TEXAS WATER DEVELOPMENT BOARD

REPORT 31

TECHNICAL PAPERS ON SELECTED ASPECTS OF THE PRELIMINARY TEXAS WATER PLAN

THREE TECHNICAL PAPERS
Presented at the October 1, 1966 Meeting
Texas Section, American Society of Civil Engineers

September 1966

FOREWORD

The Texas Water Development Board has, in compliance with the requirements of the Water Resources Administration Act, prepared a preliminary Texas Water Plan and held 27 public hearings in river basins throughout the State on its preliminary plan. In addition, the Board held three public meetings to assure the widest possible distribution of information concerning the Plan. At each of these hearings, the Board presented its preliminary Plan for development of the river basin in which the hearing was held, outlined proposed diversions that were a part of the Plan, and invited the views, comments, criticisms and suggestions of those interested in water development.

The Water Resources Administration Act, directing the preparation of the Texas Water Plan and the hearings, requires that "thereafter in preparing its plan the Board shall give consideration to the effect such plan will have on the present and future development, economy, general welfare, and water requirements of the areas of such river basin" or "of the areas affected".

On September 21, 1966 the Board released a statement relative to the preliminary Plan and outlined a program of work to examine in as much detail as is logical and feasible each of the many valid suggestions, criticisms and proposals for Plan modification or alternatives to the proposed Plan.

As a continuation of its policy of providing the widest possible distribution of information concerning the preliminary Plan the following three papers were prepared and presented at the October 1, 1966 meeting of the Texas Section American Society of Civil Engineers. These papers describe information relative to the Preliminary Plan and do not reflect possible modifications to the Plan which may result from the program of work outlined by the Board in its September 21, 1966 statement.

The Board is appreciative of the active consideration the Texas Section, American Society of Civil Engineers has given to sound water resources planning and development in Texas.

Texas Water Development Board

Joe G. Moore, Jr.
Executive Director

THE PRELIMINARY TEXAS WATER PLAN

John J. Vandertulip[1] and
Lewis B. Seward[2]

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[1] Chief Engineer, Texas Water Development Board; Member, ASCE
[2] Assistant Chief Engineer, Texas Water Development Board; Member, ASCE

Introduction

During the period following World War II Texas experienced all the problems associated with growth including inadequate facilities to meet mushrooming water requirements, floods, an intensive interest in water-oriented recreation, depletion of ground water reservoirs, agricultural drainage, erosion and needs for soil conservation, pollution problems of streams and in the major bay and estuary systems, and need for enlarged and new navigation facilities.

In 1964 Texas faced a multitude of uncoordinated water development proposals by cities, regional water authorities and districts, and Federal agencies, aggregating proposed costs in excess of 5 billion dollars. Many proposals were conflicting, and serious omissions in planning concepts were evident. Governor John Connally in August 1964 authorized the State agencies to carry on an accelerated planning program and develop a long-range State Water Plan, comprehensive in scope, and to include all areas of the State. This accelerated planning program was to include but not be limited to consideration of all proposals by Federal agencies together with those by non-Federal entities.

This paper describes the approach to planning, planning concepts and planning problems, and summarizes the preliminary Texas Water Plan.

Previous Investigations

Planning for the development and use of Texas water evolved through the past five decades as the problems, needs, and interrelationships regarding water were better defined. This evolution resulted from a combination of economic, engineering, political and sociological factors. Economic growth and water shortages provided the impetus, and the scope of planning broadened and deepened with an increasing awareness and understanding of the numerous water-related factors affecting the growth of the State and the Nation.

The 1950 through 1956 drought affected the entire State. Two hundred forty-four of the State's 254 counties were designated as drought disaster areas. Following World War II water facilities lagged behind growing municipal and industrial requirements. In 1949 Texas had 63 major dams in operation and 12 under construction. Construction was initiated on 27 more dams during the period 1950-1956. Those which were completed during the drought provided little immediate relief since there was very little water in the streams to impound. Cities and water districts, dependent entirely or in part on ground water, added new wells during the drought years, generally for increased capacity to existing systems. During the 1951-1956 period, over 600 cities or water districts added new wells.

Heavy rains during the period mid-March to early June resulted in flooding in most areas of Texas. The Legislature considered the recent experience of Texas and in special session in late 1957 adopted the Water Planning Act of 1957. That Act provided for the creation in the Board of Water Engineers of a Planning Division, the assignment of planning functions and appropriations for planning.

The Board, in accordance with the Act, prepared a progress report to the 56th Legislature titled "Texas Water Resources Planning at the end of the year 1958." It also participated in the preparation of a joint report with the Corps of Engineers, Bureau of Reclamation, and Soil Conservation Service entitled "Water Developments and Potentialities of the State of Texas" completed in June 1958 and later printed as Senate Document 111, 85th Congress, Second Session.

During and following the 1950-1956 drought the river authorities developed master plans or reviewed and amended previous plans. Cities launched investigations to determine future water requirements and means to meet them. Federal agencies in response to various Congressional directives prepared investigation of areas not previously studied, or restudied areas included in previous investigations.

The Board, in cooperation with river authorities and cities, prepared a report titled "A Plan for Meeting the 1980 Water Requirements of Texas," May 1961.

The creation of a United States Study Commission-Texas was authorized by Congressional Act on August 28, 1958. Its assignment was to formulate a basic, comprehensive, and integrated plan for development of the land and water resources for the area of study, which included 62 percent of Texas. That Commission's report was published in March 1962. While potentials for development were enumerated and possible means for meeting water requirements shown, implementation of the outlined plan was not continued by a formal organization.

The Bureau of Reclamation and Corps of Engineers subsequently completed several reports on specific projects mentioned by the Study Commission report. Local entities--cities, river authorities, and water districts--were also suggesting projects in their areas, some of which conflicted with proposals of Federal agencies.

At the time Governor Connally's August 1964 letter was received the State had a tremendous reservoir of water resources planning information. Importantly the State had during the previous decades carried on an extensive data acquisition program on stream flows, reservoirs and reservoir contents, ground water, quality of water, sediment loads and reservoir sedimentation, evaporation rates, water uses, topographic mapping and inventories of irrigated and irrigable lands. Much of these data were obtained through cooperative programs with local entities and the U.S. Geological Survey. These data and a myriad of other information, while incomplete in some respects, provided a basis for full scope planning.

Approach to Planning

In the early stages of development of the Texas Water Plan several significant actions were taken.

Three State supported universities were invited to participate on specific assignments. The Bureau of Business Research and Environmental Engineering Department of the University of Texas were asked to provide projections of future municipal and industrial water requirements for each area of the State, including projections of population, and to project the volume and quality characteristics of municipal and industrial return flows. The University of Texas also participated in further study on bay and estuaries problems and requirements. Texas A&M University prepared a monumental interdisciplinary study of the opportunities for irrigation in Texas and the needs for irrigation within the national economy and Texas opportunities. Texas Technological College made five studies relating to the economics of irrigation use in the Texas High Plains area and problems associated with water conservation on the High Plains and the reuse of treated sewage effluents.

An advisory and review group was formed--the Consulting Advisory Panel for the Plan. The Panel members were selected to provide outstanding legal, engineering, hydrologic, and economic capability, to advise on the development of the planning program, and to review the various phases of the program as it progressed toward completion. Its membership included Mr. Joe M. Kilgore, Attorney, as Chairman; Mr. Harvey O. Banks, Consulting Engineer; Mr. William F. Guyton, Consulting Hydrologist; Dr. Allen V. Kneese, Resources Economist; and Mr. Mason Lockwood, Consulting Engineer.

A study styled "The Potential Contribution of Saline Water Conversion to Future Water Supply in Texas" was formulated in late 1964 and begun in the spring of 1965. This investigation of the Board under contract with Office of Saline

Water, Department of the Interior will be completed in the fall of 1966. Southwest Research Institute, Houston, is conducting the study under contract with the Board, with portions of the study carried out by Board personnel.

In addition to increasing the full time staff of the State water agency, consulting firms were retained from time to time during the course of the Plan's preparation. Fifteen consulting firms were used for such assignments. Federal and State agencies provided assistance and consultation during the course of the work.

Importantly, all possible work which could be effectively programmed for analyses by electronic computers was so scheduled. High speed computers of the State Comptroller, State Highway Department, and the University of Texas Computation Center were utilized by the staff during the preparation of the Plan.

Planning Concepts

Certain principles or concepts were established to guide the water planning program. These concepts expressed the political, economic, and social values essential to natural resource development and management. The Texas Water Plan was formulated using the following concepts of water development:

1. Water planning - and the selection between alternative development patterns - has a profound impact on the State - politically, economically, socially, and culturally.

2. The State's leadership in water planning is required to assure the equitable distribution of available water supplies in the future.

3. Surface waters are waters of the State, with permits for use administered by the Texas Water Rights Commission.

4. Sound planning recognizes and is guided by the proper exercise of the functions of the State, local and Federal agencies responsible for water development.

5. Ground water in Texas is an essential resource. Study of an integrated system of ground and surface water use to meet the problems of local areas offers promise of significant value.

6. In planning possible diversions from river basins, determinations of excess water were based not only on the projected water requirements of the basins of origin for 50 years, but also provided substantial allowance for future additional requirements.

7. Water quality management is an integral part of the planning - both as a constraint on meeting future water needs when quality conditions are impaired, and as an obligation where streamflow is nearing complete control.

8. Fresh water inflows are required to maintain the bays and estuarial resource in Texas although the volumes and times of need cannot be definitely determined with present knowledge. Comprehensive study of land and water uses, in these areas including concurrent aquatic life investigations, is essential.

9. Benefits of aesthetic and recreational enjoyment of the water resources of the State merit full consideration.

10. The State must participate financially in the construction, and operation and maintenance of some elements of the planned water storage and conveyance facilities if it is, in fact, to be in a position to guide the course of water development.

11. Both the cost of water in reservoirs, and the cost of transportation to areas of use, should be ultimately borne by the user and those who benefit directly from its use and distribution.

12. Planning is not a one-time effort but must be a continuing effort - hence a physical plan must be a part of a planned program of continuing effort by State, local and Federal interests.

Planning Problems

Texas is a challenging opportunity for a resource planning program because of its size--23 river basins requiring individual hydrologic analysis; its climatic and topographic diversity; and its transitional character as it moves from an agriculturally-oriented frontier to an intensively urbanized industrialized economy.

Climatological conditions in Texas are marked by extremes in temperature, precipitation rates, and the variation and extent of catastrophic weather which affects all regions of the State. The climatic patterns of the State are determined essentially by the interaction of moisture-laden Gulf air masses moving northwestward into the State colliding with dryer, relatively cooler air masses moving southeasterly from the continental interior.

The wide range in physical conditions controlling water resource occurrence in Texas is principally the consequence of variations in the plains environment which characterizes most of the State. Texas is a part of four major physiographic subdivisions of North America--the Gulf Coastal Forested Plain, the Great Western Lower Plains, the Great Western High Plain, and the Rocky Mountain Region.

The State is topographically a series of plains. From the northwest to the Gulf, there are three major plains divisions--the Staked Plains, or Llano Estacado, the North Central Plains, and the Gulf Coastal Plains.

Topographically, Texas slopes generally in a northwest to southeast direction. The excess surface water in the eastern one-fourth of the State is at an elevation of about 500 feet or less, while some major future water deficiencies in central and west Texas are at elevations of 1000 to 3500 feet.

Discharges of Texas streams vary within wide ranges as does the precipitation rates. Approximately three-fourths of the State's total surface water resource occurs in the eastern one-fourth of the State. Approximately 10 percent of the total runoff in the State is from flat coastal areas where capture of the water is difficult because of limited reservoir sites.

Long-range water resource development requires careful evaluation and consideration of the distinctive areas for which planning is required. In Texas, as a consequence of a wide range of climatic, topographic, and economic diversity, certain areas present unique problems, both of water supply and development, which do not lend themselves to solution by an application of statewide, or even basin wide, criteria.

In the program which led to the Texas Water Plan particular attention was given to these unique areas, and an effort made to reach solutions which are realistic within terms of the conditions existing within each area, and yet which are compatible with the objectives of the long range Plan.

Future Requirements For Planning

Water requirements were projected to 2020 for municipal, industrial, irrigation and mining water purposes, together with requirements for navigation, wildlife refuges, water quality in streams and bay and estuary, water-oriented recreational needs and opportunities, hurricane protection and stream flood problems, needs for agricultural drainage for soil conservation, including the upstream flood retardation program.

Projections of population and industrial water requirements were made by the Bureau of Business Research of the University of Texas in cooperation with the Texas Water Development Board. The method of projection used has been developed by the Bureau of Business Research over the past 17 years, during which time it has been studying the problems of water requirements and industrial and population growth. In the early studies, the Bureau of Business Research collected information on water use needed for computing future water requirements, but in the present study these data were furnished by the Water Development Board. A continuing program has been carried on by the State since 1955 of surface water and ground water uses by municipalities and industries. These data were rechecked with each municipality and also cross-checked with data of the State Department of Health. A continuing inventory of new industries and expansion of existing industries, plus pertinent municipal economic data, are maintained by the Bureau of Business Research.

In early 1965, the Board, in cooperation with the Bureau of Business Research and the Houston Chamber of Commerce Water Supply Committee, developed a questionnaire on industrial water use. The questionnaire, transmitted to each industrial water user in the State, provided detailed information on the amounts of water used, the sources of water supply, the amounts of water being reused, and information on the industries' own projections of their future water requirements. These data were used, together with the resources information developed by the Bureau of Business Research, in the projection of future industrial water requirements.

The basic consideration in population projections for small areas were the economic factors in each area. Forecast of population in small areas are complicated by the ease with which population moves as job opportunities declined in one area and expanded in another. The forecast of population used in planning place more emphasis on the number of jobs that will be provided in a given area than on the birth and death rates in that area. Population forecasts for each area have been harmonized with the total population forecast for the entire State.

The State was divided into 32 trading areas, each including a major city in the territory surrounding it. Each of these trading areas was considered an economic unit, and its future growth projected in the light of the resources that it was believed that the area would produce and export in future years.

When the increase in employment expected to result from this export of goods and services was projected, a total population which could be supported by this increase of employment was computed. From the amount of water presently being used in each area, as determined from data obtained from the Water Development Board, it was then possible to compute the water requirements for the future. The nature of industry and the amount of water normally required for its operation were taken into account and water requirements were broken down into domestic consumption and industrial consumption.

Inherent in the projections is the assumption that if ample supplies of satisfactory quality water are available at reasonable cost the indicated population and water requirement levels will be reached. A reasonable price of water has been assumed to be on the order of those experienced in the past. Also inherent in the projection is the assumption that development will proceed in accordance with what has been feasible in the past at the experienced cost of water and the resources available. It is important to recognize that projections of population and water requirements are subject to many errors, and it is important that these projections be reviewed whenever new information is available. A continuing program of data collection and evaluations and regular review of the projections will provide information for revising programs in the scheduling of projects.

The population of Texas has increased from 1.5 million in 1880 to 9.6 million in 1960. During this 80 year period the population of Texas has increased more than 6 times while the population of the United States has increased only 3 1/2 times. Thus, the population of Texas has increased more rapidly than the population in the nation as a whole. Projections of the national populations have been made by the Senate Committee on Water Resources, the United States Census Bureau, and the Adhoc Water Resources Council.

Additionally, projections of populations have been made by the Texas A&M Rural Sociology Department.

Projections of State populations for this plan were made independently and then checked against these four projections. These comparisons show that the population projections used in the plan are between the minimum and maximum projections of the three Federal entities and the A&M study. The projection of State population growth was distributed by trade areas, thence by counties and cities, in accordance with a trade area industrial model. The population projection for the State is shown to increase from 9.6 million in 1960 to 17.8 million in 1990 to 30.5 million in 2020.

Per capita water uses were determined for each city in the State for the period 1956 to 1962 on a 7-year basis from data obtained from the State Department of Health, and for the period 1960-1964 from the municipal water supply facility inventory conducted by the staff of the Water Development Board. Information taken from the Industrial Water Use Inventory of 1964 was utilized to separate industrial water use from reported municipal uses, if the industrial use was shown to come from a municipal system. This prevented a duplication in the water requirements projections.

Per capita uses of water for each region of the State were compared for cities of like sizes in the same geographic area. Projections of increased uses were also used on the basis of past increases in each region. Adjustments in future per capita uses were made for those cities having smaller increases historically to reflect increased commercial uses as these cities matured. A comparison for each city was made of the projected uses with all available data, and projected uses with all available reports, and projections made by other agencies and entities. Non-industrial water usage, that is the domestic, municipal and commercial use, was then developed by multiplying the per capita uses by the projections of population. These values were then converted to annual quantities in acre-feet per year.

The methodology previously described was utilized for projecting industrial water requirements for each trade area and then in distributing this industrial usage in the trade area. This distribution by counties was then recombined to provide information by river basins.

Municipal and industrial water requirements for the State are shown to increase from 2.58 million acre-feet in 1960 to 6.51 million acre-feet in 1990 to 12.07 million acre-feet in the year 2020. Data by river basins for these three periods for the municipal and industrial requirements are contained in Table 1.

The Soil Conservation Service had previously assisted the Board by helping to inventory the Texas irrigation in 1958 and again in 1964. These inventories revealed that Texas has 37 million acres physically suited for irrigation. Although all parts of Texas contain some of these irrigable lands, 60 percent occurs in West Texas and the High Plains, with most of the remainder along the Coast, the Coastal Bend, the Winter Garden, areas below the Balcones Escarpment, and in the Lower Rio Grande Valley. To obtain information on the future potentials of irrigation on a basis comparable to estimating future municipal and industrial growth and water needs, Governor Connally sought and received the cooperation of a sizeable contingent of the staff at Texas A&M University to study the potential for irrigation in all of the land resource areas of Texas. The A&M studies, showed that if water is not a limiting factor, physically or cost-wise, 16.7 million acres could be profitably irrigated to produce crops that can be expected to be produced in Texas toward fulfilling the 2020 needs for food and fiber. All but 17 percent of this would be concentrated in irrigation areas of West Texas and the High Plains, the Valley, the Winter Garden,

Table 1.--Municipal and industrial water requirements by basin

(in acre-feet)

Basin	1960			1990			2020		
	Mun.	Ind.	Total	Mun.	Ind.	Total	Mun.	Ind.	Total
Canadian	38,204	79,973	118,177	100,000	169,900	269,900	148,000	223,200	371,200
Red	43,240	26,212	69,452	94,200	78,800	173,000	172,100	118,700	290,800
Sulphur	10,366	24,118	34,484	27,100	37,300	64,400	55,500	45,500	101,000
Cypress	11,403	46,084	57,487	22,700	81,700	104,400	41,800	111,700	153,500
Sabine	23,301	69,168	92,469	55,200	346,100	401,300	131,200	755,600	886,800
Neches	30,047	120,852	150,899	88,000	353,200	441,200	202,000	668,000	870,000
Neches-Trinity	16,324	96,695	113,019	47,200	341,000	388,200	108,600	703,100	811,700
Trinity	282,830	119,887	402,717	728,900	196,500	925,400	1,394,300	300,300	1,695,100
Trinity-San Jacinto	5,677	42,367	48,044	12,400	75,300	87,700	29,600	122,500	152,100
San Jacinto	176,799	248,801	425,600	445,300	792,600	1,237,900	914,600	1,522,800	2,437,400
San Jacinto-Brazos	36,693	104,197	140,890	93,200	254,500	347,700	217,900	415,300	633,200
Brazos	131,034	93,087	224,121	300,400	159,400	459,800	557,000	233,500	790,500
Brazos-Colorado	5,713	21,698	27,411	12,900	53,300	66,200	32,500	87,400	119,900
Colorado	103,303	40,927	144,230	243,300	94,000	337,300	459,300	145,200	604,500
Colorado-Lavaca	1,576	4,521	6,097	4,000	35,900	39,900	7,800	80,800	88,600
Lavaca	3,239	2,203	5,442	6,400	8,500	14,900	10,600	16,300	26,900
Lavaca-Guadalupe	2,010	39,213	41,223	6,400	124,000	130,400	12,400	233,900	246,300
Guadalupe	19,885	23,862	43,747	48,800	41,200	90,000	102,700	59,000	161,700
San Antonio	99,783	20,925	120,708	231,900	48,200	280,100	369,200	78,000	447,200
San Antonio-Nueces	7,082	6,739	13,821	15,700	12,600	28,300	30,600	18,100	48,700
Nueces	13,543	6,370	19,913	25,400	14,100	39,500	44,800	22,300	67,100
Nueces-Rio Grande	104,900	59,083	163,983	213,300	147,100	360,400	420,400	240,600	661,000
Rio Grande	90,275	26,167	116,442	180,100	46,300	226,400	331,900	70,400	402,300
State Total	1,257,227	1,323,149	2,580,376	3,002,800	3,511,500	6,514,300	5,794,800	6,272,700	12,067,500

in the rice areas along the Coast, and the Coastal Bend. The 17 percent would be scattered, usually individual farms and fields, in Central and East Texas supplied from ground water or direct diversion from streams and small up-stream on-farm impoundments.

Ground water is used for over 80 percent of all Texas irrigation, principally on the High Plains and other West Texas areas, the Winter Garden and for much of the rice irrigation along the Coast. Ground water is expected to become increasingly unavailable for economical irrigation in many of the areas, especially in West Texas, the High Plains, and the Winter Garden. Out-of-State water will need to be imported to West Texas and the High Plains area to supply irrigation needs there that dwindling ground water cannot sustain. Taking into account the anticipated reductions in ground-water-supplied irrigation in amounts of irrigation that can be expected to be economically feasible, using only available surface water from in-State sources, a 2020 proposed plan level of irrigation was determined.

It should be made clear that the proposed planned level of this irrigation in any area of Texas is based on the assumption that irrigators will be able to, and will pay for, the surface water they use on a basis that will cover the cost of developing and delivering the water to the point of use. The planned irrigation, without out-of-State water, will by 2020 provide an estimated 5.9 million acres of irrigation in Texas. This proposed development would include some expansion over current levels in rice production on the Coast, produced in areas where urban and industrial expansion is expected to be less of a factor in the future use of both land and water; development of upper and lower Coastal Bend irrigation projects in the Corpus Christi area which would ultimately provide one-half million acres of irrigation; augmentation of water supply for about 170,000 acres of Valley irrigation for which adequate supply is not now available from the Rio Grande; an ultimate net expansion in irrigated area of the Valley of about 330,000 acres.

Expansion of irrigated acreage is expected to take place also in Central and East Texas, but the acreage is likely to remain small compared to these concentrated project-type areas. In East Texas, agricultural trends are distinctly away from intensive crop production, and Central Texas areas are, in general, trending strongly toward a livestock economy. Nevertheless, some, mostly individual field and farm, irrigation is likely to develop and persist where these tracts are located for efficient use of available ground and surface water.

Irrigated areas and water requirements for 2020 are shown in Table 2 by river basins, and the lands projected to be served from ground water, non-project surface water and project surface water sources. This table does not include surface water requirements for lands in the High Plains, North Central Texas, and Trans-Pecos areas, some of which are currently irrigated. The acreage and surface water requirements for these areas by river basins are:

River Basin	Acreage-1000 Acres	Water Requirements 1000 acre-ft.
Canadian	538.3	1,176.6
Red	1,408.9	2,754.7
Brazos	2,162.5	4,326.6
Colorado	2,854.9	5,748.5
Rio Grande	351.7	1,200.0
	7,316.3	15,206.4

Water requirements for secondary recovery operations in oil and gas fields were prepared by the Mid-Continent Oil and Gas Association and also by Dr. Paul Torrey, Oil and Gas Consultant, under contract to the Water Development Board.

Table 2.--Irrigation by river basins in year 2020

Basin	Ground Water Use		Non-Project Surface Water Use		Project Surface Water Use		Total Irrigation	
	1,000 Acre	1,000 Acre-Ft.	1,000 Acre	1,000 Acre-Ft.	1,000 Acre	1,000 Acre-Ft.	1,000 Acre	1,000 Acre-Ft.
Canadian 1/	1,442.2	966.2	0	0	0	0	1,442.2	966.2
Red 1/	317.8	308.9	75.1	135.0	42.0	114.0	434.9	557.9
Sulphur	0	0	14.8	22.0	0	0	14.8	22.0
Cypress	5.0	6.0	4.8	5.7	0	0	9.8	11.7
Sabine	4.0	10.9	31.3	46.7	4.0	16.9	39.3	74.5
Neches	9.5	24.1	12.0	20.6	6.7	28.3	28.2	73.0
Neches-Trinity	0	0	0	0	117.0	495.1	117.0	495.1
Trinity	30.6	57.2	109.4	131.1	20.0	91.4	160.0	279.7
Trinity-San Jacinto	6.4	25.0	0	0	10.0	45.7	16.4	70.7
San Jacinto	53.9	209.1	0	0	0	0	53.9	209.1
San Jacinto-Brazos	9.5	36.9	0	0	72.8	332.7	82.3	369.6
Brazos 1/	521.3	472.5	121.0	134.6	39.9	96.4	682.2	703.5
Brazos-Colorado	15.4	59.7	0	0	39.7	181.4	55.1	241.1
Colorado 1/	138.3	171.3	26.4	42.9	61.9	146.8	226.6	361.0
Colorado-Lavaca	17.0	70.0	0	0	34.8	167.4	51.8	237.4
Lavaca	42.3	173.1	0	0	42.7	190.1	85.0	363.2
Lavaca-Guadalupe	11.0	45.0	0	0	14.0	52.0	25.0	97.0
Guadalupe	15.8	23.5	22.3	28.6	0	0	38.1	52.1
San Antonio	31.4	49.9	16.0	19.5	0	0	47.4	69.4
San Antonio-Nueces	15.8	22.0	0	0	180.0	313.2	195.8	335.2
Nueces	74.8	125.9	23.0	25.9	20.0	35.4	117.8	187.2
Nueces-Rio Grande	4.2	6.0	0	0	1,328.3	2,803.5	1,332.5	2,809.5
Rio Grande 1/	38.5	131.0	25.0	64.3	322.7	830.9	386.2	1,026.2
State Total	2,804.7	2,994.2	481.1	676.9	2,356.5	5,941.2	5,642.3 2/	9,612.3

1/ These totals do not include import water from out-of-State sources.
2/ Some additional project irrigation to be completed after 2020.

Projections by the Mid-Continent Oil and Gas Association were based upon needs in known fields, while Dr. Torrey's estimates are slightly higher and reflect anticipated additional discoveries. For this reason the slightly higher figures prepared by Dr. Torrey have been used for planning purposes.

Although navigation facilities presently exist only in the lower ends of river basins and along the Texas Gulf Coast, consideration was given to the possibility of the future feasibility of extension of navigation facilities up the main rivers. Any such extension of navigation would require a series of dams and locks at appropriate locations. Lockage heights were estimated from river profiles and water requirements computed on the basis of 12 lockages per day plus leakage and evaporation losses, except for those streams in which detailed feasibility studies were already available. Generally navigation lockage requirements were found to be largest in the middle to upper portions of the river basins, although this varied due to the location of existing, under-construction, or proposed major reservoirs. While these upstream lockage water requirements are large, the net basin navigation requirement used was the lowermost lockage in the system. Navigation facilities, when designed, should provide that excess lockage water from upstream lockages can be diverted for other uses in the lower reaches.

Water quality management is an essential part of the Texas Water Plan. Of special concern is the quality in streams, reservoirs, the requirement for clean water for municipal and other uses, including recreation, and the effect of increased waste discharges on downstream uses and fish and wildlife. Return flows were computed for the projected municipal and industrial water requirements and from future irrigation. Return flows to streams above possible points of diversion have been included with the total water resources available for additional uses.

Each of the water-related needs for flood control, hurricane protection, agricultural drainage, upstream flood retardation, wildlife refuges were developed with information from appropriate State and Federal agencies. The water quality aspects of the plan will be discussed in a separate paper which follows.

Although recreation is not a water requirement in a multi-purpose project, economic projections of recreational use of reservoirs was made by the staff with the assistance of Dr. Herbert Grubb of Texas Technological College and Dr. Jack Knetsch of Resources for the Future, Inc. The mathematical model for the projection of recreational uses of proposed reservoirs was developed giving consideration to existing, under-construction and proposed reservoirs throughout the State. In order to develop this model it was necessary to obtain considerable economic information in the field for representative existing reservoirs throughout the State. These data were obtained in cooperative field surveys made by personnel of the Texas Water Development Board and Parks and Wildlife Department, with assistance from the Texas Highway Department in the summer of 1965. Recreational data for Texas reservoirs was also obtained from surveys conducted by the Corps of Engineers.

Planning Methodology

Investigations were made of the amounts of ground water and surface water currently used in each area and the sources, locations and purposes of these uses. Determinations were made of the additional ground and surface water which could be developed without respect to the points of use. Ground water determinations were made for each major and minor aquifer and consideration given to the quality of water from these formations. The additional surface water which could be developed in a basin were determined by a series of studies of alternative combinations of existing and proposed reservoirs. Initially 173 proposed reservoir sites were included in the preliminary studies for evaluation.

Inflows into the existing and proposed reservoirs were modified for upstream programs of development. Allowances were made for sedimentation to future points of time for existing and under-construction reservoirs. Estimates were made of the sediment capacity requirements for each of the proposed reservoirs. Alternative proposed reservoir sites, or enlargement of existing reservoirs, were studied at various capacities with varying assumed combinations of proposed reservoirs at upstream locations. Total yields from the combination of various reservoirs with various sizes were obtained. The yield versus capacity characteristics of each reservoir were examined and, in conjunction with cost data, preliminary determinations made of the optimum reservoir conservation capacity.

Consideration was then given to the geographic location of these proposed reservoirs and ground water sources with reference to projected water requirements, the present sources used to obtain supplies, and the most economical means of meeting projected requirements. Return flows from future water requirements were estimated and when above points where flow could be controlled, added in as additional yield. In coastal basins ground water available on a continuing basis were used as a part of the future water requirement. The remainder of the requirement shown as deficiencies were indicated to be served by importation.

A fundamental concept adopted early in the plan formulation was that insofar as possible water uses would be supplied from water sources within the basin, including surface and ground water when such supplies could be furnished economically and efficiently. After the projected 50-year water demands in each basin were analyzed and an available in-basin supply planned to meet these uses, some basins were found to have excesses and some deficiencies of available water over the anticipated need of the basin in the year 2020.

Because of length some basins had indicated deficiencies in one part of the basin and surpluses in the other. For example, the Trinity and San Antonio River basins have demands for water in the upper portions which exceed the upper in-basin supplies where the lower portions of the basin have indicated excesses. Because of the geographic and hydrologic nature of such basins and because of economic considerations, the excesses in the lower basin did not appear feasible for use to meet upper basin deficiencies.

During the early phases of the planning investigations, a listing of the water permits and certified filings were reviewed. Water permit considerations on all major reservoirs and major direct diversions from streams were given the fullest consideration in the development of the preliminary plans for each basin.

The Preliminary Texas Water Plan

Through the information on water resources, requirements, and water-related problems developed during the planning process, and the information available from other studies, and on the basis of the methodology adopted, the Texas Water Plan was formulated as a flexible guide to the course of water development to the year 2020. The Texas Water Plan proposes a coordinated State-Local and Federal program of continuing effort which will:

1. Serve projected 2020 municipal and industrial water requirements from supplies developed from existing and under-construction major reservoirs, ground water supplies, and 53 proposed new reservoirs, modification of 6 existing reservoirs, and construction of 2 salt-water barriers.

2. Consider all existing water rights.

3. Supply non-project irrigation from streams and ground water, plus increases of rice irrigation through existing facilities on the Coastal Plains.

4. Supply new irrigation projects for 500,000 acres in the Coastal Bend and about 330,000 new acres in the Lower Rio Grande Valley plus water for some 170,000 acres previously irrigated in the Valley.

5. Work toward additional irrigation in the High Plains and Trans-Pecos region by importation of water from out-of-State.

6. Provide for projected water requirements for secondary oil recovery programs.

7. Meet stream water quality requirements.

8. Provide for bay and estuary requirements with tolerable water shortages on interim basis.

9. Provide for serving the projected water requirements of wildlife refuges.

10. Provide additional recreational opportunities in the proposed multi-purpose reservoirs.

11. Include flood control storage as a project purpose in 30 proposed reservoirs, plus channel improvement and levee projects.

12. Integrate future feasible navigation projects on Texas streams into the Plan.

13. Include additional upstream watershed programs on 17,584,000 acres for erosion control and land treatment, plus 2,510 additional flood water retarding structures and 1,193 miles of additional channel improvement.

14. Include needed projects for drainage of agricultural wetlands.

15. Support projects to alleviate natural pollution in the upper Red and Brazos River basins.

16. Support hurricane protection projects along the Gulf Coast.

The proposed reservoirs contained in the Texas Water Plan are shown in Table 3 together with the construction costs and capacities of these proposed

Table 3.--Construction costs and capacities of proposed reservoir development*

River basin	Reservoir	Storage capacity in thousands of acre-feet				Construction cost in millions of dollars
		Flood control	Conser-vation	Sediment	Total	
Red	Sweetwater	0	33.0	16.9	49.9	4.2
	Timber Creek	0	12.0	1.0	13.0	2.3
	Bois d'Arc	73.1	92.5	13.9	179.5	13.9
	Big Pine	54.7	77.9	6.0	138.6	10.0
	Pecan Bayou	0	369.8	13.5	383.3	16.6
	Lake Kemp modification	200.0	245.8	80.2	526.0	7.1
Sulphur	Cooper	127.5	273.0	9.3	409.8	18.0
	Sulphur Bluff I	0	548.2	87.2	635.4	31.2
	Naples I	454.7	1,466.5	135.8	2,057.0	74.9
	Naples II	701.7	2,220.0	190.0	3,111.7	41.9
	Texarkana modification	1,687.7	802.9	125.8	2,616.4	13.0
Cypress	Franklin County	0	71.8	1.2	73.0	3.5
	Titus County	132.8	287.0	2.9	422.7	12.0
	Lake O' the Pines modification	461.2	377.1	3.8	842.1	5.9
	Marshall	0	775.0	7.3	782.3	25.1
Sabine	Mineola	668.8	167.1	11.0	846.9	49.5
	Lake Fork	357.6	498.8	18.9	875.3	45.9
	Kilgore No. 2	0	14.0	1.0	15.0	2.0
Neches	Blackburn Crossing enlargement	0	401.4	8.6	410.0	12.3
	Ponta	649.2	810.0	25.4	1,484.6	51.8
	Rockland	1,440.5	1,787.9	58.9	3,287.3	84.5
Trinity	Bridgeport modification	0	396.1	37.0	433.1	3.0
	Aubrey	258.3	603.8	37.8	899.9	34.1
	Lakeview	136.7	306.4	45.6	488.7	31.8
	Richland Creek	0	1,000.0	135.5	1,135.5	30.0
	Tehuacana Creek	0	374.0	33.5	407.5	19.7
	Tennessee Colony	2,144.3	1,032.5	190.0	3,366.8	137.1
	Bedias	0	488.0	16.7	504.7	25.2
	Wallisville	0	46.7	12.4	59.1	16.3
	Lavon modification	275.6	380.0	92.6	748.2	31.4
San Jacinto	Cleveland	0	479.8	4.2	484.0	18.7
	Lower East Fork	0	330.7	7.3	338.0	35.1
	Lake Creek	0	200.0	6.0	206.0	15.0
	Humble	0	511.0	15.0	526.0	60.0
Brazos	Millers Creek	0	17.5	8.0	25.5	5.4
	Breckenridge	0	550.0	67.0	617.0	19.6
	De Cordova Bend	0	105.4	44.6	150.0	15.0
	Stephenville	0	40.6	10.9	51.5	2.5
	Aquilla Creek	111.5	59.7	28.1	199.3	23.6
	North San Gabriel	87.7	36.1	7.0	130.8	14.1
	Laneport	130.1	91.9	22.2	244.2	32.2
	Cameron	0	1,200.0	18.0	1,218.0	32.5
	Navasota No. 2	550.7	1,315.4	69.5	1,935.6	61.1
	Millican	359.0	1,125.8	72.0	1,556.8	58.6
Colorado	Robert Lee	0	454.8	34.0	488.8	12.8
	Stacy	659.3	650.0	50.0	1,359.3	26.4
	Upper Pecan Bayou	102.7	93.5	10.1	206.3	10.5
	Columbus Bend	481.7	395.2	88.1	965.0	44.2
	Matagorda	0	61.4	28.6	90.0	31.3
	Brownwood replacement	0	133.2	10.2	143.4	7.3
Lavaca	Palmetto Bend	0	230.0	55.0	285.0	51.0
	Garcitas	0	63.0	4.0	67.0	22.0
Guadalupe	Ingram	36.4	53.5	.5	90.4	8.5
	Cloptin Crossing	107.0	146.8	3.2	257.0	14.5
	Lockhart	0	59.9	9.5	69.4	5.0
	Cuero (I and II)	843.0	2,816.0	50.0	3,709.0	117.5
	Confluence	0	406.0	33.0	439.0	63.0
San Antonio	Cibolo	218.0	172.0	28.0	418.0	26.5
	Goliad	702.0	958.0	42.0	1,702.0	50.5
Nueces	Choke Canyon	0	686.0	14.0	700.0	31.9

* Does not include salt-water barriers

reservoirs. The total capital cost of the units of the State Water Project and the reservoirs not a part of the State Water Project total $2,734,000,000.

Each of the proposed reservoirs were examined for a staging in order to meet the projected water requirements together with the existing sources of supply. This investigation resulted in the preliminary staging of reservoir construction for the period 1967 to 2020 contained in Table 4.

The Next Steps

After completion of the preliminary Plan the Water Development Board prepared 23 separate reports containing summaries of the proposed preliminary Plan of water resources development in each of the river basins. The Board then held 27 public hearings in river basins throughout the State on its preliminary plan for the development of Texas water resources to meet water needs for the next 50 years. In addition, the Board held 3 public meetings to assure the widest distribution of information concerning the Plan.

At each of these hearings the Board presented its preliminary Plan for development of the river basin in which the hearing was held, outlined proposed diversions that were a part of the plan, and invited the views, comments, criticisms and suggestions of those interested in water development. Testimony was recorded and an opportunity given for formal statements to be added to the official record by September 15, 1966, or 30 days after the hearing date, whichever was later.

The Water Resources Administration Act, directing the preparation of the Texas Water Plan and the hearings, requires that

> "Thereafter in preparing this Plan the Board shall give consideration to the effects such Plan will have on the present and future development, economy, general welfare, and water requirements of the areas of such river basin"

Table 4.--Preliminary staging of reservoir construction, 1967 - 2020

1967 - 1979	1980 - 1990	1990 - 2020
Cooper	Richland	Sweetwater
Cuero I & II	Tehuacana	Naples I & II
Goliad	Ingram	Texarkana Modification
Palmetto Bend	Mineola	Pecan Bayou
Cibolo	Lake Fork (Sabine)	Marshall
Confluence	Stacy	Bedias
Aubrey	Sulphur Bluff I	Cameron
Lakeview	Choke Canyon	Big Pine
Columbus Bend	Miller Creek	Upper Pecan Bayou
Garcitas	Rockland	Ponta
Stephenville		Cleveland
Cloptin Crossing		Humble
Aquilla Creek		Lower East Fork
Millican		Lake Creek
Brownwood Replacement		Navasota No. 2
Lockhart		Matagorda
Breckenridge		Franklin County
Bois d'Arc		Titus County--Staging dependent on navigation
Lake O' the Pines Modification		
Kilgore No. 2		
Timber Creek		

Already Scheduled for Construction

Bridgeport Modification
Lavon Modification
Blackburn Crossing Enlargement
North San Gabriel
Laneport
Wallisville
De Cordova Bend
Robert Lee
Lake Kemp Modification

Tennessee Colony - Authorized, possibly early construction for flood control.

or "of the areas affected." During the immediate future, the Board will be engaged in this process.

The Board in a statement released on September 21, 1966 outlined a 16 item work program of studies of alternatives. The Board will proceed with these engineering, hydrologic, and economic studies as rapidly as personnel and funds permit, to analyze the suggestions, criticisms, and alternatives presented at the public hearings. These studies and others as the Board may determine, will be conducted to provide adequate information on the basis of which proposed modifications of the plan may be accepted or rejected.

The statute states:

> "When the Board has prepared and examined the completed Plan, the Texas Water Commission or its successors shall, upon request of the Board, hold a public hearing on said Plan to determine whether or not said Plan gives adequate consideration to the protection of existing water rights in this State and to determine whether or not said Plan takes into account modes and procedures for the equitable adjustment of water rights affected by said Plan. After such hearing and upon notification by the Texas Water Rights Commission that the Plan appears to give adequate consideration to the protection of existing water rights and does take into account the equitable adjustment of water rights affected by said Plan, the Board shall formally adopt the State Water Plan."

The statute further provides that:

> "When formally adopted by the Board, the State Water Plan shall be a flexible guide to State policy for the development of water resources in the State."

After these steps are accomplished the State will have reached its first objective in planning--a flexible guide for the long-range development of its water resources. However the plan is only the first step in a long journey and the State has to look to means for the plan's implementation. The implementation will involve both engineering and economic feasibility studies of units of the Plan, plus continuing programs of collection and analysis of basic information to support the decision-making process of water resources development. Importantly the planned program of work will involve efforts by local, State and Federal agencies.

A continuing program of planning is essential for proper staging of projects and required to provide for changing conditions, together with modifications indicated from future detailed feasibility studies. The statute provides:

> "The Board shall also make such modifications and amendments to said State Water Plan as experienced and changed conditions make advisable and the Texas Water Commission or its successors shall, when requested by the Board, hold a public hearing in the same manner and for the same purposes as specified herein on the original State Water Plan. Any modifications or amendments so adopted by the Board shall become a part of the said Plan."

Studies made during the course of the planning indicate that additional Funds, tentatively styled the Texas Clean Water Fund and the State Recreation Fund, will need to be created. The Clean Water Fund is required to provide State assistance in the financing of regional waste collection, treatment and disposal programs to be conducted by local agencies, and the State

Recreation Fund to finance the State's share of cost allocated to recreation and to the enhancement of fish and wildlife resources in connection with the projects contained in the proposed Texas Water Plan.

THE PROPOSED STATE WATER PROJECT

Lewis B. Seward[1] and
John J. Vandertulip[2]

[1] Assistant Chief Engineer, Texas Water Development Board; Member, ASCE
[2] Chief Engineer, Texas Water Development Board; Member, ASCE

Introduction

The development of the water resources in Texas has two goals. The first goal is to develop those resources, including surface and ground water and return flows, to satisfy those needs which lie within the basin of supply; and the second, to develop a method for supplying water to those basins where water demands within basins with deficient supply may be met by transfer water from basins of surplus, by importation of water from outside the state, by saline water conversion, or by exchange of water.

To achieve these two goals in Texas a detailed study was made of the water demands by basins and supplies of each basin available for supplying those demands. A study was made of alternative possibilities for the movement of large volumes of water from areas of the State with surplus waters to areas of deficiencies utilizing reservoirs, canals, pump stations, tunnels and natural river channels.

Inherent in the successful development of such a program of water transfer was the need to assure that the needs of each basin were met, and that the water designated to be moved from the areas of surplus was truly surplus to the foreseeable future needs of the basins of origin.

Essential also was the need to build into the Plan a program for orderly water development and flexibility to insure that in the years to come modifications can be accommodated without a major disruption. Such flexibility can be provided to a significant measure by providing sufficient capacity in conduits with realistic economics and financing to provide for opportunities in increasing benefits should they occur.

The plan for interbasin transfer involving moving water from the east to the west and consists of a system of reservoirs, pump stations, transfer conduits and, when possible, natural channels. It is a fundamental premise of the plan that the units will be built as they are required.

For the purpose of this paper, the State Water Project has been divided for convenience of description. These are the Cypress, Sulphur, Red, Trinity, Brazos divisions, and the Coastal Aqueduct. The Red Division includes the pump stations and reservoirs necessary to transport water from the lower Red to the Sulphur and Trinity Basins. The Sulphur Division consists of those reservoirs and pumping stations necessary to develop the waters of the Sulphur Basin, and to transmit a portion of the waters to the Trinity River. The Cypress Division includes the reservoirs and pumping plants necessary to develop water in the Cypress Basin, and to transport a part of the surplus to the Sulphur River. The Trinity Division includes the conduit and pump stations necessary to deliver water from Lavon Terminal to the Dallas-Fort Worth area and to the Trinity River, and the transfer facilities from the Trinity through Richland Creek, Tehuacana, and to the Brazos. The Brazos Division consists of the Brazos River channel, the transfer facilities to the Colorado and to Palmetto Bend Reservoir, and facilities from the Colorado to the San Antonio area. The Coastal Division consists of the reservoirs, aqueduct, and pump station to transport water from Palmetto Bend to the Rio Grande including Palmetto Bend, Confluence, Cuero, Cibolo, and Goliad Reservoirs, as well as the Sinton, Baffin Bay and Valley regulating reservoirs. Distances from reference points used in describing the Project are approximate. Costs are based on the 1966 index.

Sulphur Division

A key element in the State Water Project is the Sulphur Division not only because it provides the first blocks of water for transfer to the Trinity River

Division but also because it provides the facilities for receiving water from the Red River and the Cypress River basin for transfer west. By the year 2020, the units in the Sulphur Division will include Cooper Reservoir, Sulphur Bluff I, Naples I and II, converted Texarkana Reservoir, and transfer facilities.

Cooper Reservoir - Cooper Dam and Reservoir is an authorized Federal multiple-purpose project under design by the Corps of Engineers. The dam site is about four miles southeast of the town of Cooper on the South Sulphur River at approximately river mile 23. The reservoir, lying entirely within Delta and Hopkins Counties, will control runoff from 476 square miles. The principal modifications which will be required in the project as it is presently planned by the Corps for its inclusion within the State Water Project are the addition of three conduits, control gates, and discharge structures needed for the movement of water into the reservoir from downstream projects.

Cooper Reservoir will be used for flood control, water supply, and recreation and will have a maximum capacity of about 441,400 acre-feet at the time of construction. The cost of the structure will be approximately 18 million dollars. The flood control storage in Cooper Reservoir will allow for a conversion of 120,000 acre-feet on flood control storage in Texarkana Reservoir to water supply storage.

Sulphur Bluff Dam and Reservoir - The next downstream structure on the Sulphur River included in the State Water Project is Sulphur Bluff Dam and reservoir.

The Sulphur Bluff Dam site extends across the two tributary forks of the Sulphur River, crossing the South Sulphur at river mile 3.5 and the North Sulphur at river mile 5.5. The dam site is 15 miles east of Cooper, Texas and 2 miles north of the town of Sulphur Bluff. The project, within Hopkins, Delta, and Lamar Counties, will control drainage from 1,026 square miles, 645 from the South Sulphur River, and 381 from the North Sulphur River.

The Sulphur Bluff Reservoir will be used for water supply and for recreation and will have a maximum capacity of a little over 1 million acre-feet. The approximate cost of the project is about $45 million including cost of utility and highway relocations. It will be constructed in two stages, with Stage I being on the South Sulphur River, and Stage II at a much later time on North Sulphur River.

Naples Dam and Reservoir - The Naples Dam site crosses White Oak Bayou at mile 15 and Sulphur River at mile 115. The site is 43 miles southwest of Texarkana and 10 miles northeast of Mt. Pleasant. The reservoir will lie in parts of 5 counties: Bowie, Red River, Morris, Titus, and Franklin. The total drainage area upstream from the site is 2700 square miles of which 700 are in the White Oak Bayou and 200 in the Sulphur Basin. There are four oil fields--Pewitt Ranch, Talco, Christmas, and Trix-Liz--within the reservoir area. Planning estimates provide for construction of protective measures for these fields.

The Naples Reservoir will be used for water supply, flood control and recreation. A portion of the flood control storage, 700,000 acre-feet, will have been transferred from the Texarkana Reservoir. The total cost of the reservoir is about 130 million dollars including the cost of relocation of utilities and oil field protection.

Texarkana Enlargement - Texarkana Dam and Reservoir is an existing Federal multiple-purpose project constructed and operated by the Corps of Engineers. Impoundment began in June 1956. The dam is eleven miles southwest of the City of Texarkana on the Sulphur River at mile 45. The reservoir borders Bowie and Cass Counties and extends into Morris, Titus and Red River Counties. The total contributing drainage area is 3443 square miles. In addition to the 120,000 acre-feet of flood control storage converted in conjunction with Cooper Reservoir, it is anticipated that 700 thousand acre-feet of Texarkana Reservoir flood control storage will be exchanged for equivalent storage in Naples Reservoir. The total cost for enlarging, including raising Naples Reservoir to accommodate exchanged flood control space, is approximately 14 million dollars.

Transmission Facilities Sulphur Basin - Transmission facilities are needed to integrate the reservoirs in the Sulphur Basin into the coordinated system of transfer envisioned by the State Water Project. These transmission systems include: Naples Transmission Channel and Pump station transporting water from Texarkana to Naples Reservoir; Talco Transmission Channel and Pump Station and Sulphur Transmission Channel and Pump Station carrying water from Naples Reservoir to Sulphur Bluff Reservoir; Cooper Transmission Channel and Pump Station.

The Naples Transmission Channel will start at the upper end of the Texarkana Reservoir and will convey water 20,000 feet to the Naples Pump Station. This canal will follow the general alignment of the natural river channel.

The Naples Pump Station will be near the left (north) edge of the Sulphur River floodplain and near the downstream toe of Naples Dam, and will lift Texarkana Reservoir water up into Naples Reservoir. The pumping head will vary with the stage of Texarkana and Naples Reservoirs with a maximum lift of 99 feet.

The Talco Pump Station will be near the headwaters of Naples Stage II Reservoir 3/4 mile north of the town of Talco and will pump Naples Reservoir water to the design level of the Sulphur Bluff Transmission Channel. Pumping-heads will vary with the stage of Naples Reservoir with a maximum lift of 83 feet.

The Talco-Transmission Channel will be excavated in the upper end of Naples Stage I Reservoir. About one-half of the channel at the eastern end will follow the general alignment of the existing river channel and the remainder will follow the south edge of the floodplain. Its purpose will be to convey water to Talco Pump Station during low stages of Naples Reservoir. During normal Naples Reservoir stages, pumpage could be directly from the reservoir. The channel will be about 51,000 feet in length. A levee will be constructed on the north side of one portion of the channel to prevent flood flows and wave action from silting up the channel. The reservoir side of the levee will be protected by riprap.

The Sulphur Bluff Pump Station will be in the right abutment south of the spillway. It will lift the water transmitted from downstream reservoirs via the Sulphur Bluff Transmission Channel up into Sulphur Bluff Reservoir. Pumping head will vary with the stage of Sulphur Bluff Reservoir with a maximum of 69 feet.

The Sulphur Bluff Transmission Channel will extend from the Talco Pump Station near the town of Talco upstream to the Sulphur Bluff Pump Station. It will be about 113,000 feet in length. The eastern two-thirds will extend along the hill line forming the south side of the Sulphur River floodplain, and the remainder will be along the old natural channel of the South Sulphur River.

The Cooper Transmission Channel will be excavated in the upper end of Sulphur Bluff Stage I Reservoir along the general alignment of the South Sulphur River channel. Its purpose will be to convey water to the Cooper Pump Station during low stages of Sulphur Bluff Reservoir. During normal Sulphur Bluff stages, pumpage could be directly from the reservoir. The channel will be about 31,800 feet in length.

The Cooper Pump Station will be located near the left abutment and on the downstream side of Cooper Dam. It will lift water from the Cooper Transmission

Channel up into storage in Cooper Reservoir. Pumping heads will vary with variations in Cooper and Sulphur Bluff Reservoir stages with a maximum of 82 feet.

The Cooper-Lavon Transmission Line is from Cooper Reservoir to the Lavon Terminal south of Lavon Reservoir, a distance of 68.3 miles. The water is pumped from Cooper Reservoir to an elevation of 480 feet. The water is lifted three times enroute to Lavon Terminal. The first lift is 53 feet at the Hunt-Hopkins County line; the second 95 feet at the South Sulphur River; and the third lift is 23 feet at the Sabine River. The South Sulphur River is used as a canal for part of the route and a channel dam is constructed for this purpose. The water from this canal is released into the East Fork of the Trinity River through Forney Reservoir.

Red River Division

Project elements in the Red River Division include a Red River Diversion Dam, and channel to carry water to the Pecan Bayou Pump Station, at which point Red River water will be diverted into Pecan Bayou Reservoir, an offstream storage project. Releases from Pecan Bayou Reservoir will flow through the Red-Sulphur divide by means of a gravity flow tunnel, 15,000 feet long which discharges to a $9\frac{1}{2}$ mile channel to Naples Reservoir.

Pecan Bayou - The Pecan Bayou Dam site lies across Pecan Bayou 6 miles northeast of Clarksville at river mile 23. The dam and reservoir site is in the northern part of Red River county. The reservoir would serve the purposes of regulation of Red River diversion, and regulation of flows in the Pecan Bayou watershed. The total yields are estimated at approximately 647,000 acre-feet yearly. Pecan Bayou Dam will be an earth embankment about 18,000 feet long, and will cost approximately 18 million dollars.

The Red River Transmission Facility necessary to tie the Red River into the State Water Project are the Red River Diversion Dam and the Red River Transmission Channel to the Pecan Bayou Pump station, at which point water will be lifted in the Pecan Bayou Reservoir. The elevation of Pecan Bayou Reservoir will be selected so as to permit gravity flow into a 10-foot diameter, 15,000 tunnel through the Red-Sulphur Divide. The tunnel will discharge into Young Creek and thence into Kickapoo Creek and Naples Reservoir.

Red River Diversion Dam - The Red River Diversion Dam will be on the Red River between Red River County, Texas and McCurtain County, Oklahoma. It will be 14 miles northeast from Clarksville, Texas and 10.5 miles south from Idabel, Oklahoma. The dam will create a head at the entrance of a diversion channel about fifteen feet above the normal water surface, permitting gravity diversion along nine miles of excavated channel to the Pecan Bayou Pump Station. The dam will consist of five 200-foot collapsible dam sections. The dam sections are inflated with water pressure to maintain their design control elevation. The bag pressure is automatically adjusted so as to maintain a constant pool level. During extreme floods, the bags become completely deflated, permitting unrestricted flow through the open bays. The bags will be supported by a heavy concrete slab anchored to piles. Underseepage will be controlled by continuous steel sheet piling driven along the downstream edge of the foundation slab. Diversions will be regulated to provide for the necessary passage of water to meet downstream requirements.

The Red River Diversion Channel will extend from the diversion pond along the left side of the Pecan Bayou floodplain to the Pecan Bayou Pump Station, a channel distance of about 48,200 feet. It will have a distance flow of about 2,500 second-feet. The material excavated from the channel will be used to construct a levee on the creek side of the channel for protection against damage from Pecan Bayou floods.

Pecan Bayou Pump Station will be near the left (north) abutment and near the downstream toe of Pecan Bayou Dam. It will lift Red River water up into Pecan Bayou Reservoir. The installed capacity provides for the design diversion capacity of 1,500 second-feet with one spare pumping unit. Pumping heads will vary with the stage of Pecan Bayou Reservoir with a maximum of 98 feet. The average operating head will be about 85.3 feet.

Pecan Bayou Tunneled Conduit and Transmission Channel - Water will be transmitted from Pecan Bayou Reservoir to Naples Reservoir by gravity via a 10-foot diameter, 15,000 long tunnel through the Red-Sulphur River divide. The tunnel will discharge into Young Creek, then into Kickapoo Creek and finally into Naples Reservoir. The tunnel will have discharge capacities varying with Pecan Bayou Reservoir stages. At top of water supply pool, elevation 428.0, the capacity will be about 975 second-feet (705,000 acre-feet per annum), and at elevation 418.0 it will be about 850 second-feet (615,000 acre-feet per annum). The invert at entrance of the tunnel will be at elevation 380.0 which is the bottom of the active water supply pool. Discharges will be controlled by sluice gates at the tunnel entrance. The channel of Young Creek will be enlarged and masonry retards will be installed for velocity control in reaches with excessive slopes.

The Texoma Transmission Channel is from Lake Texoma to White Rock Creek for quality control in the Trinity River by augmenting low stream flow. The canal would be 84.5 miles long exclusive of 21.0 miles of pipe line. The water is pumped from Lake Texoma at an average lift of 137 feet. A second lift of 56 feet is required south of Perrin Air Force Base. Approximately 39% of the canal excavation is in chalk and would require blasting.

Cypress Division

Storage projects required in the Cypress Basin will be Franklin County, Titus County, and Marshall Reservoirs. Lake O'Pines, an existing reservoir, will be used as a segment of the transfer facility although none of the yield from this reservoir will be exported.

Marshall Transmission Line connects Marshall Reservoir to Lake O'The Pines and is 8.6 miles long with a headgate provided at the outlet of the canal. Water is pumped from Marshall Reservoir to elevation 310. Lake O'The Pines Transmission Channel connects Lake O'The Pines to Titus Reservoir through a route 30.2 miles long. Water is pumped from Lake O'The Pines Reservoir to elevation 302 near Ore City. A lift of 62 feet is required near the town of Pittsburg to allow the water to flow into Titus Reservoir. Dams were required to cross Prairie Creek and Greasy Creek. These were preferred to siphons to avoid unnecessary head loss. Headgates were provided at the entrance and exit of these two reservoirs and at the outlet of Titus Reservoir to protect the Canal from flood rises on the reservoirs. One siphon was required to cross U. S. Highway 259.

Titus Transmission Channel extends from Titus Reservoir to Naples Reservoir and is 8.0 miles long. Water will be pumped from Titus Reservoir to elevation 382. The route requires one lift of 51 feet near Interstate Highway 30.

Franklin County Dam and Reservoir (Site No. 1) will be in the Cypress River Basin in Franklin County, 6 miles northeast of Winnsboro on Big Cypress Creek. The drainage area above the dam is 75 square miles.

The dam will be an earthfill structure 5,300 feet long and 75 feet high with the top of dam at elevation 395.0 feet msl. The reservoir will have a capacity of 73,000 acre-feet and an area of 3,400 acres at the top of the conservation pool 378.0 feet msl. The yield will be 28,500 acre-feet per year. Estimated cost of the project is about $3\frac{1}{2}$ million dollars.

Titus County Dam and Reservoir will be in the Cypress River Basin in Titus and Franklin Counties, 6 miles in a southerly direction from Mount Pleasant on Big Cypress Creek.

The dam will be an earthfill structure approximately 13,000 feet long and 78 feet high with top of dam at elevation 360.0 feet msl. The drainage area above the dam will be 273 square miles.

The reservoirs will have a capacity of 289,900 acre-feet and an area of 11,684 acres at elevation 343.2 feet msl. The capacity includes 2,900 acre-feet allocated to sediment reserve. The yield will be approximately 96,000 acre-feet per year. The project is estimated to cost about 12 million dollars.

The proposed dam will have a concrete gated spillway with crest elevation 326.0 feet msl. Four 40 ft. x 20 ft. tainter gates will regulate the discharge. The reservoir will have a flood control capacity of 132,800 acre-feet at elevation 352.2 feet msl.

Marshall Dam and Reservoir will be in Harrison County, 9 miles northwest of Marshall on Little Cypress Bayou a tributary of Big Cypress Creek. The drainage area above the dam will be 655 square miles.

The dam will be an earthfill structure approximately 9,500 feet long and 70 feet high with top of dam at elevation 270.0 feet msl.

The reservoir will have a capacity of 782,300 acre-feet and an area of 32,120 acres at top of conservation storage elevation 257.6 feet msl. The yield will be approximately 325,000 acre-feet per year and is estimated to cost a little over 25 million dollars.

The proposed dam will have a concrete gated spillway with crest elevation 232.0 feet msl. Seven tainter gates (40 feet by 28 feet), will regulate the discharge.

A water supply and low-flow outlet structure will be installed as required for future water delivery.

Trinity Division

The storage and transmission facilities of the Trinity Division of the State Water Project play an important part in the multiple-use, multiple-benefit aspect of the Project. Movement of water through the Division effects important water quality improvement in the Trinity River, as well as providing for needs in the basin for water supply.

Water from Cooper Reservoir in the Sulphur Division is pumped from Lavon Terminal to White Rock Creek across the East Fork of the Trinity River through a pipe line 18.9 miles long and a gravity canal 7.6 miles long. The canal terminates at the White Rock Creek for low flow augmentation below the Dallas waste treatment plant and a portion pumped on to the Carrollton Terminal and into Lake Grapevine. Water will also be diverted at the Carrollton Terminal to proposed Lock and Dam Number 20 on the Trinity River below the Village Creek Sewage Treatment Plant for stream augmentation.

The water released to the East Fork of the Trinity will join with water from Lake Texoma water released into White Oak Creek and Village Creek, and flow through the natural channel of the Trinity River to proposed Lock and Dam 11 on the Trinity. At this point the water including approximately half of the return flows from Dallas and Fort Worth will be diverted to Richland Reservoir through a canal 8.1 miles long. Water in the canal is pumped from elevation 270 the minimum navigation elevation, to elevation 318.5, with a headgate at Richland Reservoir to protect the canal from flood rises on the reservoir.

From Richland Reservoir the water will flow into Tehuacana, and thence will be routed 40.3 miles to the Brazos River via Elm and Big Creeks in Limestone County. Tehuacana Reservoir will be connected to Richland Reservoir by a channel so that water routed to Richland Reservoir may be removed to elevation 451. Minimum pumping level is elevation 295. Two additional lifts are required to reach the Brazos watershed. The first lift is 70 feet at Mexia Pumping Plant and the second is 68 feet at Christmas Creek Pumping Plant. Special siphons were required to cross the Navasota River on the way to the Brazos. The water will flow in the natural channel of Elm and Big Creeks for about 34 miles to the point it enters the main stem of the Brazos River near Highbank in Falls County from which it flows along the natural channel of the Brazos for a distance of about 160 stream miles to San Felipe in Austin County.

Brazos Division

Near San Felipe a concrete channel dam will be constructed across the Brazos and water lifted 54 feet to a reservoir on Bullinger Creek. A pump station near the reservoir lifts the water an additional 62 feet to an elevation from which point it can flow by gravity in a 33.7 mile long canal to the Colorado River at Altair. Five special siphons are required to cross Little Bernard Creek, San Bernard Creek, Church Creek, Coushatta Creek and State Highway No. 102 and a railroad.

At this point 240,000 acre-feet of water annually will be released as required to the lower Colorado to replace water diverted upstream on the Colorado from Stacy Reservoir to the San Angelo-Midland-Odessa area and from the Austin area to the San Antonio area.

The route from the Colorado River to Palmetto Bend Reservoir is 13.5 miles long. A concrete channel diversion dam will be constructed on the Colorado

River at Garwood and controlled diversion works installed. No pumping is required as the canal can be excavated deep enough to assure gravity flow to West Mustang Creek near New Taiton and thence into the Mustang Creek arm of the Palmetto Bend Reservoir. A headgate is required at the head of West Mustang Creek and 28 miles of channel improvement is necessary to carry the flow.

The Colorado-San Antonio Conduit - This conduit will run from the Highland Lakes to San Antonio, a distance of about 75 miles. An estimate of 38 million dollars has been made of the cost of the entire transmission system including the pump stations but excluding reservoir storage. However, until the actual system has been designed and the method of operation determined this estimate must be considered very preliminary.

Coastal Division

The Coastal Division of the State Water Project is the major conduit in the State Water Project. It consists of about 190 miles of canal, 2 main line reservoirs, 5 main line pumping plants, 3 regulation reservoirs and associated pumping plants. Palmetto Bend Reservoir will deliver an average of a little over 3 million acre-feet annually of which about 1.4 million will flow in the last reach in the lower Rio Grande Valley with the remainder used along the way for all purposes including wildlife refuges and quality control in the bays and estuaries. Water would be delivered to three major irrigation units: i.e., the Sinton, Baffin Bay, and Lower Rio Grande Valley. The Sinton and Baffin Bay units are referred to collectively as the Coastal Bend units. Also included in this reach are the reservoirs (Goliad, Cibolo and Cuero) in the San Antonio and Guadalupe Basins. Yields from these reservoirs could make possible the early delivery of water to the Rio Grande Valley.

Conduits - Coastal Division - The coastal canal of the State Water Project begins at the Palmetto Bend Reservoir. The Lavaca Pumping Plant on the Lavaca arm of the reservoir will have a lift of 18 feet to discharge into the Coastal canal. The water will flow 24 miles to Confluence Reservoir where a check drop structure will be located.

Confluence Pumping Plant will lift water 21 feet into the reach of the canal which flows 60 miles to the inlet end of the Nueces River siphon. In this reach will be Woodsboro and Aransas Pumping Plants, with pumping lifts of 16 and 27 feet respectively. In this reach water will be diverted to irrigate 200,000 acres in the Sinton Unit.

Diversions from the canal will be through turnouts which connect with the canals of the Sinton Unit distribution system. Releases will also be made from the canal for industrial water in the Corpus Christi area.

The downstream reach of the canal begins at the inlet of the Nueces River siphon and extends 28 miles to San Fernando Creek.

Nueces Pumping Plant will be located about a mile south of the Nueces River and have a lift of 21 feet. The canal capacity would be reduced at the end of this reach to allow for diversions from the canal for irrigating 300,000 acres in the Baffin Bay Unit. These diversions will be made by means of turnouts which would connect with canals of the Baffin Bay unit distribution system.

The next reach will extend 77 miles from San Fernando Creek to the end of the canal west of Raymondville. Diversion from the canal will be made to irrigate about 330,000 new acres in the Lower Rio Grande Valley Unit, plus water for about 170,000 acres of previously irrigated lands for which water is not available from the Rio Grande.

The canal system includes three offstream regulating reservoirs with embankments on all sides to supplement the canal in making deliveries during periods of peak demand.

Sinton regulating reservoir will have a surface area of 2350 acres and a capacity of 47,000 acre-feet. Baffin Bay regulating reservoir will adjoin one of the main canals of the Baffin Bay Unit, and will have a surface area of 2370 acres and a capacity of 32,000 acre-feet. The Valley regulating reservoir will adjoin the canal and will have a surface area of 2100 acres and a capacity of 33,000 acre-feet.

Each of the regulating reservoirs will have a pumping plant and outlet works to transfer water between the reservoir and the adjoining canal. The reservoirs will be filled during months when demands on the interbasin canal are less than capacity. In months of peak demand, the stored water could be released to meet demands in excess of inflow from the preceding reach of the canal. The regulating reservoirs would not be constructed until peak demands exceed the capacity of the canal.

Reservoirs - Coastal Division - Goliad Dam and Reservoir will be in the San Antonio River Basin in Goliad County, 6 miles upstream from Goliad on the San Antonio River. The dam as proposed will be an earthfill structure 26,000 feet long and 133 feet high with top of dam at elevation 238.5 feet msl costing approximately $51 million dollars.

The reservoir will have a total capacity of 1,702,000 acre-feet with 702,000 acre-feet allocated to flood control, 42,000 acre-feet to sediment, and 958 acre-feet to water supply. The area will be 36,400 acres at conservation pool elevation 207.0 feet msl.

The drainage area above the dam is 3859 square miles.

An outlet structure will provide service spillway, low flow outlet and water supply connection.

Goliad Reservoir in addition to developing about 100 thousand acre-feet of water will recapture and make available for use in the State Water Project over 200 thousand acre-feet of return flow from San Antonio.

Cibolo Dam and Reservoir will be in the San Antonio River Basin in Wilson County, approximately 3 miles southwest of Stockdale on Cibolo Creek with an upstream drainage area of 752 square miles.

The dam will be an earthfill structure 18,570 feet long and 109 feet high with top of dam at elevation 427.0 feet msl.

The reservoir will have a capacity of 418,000 acre-feet and an area of 16,800 acres at elevation 416.4 feet msl. Of this capacity, 218,000 is for flood control, 172,000 for water supply and 28,000 for sediment. The estimated cost of the structure is 22.8 million.

Cuero Dam and Reservoir will be located in the Guadalupe River Basin in DeWitt County, 4 miles upstream from Cuero on the Guadalupe River and Sandies Creek.

The project will be constructed in two stages. Stage I is on the Guadalupe River, and Stage II on Sandies Creek (Westoff Dam) with a connecting channel between the two reservoirs. The estimated cost for both stages is $117,336,000.

Cuero Stage I Dam will be an earth embankment with a concrete gate-controlled spillway and an outlet structure. The length of the dam will be 6.4 miles with a maximum height of 135 feet, with crest elevation 276.0 feet msl.

Stage II of Cuero Dam will be an earth embankment with a service spillway discharging into Sandies Creek. The connecting channel between the two reservoirs will serve as a spillway to discharge flood flow from Stage II into the Cuero I Reservoir and spillway. The length of the dam will be 2.7 miles with a maximum height of 116 feet, with crest elevation 271.0 feet msl.

The drainage area of the Cuero Stage I Dam is 4,182 square miles and for the Stage II Dam 671 square miles.

The combined storage capacity of the two reservoirs will be 3,709,000 acre-feet at elevation 257.0 feet msl and includes 243,000 acre-feet flood control, 2,816,000 acre-feet water supply and 50,000 acre-feet sediment storage.

The area of the combined reservoirs at elevation 257.0 feet msl will be 123,400 acres and at elevation 249.6, top of water supply, 103,900 acres.

Confluence Reservoir is formed by dams on the Guadalupe at mile 22.8 and San Antonio River at mile 10.6 above their junction, plus a large connecting channel to combine the separate impoundments into a single reservoir.

The purpose of the reservoir is to transmit water from upstream reach of the Coastal canal across the Guadalupe and San Antonio Rivers to the lower reach via Confluence Pumping Plant and permits reducing the capacity of the canal to a significant degree by providing regulating storage for a portion of the flood waters which would normally flow to the Gulf of Mexico. The reservoir will store approximately 439,000 acre-feet of water and will cost approximately 64 million dollars.

Possible Extensions of the State Water Project

One of the possibilities which has been envisioned, when considering the movement of water into the Lower Rio Grande Valley through the State Water Project, is of extending the effect of the Project without necessarily extending the physical works of the Project by coordinating the delivery of water from the State Project and Falcon, and from under-construction Amistad Reservoirs. This might be accomplished by utilizing the capacity of the State Project to deliver water, during off peak periods, to supply the area of the Rio Grande Valley which normally would require releases from Falcon and Amistad Reservoirs.

In this way water might be held in Falcon Reservoir until later in the year for release when peaking flows will be needed from the Project. In this way there may be provided a degree of storage regulation for the Project in addition to that provided by the small regulating reservoirs. The coordination with Amistad may have additional value because Amistad is at an elevation 700 feet higher than Falcon, and water from this reservoir can be delivered to the Winter Garden Area in the Nueces Basin, an area which now depends upon ground water for its major supply. While there does not appear to be any immediate danger that the ground water supply is failing it would be prudent planning to anticipate the possible importation of a surface water supply if possible for providing conjunctive operation of surface and ground water in order to extend the local supply.

Coordinating the State Project deliveries with Amistad would in a sense establish a water bank account in Amistad. Water held back in Amistad would be exchanged for water in the Project at off peak periods to supply areas in the Lower Valley which normally require releases from Amistad. The water in the bank account would be delivered to the Winter Garden area or the area along the Rio Grande between Amistad and Falcon. These concepts have been set forth as potentialities only, with the anticipation that the studies into the feasibility of the State Water Project would explore these possibilities.

An additional opportunity for extending the benefits of the project is provided by its built-in flexibility. This flexibility occurs by virtue of having to size the transfer facilities to provide peaking capacity. Since this peaking capacity is needed only at certain times during the year, it might be available at other times for transporting and releasing water to be exchanged in the lower reaches of rivers such as the Brazos and Colorado for water stored and diverted in the upper reaches.

Supplemental Water Requirements for the Area Served by Coastal Aqueduct

Future supplemental requirements for municipal and industrial water in the Lower Rio Grande Valley, industrial water in the Corpus Christi area, and irrigation water supplies in the Lower Rio Grande Valley and Coastal Bend areas would be provided from the Coastal Aqueduct. In providing such water supplies, losses would be incurred from the Aqueduct due to seepage, evaporation, operating losses, and other causes. These losses have been estimated as amounting to 19.7 percent of the total quantity of water supplied.

In the preliminary planning of staging of dams and reservoirs in the upper basins to provide water supplies to meet these and other requirements, it was assumed that the full dry-year demand for irrigation water in the Lower Rio Grande Valley and Coastal Bend areas would be provided during the critical period of shortage of water supplies; that is, that no shortage in irrigation supply would be permitted. It was similarly assumed that no shortage would be permitted in municipal and industrial water supplies. However, it was assumed that under conditions of extreme drought, when maximum supplemental water requirements in the demand area would coincide with critical shortages of stored water in the supply area, provision of fresh water releases to the coastal bays and estuaries could be deferred. Thus, although capacity would be provided in the Coastal Aqueduct and in other water transportation facilities for delivery of the full amount of required inflow to the bays and estuaries when water was available (i.e. during periods when water supplies in the upper basins were not critically short), storage would not be specifically provided in the upper basin system to meet these requirements on a firm basis throughout the critical period of analysis.

The estimated supplemental water requirements assumed to be provided from the Coastal Aqueduct for purposes of staging the required facilities in the upper basin system are summarized in Table 1.

Table 1

Requirements for Supplemental Water
In Areas Served By
Upper Basin Transfer System
And South Texas Canal
(Quantities in Thousands of Acre-Feet per year)

	1975	1980	1990	2000	2010	2020
Lower Valley M&I	5	20	45	75	110	150
Lower Valley Old Irrigation[a]	285	285	285	285	285	285
Lower Valley New Irrigation[b]	90	335	795	820	820	820
Corpus Christi Industrial	0	0	30	100	165	225
Coastal Bend Irrigation	0	0	480	875	875	875
Canal Losses[c]	75	125	320	425	445	465
Subtotal, S. Texas Canal	455	765	1,955	2,580	2,700	2,820
San Antonio M&I	0	0	5	50	110	170
Stacy Res. Depletions	0	0	5	25	45	70
Lower Colorado R. Shortage	0	0	0	0	0	90
Dallas-Ft. Worth M&I	0	0	0	0	105	350
Trinity R. Water Quality[d]	115	125	0	0	0	0
Subtotal, Upper Basin System	115	125	10	75	260	680
Total System	570	890	1,965	2,655	2,960	3,500

[a] On lands formerly receiving water from Rio Grande system.
[b] On lands not formerly irrigated.
[c] Estimated at 19.7% of total uses.
[d] In excess of quantities imported from Sulphur River for other purposes.

Area Served by upper basin system - Supplemental water requirements provided from the upper basin transfer system would include municipal and industrial supplies to San Antonio through exchange of water from the Colorado River, municipal and industrial supplies in the Upper Trinity basin cities, make-up of depletions in the firm yield of the Lower Colorado River Authority system caused by construction and operation of Stacy Reservoir on the upper Colorado River, and provision of fresh water inflows for enhancement of the water quality of the Trinity River in its reaches through and below the Dallas-Fort Worth urban complex. For purposes of staging the required facilities in the upper basin system, it was assumed that no shortages would be permitted in any of these requirements during critical supply periods.

The estimated water requirements which would be provided from the upper basin transfer system are summarized by decades in Table 1. In this table, only the water quality requirements in excess of the quantities of fresh water which would be imported through the system to the upper Trinity River basin for other purposes are listed.

Available Water Supplies

The estimated water supplies available to the upper basin transfer system and the Coastal Aqueduct are summarized by decades in Table 2. In estimating the supply which would be available to the system from any basin, it was assumed that all local requirements within that basin would be fully met before any surplus waters could be exported. In some instances, as at Cuero Reservoir and in the lower Colorado and Brazos River basins, considerable quantities of water may be available to the system on an interim basis during the early years, but these excesses would diminish over time as local requirements increase.

As is shown in Table 2, it is assumed that the diversion from the Red River at Lake Texoma would be constructed at the earliest possible time in

Table 2

Estimated Water Supplies Available to Upper Basin Transfer System And South Texas Canal (Quantities in Thousands of Acre-Feet per year)[a]

	1975	1980	1990	2000	2010	2020
1. San Antonio-Guadalupe Basins						
Goliad yield	120	120	120	120	120	120
Cibolo yield	35	35	35	35	35	35
Surplus from Cuero[b]	120	100	55	30	15	5
Other basin surpluses[c]	110	95	55	50	40	30
San Antonio return flow	125	145	160	180	205	230
Return flow to Confluence[d]	35	35	40	40	45	50
Basin Total	545	530	465	455	460	470
2. Lavaca-Navidad Basins						
Basin Total[e]	--	115	115	115	80	15
3. Colorado R. Surplus						
Basin Total[f]	--	430	280	170	50	0
4. Brazos R. Surplus						
Basin Total[g]	--	--	295	230	160	0
5. Trinity R. Basin						
Richland Cr. yield	--	--	200	200	200	200
Tehuacana yield	--	--	55	55	55	55
Return flow to Richland Cr.	--	--	15	15	20	20
Dallas-Ft. Worth return flow	--	--	225	285	310	370
Texoma diversion	140	140	140	140	140	140
Basin Total	140	140	635	695	725	785
6. Sulphur R. Basin						
Sulphur Bluff I yield	--	--	120	120	120	120
Naples I yield[i]	--	--	630	630	630	630
Texarkana exchange[h]	--	--	--	200	200	200
Pecan Bayou diversion	--	--	--	645	645	645
Naples II yield[i]	--	--	--	--	--	245
Basin total	--	--	750	1,595	1,595	1,840

Table 2
(Cont'd.)

	1975	1980	1990	2000	2010	2020
7. Cypress Creek Basin						
Surplus from Titus County[h]	--	--	--	--	--	80
Surplus from Franklin County[h]	--	--	--	--	--	20
Marshall yield	--	--	--	--	--	325
Basin total	--	--	--	--	--	425
SYSTEM TOTAL	685	1,215	2,540	3,260	3,070	3,535

a/ Rounded to nearest 5,000 acre-feet

b/ Yield of Cuero plus return flows, in excess of local requirements.

c/ Surpluses from Canyon, Lockhart, and Cloptin Crossing Reservoirs, plus spring flows.

d/ Return flows originating below Cuero and Goliad.

e/ Yield of Palmetto Bend plus return flows, in excess of local requirements.

f/ Surplus flows in lower Colorado River basin, in excess of requirements in Lavaca, Colorado-Lavaca, and Colorado-Brazos basins.

g/ Surplus flows in lower Brazos River basin, in excess of requirements in San Jacinto-Brazos basin.

h/ Yield available to system.

i/ Total yield of Naples I and II would be reduced from 875,000 to 825,000 acre-feet per year upon construction of Sulphur Bluff II.

order to provide fresh water inflows to enhance the quality of the Trinity River in its reaches through and below the Dallas-Fort Worth area. However, these fresh water inflows could not be re-diverted for consumptive use in areas served by the Coastal Aqueduct until diversion and transportation facilities were constructed from the Trinity River to Palmetto Bend Reservoir.

Staging of Facilities - By comparing the estimated future requirements for supplemental water in the areas served by the State Water Project with surplus water supplies available to the Project, it was possible to estimate the approximate times at which the various transfer and storage facilities proposed in the Project would be required for construction. The facilities proposed for inclusion in the State Water Project were then staged so that available firm supply would at all times exceed the growing requirement.

Summary of Costs

Evaluation of a project includes consideration of all of the capital costs in relation to the benefits to accrue to the project. Estimated total capital costs of the State Water Project for this purpose is as follows:

Cost of reservoirs in State Water Project.	$604,000,000
Cost of transfer facilities.	460,000,000
Cost of Coastal Aqueduct	220,000,000
Cost of regulating reservoirs.	30,000,000
Cost of irrigation distribution systems.	250,000,000
Total cost of State Water Project.	$1,564,000,000

WATER QUALITY ASPECTS
OF THE
PRELIMINARY TEXAS WATER PLAN

Jerry T. Thornhill[1]

[1] Water Quality Specialist, Texas Water Development Board

Introduction

A basic part of the Texas Water Plan and any plan involving water-resource development is water-quality management. Essentially, water-quality management envisions a system for providing the right water quality at the right place. It embodies a set of procedures for keeping each segment of a surface-water resource in the continuous dynamic balance necessary to meet the requirements of each significant use. Land use management, waste treatment and disposal practices, sources of natural pollution and their abatement, operation of existing and proposed reservoirs, the need for State participation in local or regional systems designed to improve waste-discharge practices, and carefully designed programs of stream management are all part of the overall water-quality management problem.

On considering water quality in the Water Plan, two basic assumptions were made; (1) all discharges of municipal and industrial wastes will be treated and controlled so as to protect the public health and to prevent aesthetically objectionable conditions; and (2) pollution of water resources due to oil-field brines will be completely abated over time. Some basic concepts were also necessarily developed which apply within the framework of a program for planning the development of water resources.

In developing water-quality considerations for water resources to be used for domestic needs, the controlling factor must be the protection of the health and welfare of humans using the resource. The planning agency must also consider the water-quality requirements for all beneficial purposes set out by law in Texas; and water-oriented recreation, fish and wildlife mitigation and enhancement, and the cultural and aesthetic enjoyment of society.

All quality objectives, and measures adopted to achieve these objectives, must be realistic to provide effective machinery of enforcement. Thus, standards for a given stream must be based on the total uses of the water in the stream.

The critical significance of water-quality management stems from the well-known expanding demand for water against an essentially fixed supply. Therefore, the reuse of water must be accepted as a necessary part of our water-resource picture if we are to realize the full benefit from this resource. As a consequence, it is essential that the very highest standards of treatment of municipal and industrial effluents are maintained.

A final concept, essential to water-quality management, is that very close coordination must be maintained between the water-planning agency and the water pollution control agency. This insures the translation of water-quality objectives into effective water-quality control.

Included in the process of developing water-quality concepts was the formulation of proposed water-quality criteria. In developing the criteria, the staff of Development Board met with personnel of the State Department of Health, Parks and Wildlife Department, and with private consultants to discuss fully all aspects of the subject. In addition to agreeing upon some general planning concepts and principles to be observed in considering water-quality aspects of the Plan, the group also developed criteria for consideration when dealing with fish and aquatic life, municipal water use, industrial water use, irrigation water use, reservoirs (to maintain recreation and sports fishing), and municipal, industrial and irrigation uses of ground water. (See Appendix A.)

To achieve the objectives as laid out, it was necessary to determine the present stream quality in order to evaluate the effects of the planned programs of development upon each river basin. Included in the determination of present stream quality was a determination of the present water uses in each basin, an evaluation of the quality and quantity of all waste discharges presently reaching the stream, and a projection for future effects.

National Engineering Company prepared, under contract with the Water Development Board, a compilation and evaluation of existing water-quality data from available sources. Their report, titled "Surface Water Quality in Texas", indicated definite areas of water-quality impairment by organic and inorganic contaminants. Areas reflecting water-quality degradation from organic contaminants included portions of the Trinity, San Jacinto, San Antonio and Rio Grande Basins. Inorganic contaminants were reflected in parts of all basins, with the possible exception of the Sulphur, Cypress and Sabine Basins.

The information presented by National Engineering Company, together with information from the U.S. Geological Survey, State Department of Health and from the files of the Development Board were compiled and evaluated for presentation in the summaries for each basin hearing. In addition, projected return flows and the effect of these flows on future water quality were determined and reported in the basin summaries. Unfortunately, increases in population and industry will not only increase the demand for water, but will also increase the volume of return flows to Texas streams.

A report titled "Return Flows in Texas--Quality and Quantity of Municipal and Industrial Wastewater Streams", prepared for the Board by Dan M. Wells and Earnest F. Gloyna of the Center for Research in Water Resources, The University of Texas, estimated the projected return flows from municipal and industrial complexes throughout the State. The report indicated the present municipal and industrial waste-water releases to be 0.8 and 1.3 million acre-feet per year, respectively. Projected total waste-water releases were expected to reach 2.9 and 5.9 million acre-feet per year by 1980 and 2020. The report also estimated that by 1970 advanced waste-water treatment would be required in some areas.

Present levels of treatment will be inadequate for projected future volumes from municipal and industrial waste-water treatment plants. In this regard, a centralization of urban sewage systems probably offers more promise than any other general development in pollution control. A report, "Preliminary Report on Waste Collection, Treatment and Disposal in Certain Urban Areas in Texas", prepared for the Water Development Board by Forrest and Cotton, in conjunction with Freese, Nichols and Endress and Lockwood, Andrews and Newnam, Inc., provided information to estimate capital costs for the facilities required to serve 21 major metropolitan areas of the State. The estimates indicated that the costs will reach almost one billion dollars by 1990. The report emphasized, however, that the regional approach: allows more effective planning for a large area; allows flexibility in serving communities involved; promotes economy of construction by providing one or more large plants as compared to a multiplicity of small plants; increases efficiency of operation; promotes economy of operation; provides economy in maintenance procedures; enhances industrial growth; and relieves individual cities of direct day-to-day responsibility of sewage treatment. Still to be worked out in each instance is the proper agency to operate such a regional treatment facility. Most important, however, is the fact that centralized treatment facilities promise to offer significant reduction in the pollutional load on many of our streams.

Another influence for the necessity for improved waste treatment is the fact that we cannot depend upon using much of a stream's assimilative capacity for the dilution of municipal and industrial waste. Increasingly, this assimilative capacity will be required to accommodate that pollution from land use which is beyond practical control.

In addition, the necessity for treatment of all waste has been stressed by the Federal Water Pollution Control Administration. Although the "Guidelines for Establishing Water Quality Standards for Interstate Waters" were available prior to release of the Preliminary Plan in May, 1966, there were questions regarding the proper interpretation of several of the guidelines. Policy Guideline No. 8, states, "No standard will be approved which allows any wastes amenable to treatment or control to be discharged into any interstate water without treatment or control regardless of the water-quality criteria and water uses adopted. Further, no standard will be approved which does not require all wastes, prior to discharge into any interstate water, to receive the best practicable treatment or control unless it can be demonstrated that a lesser degree of treatment or control will provide for water quality enhancement commensurate with proposed present and future water uses". In discussing the guidelines at Norman, Oklahoma on June 27 and 28, 1966, Mr. James Quigley, Commissioner, Federal Water Pollution Control Administration, stated that Policy Guideline No. 8 means, "from this point forward, treatment of waste will be necessary". He further elaborated that the first sentence of guideline No. 8, "mandates primary treatment;" and the second sentence, "alludes to secondary treatment".

Increased return flows and major modifications in the flow of the rivers could greatly affect the quality of water in the bay systems. Recognizing the present unsatisfactory conditions of the bays and estuaries, their increasing value, and possible further deterioration of the water quality due to increased return flows, the Development Board authorized and financed studies of the impact of return flows on the Texas bay systems and possible structural, hydraulic, and operating modifications of the system.

A report titled, "Return Flows--Impact on Texas Bay Systems", prepared for the Board by Bryant-Curington, Inc., indicated the results of a study designed to collect available data and to describe the general ecology of the bays, develop a mode of waste water estimation and project return flows to each bay system; and within the availability of the data prepared estimates on both the physical exchange and biological degradation which may occur as the diluted waste waters are transported into and through the bays. Attention was also directed to the fresh-water inflows necessary for each of the major bays and estuaries to preserve the existing fish and wildlife resources and the fresh-water inflows necessary to prevent the development of nuisance conditions under present and anticipated conditions. The report estimated that by 1980 about 1 million acre-feet of dilution water may be required for Galveston Bay to maintain the present level of dissolved oxygen, and about 3 million acre-feet to maintain relative phosphate levels. By 2020 the requirements for the Bay may be as high as 3 million acre-feet and 12 million acre-feet, respectively. A report, titled "Water for Preservation of Bays and Estuaries", prepared for the Board by Lockwood, Andrews and Newnam, Inc., forecasted that 2.45 million acre-feet of fresh-water inflow would be needed in the six bays and estuaries to maintain them for recreation and fish spawning. The bays and estuaries studied were: Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay, and Baffin Bay and Upper Laguna Madre. The estimate of necessary fresh-water inflow was based on the concept of making maximum use of Gulf water to minimize the fresh-water needs. Also, "fresh water" could include return flows properly treated to meet peculiar requirements of the estuary. The study included consideration of possible structural, hydraulic and operating modifications of the bay systems.

In addition to the previous studies, the Texas Water Pollution Control Board is initiating a comprehensive study of the Galveston Bay System. The study, which will be conducted cooperatively by State, local and Federal government entities, will hope to determine the optimum quality of water necessary to maintain the Bay as a spawning and nursery ground for fish, and as a recreational area. Currently, a work plan is being prepared to organize, schedule and coordinate the work required for the comprehensive study.

Water-quality conditions become a particular concern in a plan for progressive development of water resources through the impoundment of water in reservoirs, and its movement through conveyance facilities. Proposed transfers from Cypress Creek Basin include the movement of water from Marshall Reservoir (through Lake O'the Pines) and Titus County and Franklin County Reservoirs to Naples Reservoir in the Sulphur River Basin. Total dissolved solids concentrations in the Cypress Basin reservoirs will probably range from 80 to 150 ppm (parts per million), and the mixed water transferred to Naples will contain about 100 ppm.

The use of water from the Red River Basin involves the proposed diversion of 140,000 acre-feet per year from Lake Texoma to the Trinity River via White Rock Creek for augmentation of flow of a section of the upper Trinity; the diversion of 617,000 acre-feet from the lower Red River into Pecan Bayou Reservoir; and the pumpage of this water, plus the local yield of Pecan Bayou, to Naples Reservoir for subsequent transfer to the Trinity River Basin.

The concentration of total dissolved solids in Lake Texoma for the past 10 years has averaged about 1,000 ppm, and in the lower Red River the average has been about 800 ppm. If the salinity-control measures proposed by the U.S. Corps of Engineers are carried out, they may reduce the average total dissolved solids concentration in Lake Texoma and at the Pecan Bayou diversion site to about 800 and 600 ppm, respectively. Even with improvement, the mineral quality of the water of Red River will be poor in comparison with most other water involved in the State Water Project. However, selective pumping from the lower Red River during periods of flow in excess of base-flow will provide a better quality water than that shown for the average.

Water resource developments in the Sulphur River Basin will include Cooper, Sulphur Bluff, Naples, and Texarkana reservoirs, with Naples Reservoir receiving water transferred from the Red and Cypress Basins, and Cooper Reservoir serving as the terminal for transmission to the Trinity River Basin. The reservoirs of the Sulphur River Basin will impound water containing from 100 to 175 ppm total dissolved solids. The average for the basin, exclusive of imports, will be about 150 ppm.

When the system is completely operational, the water available for transfer from Cooper Reservoir to Lavon Reservoir in the Trinity River Basin will contain from 190 to 250 ppm total dissolved solids. Any reduction in the percentage of water derived from Red River will reduce correspondingly the total dissolved solids in Cooper Reservoir.

Lavon Reservoir on East Fork Trinity River will receive water transferred to the Trinity Basin from the Red, Sulphur, Cypress, reservoir system. The natural yield of Lavon is similar in quality to the water which will be imported.

Under 2020 conditions of the State Water Project, 449,100 acre-feet will be pumped annually from Lavon for use in the Dallas area, 110,000 acre-feet to West Fork Trinity River below Fort Worth for augmentation of flow, and 330,000 acre-feet released in White Rock Creek for augmentation of flow in the Trinity River below Dallas. The remaining water transferred from Cooper Reservoir will be released from the Lavon Terminal through Forney Reservoir into East Fork Trinity River and thence will flow to the main stem of the Trinity River for subsequent transfer to the Brazos.

At the Trinity River transfer point, above Tennessee Colony Reservoir, the flow of the Trinity will consist principally of the transferred water, as described above, and return flows from the Dallas-Fort Worth area. These return flows are expected to amount to 782,100 acre-feet per year and to contain from 450 to 500 ppm dissolved solids. Runoff from the uncontrolled drainage area of the Trinity River Basin will not significantly affect the average quality of the water at this site and the water available for transfer in the State Water

Project out of the Trinity will probably contain from 270 to 330 ppm total dissolved solids.

To the water diverted from the Trinity River will be added the yield of Richland Creek and Tehuacana Creek Reservoirs, with slight resultant dilution. Thus, the water added to the Brazos River below Waco will probably average from 270 to 325 ppm total dissolved solids.

The quality of water in the lower Brazos River, as measured at Richmond, varies widely, due partly to variations in flow, but depending also on the proportion of the water which originates in the salt-contributing upper Brazos drainage area. During three representative years the discharges and weighted-average total dissolved solids were as follows:

1959 - 3,200,000 acre-feet, 323 ppm

1962 - 3,260,000 acre-feet, 551 ppm

1963 - 1,998,000 acre-feet, 513 ppm

Proposed salinity-control measures in the upper Brazos might have reduced these concentrations to 260, 485, and 410 ppm, respectively.

Under the operation of Brazos River Basin reservoirs contained in the Texas Water Plan, quality in the lower Brazos will be altered by the additional use of good-quality water from Bosque and Little Rivers and by return flows from municipalities. As the result of these changes and the proposed addition of State Water Project interbasin transfers, the following ranges of total dissolved solids may be expected at the Brazos-to-Colorado transfer terminal near Hempstead:

With 1959 flows - 270 to 330 ppm

With 1962 flows - 375 to 435 ppm

With 1963 flows - 320 to 380 ppm

The water being transferred into the Colorado River Basin will flow for a short distance down the river and thus will mix with the water in the stream, which will include return flows from the area below Austin. Natural runoff in the Colorado contains from 250 to 350 ppm total dissolved solids, and the return flows in the Colorado River Basin will contain 450 to 550 ppm. The net result will be only a slight change in the quality of the water transferred from the Brazos, and the water available for use in the lower Colorado River Basin and for transfer to the Lavaca Basin will contain from 275 to 430 ppm total dissolved solids.

Water will be transferred from the Colorado River to a tributary of the Navidad River and thence to Palmetto Bend Reservoir. The yield of the Lavaca River Basin is low in total dissolved solids content, (200 to 300 ppm), and will dilute slightly the Project water. On transfer from Palmetto Bend to Confluence Reservoir the water will probably contain 270 to 425 ppm total dissolved solids.

Confluence Reservoir, at the mouths of the Guadalupe and San Antonio Rivers, will serve as regulating storage for the Project. In addition to the imported water, the reservoir will receive much of the yield of Cuero and Goliad Reservoirs. Little change in quality will occur as a result of the mixing, and the combined storage in Confluence Reservoir will average between 280 to 430 ppm total dissolved solids. As no other large volumes of water will be added to the transfer system, little additional change will occur in the quality of the water before its delivery to users in the Coastal Bend and Rio Grande Valley areas.

Another water-quality aspect of the Plan is the utilization of the State's saline-water resources. Economic studies are being conducted to determine the potential contribution of saline water conversion to future water supplies of the State. The present study, which will be completed in late 1966, consists of evaluating all the cities in the State whose 1960 population was over 1,000. Of 586 communities evaluated, 37 are possible candidates for saline-water conversion.

The criteria used in the evaluation of the communities were: population and economic base; rainfall (cities with an average annual rainfall in excess of 40 inches were eliminated, except Galveston and Texas City); water supply; water quality; alternate sources; and supplies of brackish water.

Problems that must be given proper consideration when dealing with saline-water conversion are the methods and costs of disposal of the effluent from the conversion process. Careful study must be given to the proper disposal of the effluent so that other resources are not destroyed in the process of developing a water supply. Methods for disposal that have been evaluated in this study include: subsurface injection; lined surface pits; discharge into surface-water courses; reuse; and mixing with municipal return flows.

A final aspect of water quality which received consideration in the Plan is natural pollution in streams in the western part of the State. Large volumes of surface water, and some ground water are being polluted by salt from salt-water springs and seep areas in the four largest river basins of Texas. Pollution from natural sources is extremely severe in the Pecos River of the Rio Grande Basin, the Colorado River Basin, the Brazos River Basin and the Red River Basin.

The chemical quality situation in the Red River Basin was intensively investigated by the United States Public Health Service under a federally financed project titled "The Arkansas-Red River Basin Water Quality Conservation Project". The Public Health Service, in conducting the early phases of this investigation, had as its objectives; (1) to locate and define the significant natural and man-made sources of salt pollution, (2) to determine the effects of these sources on the quality of water in the receiving streams, (3) to propose possible methods and procedures for reduction of these highly mineralized discharges, (4) to estimate the results of reduction of these discharges on stream quality, and (5) to determine the benefits of water-quality improvement to present and future municipal, industrial and agricultural water users. At the conclusion of the Public Health Service study, the following suggestions were made to the Corps of Engineers: to determine the feasibility of elimination of the brine problem by; (1) subsurface disposal, (2) permanent storage-retention of concentrated brines in the source area, (3) elimination of fresh recharge water to the brine generation areas, (4) imposition of back pressure on brine springs to suppress flows, (5) transportation of concentrated brine to non-damaging sites, and (6) utilization of salt.

The Corps of Engineers followed up the initial study by preparing a report on the problem, the main purpose of which was to describe the hydraulics of the river system, to design a structure for controlling the salt water to keep it out of the main river course and to report on the results of experimental projects such as the ring dike at Estelline Springs, near Estelline, Texas. The report, "Arkansas-Red River Basins, Water Quality Control Study, Texas-Oklahoma-Kansas, Part I", proposed construction of the Wichita River Project, Texas, for control of natural chloride pollution in the Wichita River Basin. The project includes three low-flow dams; one each on the North, Middle and South Forks of the Wichita River; two brine reservoirs, one on Canal Creek and another on a small tributary of the North Fork, and pumping plants and pipelines to transmit the brine from low-flow sites to the brine reservoirs. Based on the fact that a continuing reduction in chlorides will result through leaching and with continuing proper disposal methods, it does not appear unreasonable to anticipate an 85 percent reduction in man-made chloride by the year 1975.

A second report by the Corps, titled, "Arkansas-Red River Basins, Water Quality Control Study, Texas-Oklahoma-Kansas, Part II," proposed a Red River Project which would consist of four brine reservoirs and four brine collection systems and pumping systems which would supplement the Wichita River Project.

After a thorough review of these proposed natural pollution control projects they were included as an important phase of the Texas Water Plan.

Investigative activities in the Brazos River Basin have been conducted on Federal, State and local levels. Some of the agencies involved in investigative activities in the basin are the Brazos River Authority, Texas A&M University, the Texas Water Development Board and the U.S. Geological Survey. In addition, the Corps of Engineers has a multiple purpose investigation of the Brazos River Basin in progress which includes study of remedial measures for natural pollution in the Upper Brazos.

In 1962, the U.S. Geological Survey initiated a study of the occurrence and subsurface movement of highly mineralized ground water throughout the Permian Basin in New Mexico, Texas, Oklahoma and Kansas. The purpose of the project is to determine the complex geo-hydrologic factors relating to underground sources and movement of mineralized water in the formations of this region. Specific study has been underway in the upper Brazos Basin to gain an understanding of the movement of the mineralized water measured at the principal brine emission areas.

The Water Development Board has investigated areas of soil damage in some counties in the basin. Significantly large areas of cultivated land in Jones and Fisher counties, for example, have been seriously affected by soil salinization. Several preliminary conclusions as to possible causes have been stated, however, it appears that a combination of causes are responsible for the problem as a whole.

Investigations sponsored by the Colorado River Municipal Water District revealed that there was a considerable amount of highly mineralized water in the Colorado River above the Robert Lee Reservoir site. Much, if not most, of the salt water is oil-field brine from the oil fields of the area. Since the natural brine occurs with the oil-field brine in the river, both are being dealt with under the same program. This salt water alleviation program consists of a plan for catching the low flow of the river and then selling the salt water to companies that will use it for water flooding in various oil fields in the area. This particular approach to dispose of saline water is somewhat different from means of salt-water control being used elsewhere in the State.

Investigations to determine the source and extent of salt water which affects the Red Bluff Reservoir have been made by the U.S. Geological Survey and Pecos River Commission. The investigation revealed that the principal source of salt water was saline ground-water discharges into the Pecos River at Malaga Bend, New Mexico, about 6 miles north of the state boundary. The brine-yielding geological formation was studied in sufficient detail to show that by pumping brine from the formation, the water level in the formation could be controlled in such a way that the brine would not enter the river.

The Congress authorized the Bureau of Reclamation to construct the Malaga Bend Experimental Salinity Alleviation Project in 1958. The facilities for collecting and disposing of the salt water at Malaga Bend have been constructed and the project is being evaluated during its operation. Disposal of the salt water is into a large natural depression where the water will be evaporated leaving the precipitated salt. Operation and maintenance of the pumpage and disposal system is being carried on by the Red Bluff Water Power Control District.

Recommended action as envisioned by the Water Development Board includes: continued and expanded research into the hydrologic systems contributing to the natural pollution load of these river basins and into local ground-water supplies. This will include a continued analysis of projects currently under study. After a complete evaluation of projects now in operation, recommendations can be made for future studies and useful information provided for design and construction of salinity control projects in the Red and Brazos Basins.

While the Development Board, in determining the water uses for the planned projects, sets the general guidelines for water quality necessary for these uses, the Water Pollution Control Board has the responsibility for actually setting stream standards and, through its permitting procedure, controlling the volume and quality of effluent discharges into streams.

For each of the river basins the Pollution Board prepared a draft of water-quality criteria based on information available for the period 1957-1965. The criteria were submitted to the participants at each of the basin hearings which were held jointly with the Development Board, and comments solicited. After comments have been received, a review will be made of all information available and the draft material will be revised, where necessary. The Water Pollution Control Board is giving consideration to holding 4 or 5 regional hearings for the purpose of allowing the people of these regions to submit additional comments on the revised material. Upon completion of the review of such comments as may be received, the Water Pollution Control Board will adopt the revised criteria as standards for the specific streams and submit them to the Federal Water Pollution Control Administration for approval. These guidelines will then govern the issuance of permits by the Pollution Board.

In any attempt for water-quality management, water quantity and water quality are inseparable, thus, administrative functions involving water development, water rights and water-pollution control must be carefully evaluated. Any plan for water development which includes proposed impoundments, movement of water through conveyance facilities and return flows, crosses these administrative lines and emphasizes the necessity for those agencies involved to closely correlate their activities.

APPENDIX A

PROPOSED WATER QUALITY CRITERIA FOR FORMULATION OF TEXAS WATER PLAN

PROPOSED WATER QUALITY CRITERIA FOR FORMULATION OF TEXAS WATER PLAN

1. General Planning Concepts and Principles

A. Wherever feasible within reasonable economic cost limits, municipal surface supplies shall be obtained from sources lying upstream from major discharges of treated municipal sewage and industrial wastes. There will be, however, no absolute prohibition against the establishment and use of adequately designed and operated sewerage systems in such watersheds.

B. In evaluating the assimilative capacity of a stream reach, particularly reservoirs, and of the coastal bays and estuaries, allowance shall be made for the pollutants added by uncontrollable runoff from urban-industrial areas and from agricultural areas.

C. All reservoirs, except water system regulating reservoirs, will be utilizable for sportfishing and recreation.

D. Within reasonable technological and economic limits, no stream quality conditions shall be permitted which would be inimical to fish and aquatic life.

E. Low flow augmentation for assimilation and transport of treated municipal sewage and industrial wastes will be considered as a permanent solution only in event no other procedure is found to be feasible for maintenance of specified criteria. It may be considered as an interim aid where it is found to be economically desirable and can be accomplished without detriment to other requirements.

F. Dilution of naturally poor quality water will be considered where this would not result in waste of water.

G. All feasible means will be used to control and dispose of sources of naturally poor quality water such as saline springs.

has been successfully used, and it is not economically feasible to improve the stream quality through dilution, greater concentrations will be permitted. Sulphates shall not exceed 250 mg/1 insofar as is feasible.

C. Industrial Use (General use)

1) Water satisfactory for municipal supplies will generally be satisfactory for industrial fresh water supplies, and USPHS Drinking Water Standards, 1962, recommended limits, and as further qualified above for municipal use, as regards mineral constituents will prevail. Where a large industrial use requiring high quality fresh water exists or is anticipated, chloride concentrations should not exceed 100 mg/1. Where water is required of a superior quality to that normally available from a surface supply, it shall be assumed that the industry will provide additional water treatment.

D. Irrigation Use

1) Use criteria are based on irrigation water classification system developed by University of California at Davis and United States Salinity Laboratory at Riverside. Criteria for Class I irrigation water to be met wherever economically feasible.

Class I - Excellent to good, or suitable for most plants under most conditions.

Category	Quality
% Sodium $\left(\frac{Na \times 100}{Na + Ca + Mg + K} \text{ as Meq./1}\right)$	30-60%
Boron	general 0.5 Mg/1. tolerant plants 1.5 Mg/1
Chloride (Cl)	195 Mg/1
Sulphate (SO_4)	480 Mg/1
Spec. Conductivity Micro mho/Cm^2 @ 25°C	1000
Total Dissolved Solids	700 Mg/1

Category	Quality
Class II - Good to injurious, harmful to some plants under certain conditions of soil, climate, practices.	
% Sodium $\left(\frac{Na \times 100}{Na + Ca + Mg + K \text{ as } Meq/1}\right)$	30-75%
Boron	.5 - 2.0
Chloride (Cl)	570 Mg/1
Sulphate (SO_4)	960 Mg/1
Spec. Conductivity Micro mho/Cm^2 @ 25°C	3000
Total Dissolved Solids	2100 Mg/1
Class III - Injurious to unsatisfactory, unsuitable under most conditions.	
% Sodium $\left(\frac{Na \times 100}{Ma + Ca + Mg + K \text{ as } Meq/1}\right)$	>70%
Boron	>2.0 Mg/1
Chloride (Cl)	>570 Mg/1
Sulphate (SO4)	>960 Mg/1
Spec. Conductivity Micro mho/Cm^2 @ 25°C	>3000
Total Dissolved Solids	>2100 Mg/1

E. Additional criteria for reservoirs - to maintain recreation and sport-fishing.

1) It is assumed that concentrations of nutrients, i.e. total C total N and P will be maintained at such levels as not to stimulate undesirable aquatic growths.

4. Ground Water Criteria

A. Municipal use

1) USPHS Drinking Water Standards, 1962, recommended limits, insofar as those constituents which cannot be removed by conventional water treatment processes are concerned, except SO_4 which shall not exceed 75 mg/1 if economically feasible to attain.

a) Where water having greater concentrations of mineral substances from uncontrollable sources up to a TDS concentration of 1000 mg/1 has been successfully used, greater concentrations will be permitted. Sulphates shall not exceed 250 mg/1 insofar as is feasible.

B. Industrial Use (Raw water surface supply)

1) Water satisfactory for municipal supplies will generally be satisfactory for industrial fresh water supplies, and USPHS Drinking Water Standards, 1962, recommended limits, and as further qualified above for municipal use, as regards mineral constituents will prevail. Where a large industrial use requiring high quality fresh water exists or is anticipated, chloride concentrations should not exceed 100 mg/1. Where water of a superior quality to that normally available from a present supply, it shall be assumed that the industry will provide additional water treatment.

C. Irrigation Use

1) Use criteria are based on irrigation water classification system developed by University of California at Davis and United States Salinity Laboratory at Riverside. Criteria for Class I irrigation water to be met wherever economically feasible. Class I - Excellent to good, or suitable for most plants under most conditions.

Category	Quality
% Sodium (Na x 100 / (Na + Ca Mg + K as Meq./1)	30-60%
Boron	general 0.5 Mg/1. tolerant plants 1.5 Mg/1
Chloride (Cl)	195 Mg/1
Sulphate (SO_4)	480 Mg/1
Spec. Conductivity Micro mho/Cm^2 @ 25°C	1000
Total Dissolved Solids	700 Mg/1

Class II - Good to injurious, harmful to some plants under certain conditions of soil, climate, practices.

% Sodium (Na x 100 / (Na + Ca + Mg + K as Meq/1)	30-75%
Boron	.5 - 2.0

Category	Quality
Chloride (Cl)	570 Mg/1
Sulphate (SO_4)	960 Mg/1
Spec. Conductivity Micro mho/Cm^2 @ 25°C	3000
Total Dissolved Solids	2100 Mg/1

Class III - Injurious to unsatisfactory, unsuitable under most condi-tions.

% Sodium $\left(\frac{Na \times 100}{Ma + Ca + Mg + K \text{ as } Meg/1}\right)$	>70%
Boron	>2.0 Mg/1
Chloride (Cl)	>570 Mg/1
Sulphate (SO4)	>960 Mg/1
Spec. Conductivity Micro mho/Cm^2 @ 25°C	>3000
Total Dissolved Solids	>2100 Mg/1