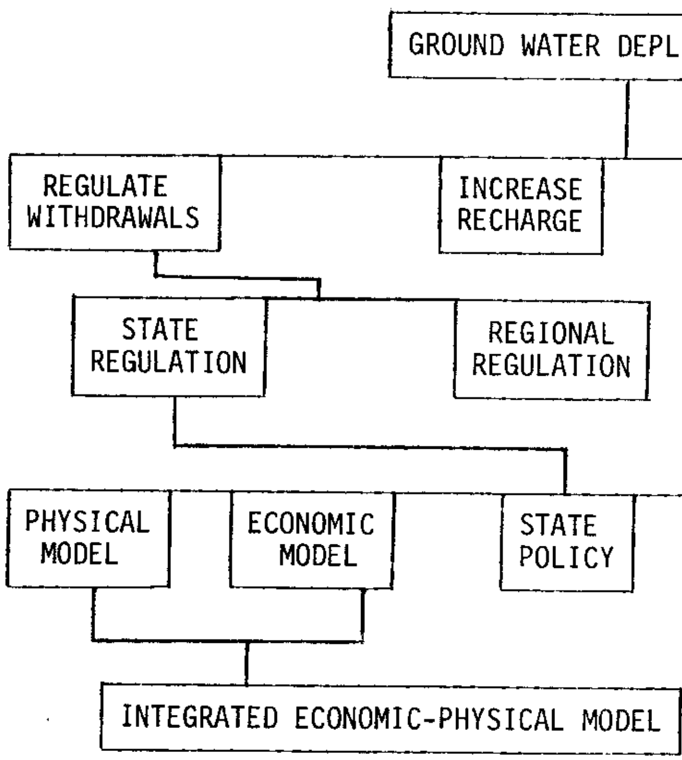
    e. Reduction in rural population

Consequently, research is essential. In any event cost estimates will be needed as a base for evaluation of alternatives.

The possibility of increasing recharge was discussed. Rainmaking was, by consensus, not suitable for an OWRR-financed study. Inadvertent weather modification might be suitable for study to determine limits of rainmaking potential in given areas. Reduction in use was also discussed. The Jackson bill for land use management, and its impact on water use was discussed. Importation of water was mentioned briefly.

The most important joint research project was considered to be the collection of physical data on the Ogallala Aquifer, utilizing mutually agreed upon standards and preparation of a series of base maps to show physical information (water depths, elevation of base of aquifer, transmissivities, thickness, depth to water, TDS, etc.). Then the economist could prepare similar maps using economic parameters to interface with maps physical and hydrologic features.

A diagram of one branch of the study chain follows:



Ground Water Pollution

Marvin T. Edmison

The participants spent some time discussing the schematic diagram and the explanatory material in Dr. Warren Hall's Role of Research in Problem Solving. It soon became apparent that time would not permit us to treat the whole area of ground water pollution in the excellent manner contained in Dr. Hall's systematic procedure. However, the time was well spent and emphasized the complexities involved in surveying a general problem area, breaking it down into suitable sub-problems, and analyzing each in an attempt to identify information gaps where research is needed to provide information necessary for solving the problems.

The participants then developed their own outline of the sub-areas involved in ground water pollution, as follows:

Ground Water Pollution

I. Surface sources of pollution
   A. Man-made (cultural)
      1. Agriculture
         a. Feed lots
         b. Irrigation
         c. Fertilizers and pesticides
      2. Industrial
         a. Manufacturing wastes
         b. Mining wastes
         c. Brine disposal

3. Urban

   a. Runoff

   b. Sewage disposal

   c. Solid waste disposal

B. Natural

1. Salt water

2. Nitrates

3. Other (heavy metals, etc.)

II. Subsurface sources

A. Man-made (cultural)

1. Urban-sewage disposal by subsurface means

2. Agriculture-recharge

3. Industrial

   a. Disposal in wells, shafts, and caverns

      (1) Nuclear
      (2) Oil field injection
      (3) Other industrial wastes
      (4) Thermal

   b. Well drilling-oil and other

   c. Mining-underground wastes

B. Natural--pollution of ground water by movement of salts and other undesirable naturally-occurring substances across interfaces.

Following completion of the outline, the participants decided to take some of the limited time for a semi-detailed analysis of the subproblem, Management of Sewage Disposal in Relation to Possible Ground Water Pollution. Not every step in the Hall analysis was followed. However, it was decided that the problem could be subdivided into alternatives, as follows:

1. Regulation

   a. Permits or licenses

   b. Establishing effluents standards

It was agreed that the participants were not qualified to specify the kind of research that might be needed to determine the best use of permits in the control of sewage disposal. It was agreed that some research in this area might be appropriate. It was also agreed that more research should be done on acceptable standards.

2. Treatment

   a. Urban combined systems

   b. Septic tanks

After considerable discussion, it was agreed that research on improvement of combined systems should be continued, but that there was little, if any, need for more research on septic tanks as such. There was unanimous agreement that much research emphasis should be placed on the fate of liquid wastes dispersed upon saturated and unsaturated soils--in relation to possible ground water pollution. It was also agreed that research is needed on effective use of economic incentives in the management of sewage disposal--both rewarding and punitive. The question of research on improved methods for training of operators and managers of treatment systems was discussed at some length without developing a clear cut majority opinion, although it was agreed that efficient management and operators are essential.

3. Dilution

It was decided that dilution is a well-understood technical tool which is economically unfeasible in most instances--no further research justified.

4. Do nothing

Although no specific research was recommended on the results of a do-nothing policy, it was agreed that such an alternative could only lead to catastrophe. The problems which could result in the San Antonio, Texas, area were cited as an example.

After proceeding this far in considering the problem of management of sewage disposal, it was decided to use the short time remaining to develop a list of research needs in the area of ground water pollution as seen by the participants. Although all were considered to be important, those marked with an asterisk (*) were considered to be urgent as to overall importance and as to the need for action now. They are:

*1. Ground water quality modeling

2. Natural pollution--salts, metals, etc.

3. Oil field brines

4. Well construction and plugging

*5. Fate of pollutants

6. Indirect techniques for determination of aquifer parameters

7. Improved monitoring equipment

8. Effects of pollutants

9. Use of economic incentives

10. Effect of phreatophytes on ground water pollution

*11. Institutional structure for ground water management

12. Urban Wastes in relation to limestone aquifers

*13. Nutrient cycle - nitrogen, phosphorus, etc.

14. Movement of viruses
15. Identification of pollutants
16. Effects of injection wells
17. Improved techniques and equipment for remote sensing
18. Induced degradation of pollutants, e.g., hydrocarbons in situ
19. Improved land use and land use management

*20. Movement of liquid wastes in unsaturated soils

*21. Movement of liquid wastes in carbonates

*22. Effect of liquid wastes on physical characteristics of filter media

Not mentioned above as such was agreement by the participants that concerted research efforts are urgently needed on major aquifers in the region. It is of interest to compare our deliberations with those of other groups, e.g., Summary of Research Needs Workshop of Ground Water Committee; Hydrology Division, American Society of Civil Engineers, December 1972; and the Proposed Report of the National Water Commission. Urgent problems have been identified. Commitment of resources adequate to support necessary research is required immediately, if valid decisions are to be made in time to avert disaster.

Land Subsidence

Elvin J. Dantin

The discussion group on the problem of land subsidence was represented by Mr. A. N. Cameron, U. S. Geological Survey, Baton Rouge, La; Mr. Fred M. Loo, Colorado Division of Water Resources, Denver, Colorado; and Dr. Lonnie L. Jones, Texas A&M University, College Station, Texas. The Chariman of the session, E. J. Dantin, started the session by explaining the use of the flow diagram "The Role of Research in Problem Solving" as an exercise in defining research problems.

All participants agreed that land subsidence was a problem and a timely subject for discussion and analysis. After much discussion the objective was resolved to be--to halt subsidence due to ground water withdrawal.

For each selected alternate course of action the same question and statements came up yielding definitive problems to be studied.

Seven possible courses of action were analyzed with three rejected. The selected alternative courses of action were:

1. Do not alter pumping
2. Reduce pumping
3. Halt pumping
4. Import water and inject

Some of the more pertinient questions or statements relating to 1, 2, 3, 4 are as follows:

1. What are the acceptable limits of land subsidence in a given area? What are we looking at--rates of subsidence? Total subsidence?

2. The problem may be immediate in some areas and long term in another.

3. How long will it take to halt subsidence? Do we apply the brakes? How long will it take to stop?

4. What alternate water supply will be needed to replace that which is being obtained from pumpage?

5. What are the sociological, legal, and economical impacts of the selected alternative courses of action?

6. What about constitutional arrangements? Restraints? It might be easier to do one thing in Louisiana than in Texas.

7. Perhaps 90 percent of the consolidation has occurred and any action to halt or reduce pumping will not be effective.

It was concluded by the group that the problem of land subsidence due to ground water withdrawal should be researched by a multidisciplinary team to evaluate all four alternatives with respect to physical, sociological, economical, institutional, and legal parameters that will effect the selection of a final course of action.

To evaluate these alternatives the following information must be obtained:

1. Identify the problem areas in the Gulf Coast Region

2. Assess and monitor rates of pumpage versus land subsidence area by area and by water bearing zones

3. Ascertain the relationship of pumpage to population, growth, industrial development, etc., accurately

4. Determine alternate sources of water to replace pumpage

Allocation of Water Resources

William L. Powers

I. Interstate river compacts

   A. Arkansas River

   B. Sabine River

   C. Canadian River

   D. Rio Grande River

II. Interstate ground water compacts

   (Specifically the Ogallala compact proposed by Bittinger & Associates)

III. Intrastate water plans

   (Is there any problem common to the development of all the individual state plans?)

IV. State water codes

   (Water rights law)

V. Interbasin transfers

VI. Reservoir management

   A. Water supply

   B. Flood control

   C. Irrigation

   D. Power

   E. Recreation

   F. Navigation

   G. Low flow augmentation

   H. Fish and wildlife

Subproblem Analysis--Reservoir Management

Illustrative Location--Conservation Storage of Major Flood Control Reservoirs in Kansas

Brief Description--The Water Supply Act of 1958 provided for the development of municipal and industrial water and water quality control in connection with flood control, irrigation, or multipurpose projects. This development must be repaid by state or local interests and in turn is the subject to state or local management. The repayment is interest free for up to 10 years after project construction and may be made over a period of up to 50 years. This type of storage exists now in 16 reservoirs throughout the eastern one-third of Kansas and also in eastern Nebraska, Iowa, and Missouri.

The management of this storage deserves appreciable additional attention in all of its hydrologic, biologic, economic, and social dimensions, but is a major policy concern for Kansas in terms of repayment. The Kansas Water Resources Board by state legislative action is responsible for administering the timely repayment of this obligation and must either plan rate schedules for the sale of municipal, industrial, or agricultural water or plan to make the payments from the general revenue fund. The current repayment plan relates directly to a concept of full use of conservation storage by municipalities, industries, or agriculture. It is not clear how the potential need for diffused source pollution control or the possible elevation of recreation to an equal status with water supply would effect this plan. For example, how does potential reservoir yield vary with the implementation of alternative criteria for minimum pools levels? That is, how much yield is sacrificed to maintain higher minimum pools than now visualized and what recreational benefits are thereby obtained? Would a decision to maintain higher minimum pools lead to higher efficiency of water supply use?

These reservoirs are a major surface water resource subject to man's regulation and are an important aspect of Missouri River Basin concern.

Possible Alternatives

I. Use conservation storage as municipal, industrial, or agricultural water supply

   A. Determine the rate structure depending on decisions to:

      1. Charge the same to all customers or allow prices to vary

      2. Charge the same from all reservoirs or allow prices to vary

      3. Charge the same for all amounts or allow prices to vary

   B. Determine the rate contract period depending on:

      1. Administrative difficulties

      2. State statute limitations

   C. Determine the degree of treatment at the reservoir

II. Use conservation storage for recreational purposes

   A. Determine the degree of public and private access

   B. Determine the type, location, and number of facilities required to enhance:

      1. Boating

      2. Fishing and hunting

      3. Picnicking

      4. Camping

      5. Swimming

   C. Determine the effect of private and public development on the water quality

D. Determine the appropriate charges for use or recreation facilities

E. Determine the law enforcement requirements as well as other jurisdictional problems that may arise

III. Use conservation storage as power plant cooling water supply and recycling reservoir

A. Determine the compatibility with other uses in terms of:

1. Water temperature

2. Other water quality parameters

3. Water quantity available

B. Determine evaporation requirements for different sizes and types of power plants

IV. Use conservation storage for dilution of downstream diffused source pollution

A. Determine the relative severity of diffused and point source pollution

B. Determine the technical and institutional management strategy

V. Augment the conservation storage for any prospective use by purchasing the flood control storage and instituting flood plain management downstream

A. Determine the proper mix of flood plain zoning, flood proofing, and flood insurance

B. Affect hydrologic analysis procedures which will expedite the current time consuming and expensive studies required

C. Determine the seasonal variations in need for structural and non-structural flood control and analyze in conjunction with seasonal variations of other uses

VI. Use conservation storage for fish and wildlife refuge

VII. Do not use conservation storage! Let it become part of federally controlled flood control storage

NOTE: Alternatives I, II, and III above could interfer with one another in terms of quality effects and requirements. Also a mutual demand on the quantity of water in terms of evaporation losses and water supply rules out complete compatibility.

Research Needs Analysis--Alternative I.A.1.

"Use conservation storage as municipal, industrial, or agricultural water supply and establish a rate structure which varies between customer types"

Each customer type should be charged a price which is equal to the particular marginal cost of supply. Each customer type also exhibits a water demand curve which describes the willingness to pay for various amounts of water. When both the demand curves and marginal cost of supply curves are known, an optimal price can be established and the total customer benefits can be estimated. This optimal price might well not be the same for each customer type. The demand curve concept can also be used to regulate water use by changing price.

Will it work? Maybe

Why not?

1. The demand curves for municipal, industrial and agricultural users must be quantified

2. The marginal cost of supply must be determined for each type use

3. The rate structure must generate revenue which will meet some proposed repayment schedule to the federal government or else contributions from some other tax source such as the state general tax fund must make up the difference

4. If the optimal rate structure generates revenue greater than that required for repayment some equitable reapportionment must be made

5. Water supply benefits must be appropriately compared to benefits from other alternatives in order to justify any rate schedule

Research Needs Analysis--Alternative II.A.

"Use conservation storage for public recreational purpose"

Recreation is fast becoming a high priority use of reservoir storage. There is evidence that the "value-in-use" for recreation may be higher than the "value-in-use" for other alternatives. It is predicted that recreation demand will increase with time as industrial productivity increases and more public leisure time becomes available. If these assumptions are true, reservoir recreation may assume a high status.

Will it work? Maybe

Why not?

1. Recreation benefits need to be quantified and compared to other alternative benefits
2. 1958 Water Supply Act should be tested to see if recreation qualifies as a proper use
3. Alternative M & I uses must be found and costs determined in order to estimate loss of M & I efficiency
4. Quality deterioration must be predicted for various recreational uses
5. Effect, whether adverse or positive, must be determined on surrounding communities
6. Seasonal recreational use pattern must be established for possible reversion to other uses in "off" season
7. Compatibility of various recreational uses must be established

Water Conservation

William L. Powers

Definition--Water demand exceeds supply in many areas so conservation is needed.

The demand for water in the Southern Plains River Basins Region (SPRBR) increases each year. The National Water Commission estimates the water demand in the SPRBR to be 67.7, 120.1, and 175.3 billion gallons per day in 1980, 2000, and 2020 respectively. The following table shows the future demands and estimated surface water supply for the water resources regions within the SPRBR.

Future water demands and surface supply by water resources region in the Southern Plains River Basins Region expressed in billions of gallons/day.

Water Resources Regions	Future Water Demands 1980	2000	2020	Surface Supply
Lower Mississippi	12.8	28.0	39.4	395
Ark-White-Red	17.5	25.3	31.6	96
Texas-Gulf	29.1	57.3	92.6	39
Rio Grande	8.3	9.5	11.7	5
TOTAL	67.7	120.1	175.3	535

Adapted from Table 5, pages 1-19 of the Draft of the Water Commission Report of 1972 and Plate 86 of the Water Atlas of the United States by Miller et. al. 1973.

From this table it is seen that the Texas-Gulf and Rio Grande water resources region will not have enough surface water to meet their demands. Although not shown in the table, this is also true for areas of western

Kansas and Oklahoma. This means that portions of the projected water demands must be supplied from ground water sources. Many of these sources have shown declining water levels for the period 1940-1970. For example, declines of 10 to over 30 feet are common in some counties of western Kansas. In the High Plains of Texas, yearly declines of water table levels average from 1 to 5 feet per year.

This projected demand for water along with declining water levels suggests a need for more efficient conservation practices. At present the irrigation efficiency ranges from 30 to 75 percent with a national average of about 50 percent. There is a definite need to increase this efficiency especially since a large portion of the future water demand for the High Plains is expected to be used by agriculture.

There is considerable pressure from the public to conserve water. An example is the comment, "Better control of the use of this water must come before we all run dry," taken from an editorial in the May 29, 1971 McPherson (Kansas) Sentinal entitled "How Much Water Can We Use for Irrigation?"

Water is an essential ingredient in many economic activities. Agriculture is one of these activities which is a heavy user of water, particularly in the more semi-arid areas of our region. The National Water Commission Report describes water use in the semi-arid south:

"The Southern High Plains of West Texas comprise all or part of 28 contiguous counties south of the Canadian River bordering New Mexico. Most of the irrigated acreage has been developed since World War II. The population of the area has increased in the major towns and cities during this period and is now over 600,000 (U. S. Bureau of the census, January 1971). The area is heavily dependent on irrigation. Pumpage in 1953-61 averaged five million acre-feet annually, compared to estimates of annual recharge of only 100,000 to 350,000 acre-feet (Hughes and Harmon, 1969). As a result, the resource is being rapidly depleted. Precipitous declines in agricultural production are forecast by 1990, with cotton production reduced to 65 percent of that in 1966 and grain sorghum to 20 percent. These could be offset to some degree by return to dryland farming. By 2015, irrigated acreage, without other sources of water, is expected to decline from four million acres at present to 125,000 acres, water pumpage from 4.1 million to 95,000 acre-feet annually, and value of agriculture production from $430 to $128 million per year (Hughes and Harmon, 1969b). While one may argue about the specifics of the forecasts, there is little argument about the general prospects for the future."

The report indicates that similar situations are developing in portions of New Mexico, Oklahoma, eastern Colorado, and western Kansas.

The growing demand for water due to increased population, energy production, irrigation, and municipal and industrial use has significantly increased our need to conserve our precious water resources. Simultaneously, full and efficient utilization of our water resources will be required. Some alternative actions to achieve those goals are identified below.

Alternative Actions

I. Develop more efficient systems

  A. Municipal and Industrial

    1. Delivery system losses

    2. Recycle--reuse

3. Reduce application losses
4. Conjunctive use
5. Reduce demands
6. Pricing

B. Agriculture

1. Delivery system losses
2. Irrigation system design
3. Irrigation scheduling
4. Reduce evaporation and transpiration
5. Crop and soil management
6. Recycle--reuse

II. Reduce surface water losses

A. Evaporation
B. Water harvesting
C. Land treatment, cropping systems, soil conservation
D. Ground water recharge; infiltration and percolation
E. Impoundment and watershed management

III. Formulate alternative water management policies

A. Pricing; repayment
B. Water law; water rights and water appropriation; ground water and surface water
C. Irrigation requirements, consumptive use
D. Water management districts, watershed management
E. Runoff, non-point pollution
F. State and interstate water plans; interstate compacts
G. Beneficial uses and priorities

1. Flood control
2. Water quality
3. Recreation
4. Irrigation
5. Municipal and industry
6. Fish and wildlife

IV. Educate present water users

A. Water use patterns, water supply, water demand
B. Water distribution and appropriation policies
C. Economic, social, and environmental pressures
D. Information dissemination, public awareness

V. Control water quality

A. Recycle--reuse
    1. Legal, institutional, policy
    2. Treatment
B. Tail water, return flow
C. Tolerant crops
D. Salinity, waste heat, pollutants
E. Runoff
F. Waste treatment
G. Non-point source pollution

VI. Water importation and interbasin transfer

A. Water requirement supply
B. Feasibility
    1. Engineering
    2. Economics

3. Political problems

VII. Weather modification and precipitation augmentation

A. Weather modification techniques

B. Hail and severe storm suppression

C. Measurement and monitoring techniques

D. Effects upon watersheds and impoundments

E. Political, legal, and economic implications

VIII. Control water use

A. Regulate withdrawals

1. Local, state, national policies

2. Metering, pricing, taxation

B. Establish water requirements--consumptive use, municipal, and industrial requirements

C. Educate water users

D. Delivery and application losses

E. Water quality requirements

IX. Do nothing

A do nothing policy would probably result in eventual depletion of some ground water supplies and increase demands for both ground and surface water. Depletion of surface and ground water reserves would dictate reversion to dryland farming and/or rural, urban, and industrial relocation accompanied by severe economic and social implications.

Environmental Impacts

Robert E. Babcock

Definition--Recreational stresses on Arkansas' many rivers and lakes has a definite impact on the environment.

Subproblem Analysis--Recreational stress on lakes and rivers

Buffalo National River

The Buffalo River of northwest Arkansas has become a popular recreation site during the past two decades. Such facilities as the Buffalo River State Park and Lost Valley State Park have been very successful. The river drains 1,338 square miles with an estimated stream acreage of 1,560. It has an average fall of 10 feet per mile and flows beneath magnificent multicolored cliffs which, in the upper reaches, extend nearly 700 feet above the river's clear quiet pools and rushing rapids. It flows through a countryside of mountains ranging in elevation to 2,400 feet, past unique caves and waterfalls, old pioneer cabins, long abandoned homes of cliff dwellers, and spectacular rock formations. Within its watershed may be found some 700 species of plant life, a habitat for some 250 species of birds, and a variety of game animals. In its aquatic habitat may be found a variety of game fishes, expecially the famous smallmouth bass for which anglers travel long distances to lure with rod and reel. The Buffalo River is known throughout the United States for its outstanding recreational opportunities for the fisherman, canoeist, camper, hiker, naturalist, scientist, and others who will marvel at its unique beauty (State Committee on Stream Preservation, 1969).

Public Law 92-237 established the Buffalo National River in March of 1972. Under this legislation, the National Park Service will acquire most of the land along approximately 132 miles of the stream. As a National River, there is little doubt that there will be increased recreational use of the stream. The pressures from use of the river along with the associated activities have the potential of altering water quality within the basin.

In addition to the land which will be acquired by the National Park Service, private lands within the watershed will be subjected to various types of land use patterns which also have the potential of altering the quality of water in the Buffalo River.

The value of the Buffalo River as a national asset is predicated on maintaining a high quality of water throughout the basin. Alteration of water quality can produce distinct changes in the aquatic ecosystems resulting in a dramatic change in the nature of the river.

Beaver Reservoir

The White River System above Beaver Reservoir offers a unique opportunity to study the accumulation of nutrients from various sources in a newly opened body of standing water. This river system is located in northwest Arkansas with the headwaters originating in the Boston Mountains of the Ozark Range. There are no other significant hydraulic structures upstream from Beaver Reservoir. The upper reaches of this drainage system are generally devoid of large population concentrations.

The city of Fayetteville, Arkansas, is the largest city in this system. It releases its sewage effluent into the White River above Beaver

Reservoir. Another city, Springdale, releases its sewage effluent into an ajoining watershed, but portions of the city's urban runoff is released to the reservoir. There is a concentrated area of agriculture activity which is located for the most part on one of the major branches of the main stream of the White River. The agriculture activities of this area are limited mostly to pasture land and poultry production.

Superimposed upon these stresses is the heavy demand for Beaver Reservoir as a recreational area. Bacterial and chemical pollution of Beaver Reservoir has occurred as a result of septic tank drainage from developed recreational areas. The pressure of mountainous terrain and poor soil conditions surrounding the reservoir increases the possibility of poor functioning of the absorption field. This in turn increases the possibility of disease transfer and increased enthrophication of the reservoir. Projections indicate that in excess of two million gallons per day of waste will be produced within the general area of the reservoir by 1990. This volume of waste water will obviously create environmental problems that must be analyzed.

Alternatives

I. Bare-Bones monitoring program
   A. Chemical
   B. Physical
   C. Biological
II. Intensive monitoring program
   A. Remote sensing
   B. Aerial photography

C. Space overflights

D. Ground truth verification (chemical, physical, and biological)

E. Management Information System

III. Feasibility studies

A. New and perceptive means of assessing water quality

B. Recreational area management methods

C. Land management

D. Regulation

IV. Inspirational research

A. Education on new practices

B. New technology

C. New structural measures

V. Do nothing

A. Heavy recreational use

B. Decrease in water quality

C. No base line data on water quality

Energy Production and Water Resources Management

John W. Clark

WATER PROBLEMS ASSOCIATED WITH ENERGY PRODUCTION

Source	Phase	Problem	Alternative	Sub-Problem	Alternative	Sub-Problem	Alternative
1. Crude Oil	A. Drilling	1. Requires water for lubrication and particle removal					
	B. Primary Recovery	1. Brine Disposal	A. Discharge as is	1. Legal 2. Pollution of ground-water and surface water	A. Determine effect of contaminates on water resources	1. Economics	
			B. Dilution	1. Volumes 2. Concentrations			
				3. Source of dilution water	A. Utilize present supplies	1. Legal 2. Economics 3. Transportations	
					B. Further develop water resources	1. Economics 2. Legal 3. Locations 4. Transportation	
					C. Importation	1. See 1-B-1-B-3-B	A. Determine feasibility of interbasin transfers
				4. Increased runoff	A. Determine effect of increased runoff	1. Economics	
			C. Desalt	1. Degree of treatment 2. Desalting method	A. Ion exchange	1. Economics 2. Rates 3. Power requirements 4. Residue disposal	A. Determine uses of residue
					B. Electrodialysis	1. See 1-B-1-C-2-A	
					C. Determine if other methods are practical	1. See 1-B-1-C-2-A	
					D. Develop new methods	1. See 1-B-1-C-2-A	
			D. Separate	1. Degree of treatment 2. Separation process	A. Evaporation	1. See 1-B-1-C-2-A	
					B. Freezing	1. See 1-B-1-C-2-A	
					C. Reverse osmosis	1. See 1-B-1-C-2-A	
					D. Determine if other methods are practical	1. See 1-B-1-C-2-A	
					E. Develop new methods	1. See 1-B-1-C-2-A	
		2. Pollution of ground-water due to improperly plugged wells or deteriorated casing	A. Maintain as is	1. Legal 2. May have adverse effect on future supplies of fresh water	A. Determine effect of contaminants on ground-water resources	1. Detection 2. Economics 3. Aquifer properties 4. Extent of contamination	A. Tracers
			B. Locate and repair leaks	1. Detection 2. Economics 3. Method of repair	A. Tracers		

WATER PROBLEMS ASSOCIATED WITH ENERGY PRODUCTIONS

Source	Phase	Problems	Alternative	Sub-Problem	Alternative	Sub-Problem	Alternative
	C. Secondary Recovery	1. Water-flooding requires large quantity of water	A. Obtain water from available sources	1. Legal 2. Economics 3. Appropriation			
			B. Further develop present resources	1. Legal 2. Appropriation 3. Economics 4. Location			
			C. Importation	1. Legal 2. Economics 3. Transportation			
			D. Treatment and utilization of brine produced by primary recovery	1. See 1-B-1-C and 1-B-1-D 2. Filtering 3. Settling 4. Corrosion inhibition 5. Softening 6. Bactericide			
		2. Water-flooding may pollute groundwater resources	A. Insure proper quality of water is used for water-flooding	1. Enforcement 2. Economics 3. Monitoring			
			B. Insure that mixing does not occur	1. See 1-C-2-A			
			C. Determine effect of improper mixing on fresh water supplies	1. Economics 2. Monitoring			
	D. Processing	1. Requires large quantity of suitable water	A. See 1-C-1				
			B. Treat saline water resources	1. See 1-B-1-C and 1-B-1-D			
		2. Produces much waste water	A. Discharge as is	1. See 1-B-1-A			
			B. Dilution	1. See 1-B-1-B			
			C. Treatment	1. See 1-B-1-C and 1-B-1-D			
		3. Thermal pollution due to cooling water	A. Discharge as is	1. Legal 2. Pollution of surface water	A. Determine effect of heated water on aquadic life		
			B. Dilution	1. See 1-B-1-B			
			C. Treatment	1. Method to use	A. Cooling towers	1. Economics 2. Losses	
					B. Spray or holding ponds	1. Economics 2. Losses	
	E. Transportation	1. Effect of oil spills on environment	A. Neglect effect	1. Legal 2. Effect on aquadic life 3. Esthetics	A. Determine effect		
			B. Reduce spills	1. Method	A. Early detection	1. Economics	
					B. Better supervision	1. Economics	
					C. Strict enforcement of regulations	1. Economics	
					D. Exercise more caution		
			C. Recovery	1. Recovery method	A. Skimmers	1. Economics	
					B. Absorpsion techniques	2. Residue disposal	
					C. Develop more efficient recovery devices	1. Economics 2. Technology	

WATER PROBLEMS ASSOCIATED WITH ENERGY PRODUCTIONS

Source	Phase	Problems	Alternative	Sub-Problem	Alternative	Sub-Problem	Alternative
2. Natural Gas	A. Drilling	1. Requires water for lubrication and particle removal					
	B. Primary Recovery	1. Brine disposal if Associated Gas	A. See 1-B-1				
	C. Transmission	1. Separators produce small quantities of waste water					
		2. Cooling of compressor stations	A. Water may be utilized	1. Cooling of water	A. Cooling towers	1. Evaporation 2. Economics 3. Rates	
					B. Spray ponds	1. Evaporation 2. Economics 3. Rates	
	D. Secondary Recovery	1. See 1-C					
	E. Processing	1. Absorption extraction method requires water	A. See 1-C-1	1. Cooling of equipment	A. Water for coolant	1. Cooling of water	A. Cooling towers
				2. Treatment of water	A. See 1-C-1-D		B. Holding Ponds
		2. Refrigeration method requires water	A. See 1-C-1	1. Cooling of water	A. Cooling towers	1. Economics 2. Rates 3. Evaporation	
					B. Holding ponds	1. Economics 2. Rates 3. Evaporation	
				2. Treatment of water	A. See 1-C-1-D		
3. Coal	A. Strip Mining	1. Acid mine drainage	A. No action	1. Legal 2. Possible Pollution of surface and ground water resources	A. Determine extent of and effect of contaminates on water resources	1. Economics 2. Detection	
			B. Control drainage	1. Defining system characteristics 2. Acid formation rates of refuse pile			
				3. Testing of potential abatement measures 4. Economics	A. Implementation of best procedure	1. Evaluation of degree of abatement	
		2. Soil Erosion	A. No action	1. Legal 2. Loss of soil 3. Excessive sediment to surface water	A. Determine quantity of sediment	1. Monitoring	
					B. Establish holding ponds	1. Economics	
			B. Control erosion	1. Method to use	A. Provide vegetation	1. Vegetation may not grow	A. Lime treatment of soil B. Provide layer of topsoil
					B. Terrace	2. Economics	
		3. Esthetics	A. Reclaim land	1. Economics 2. Political 3. Technical feasibility			
				4. Large water requirement	A. See 1-C-1		
				5. Leveling 6. Soil treatment 7. Vegetation	A. See 3-A-2-B-1-A		

WATER PROBLEMS ASSOCIATED WITH ENERGY PRODUCTIONS

Source	Phase	Problems	Alternative	Sub-Problem	Alternative	Sub-Problem	Alternative
	B. Processing	1. Crushing and piling operations create much dust	A. Water used to suppress dust	1. Possible detrimental effects of drainage	A. Determine effect of drainage on environment	1. Economics	
					B. Treatment of waste water	1. Method of treatment 2. Economics	A. See 1-B-1-C and D
					C. Discharge as is	1. Legal	
				2. Availability of water	A. See 1-C-1		
		2. Transportation of ash	A. Water used to transport ash	1. Waste water produced	A. Treatment of waste water	1. Method of treatment	A. See 1-B-1-C and D
					B. Discharge as is	1. Legal 2. Effect of water resources	A. Determine effect
				2. Availability of water	A. See 1-C-1		
		3. Dust suppression on roads	A. Water used to suppress dust	1. Availability of water	A. See 1-C-1		
4. Coal Gasification	A. Mining of coal	1. See 3-A	A. Determine feasibility of in-situ operations				
	B. Conversion process	1. Condenser cooling requires large quantities of suitable water	A. See 1-C-1				
			B. Treat saline water resources	1. See 1-B-1-C and 1-B-1-D			
			C. Use another cooling media	1. Economics 2. Loss of efficiency			
			D. Recirculate	1. Loss of efficiency 2. Rates 3. Evaporation 4. Scale buildup 5. Economics			
		2. Thermal pollution of "once through" water	A. Discharge as is	1. Legal 2. May adversely affect aquatic life	A. Determine degree of pollution	1. Economics	
					B. Determine effect on aquatic life	1. Economics	
			B. Mix with cool water	1. Availability of cool water 2. Economics 3. Rates 4. Degree of thermal pollution	A. See 1-C-1		
			C. Cool before discharge	1. Method to use	A. Holding ponds	1. Rates 2. Economics	
					B. Cooling towers	1. Rates 2. Economics	
		3. Process consumes water	A. Use process which consumes least quantity of water	1. Possible loss of conversion efficiency			
			B. Availability of water	1. See 1-C-1			
		4. Much waste water produced	A. Discharge as is	1. See 1-B-1-A			
			B. Treatment of wastes	1. See 1-B-1-C and 1-B-1-D			
		5. Large evaporation losses in absorption refrigeration systems	A. Accept losses	1. Large water requirement	A. See 1-C-1		
			B. Determine ways to reduce evaporation	1. Economics			
			C. Use mechanical refrigeration	1. Economics			

WATER PROBLEMS ASSOCIATED WITH ENERGY PRODUCTIONS

Sources	Phase	Problems	Alternative	Sub-Problem	Alternative	Sub-Problem	Alternative
5. Nuclear Fission	A. Mining and ore processing	1. Mining and crushing of ore may require small amounts of water					
		2. Water used in low-grade ore processing	A. See 1-C-1				
		3. Waste water disposal	A. Discharge as is	1. Legal 2. Possible detrimental effects of contamination	A. Determine effect of plant effluent on environment		
			B. Utilized tailings ponds	1. Possible pollution of ground-water resources	A. Monitor ground-water concentrations		
			C. Treatment	1. See 1-B-1-C and D			
		4. Some water used for dust control					
	B. Fuel preparation	1. Isotopic separation	A. Gaseous Diffusion	1. Requires large power plant	A. See 9-A		
	C. Plant operation	1. Requires high purity water	A. Treat intake water	1. Treatment method	A. See 1-B-1-C and D		
		2. Cooling of reactor	A. Water used as a coolant	1. Requires large amounts of water	A. See 1-C-1		
				2. Thermal pollution	A. Discharge as is	1. Legal 2. Possible detrimental effect on aquatic life	A. Determine effect on aquatic life
					B. Mix with cool water	1. Availability of cool water 2. Economics 3. Rates 4. Degree of thermal pollution	A. See 1-C-1
					C. Cool before discharge	1. Method to use	A. See 4-B-2-C-1
					D. Recirculate	1. See 4-B-1-D	
		3. Discharged water must be potable	A. Determine ways to reduce radioactive content of low-level wastes	1. Method to use	A. Filtration	1. Rates 2. Economics	
					B. Ion-exchange	1. See 1-B-1-C-2-A	
					C. Evaporation	1. See 1-B-1-C-2-A	
	D. Safety	1. Neutron moderator	A. Water utilized to detect increases in power				
		2. Emergency core cooling required	A. Water used for core spray and low-pressure injection				
			B. Water used for suppression pools				
	E. Waste Disposal	1. Discharge of radioactive waste water	A. Discharge as is	1. Legal 2. Monitoring 3. Possible detrimental effect on environment	A. Determine impact on environment		
			B. Mix with cooling water to meet discharge criteria	1. Legal 2. Monitoring 3. Economics 4. Rates	A. Determine impact on environment		
			C. Treatment	1. See 1-B-1-			

WATER PROBLEMS ASSOCIATED WITH ENERGY PRODUCTIONS

Sources	Phase	Problems	Alternative	Sub-Problem	Alternative	Sub-Problem	Alternative
6. Shale Oil	A. Site Selection	1. Highly dependent on water supply	A. See 1-C-1				
		2. Probable long-life projects requiring much domestic water	A. See 1-C-1				
	B. Mining	1. Large quantities may be required in mining	A. See 1-C-1				
			B. Utilize in-situ combustion	1. May be detrimental to aquifers and ground water	A. Determine effect of in-situ combustion on aquifers and ground water		
	C. Refining	1. Distillations to gasoline, naphtha, crude burning oil, etc., require suitable water for steam	A. See 1-C-1				
		2. Gases are scrubbed in water towers	A. See 1-C-1				
		3. Conversion to heavy oil and paraffin requires refrigeration	A. Use water for absorbsion refrigeration	1. Water supply	A. See 1-C-1		
		4. Plant wastes	A. Discharge as is	1. Legal 2. Possible detrimental effects on environment	A. Determine effects on environment		
			B. Treatment	1. Method	A. See 1-B-1-C and D		
7. Solar	A. Collection	1. Most efficient collectors are expensive	A. Determine feasibility of using water as a collection media	1. Economics 2. Technology			
	B. Heat transfer and storage	1. Chemical storage mediums are expensive	A. Determine feasibility of using water as a storage media	1. Economics 2. Technology			
	C. Power Generation	1. Generation of steam method requires large amounts of condenser cooling water	A. See 1-C-1				
		2. Cloudy days and nights	A. Supplement solar with another form of energy	1. See other energy sources			
			B. Locate sites in southwest	1. Water needed for growth	A. See 1-C-1		
8. Hydropower	A. Location of site	1. Most feasible sites of large plants have already been exploited	A. Determine feasibility of available small sites	1. Streamflow 2. Reduction of streamflow through consumptive use 3. Economics 4. Legal 5. Capacity			

WATER PROBLEMS ASSOCIATED WITH ENERGY PRODUCTIONS

Sources	Phase	Problems	Alternative	Sub-Problem	Alternative	Sub-Problem	Alternative
	B. Power Generation	1. Fluctuations in demand for power	A. Construct storage reservoirs	1. Streamflow 2. Legal 3. Evaporation 4. Seepage 5. Silting 6. Stability 7. Capacity 8. Economics	A. Develop multi-purpose reservoirs	1. All water is not available for power generation	A. Determine best use of water resources
9. Electric Steam Generation	A. Operation	1. Condenser cooling requires much suitable water	A. See 1-C-1				
			B. Recirculate	1. Economics 2. Rates 3. Cooling	A. Cooling towers	1. Economics 2. Evaporation	
					B. Holding or spray ponds	1. Economics 2. Evaporation	
				4. Dissolved solids increase 5. Reduced cooling efficiency			
		2. Thermal pollution of "once through" water	A. See 5-C-2-A-2				
		3. Boilers require high-quality water	A. See 1-C-1-D				
		4. Water may be utilized for air pollution control	A. See 1-C-1	1. Disposal of effluent	A. See 1-B-1		
10. Geothermal	A. Drilling	1. Water required for lubrication and particle removal					
	B. Steam Wells	1. Abrasive particles associated with steam	A. Determine ways to remove particles	1. Economics 2. Technology 3. Reduction of efficiency			
			B. Use Secondary heating fluid	1. Fluid to use 2. Reduction of efficiency 3. Economics			
		2. Rate of depletion of reservoir steam	A. Determine reservoir steam supply	1. Economics 2. Technology			
		3. Disposal of waste heat	A. Discharge to surface water	1. Legal 2. Possible detrimental effect on aquatic life	A. Determine effect on aquatic life		
			B. Cool before discharge	1. Method	A. Holding or spray ponds	1. Rates 2. Economics	
					B. Cooling towers	1. Rates 2. Economics	
		4. Unknown effect of added moisture to atmosphere	A. Determine effect on atmosphere	1. Technology 2. Economics			
		5. Highly corrosive gases	A. Develop corrosion Control	1. Method 2. Economics	A. Cathodic protection B. Coatings C. Inhibitors		
			B. Use secondary heating fluids	1. See 10-B-1-B			

WATER PROBLEMS ASSOCIATED WITH ENERGY PRODUCTIONS

Source	Phase	Problem	Alternative	Sub-Problem	Alternative	Sub-Problem	Alternative
		6. Seismic effects from release of pressure	A. Determine seismic effects	1. Technology 2. Economics			
	C. Hot Water Wells	1. Control of corrosive water	A. See 10-B-5				
		2. Disposal of of boron and ammonia	A. Injection wells	1. Drilling 2. Rates 3. Seismic effects			
		3. Highly mineralized water	A. Develop control of mineral deposition	1. Economics			
			B. Treatment of mineral water	1. See 1-B-1-C and D			
		4. Relatively low temperature of water	A. Develop low temperature turbines	1. Loss of efficiency 2. Economics			
			B. Utilize secondary fluids	1. Loss of efficiency 2. Economics			
		5. Land subsidence from pumping	A. Minimize effects of subsidence				
			B. Injection of water	1. See 10-B-6-A 2. See 1-C-1	A. Recirculate		
		6. Reliability of supply	A. Determine reservoir supplies	1. Technology 2. Economics			
		7. Disposal of heated waste water	A. Discharge as is	1. See 10-B-3-A			
			B. Cool before discharge	1. See 10-B-3-B			
	D. Hot Rock Wells	1. Impermeability of rocks	A. Nuclear blast	1. Legal 2. Economic 3. Control 4. Subsidence 5. Seismic			
			B. Hydraulic fracturing	1. Pressures 2. Control	A. Determine control methods	1. Economics	
				3. Supply of water	A. See 1-C-1		
		2. Supply of water for circulation	A. See 1-C-1				
		3. Treatment of water after circulation	A. See 1-B-1				
11. Wind	A. Power Generation	1. Windless days	A. Store excess power on windy days	1. Method to use	A. Electrolysis of water	1. High quality water needed	A. See 1-B-1-C and D
						2. Use of H_2 & O_2	A. Burn B. Combine with organics to form methane & methanol
					B. Compress air		
					C. Pump water to higher elevation	1. See 1-C-1	
			B. Supplement with other energy sources	1. See other sources			

WATER RESOURCES RESEARCH PROGRAM FOR THE SOUTHERN PLAINS RIVER BASINS REGION

Jack R. Runkles

Priority Water Resources Problems and Sub-problems for the Southern Plains River Basins Region

The problem analysis workshops provided the information necessary to establish priorities for problems, sub-problems, sub-sub-problems, etc. in the Southern Plains River Basins Region. Most of the common problems associated with water quantity, quality, planning, and management do occur in the region; but the intensity of each problem varies within the region. Present priorities will change, depending on progress of research and technology in water resources. Table 2 lists the regional problems and sub-problems according to the following classification:

1. A "Critical" problem (C) is one deemed to be of such decisive importance that its solution is essential to the future welfare of the region.
2. A "Severe" problem (S) is an extremely exigent one requiring immediate remedy if a highly undesirable condition is to be corrected or avoided.
3. An "Important" problem (I) is one, the solution to, or correction of which will provide a definite improvement in the socio-economic or physical condition of the region.
4. A "Minor" problem (M) is one which is annoying, troublesome, or causes minor hardships or inconvenience but whose correction would create a distinctly improved condition or situation.

Management of the excess water is an important sub-problem in the region. Floods are serious and expected to become critical in the next few years. There needs to be continuing efforts in the region to reduce erosion, provide drainage and salvage, and conserve water as much as

Table 3. Priority Classification of Water Resources Problems for the Southern Plains River Basins Region.

PROBLEM AREAS		Priority
I. WATER QUANTITY PROBLEMS		
A. Management of Excess Water		
1. Floods		S
2. Erosion		I
3. Drainage		I
4. Salvage and Conservation		I
5. Damage Prevention		
6. Floods - Hurricane Related from Land Subsidence		S
B. Supply Availability Problems (in & off channel)		
1. Watershed Use Impact		I
2. Seasonally Deficient Supplies		S
3. Annual Short Supply		S
4. Drought Frequency & Persistence		S
5. Minimum Flow Maintenance		S
6. Ground Distribution & Transport		
7. Ground Recharge		C
8. Recreational Requirements		I
9. Strip Mining Reclamation Requirements		C
C. Water Utilization Problems		
1. Reclamation and Reuse		S
2. Irrigation Use Efficiency		C
3. Urban Use Efficiency		I
4. Industrial Use Efficiency		I
5. Recreational & Wildlife Efficiency		I
6. Quantity-Quality Interactions		S
7. Wetlands		S
8.		
D. Water Allocation Problems		
1. In Channel Reservation		S
2. Off-Channel Non-Consumptive Use		
3. Off-Channel Consumptive Use		C
4.		
5.		

CLASSIFICATION LEGEND

C – Critical
S – Severe
I – Important
M – Moderate

Table 3. Continued.

PROBLEM AREAS		Priority
II. WATER QUALITY PROBLEMS		
A. Groundwater Quality Protection		
1. Saline Intrusion		S
2. Surface Leachates		S
3. Toxic Trace Substance		S
4. Deepwell Waste Disposal		S
5. Oil & Gas Production		C
6.		
B. Upland Watershed Quality Degradation		
1. Diffuse Sources of Contaminants		
(a) Nutrients		S
(b) Pesticides & Herbicides		S
(c) Feedlot Runoff		S
(d) Organic Residues		I
(e) Soil Erosion		I
(f) Mining Residues – Strip Mining		S
(g) Other Cultural Waste		M
(h) Land Use Patterns		
(i) Salinity Management		C
(j)		
2. Point Source of Contaminants		
(a) Industrial Waste		S
(b) Urban/Domestic Waste		S
(c)		
(d)		
C. Lake and Reservoir Quality Degradation		
1. Recreational Development		S
2. Diffuse Sources		I
3. Bio-Physical-Chemical Interaction		I
4. Water Level Controls		I
5. Heat Discharge		I
6. Saline Accumulations		I
7. Deoxygenation		S
8. Eutrophication		S
9. Sediment Water Exchange of:		
(a) Nutrients		I
(b) Heavy Metals		I
(c) Chlorinated Hydrocarbines (etc.)		I
10.		
11.		
D. Inland & Coastal Wetland Quality Mgmt.		
1. Channelization Impact Assessment		I
2. Toxic Waste Impact Assessment		S
3. Dredging and Filling Impact Assessment		S
4. Sedimentation		S
5. Bio-Physical/Chemical Interactions		I
6. Contaminated Inflow		S
7. Flushing Characteristics		I
8. Deep Water Port Impact Assessment		S
E. Estuarine Quality Problems		
1. Dredging Impacts		I
2. Heated Discharge Impacts		I
3. Industrial Wastes		I
4. Urban/Domestic Waste		I
5. Bio-Physical-Chemical Interactions		S
6. Shoreline Area Land Use Control		S
7. Salt Water Intrusion		S
8. Deep Water Port Impacts		S
9.		
F. Urban Water Problems		
1. Diffuse Sources of Pollution		
2. Combined Sewers		
3. Urban Land Development Impacts		S

Table 3. Continued.

PROBLEM AREAS		Priority
III. PLANNING AND MANAGEMENT PROBLEMS		
A. Operations		
1. River Regulations		I
2. Canals and Aqueducts		I
3. Urban Water Treatment		I
4. Urban Water Distribution		I
5. Waste Water Collection		S
6. Waste Water Treatment		S
7.		
8.		
B. Planning Methodologies		
1. Objective Identification & Measurement		C
2. Objective Interrelationships		S
3. System Behavior Modeling		I
4. Alternatives Assessments		C
5. Trade-Off Analysis		C
6. Pricing Practices		
7. Impact of Ground Water Develement		C
8. Impact of Energy Cost		C
C. Regional Management		
1. Water Supply Systems - Interbasin Transfer		C
2. Waste Treatment Systems		I
3. Land Use Management Systems		S
4. Regional Resource Management		I
(a) Water based recreation		I
(b) Watersheds		I
5. Institutional Requirements		S
6. Legal Requirements and Constraints		S
7. Ground Water Management		S
8.		

practical. A serious problem in the Gulf Coast area of the region is land subsidence and potential flooding as a result of hurricanes which frequently occur.

Water supply problems are some of the most significant facing the region. A large part is affected annually and seasonally by deficient water supplies for agriculture as well as for municipalities and industry. Drought and pestilence occur too often in the region and result in a serious water supply problem. Maintenance of minimum flow is serious on many of the streams because of the seasonal distribution of rainfall and inadequate storage facilities. In the portion of the region which draws heavily on ground water for irrigation, ground water recharge is a critical problem needing immediate attention. The excess surface water which does occur at times during high rainfall periods should be salvaged and returned to the ground water for future use. Because of the new energy problem facing the U. S., the coal deposits in the region may be strip mined at a greater rate, thus putting additional stress on an already fully committed water resource. This expected increase in strip mining would create a very critical water supply problem for the region.

The most critical water utilization problem in the region is the efficient use of irrigation water. A substantial amount of irrigation occurs and perhaps one of the highest priorities is improving efficiency to maintain a viable irrigation agriculture in this region. Reclamation and reuse of water needs to be expanded as much as practical. The wetlands in the higher rainfall portion of the region should be better utilized for productive purposes.

Concerning water allocation, the region has a very critical problem in off-channel consumptive use along the major streams. This off-channel consumptive use is largely a result of irrigation and improving efficiency would make a contribution to solving this problem. Also, phreatophytes must be controlled. In-channel reservation is seriously low at this time on many important river basins.

Ground water quality protection is extremely important. Since ground water is so important to the region, it is necessary that the ground water resources be protected from pollution from a number of sources. Surface leachate, toxic substances, and deep well disposal all need critical evaluations so as to prevent pollution of the ground water sources. Ground water pollution from oil and gas production activities associated with secondary recovery and improperly plugged wells or deteriorated casings is a critical problem. Heavy ground water withdrawals at certain locations along the Gulf Coastal Plains is causing saline water intrusion and this problem demands immediate attention to prevent pollution of the ground water.

Maintaining the upland watershed quality is important. The diffuse sources of pollution such as nutrients, pesticides, and herbicides associated with agricultural productivity should be studied in order to prevent them from degrading the watershed quality. Potential pollution from feedlot waste is still a serious problem for the region. Salinity management is also a critical problem especially in the Rio Grande watershed. Point sources of contaminates from industrial, urban, and domestic waste need constant attention to reduce pollution of watersheds.

Recreation development is expanding on many of the lakes and reservoirs in the region. This development and the associated waste is causing serious pollution of lakes and reservoirs. Waste management and treatment for this type of development should be investigated.

The impact of toxic wastes on the quality management in the inland and coastal wetland should be assessed. Sedimentation is excessive on many basins but inadequate to maintain the shoreline at other locations. Contaminated inflows remains a serious problem especially in the highly industrial areas. Dredging and filling has caused serious problems in wetlands. The coastal shoreland area land use control is deficient and is becoming very critical in the region. Two deep water ports are planned for the region and the impact of these on the water resources is a serious potential problem. In urban water problems, the urban land development impacts should be evaluated to determine the effect on water quality.

The planning and management problems are extremely important in the region. Wastewater collection and treatment problems are serious and need attention to prevent these from becoming more critical in time. Planning methodologies are critically deficient in the region especially on social and economic parameters. Objective identification and measurement is critical at this time. Objective interrelations are not well known and limit good planning. Assessment of alternatives is critical as is trade-off analysis. The impact of ground water development is extremely critical in the area especially related to irrigation from ground water and land subsidence. Since the region is the largest domestic supplier of energy resources, the impact of energy costs is critical in consideration of future planning of water resources. Impact of energy cost is perhaps one of the most critical problems at this time in the region.

Regional management for water supply systems need to be evaluated. Interbasin transfer is a critical problem that needs evaluation. Interbasin transfer of water within and external to the region should be evaluated. Land use management systems for the region are deficient. Institutional requirements, legal requirements and constraints, are deficient for good ground water management and need to be improved so as to provide better utilization of surface and ground water resources.

Research Needs for Priority Water Resource Problems in the Southern Plains River Basins Region

In view of the numerous priority water resource problems and sub-problems identified for the region, only those rated as critical and serious were considered for evaluation of research needs. In evaluating the knowledge gaps associated with the solution of certain problems and the research needs related to these knowledge gaps, consideration was given to current water resources research programs at the federal and state level. The priority research needs for the critical and serious water resource problems in the region are given in Tables 3, 4, 5, and 6.

Management of excess water is a significant problem in the region especially in the area of floods, including those related to land subsidence. The regional flood sub-problem has knowledge gaps in systems and processes associated with hydrology, biology, and planning and in engineering works. Critical research needs are associated with sediment control systems and erosion control systems. Also, research needs exist in the fields of drainage systems, flood dynamics, and sediment transport and deposition processes. Research in the flood plains ecosystems is needed to better understand the impact of flooding on these systems.

Table 4. Research Needs for Priority Water Quantity Problems and Sub-Problems in the Southern Plains River Basins Region.

RESEARCH NEEDS

I HYDROLOGICAL SYSTEMS AND PROCESSES

PROBLEM AREAS	PERTINENT PROBLEM AREA	A. Precipitation	B. Non-Channel Run-off Response	C. Channel Run-off Response	D. Infiltration	E. Interflow	F. Groundwater Recharge	G. Groundwater Reservoirs	H. Plant-Soil-Water Interactions	I. Evaporation	J. Flood Dynamics	K. Statistics of Precipitation	L. Statistics of Run-off	M. Drought	N. Soil Erosion	O. Sediment Transport and Deposition	P. River, Lake, and Reservoir Mechanics	Q. River, Lake, and Reservoir Geo Chemistry	R. River, Lake, and Reservoir Bio-Hydrology	S. Water Geochemistry	T. Snow, Ice, Permafrost	U. Karst Hydrology	V.	W.	X.	Y.	Z.
I. WATER QUANTITY PROBLEMS																											
A. Management of Excess Water																											
1. Floods											S					S											
2. Erosion																											
3. Drainage																											
4. Salvage and Conservation																											
5. Floods-hurricane related from land subsidence							I	I			I																
B. Supply Availability Problems (in & off channel)																											
1. Watershed Use Impact																											
2. Seasonally Deficient Supplies		C							C	S				C													
3. Annual Short Supply		C							C	S				C													
4. Drought Frequency & Persistance		C							C	S				C													
5. Minimum Flow Maintenance		C																									
6. Ground Distribution & Transport																											
7. Ground Recharge							C	S																			
8. Recreational Requirements																											
9. Strip Mining Reclamation Requirements					S		S	S							S	S											
C. Water Utilization Problems																											
1. Reclamation and Reuse																											
2. Irrigation Use Efficiency									C																		
3. Urban Use Efficiency																											
4. Industrial Use Efficiency																											
5. Recreation & Wildlife																											
6. Quantity-Quality Interaction															S	S		I	I	I							
7. Wetlands											I					I		I	S	I							
8.																											
D. Water Allocation Problems																											
1. In Channel Reservation																											
2. Off-Channel Non-Consumptive Use																											
3. Off-Channel Consumptive Use									C																		
4.																											
5.																											

CLASSIFICATION LEGEND

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Table 4. Continued

PROBLEM AREAS	PRIORITY PROBLEM AREA	A. Forested Upland Ecosystems	B. Scrub and Brush Upland Ecosystems	C. Grassland Ecosystems	D. Arid and Semi-Arid Ecosystems	E. Agricultural Ecosystems	F. Flood Plain Ecosystems	G. Creek and Intermittent Stream Ecosystems	H. Aggrading River Ecosystems	I. Degrading River Ecosystems	J. Pond and Pothole Ecosystems	K. Lake and Reservoir Ecosystems	L. Great Lakes Ecosystems	M. Freshwater Marsh and Swamp Ecosystems	N. Coastal Marsh and Swamp Ecosystems	O. Estuarine Ecosystems	P. Bio-Degradation Processes	Q. Bio-Accumulation Processes	R. Bio-Chemical Conversions	S. Photosynthesis Processes	T. Transpiration-Respiration Processes	U. Bio-Control Interactions	V. Toxin-Organism Reactions	W. Biosystem Recuperation Dynamics	X.	Y.	Z.
		RESEARCH NEEDS																									
		II BIOLOGICAL SYSTEMS AND PROCESSES																									
I. WATER QUANTITY PROBLEMS																											
A. Management of Excess Water																											
1. Floods							S																				
2. Erosion																											
3. Drainage																											
4. Salvage and Conservation																											
5. Flood-hurricane related from land subsidence															I	I											
B. Supply Availability Problems (In & off channel)																											
1. Watershed Use Impact																											
2. Seasonally Deficient Supplies					I	I																					
3. Annual Short Supply					I	I																					
4. Drought Frequency & Persistance					I	I																					
5. Minimum Flow Maintenance																											
6. Ground Distribution & Transport																											
7. Ground Recharge																											
8. Recreational Requirements																											
9. Strip Mining Reclamation Requirements																											
C. Water Utilization Problems																											
1. Reclamation and Reuse																											
2. Irrigation Use Efficiency																											
3. Urban Use Efficiency																											
4. Industrial Use Efficiency																											
5. Recreation & Wildlife																											
6. Quantity-Quality Interaction																											
7. Wetlands								C						S	S	I											
8.																											
D. Water Allocation Problems																											
1. In Channel Reservation																											
2. Off-Channel Non-Consumptive Use																											
3. Off-Channel Consumptive Use						I																					
4.																											
5.																											

CLASSIFICATION LEGEND

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Table 4. Continued

RESEARCH NEEDS

III SOCIO-ECONOMIC SYSTEMS AND PROCESSES—Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Social Goal Identification & Measurement	1 Income Production	2 Income Distribution	3 Health	4 Social Mobility	5 Environmental Protection	6 Recreation	7 Employment	8 Other	B Quantification and Measurement of Beneficial Impacts	1 Economic Projections	2 Direct User Economic Impacts	3 Indirect User Economic Impacts	4 Environmental Improvement	5 Recreational Opportunity	6 Other Social Benefits	7 Local, Regional & National Accounting of Costs and Benefits	C Quantification and Measurement of Non-Beneficial Impacts	1 Economic Cost of Achievement	2 Social Disruptions Direct and Indirect	3 Environmental Impacts	D Economic-Market System Adjustments and Trade Offs	E Social Allocation & Adjustment of Beneficial and Non-Beneficial Impacts	F Single Jurisdiction Governmental Institutions	G Multiple Jurisdiction Governmental Institutions	1 Regional Authorities	2 State Authorities	3 Interstate Compacts and Commissions	4 Federal Agencies	5 International Commissions	H Interactions of Single Purpose Boards and Authorities
I. WATER QUANTITY PROBLEMS																																
A. Management of Excess Water																																
1. Floods																																
2. Erosion																																
3. Drainage																																
4. Salvage and Conservation																																
5. Flood-hurricane related from land subsidence					I	S									I			C		C	C	S					C					S
B. Supply Availability Problems (in & off channel)																																
1. Watershed Use Impact																																
2. Seasonally Deficient Supplies																																
3. Annual Short Supply																																
4. Drought Frequency & Persistence																																
5. Minimum Flow Maintenance																																
6. Ground Distribution & Transport																																
7. Ground Recharge													C	C	S		S										C		S			
8. Recreational Requirements																																
9. Strip Mining Reclamation Requirements																																
C. Water Utilization Problems																																
1. Reclamation and Reuse													S	S			I															
2. Irrigation Use Efficiency																																
3. Urban Use Efficiency																																
4. Industrial Use Efficiency																																
5. Recreation & Wildlife																																
6. Quantity-Quality Interaction																																
7. Wetlands																																
8.																																
D. Water Allocation Problems																																
1. In Channel Reservation						S	S																									
2. Off-Channel Non-Consumptive Use																																
3. Off-Channel Consumptive Use																																
4.																																
5.																																

CLASSIFICATION LEGEND

C – Critical
S – Severe
I – Important
M – Moderate

Table 4. Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Public Participation	1 Planner Public Communication System	2 Public Education Processes	3 Public Response Evaluation	B Development of Feasible Alternatives	C Impact Analysis of Alternatives	D Alternative Plan Screening	E Sizing and Scoping Plan Levels	F Conflict Identification Process	G Conflict Resolution Process	H Political Decision Process	I Political Decision Influence Pattern	J Non-Water Social Policy Impacts on Water Resources	1 Energy Policies	2 Transportation Policies	3 Urban Growth Policies	4 Population Distribution Policies	5 Land Use Policies	6 Income & Welfare Distribution Policies	7 International Policies	8 Other
		RESEARCH NEEDS — IV PLANNING SYSTEMS AND PROCESSES																				
I. WATER QUANTITY PROBLEMS																						
A. Management of Excess Water																						
1. Floods						S	I	I		I	I						I		I			
2. Erosion																						
3. Drainage																						
4. Salvage and Conservation						C	C			C	C	S	I	I			M	M				
5. Flood - hurricane related from land subsidence																						
B. Supply Availability Problems (in & off channel)																						
1. Watershed Use Impact																						
2. Seasonally Deficient Supplies																						
3. Annual Short Supply																						
4. Drought Frequency & Persistance																						
5. Minimum Flow Maintenance																						
6. Ground Distribution & Transport																						
7. Ground Recharge										S	S											
8. Recreational Requirements																						
9. Strip Mining Reclamation Requirements						C	C			C	C				C							
C. Water Utilization Problems																						
1. Reclamation and Reuse																						
2. Irrigation Use Efficiency																						
3. Urban Use Efficiency																						
4. Industrial Use Efficiency																						
5. Recreation & Wildlife																						
6. Quantity-Quality Interaction																						
7. Wetlands																						
8.																						
D. Water Allocation Problems																						
1. In Channel Reservation						S	S	S		S	S											
2. Off Channel Non-Consumptive Use																						
3. Off-Channel Consumptive Use						S	S	I		S	S											
4.																						
5.																						

CLASSIFICATION LEGEND

C – Critical
S – Severe
I – Important
M – Moderate

Table 4. Continued

RESEARCH NEEDS

V ENGINEERING WORKS—Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Construction Materials	B Construction Processes	C Hydraulic Structures	D Hydraulic Machinery	E Desalination Systems	F Suspended Solid Separation Systems	G Sewage Treatment Systems	H Artificial Oxygenation Systems	I Water Application Systems	J Drainage Systems	K Wastewater Collection Systems	L Water Supply Treatment Systems	M Wells and Well Fields	N Groundwater Recharge Systems	O Groundwater Intrusion Barriers	P Deepwell Waste Disposal Systems	Q Sediment Control Systems	R Erosion Control Systems	S Water Harvesting Systems	T Weather Modification Systems	U Evaporation Control Systems	V	W	X	Y	Z
I. WATER QUANTITY PROBLEMS																											
A. Management of Excess Water																											
1. Floods											S							C	C								
2. Erosion																											
3. Drainage																											
4. Salvage and Conservation																											
5. Flood-hurricane related														S	S												
6. from land subsidence																											
B. Supply Availability Problems (In & off channel)																											
1. Watershed Use Impact																											
2. Seasonally Deficient Supplies																				I	C						
3. Annual Short Supply																				I	C						
4. Drought Frequency & Persistence																				I	C						
5. Minimum Flow Maintenance				C																							
6. Ground Distribution & Transport																											
7. Ground Recharge															C			C									
8. Recreational Requirements																											
9. Strip Mining Reclamation Requirements																											
C. Water Utilization Problems																											
1. Reclamation and Reuse																											
2. Irrigation Use Efficiency										C																	
3. Urban Use Efficiency																											
4. Industrial Use Efficiency																											
5. Recreation & Wildlife																											
6. Quantity-Quality Interaction						C	S	I																			
7. Wetlands																											
8.																											
D. Water Allocation Problems																											
1. In Channel Reservation																											
2. Off-Channel Non-Consumptive Use																											
3. Off-Channel Consumptive Use										C																	
4.																											
5.																											

CLASSIFICATION LEGEND

C – Critical
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Table 4. Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	RESEARCH NEEDS — VI Data Measurement Systems & Methods (Requiring Further R & D)-Cont.																								
		A Precipitation Intensity & Distribution	B Infiltration	C Ungaged Runoff	D Water Quality Monitoring Systems	E Groundwater Parameter Identification	F Evapotranspiration Rates & Distribution	G Soil Moisture & Stress Distribution	H Non Equilibrium Flow and Currents	I Shifting Control Streamflows (Unstable Bed)	J Soil Erosion	K Sediment Transport & Deposition Rates	L Remote Sensing and Electro Magnetic Radiation	M Photosynthesis Rates, Aquatic Systems	N Photosynthesis Rates, Land Systems	O Bio-Conversion Process Rates	P Trace and Toxic Substance Levels	Q Threshold Tolerance Indicators	R Ecosystem Transport Rates	S Oxygenation Deoxygenation Rates	T	U	V	W	X	Y	Z
I. WATER QUANTITY PROBLEMS																											
A. Management of Excess Water																											
1. Floods																											
2. Erosion																											
3. Drainage																											
4. Salvage and Conservation																											
5. Flood-hurricane Related																											
6. From Land Subsidence																											
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3. Annual Short Supply																											
4. Drought Frequency & Persistence																											
5. Minimum Flow Maintenance																											
6. Ground Distribution & Transport																											
7. Ground Recharge																											
8. Recreational Requirements																											
9. Strip Mining Reclamation Requirements					I	I						I															
C. Water Utilization Problems																											
1. Reclamation and Reuse																											
2. Irrigation Use Efficiency								S																			
3. Urban Use Efficiency																											
4. Industrial Use Efficiency																											
5. Recreation & Wildlife																											
6. Quantity-Quality Interaction																											
7. Wetlands																											
8.																											
D. Water Allocation Problems																											
1. In Channel Reservation																											
2. Off-Channel Non-Consumptive Use																											
3. Off-Channel Consumptive Use																											
4.																											
5.																											

CLASSIFICATION LEGEND

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Table 5. Research Needs For Priority Water Quality Problems and Sub-Problems in the Southern Plains River Basins Region.

PROBLEM AREAS	PERTINENT PROBLEM AREA	A. Precipitation	B. Non-Channel Run-off Response	C. Channel Run-off Response	D. Infiltration	E. Interflow	F. Groundwater Recharge	G. Groundwater Reservoirs	H. Plant-Soil-Water Interactions	I. Evaporation	J. Flood Dynamics	K. Statistics of Precipitation	L. Statistics of Run-off	M. Drought	N. Soil Erosion	O. Sediment Transport and Deposition	P. River, Lake, and Reservoir Mechanics	Q. River, Lake, and Reservoir Geo Chemistry	R. River, Lake, and Reservoir Bio-Hydrology	S. Water Geochemistry	T. Snow, Ice, Permafrost	U. Karst Hydrology	V. Estuary Hydrology	W.	X.	Y.	Z.
		RESEARCH NEEDS — I HYDROLOGICAL SYSTEMS AND PROCESSES—Continued																									
II. WATER QUALITY PROBLEMS																											
A. Groundwater Quality Protection																											
1. Saline Intrusion						S	S	S																			
2. Surface Leachates					S	S	C	S																			
3. Toxic Trace Substance					S	S	S	S																			
4. Deepwell Waste Disposal						S	S	S																			
5. Oil & Gas Production						C		C																			
6.																											
B. Upland Watershed Quality Degradation																											
1. Diffuse Sources of Contaminants																											
(a) Nutrients					S																						
(b) Pesticides & Herbicides					S																						
(c) Feedlot Runoff					S																						
(d) Organic Residues																											
(e) Soil Erosion																											
(f) Mining Residues– Strip Mining			C				C	C							C	C											
(g) Other Cultural Waste																											
(h) Salinity Management																											
(i)																											
2. Point Source of Contaminants																											
(a) Industrial Waste																											
(b) Urban/Domestic Waste																											
(c)																											
C. Lake and Reservoir Quality Degradation																											
1. Recreational Development																											
2. Diffuse Sources																											
3. Bio-Physical-Chemical Interaction																											
4. Water Level Controls																											
5. Heat Discharge																											
6. Saline Accumulations																											
7. Deoxygenation																											
8. Eutrophication																											
9. Sediment Water Exchanges of:																											
(a) Nutrients																											
(b) Heavy Metals																											
(c) Chlorinated Hydrocarbon (etc.)																											
10. Wetland																											
11.																											
12.																											
D. Inland & Coastal Wetland Quality Mgmt.																											
1. Channelization Impact Assessment																											
2. Toxic Waste Impact Assessment																											
3. Dredging and Filling Impact Assessment																											
4. Sedimentation															C	S											
5. Bio-Physical/Chemical Interactions																											
6. Contaminated Inflow																											
7. Flushing Characteristics																											
8. Deep Port Impact Assess.																							C				
E. Estuarine Quality Problems																											
1. Dredging Impacts																											
2. Heated Discharge Impacts																											
3. Industrial Wastes																											
4. Urban Domestic Waste																											
5. Bio-Physical-Chemical Interactions																											
6. Shoreline Area Land Use Control																											
7. Deep Water Port Impacts																							C				
8.																											
F. Urban Water Problems																											
1. Diffuse Sources of Pollution																											
2. Combined Sewers																											
3. Urban Land Development Impacts																											
4.																											
5.																											
6.																											

Table 5. Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A. Forested Upland Ecosystems	B. Scrub and Brush Upland Ecosystems	C. Grassland Ecosystems	D. Arid and Semi-Arid Ecosystems	E. Agricultural Ecosystems	F. Flood Plain Ecosystems	G. Creek and Intermittent Stream Ecosystems	H. Aggrading River Ecosystems	I. Degrading River Ecosystems	J. Pond and Pothole Ecosystems	K. Lake and Reservoir Ecosystems	L. Great Lakes Ecosystems	M. Freshwater Marsh and Swamp Ecosystems	N. Coastal Marsh and Swamp Ecosystems	O. Estuarine Ecosystems	P. Bio-Degradation Processes	Q. Bio-Accumulation Processes	R. Bio-Chemical Conversions	S. Photosynthesis Processes	T. Transpiration-Respiration Processes	U. Bio-Control Interactions	V. Toxin-Organism Reactions	W. Biosystem Recuperation Dynamics	X.	Y.	Z.
II. WATER QUALITY PROBLEMS																											
A. Groundwater Quality Protection																											
1. Saline Intrusion																											
2. Surface Leachates																											
3. Toxic Trace Substance																											
4. Deepwell Waste Disposal																											
5. Oil & Gas Production																											
6.																											
B. Upland Watershed Quality Degradation																											
1. Diffuse Sources of Contaminants																											
(a) Nutrients						C																					
(b) Pesticides & Herbicides						C																					
(c) Feedlot Runoff											C						C	S									
(d) Organic Residues																											
(e) Soil Erosion																											
(f) Mining Residues–Strip Mining					C																						
(g) Other Cultural Waste																											
(h) Salinity Management																											
(i)																											
2. Point Source of Contaminants																											
(a) Industrial Waste											S						S										
(b) Urban/Domestic Waste											S						S										
(c)																											
C. Lake and Reservoir Quality Degradation																											
1. Recreational Development												C															
2. Diffuse Sources																											
3. Bio-Physical-Chemical Interaction																											
4. Water Level Controls																											
5. Heat Discharge																											
6. Saline Accumulations																											
7. Deoxygenation												S					S							S			
8. Eutrophication												S					S							S			
9. Sediment Water Exchanges of:																											
(a) Nutrients																											
(b) Heavy Metals																											
(c) Chlorinated Hydrocarbon (etc.)																											
10. Wetland																											
11.																											
12.																											
D. Inland & Coastal Wetland Quality Mgmt.																											
1. Channelization Impact Assessment																											
2. Toxic Waste Impact Assessment														S	S	S	C		C				C	S			
3. Dredging and Filling Impact Assessment															S	S											
4. Sedimentation															S	S											
5. Bio-Physical/Chemical Interactions																											
6. Contaminated Inflow														C	C	C	S		S				S	C			
7. Flushing Characteristics																											
8. Deep Port Impact Assess.															C												
E. Estuarine Quality Problems																											
1. Dredging Impacts																											
2. Heated Discharge Impacts																											
3. Industrial Wastes																											
4. Urban Domestic Waste																											
5. Bio-Physical-Chemical Interactions																											
6. Shoreline Area Land Use Control																											
7. Deep Water Impacts																C											
8.																											
F. Urban Water Problems																											
1. Diffuse Sources of Pollution																											
2. Combined Sewers																											
3. Urban Land Development Impacts																											
4.																											
5.																											
6.																											

RESEARCH NEEDS — II BIOLOGICAL SYSTEMS AND PROCESSES—Continued

Table 5. Continued

RESEARCH NEEDS

III SOCIO-ECONOMIC SYSTEMS AND PROCESSES—Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Social Goal Identification & Measurement	1 Income Production	2 Income Distribution	3 Health	4 Social Mobility	5 Environmental Protection	6 Recreation	7 Employment	8 Other	B Quantification and Measurement of Beneficial Impacts	1 Economic Projections	2 Direct User Economic Impacts	3 Indirect User Economic Impacts	4 Environmental Improvement	5 Recreational Opportunity	6 Other Social Benefits	7 Local, Regional & National Accounting of Costs and Benefits	C Quantification and Measurement of Non-Beneficial Impacts	1 Economic Cost of Achievement	2 Social Disruptions Direct and Indirect	3 Environmental Impacts	D Economic Market System Adjustments and Trade-Offs	E Social Allocation & Adjustment of Beneficial and Non-Beneficial Impacts	F Single Jurisdiction Governmental Institutions	G Multiple Jurisdiction Governmental Institutions	1 Regional Authorities	2 State Authorities	3 Interstate Compacts and Commissions	4 Federal Agencies	5 International Commissions	H Interactions of Single Purpose Boards and Authorities
II. WATER QUALITY PROBLEMS																																
A. Groundwater Quality Protection																																
1. Saline Intrusion																																
2. Surface Leachates																																
3. Toxic Trace Substance																																
4. Deepwell Waste Disposal																																
5. Oil & Gas Production																																
6.																																
B. Upland Watershed Quality Degradation																																
1. Diffuse Sources of Contaminants																																
(a) Nutrients													S		S					C												
(b) Pesticides & Herbicides													S		S					C												
(c) Feedlot Runoff																																
(d) Organic Residues																																
(e) Soil Erosion																																
(f) Mining Residues -Strip Mining																																
(g) Other Cultural Waste																																
(h) Salinity Management																																
(i)																																
2. Point Source of Contaminants																																
(a) Industrial Waste																																
(b) Urban/Domestic Waste																																
(c)																																
C. Lake and Reservoir Quality Degradation																																
1. Recreational Development					S			S								S																
2. Diffuse Sources																																
3. Bio-Physical-Chemical Interaction																																
4. Water Level Controls																																
5. Heat Discharge																																
6. Saline Accumulations																																
7. Deoxygenation																																
8. Eutrophication																																
9. Sediment Water Exchanges of:																																
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10. Wetland																																
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D. Inland & Coastal Wetland Quality Mgmt.																																
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2. Toxic Waste Impact Assessment																																
3. Dredging and Filling Impact Assessment																																
4. Sedimentation																																
5. Bio-Physical/Chemical Interactions																																
6. Contaminated Inflow																																
7. Flushing Characteristics																																
8. Deep Water Port Impact Asses.																																
E. Estuarine Quality Problems																																
1. Dredging Impacts																																
2. Heated Discharge Impacts																																
3. Industrial Wastes																																
4. Urban Domestic Waste																																
5. Bio-Physical-Chemical Interactions																																
6. Shoreline Area Land Use Control													I	I	S	C	S										S					
7. Deep Water Port Impacts																																
8.																																
F. Urban Water Problems																																
1. Diffuse Sources of Pollution																																
2. Combined Sewers																																
3. Urban Land Development Impacts																																
4.																																
5.																																
6.																																

Table 5. Continued

RESEARCH NEEDS

IV PLANNING SYSTEMS AND PROCESSES—Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Public Participation	1 Planner Public Communication System	2 Public Education Processes	3 Public Response Evaluation	B Development of Feasible Alternatives	C Impact Analysis of Alternatives	D Alternative Plan Screening	E Sizing and Scoping Plan Levels	F Conflict Identification Process	G Conflict Resolution Process	H Political Decision Process	I Political Decision Influence Pattern	J Non-Water Social Policy Impacts—on Water Resources	1 Energy Policies	2 Transportation Policies	3 Urban Growth Policies	4 Population Distribution Policies	5 Land Use Policies	6 Income & Welfare Distribution Policies	7 International Policies	8 Other
II. WATER QUALITY PROBLEMS																						
A. Groundwater Quality Protection																						
1. Saline Intrusion																						
2. Surface Leachates																						
3. Toxic Trace Substance																						
4. Deepwell Waste Disposal																						
5. Oil & Gas Production																						
6.																						
B. Upland Watershed Quality Degradation																						
1. Diffuse Sources of Contaminants																						
(a) Nutrients																						
(b) Pesticides & Herbicides																						
(c) Feedlot Runoff																						
(d) Organic Residues																						
(e) Soil Erosion																						
(f) Mining Residues -Strip Mining																						
(g) Other Cultural Waste																						
(h) Salinity Management						S	S	I														
(i)																						
2. Point Source of Contaminants																						
(a) Industrial Waste																						
(b) Urban/Domestic Waste																						
(c)																						
C. Lake and Reservoir Quality Degradation																						
1. Recreational Development																			S			
2. Diffuse Sources																						
3. Bio-Physical-Chemical Interaction																						
4. Water Level Controls																						
5. Heat Discharge																						
6. Saline Accumulations																						
7. Deoxygenation																						
8. Eutrophication																						
9. Sediment Water Exchanges of:																						
(a) Nutrients																						
(b) Heavy Metals																						
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10. Wetland																						
11.																						
12.																						
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1. Channelization Impact Assessment																						
2. Toxic Waste Impact Assessment																						
3. Dredging and Filling Impact Assessment										S	S											
4. Sedimentation																						
5. Bio-Physical/Chemical Interactions																						
6. Contaminated Inflow																						
7. Flushing Characteristics																						
8. Deep Port Impact Assess.																						
E. Estuarine Quality Problems																						
1. Dredging Impacts																						
2. Heated Discharge Impacts																						
3. Industrial Wastes																						
4. Urban Domestic Waste																						
5. Bio-Physical-Chemical Interactions																						
6. Shoreline Area Land Use Control										S	S											
7. Deep Water Impacts																						
8.																						
F. Urban Water Problems																						
1. Diffuse Sources of Pollution																						
2. Combined Sewers																						
3. Urban Land Development Impacts			S		S		S			C	C						S		C			
4.																						
5.																						
6.																						

Table 5. Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Construction Materials	B Construction Processes	C Hydraulic Structures	D Hydraulic Machinery	E Desalination Systems	F Suspended Solid Separation Systems	G Sewage Treatment Systems	H Artificial Oxygenation Systems	I Water Application Systems	J Drainage Systems	K Wastewater Collection Systems	L Water Supply Treatment Systems	M Wells and Well Fields	N Groundwater Recharge Systems	O Groundwater Intrusion Barriers	P Deepwell waste Disposal Systems	Q Sediment Control Systems	R Erosion Control Systems	S Water Harvesting Systems	T Weather Modification Systems	U Evaporation Control Systems	V	W	X	Y	Z
RESEARCH NEEDS — V ENGINEERING WORKS—Continued																											
II. WATER QUALITY PROBLEMS																											
A. Groundwater Quality Protection																											
1. Saline Intrusion						C								S	S	C	S										
2. Surface Leachates																											
3. Toxic Trace Substance														S	S												
4. Deepwell Waste Disposal																	C										
5. Oil & Gas Production																											
6.																											
B. Upland Watershed Quality Degradation																											
1. Diffuse Sources of Contaminants																											
(a) Nutrients																											
(b) Pesticides & Herbicides																											
(c) Feedlot Runoff								S				S															
(d) Organic Residues																											
(e) Soil Erosion																											
(f) Mining Residues -Strip Mining																											
(g) Other Cultural Waste																											
(h) Salinity Management						C					C																
(i)																											
2. Point Source of Contaminants																											
(a) Industrial Waste								C																			
(b) Urban/Domestic Waste								C																			
(c)																											
C. Lake and Reservoir Quality Degradation																											
1. Recreational Development							I	I				S						I									
2. Diffuse Sources																											
3. Bio-Physical-Chemical Interaction																											
4. Water Level Controls																											
5. Heat Discharge																											
6. Saline Accumulations																											
7. Deoxygenation																											
8. Eutrophication																											
9. Sediment Water Exchanges of:																											
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(c) Chlorinated Hydrocarbon (etc.)																											
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D. Inland & Coastal Wetland Quality Mgmt.																											
1. Channelization Impact Assessment																											
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3. Dredging and Filling Impact Assessment																											
4. Sedimentation																											
5. Bio-Physical/Chemical Interactions																											
6. Contaminated Inflow																											
7. Flushing Characteristics																											
8. Deep Port Impact Assess.																											
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3. Industrial Wastes																											
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3. Urban Land Development Impacts																											
4.																											
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6.																											

Table 5. Continued

RESEARCH NEEDS

VI Data Measurement Systems & Methods (Requiring Further R & D)—Cont.

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Precipitation Intensity & Distribution	B Infiltration	C Ungaged Runoff	D Water Quality Monitoring Systems	E Groundwater Parameter Identification	F Evapotranspiration Rates & Distribution	G Soil Moisture & Stress Distribution	H Non-Equilibrium Flow and Currents	I Shifting Control Streamflows (Unstable Bed)	J Soil Erosion	K Sediment Transport & Deposition Rates	L Remote Sensing and Electro Magnetic Radiation	M Photosynthesis Rates, Aquatic Systems	N Photosynthesis Rates, Land Systems	O Bio-Conversion Process Rates	P Trace and Toxic Substance Levels	Q Threshold Tolerance Indicators	R Ecosystem Transport Rates	S Oxygenation-Deoxygenation Rates	T	U	V	W	X	Y	Z
II. WATER QUALITY PROBLEMS																											
A. Groundwater Quality Protection																											
1. Saline Intrusion						C																					
2. Surface Leachates						C																					
3. Toxic Trace Substance						C																					
4. Deepwell Waste Disposal						C																					
5. Oil & Gas Production						C																					
6.																											
B. Upland Watershed Quality Degradation																											
1. Diffuse Sources of Contaminants																											
(a) Nutrients																											
(b) Pesticides & Herbicides																											
(c) Feedlot Runoff																											
(d) Organic Residues																											
(e) Soil Erosion																											
(f) Mining Residues -Strip Mining																											
(g) Other Cultural Waste																											
(h) Salinity Management																											
(i)																											
2. Point Source of Contaminants																											
(a) Industrial Waste																											
(b) Urban/Domestic Waste																											
(c)																											
C. Lake and Reservoir Quality Degradation																											
1. Recreational Development																											
2. Diffuse Sources																											
3. Bio-Physical-Chemical Interaction																											
4. Water Level Controls																											
5. Heat Discharge																											
6. Saline Accumulations																											
7. Deoxygenation																											
8. Eutrophication																											
9. Sediment Water Exchanges of:																											
(a) Nutrients																											
(b) Heavy Metals																											
(c) Chlorinated Hydrocarbon (etc.)																											
10. Wetland																											
11.																											
12.																											
D. Inland & Coastal Wetland Quality Mgmt.																											
1. Channelization Impact Assessment																											
2. Toxic Waste Impact Assessment																											
3. Dredging and Filling Impact Assessment																											
4. Sedimentation																											
5. Bio-Physical/Chemical Interactions																											
6. Contaminated Inflow																											
7. Flushing Characteristics																											
8. Deep Port Impact Assess.																											
E. Estuarine Quality Problems																											
1. Dredging Impacts																											
2. Heated Discharge Impacts																											
3. Industrial Wastes																											
4. Urban Domestic Waste																											
5. Bio-Physical-Chemical Interactions																											
6. Shoreline Area Land Use Control																											
7. Deep Water Impacts																											
8.																											
F. Urban Water Problems																											
1. Diffuse Sources of Pollution																											
2. Combined Sewers																											
3. Urban Land Development Impacts																											
4.																											
5.																											
6.																											

Table 6. Research Needs For Priority Water Planning and Management Problems and Sub-Problems in The Southern Plains River Basins Region.

PROBLEM AREAS	PERTINENT PROBLEM AREA	A. Precipitation	B. Non-Channel Run-off Response	C. Channel Run-off Response	D. Infiltration	E. Interflow	F. Groundwater Recharge	G. Groundwater Reservoirs	H. Plant-Soil-Water Interactions	I. Evaporation	J. Flood Dynamics	K. Statistics of Precipitation	L. Statistics of Run-off	M. Drought	N. Soil Erosion	O. Sediment Transport and Deposition	P. River, Lake, and Reservoir Mechanics	Q. River, Lake, and Reservoir Geo Chemistry	R. River, Lake, and Reservoir Bio-Hydrology	S. Water Geochemistry	T. Snow, Ice, Permafrost	U. Karst Hydrology	V.	W.	X.	Y.	Z.
RESEARCH NEEDS — I HYDROLOGICAL SYSTEMS AND PROCESSES—Continued																											
III. PLANNING & MANAGEMENT PROBLEMS																											
A. Operations																											
1. River Regulations																											
2. Canals and Aqueducts																											
3. Urban Water Treatment																											
4. Urban Water Distribution																											
5. Waste Water Collection																											
6. Waste Water Treatment																											
7.																											
8.																											
B. Planning Methodologies																											
1. Objective Ident. & Measurement																											
2. Objective Interrelationships																											
3. System Behavior Modeling																											
4. Alternatives Assessments																											
5. Trade-Off Analysis																											
6. Impact of groundwater development																											
7. Impact of energy cost																											
C. Regional Management																											
1. Water Supply Systems -Interbasin transfer																											
2. Waste Treatment Systems																											
3. Land Use Management Systems																											
4. Regional Resource Management																											
(a) Water based recreation																											
(b) Watersheds																											
5. Institutional Requirements																											
6. Legal Requirements & Constraints																											
7. Groundwater management																											
8.																											

GPO 878-769

Table 6. Continued

RESEARCH NEEDS

II BIOLOGICAL SYSTEMS AND PROCESSES Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A. Forested Upland Ecosystems	B. Scrub and Brush Upland Ecosystems	C. Grassland Ecosystems	D. Arid and Semi-Arid Ecosystems	E. Agricultural Ecosystems	F. Flood Plain Ecosystems	G. Creek and Intermittant Stream Ecosystems	H. Aggrading River Ecosystems	I. Degrading River Ecosystems	J. Pond and Pothole Ecosystems	K. Lake and Reservoir Ecosystems	L. Great Lakes Ecosystems	M. Freshwater Marsh and Swamp Ecosystems	N. Coastal Marsh and Swamp Ecosystems	O. Estuarine Ecosystems	P. Bio-Degradation Processes	Q. Bio-Accumulation Processes	R. Bio-Chemical Conversions	S. Photosynthesis Processes	T. Transpiration-Respiration Processes	U. Bio-Control Interactions	V. Toxin-Organism Reactions	W. Biosystem Recuperation Dynamics	X.	Y.	Z.
III. PLANNING & MANAGEMENT PROBLEMS																											
A. Operations																											
1. River Regulations																											
2. Canals and Aqueducts																											
3. Urban Water Treatment																											
4. Urban Water Distribution																											
5. Waste Water Collection																											
6. Waste Water Treatment																											
7.																											
8.																											
B. Planning Methodologies																											
1. Objective Ident. & Measurement																											
2. Objective Interrelationships																											
3. System Behavior Modeling																											
4. Alternatives Assessments																											
5. Trade-Off Analysis																											
6. Impact of Ground Water Development																											
7. Impact of energy cost																											
C. Regional Management																											
1. Water Supply Systems																											
2. Waste Treatment Systems																											
3. Land Use Management Systems																											
4. Regional Resource Management																											
(a) Water based recreation																											
(b) Watersheds																											
5. Institutional Requirements																											
6. Legal Requirements & Constraints																											
7. Groundwater management																											
8.																											

GPO 879-744

Table 6. Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Social Goal Identification & Measurement	1 Income Production	2 Income Distribution	3 Health	4 Social Mobility	5 Environmental Protection	6 Recreation	7 Employment	8 Other	B Quantification and Measurement of Beneficial Impacts	1 Economic Projections	2 Direct User Economic Impacts	3 Indirect User Economic Impacts	4 Environmental Improvement	5 Recreational Opportunity	6 Other Social Benefits	7 Local, Regional & National Accounting of Costs and Benefits	C Quantification and Measurement of Non-Beneficial Impacts	1 Economic Cost of Achievement	2 Social Disruptions Direct and Indirect	3 Environmental Impacts	D Economic-Market System Adjustments and Trade-Offs	E Social Allocation & Adjustment of Beneficial and Non-Beneficial Impacts	F Single Jurisdiction Governmental Institutions	G Multiple Jurisdiction Governmental Institutions	1 Regional Authorities	2 State Authorities	3 Interstate Compacts and Commissions	4 Federal Agencies	5 International Commissions	H Interaction of Single Purpose Boards and Authorities
		RESEARCH NEEDS — III SOCIO-ECONOMIC SYSTEMS AND PROCESSES																														
III. PLANNING & MANAGEMENT PROBLEMS																																
A. Operations																																
1. River Regulations																																
2. Canals and Aqueducts																																
3. Urban Water Treatment																																
4. Urban Water Distribution																																
5. Waste Water Collection																																
6. Waste Water Treatment																																
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8.																																
B. Planning Methodologies																																
1. Objective Ident. & Measurement							C								S		S															
2. Objective Interrelationships							S								S		S															
3. System Behavior Modeling																																
4. Alternatives Assessments																																
5. Trade-Off Analysis																																
6. Impact of groundwater development																																
7. Impact of energy cost												S	S	S																		
C. Regional Management																																
1. Water Supply Systems Interbasin transfer												S	S	S	S		S										C					
2. Waste Treatment Systems																																
3. Land Use Management Systems												S	S	S	S	I	S					I			C		C					
4. Regional Resource Management																																
(a) Water based recreation																																
(b) Watersheds																																
5. Institutional Requirements																										C	C		C			
6. Legal Requirements & Constraints																											C					
7. Groundwater management												S	S	S	S		S								C		C		C			
8.																																

GPO 879-789

Table 6. Continued

Form OW 415

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Public Participation	1 Planner Public communication System	2 Public Education Processes	3 Public Response Evaluation	B Development of Feasible Alternatives	C Impact Analysis of Alternatives	D Alternative Plan Screening	E Sizing and Scoping Plan Levels	F Conflict Identification Process	G Conflict Resolution Process	H Political Decision Process	I Political Decision Influence Pattern	J Non-Water Social Policy Impacts on water Resources	1 Energy Policies	2 Transportation Policies	3 Urban Growth Policies	4 Population Distribution Policies	5 Land Use Policies	6 Income & Welfare Distribution Policies	7 International Policies	8 Other
III. PLANNING & MANAGEMENT PROBLEMS																						
A. Operations																						
1. River Regulations																						
2. Canals and Aqueducts																						
3. Urban Water Treatment																						
4. Urban Water Distribution																						
5. Waste Water Collection																						
6. Waste Water Treatment																						
7.																						
8.																						
B. Planning Methodologies																						
1. Objective Ident. & Measurement		S	S																			
2. Objective Interrelationships		S	S							S	S											
3. System Behavior Modeling																						
4. Alternatives Assessments		S					C															
5. Trade-Off Analysis								C		C	C											
6. Impact of groundwater development																						
7. Impact of energy cost															C							
C. Regional Management																						
1. Water Supply Systems Interbasin transfer																						
2. Waste Treatment Systems																						
3. Land Use Management Systems		C	S	S	S					S	S								C			
4. Regional Resource Management																						
(a) Water based recreation																						
(b) Watersheds																						
5. Institutional Requirements																						
6. Legal Requirements & Constraints																						
7. Groundwater management										C	C											
8.																						

GPO 879-788

Table 6. Continued

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Construction Materials	B Construction Processes	C Hydraulic Structures	D Hydraulic Machinery	E Desalination Systems	F Suspended Solid Separation Systems	G Sewage Treatment Systems	H Artificial Oxygenation Systems	I Water Application Systems	J Drainage Systems	K Wastewater Collection Systems	L Water Supply Treatment Systems	M Wells and Well Fields	N Groundwater Recharge Systems	O Groundwater Intrusion Barriers	P Deepwell Waste Disposal Systems	Q Sediment Control Systems	R Erosion Control Systems	S Water Harvesting Systems	T Weather Modification Systems	U Evaporation Control Systems	V	W	X	Y	Z
RESEARCH NEEDS — V ENGINEERING WORKS																											
III. PLANNING & MANAGEMENT PROBLEMS																											
A. Operations																											
1. River Regulations																											
2. Canals and Aqueducts																											
3. Urban Water Treatment																											
4. Urban Water Distribution																											
5. Waste Water Collection								S				C															
6. Waste Water Treatment								S				S															
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6. Legal Requirements & Constraints																											
7. Ground Water Management																											
8.																											

GPO 879-789

Table 6. Continued

RESEARCH NEEDS

VI Data Measurement Systems & Methods (Requiring Further R & D)

PROBLEM AREAS	PERTINENT PROBLEM AREA	A Precipitation Intensity & Distribution	B Infiltration	C Ungaged Runoff	D Water Quality Monitoring Systems	E Groundwater Parameter Identification	F Evapotranspiration Rates & Distribution	G Soil Moisture & Stress Distribution	H Non-Equilibrium Flow and Currents	I Shifting Control Streamflows (Unstable Bed)	J Soil Erosion	K Sediment Transport & Deposition Rates	L Remote Sensing and Electro Magnetic Radiation	M Photosynthesis Rates, Aquatic Systems	N Photosynthesis Rates, Land Systems	O Bio-Conversion Process Rates	P Trace and Toxic Substance Levels	Q Threshold Tolerance Indicators	R Ecosystem Transport Rates	S Oxygenation-Deoxygenation Rates	T	U	V	W	X	Y	Z
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6. Legal Requirements & Constraints																											
7. Ground Water Management																											
8.																											

Floods which are related to the combination of land subsidence and hurricanes have knowledge gaps in socio-economic and planning systems and processes and engineering works. Local, regional, and national accounting of costs and benefits should be determined. There should be intensive study on the regional authorities capable of managing ground water to prevent land subsidence. Social disruptions as a result of land subsidence needs research. In the planning systems and processes, impact analysis is needed, as well as development of feasible alternatives and conflict identification and conflict resolution processes.

The region is faced with a major problem of availability of water supplies. In this area, the greatest deficiency of knowledge exists in systems and processes assiciated with hydrology, society, economy, planning, and in engineering works. Significant research needs exist in the hydrologic systems and processes of precipitation, soil-plant-water interactions, drought, and evaporation. There is a critical research need in weather modification systems to overcome natural drought phenomena. Maintenance of minimal flow is a significant problem with research needs in precipitation and hydrologic structures to distribute the flow better. Ground water recharge is a critical problem in the region and it has research needs in recharge systems and better understanding the ground water aquifers involved. Also, research needs exist in the conflict identification and conflict resolution processes associated with ground water recharge. Recharge systems need to be more thoroughly researched especially in the area of sediment control prior to recharge. Strip mining reclamation has serious knowledge gaps on the influence of overburden disturbance of infiltration, ground water recharge, ground water storage, erosion, and sediment processes. Strip mining reclamation requirements greatly effect water planning and critical knowledge gaps exist in developing and assessing alternatives, conflict identification and resolution, and energy problems.

Since the region has a large amount of irrigation, there is a critical research need in improvement of irrigation efficiency. Significant research needs exist in soil-plant-water interactions and in improvement of water application systems. Also, research is needed on methodology for soil moisture stress distribution and the direct and indirect user economic benefits of improving efficiency. In water utilization problems, quality-quantity interactions are important research needs for the region. Major research needs exist in desalination systems and suspended solid separation systems. Better utilization of wetlands is important to the region and the creek and intermittent stream ecosystems need additional research to guide in the use of wetlands. Off-channel consumptive use is a significant problem to the region and soil-plant-water interactions needs extensive research. Water application systems need to be improved and the planning processes and systems also need research to improve water allocation procedures.

Ground water quality protection is a significant problem in the region and protection is needed from salt water intrusion, surface leachates, toxic substances, and deep well disposal. Important research needs exist in the area of infiltration, ground water recharge, interflow within aquifers, and ground water reservoir systems. Also, in engineering works, desalination systems need to be developed. Wells and well fields need study as do ground water recharge systems. Ground water intrusion barriers need investigation for saline water intrusion. Concerning pollution of ground water from oil and gas production activities, critical research needs exist in methods to detect the extent of ground water pollution and ways to manage or remove the polluted ground water from aquifers.

The region needs upland watershed quality protection from nutrients, herbicides and pesticides, feedlot runoff, and salintity. Research is needed on the infiltration processes and the entire agricultural ecosystem. Strip mining could seriously pollute surface and ground water resources. Critical research needs exist on strip mining waste in relation to ground water hydrology and on overburden disturbance in relation to surface erosion. Salinity management needs research in desalination systems and in drainage systems. Point sources of pollution from industrial and domestic urban wastes need research in the area of sewage treatment systems.

Lake and reservoir quality degradation from recreation development should be researched from the standpoint of lake reservoir ecosystems and on socio-economic systems and processes. Wastewater collection systems would be important to recreation development to prevent pollution.

Inland and coastal wetland quality management is important to the region. Toxic waste impact assessments, dredging and filling impact assessments, sedimentation, and contaminated inflows have significant research needs in the area of understanding biological systems and processes. The impact of deep water ports on water quality of the coastal wetlands, estuaries, and coastal waters need extensive research. The effect of accidental spills from these ports needs evaluation. Shoreline area land use control is an important problem needing research in the area of the socio-economic systems and processes. Urban water problems associated primarily with urban land development impacts need to be evaluated primarily in the planning systems and processes.

Planning and management problems have research needs associated with socio-economic and planning systems and processes. The needs are mainly concerned with objective identification and measurement, objective interrelationships, alternative assessments, and tradeoff analysis. The impact of energy cost on the various surface and ground water resources supply and utilization system needs extensive research to improve planning methods to evaluate the impact. Extensive research is needed in the area of water institutions including regional agencies to manage water resources.

The development and implementation of regional management systems is extremely important to the solution of many of the regional problems. Water supply systems, primarily interbasin transfer, should be thoroughly studied. Land use management systems, legal requirements and constraints, and ground water management problems need extensive research in the area of socio-economics systems and processes, including institutions which can manage these regional water and related land resource systems. Also, research is needed in the planning processes and systems, especially in the area of conflicts and conflict resolution.

Southern Plains River Basins Regional Water Resources Research Program Status

The research needs identified in Tables 3, 4, 5, and 6 for the Southern Plains River Basins Region represents a substantial investment of time, funds, and scientific manpower to obtain the body of new knowledge represented by the needs. The funds required to conduct this research are greatly in excess of the present budget of the Office of Water Research and Technology. The water resources systematic problem analysis program did bring into clear focus that the problems associated with the development and efficient utilization of the regional water resources are emerging faster than research is providing the solutions. A greater commitment by the states and federal water resource agencies to the solution of water problems will be necessary to prevent a critical water situation in the years ahead.

However, the identified research needs provide a basis for efficient utilization of funds by the water resources research institutes in the region. A periodic updating of research needs will be necessary to keep them current with developments in the region. Two regional projects currently in progress are an outgrowth of the problem analysis program. The regional projects have participation of several investigators from different states. The projects and participants are as follows:

1. "Adjustments Due to a Declining Ground Water Supply: High Plains of Northern Texas and Western Oklahoma"

   Participants: Texas Water Resources Institute, Texas A&M University
   Water Resources Research Institute, Oklahoma State University
   Department of Agricultural Economics, Texas Tech University

2. "Regional Water Management with Full Consumptive Use"

   Participants: Texas Water Resources Institute, Texas A&M University
   Water Resources Research Institute, New Mexico State University

One of the most critical problem areas identified by the problem analysis workshops was ground water depletion and related sub-problems. An important outgrowth of the workshops was increased information dissemination activities to give more focus to better ground water management. The Texas Water Resources Institute initiated a newsletter in which several issues focused on the ground water and related problems. Copies of the newsletter are given in the Appendix. Also, a ground water management workshop in the Great Plains States was conducted by Kansas, Texas, Oklahoma, and Nebraska to focus on ground water management and recharge. The published proceedings are available from the Nebraska Water Resources Research Institute. An outline of the topics covered in the workshop is given in the Appendix.