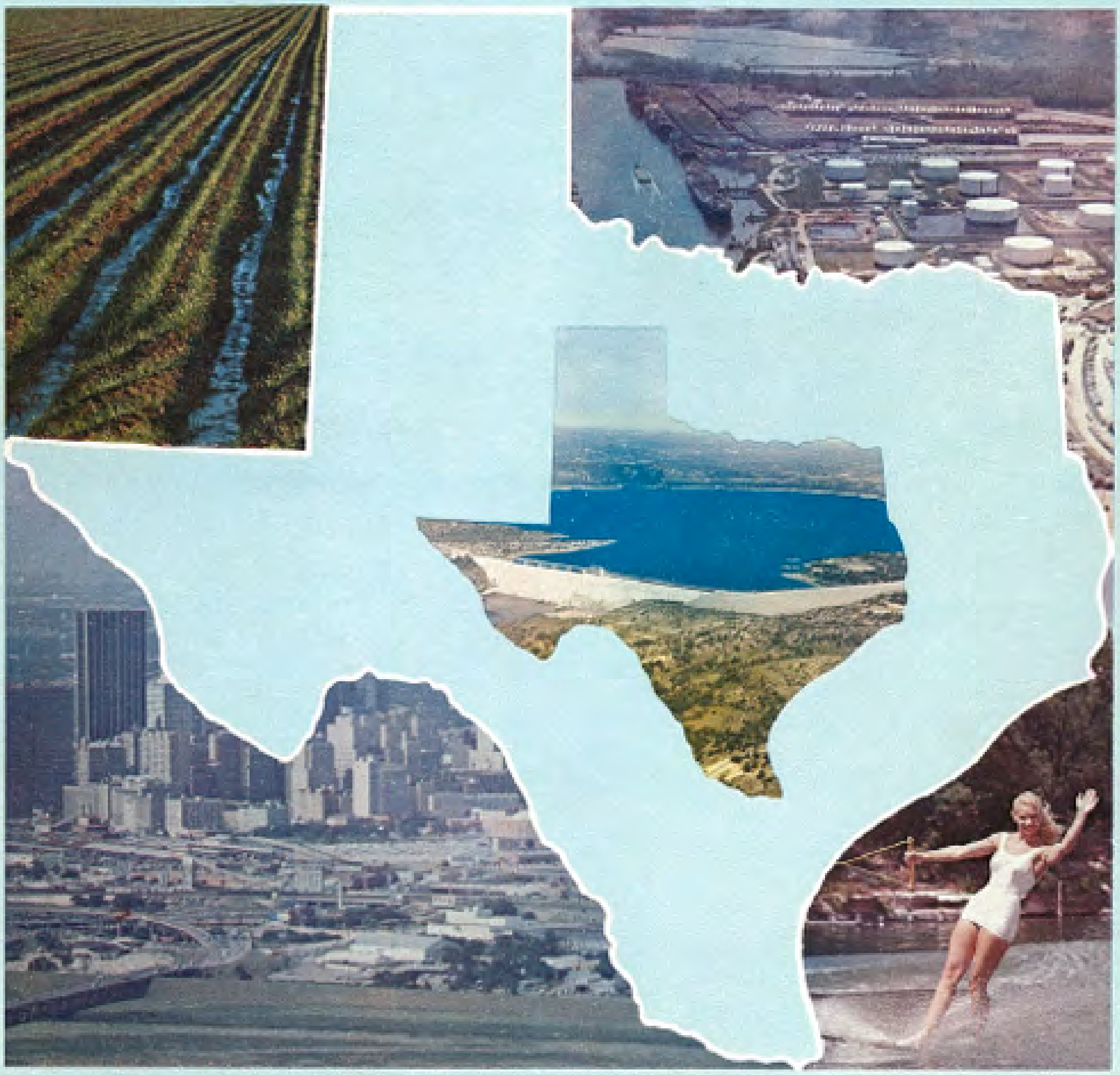
THE TEXAS WATER PLAN



TEXAS WATER DEVELOPMENT BOARD

NOVEMBER 1968


THE STATE OF TEXAS

THE

TEXAS WATER PLAN

THE TEXAS WATER DEVELOPMENT BOARD

November 1968

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TEXAS WATER DEVELOPMENT BOARD

P. O. BOX 12386
CAPITOL STATION
AUSTIN, TEXAS 78711

The People of Texas

The Honorable John Connally
Governor of Texas

The Honorable Preston Smith
Lieutenant Governor of Texas

The Honorable Ben Barnes
Speaker of the House

The Legislature of the State of Texas

Transmitted herewith is the Texas Water Plan, a flexible guide for the orderly development, conservation, and wise management of the State's water resources to meet the needs of our expanding State to the year 2020. Since Texas does not have enough water within its boundaries to meet all its needs beyond 1985 it will be necessary to seek supplementary water from outside its borders. The Plan includes the possibility of importation of large quantities of surplus water from the lower reaches of the Mississippi River to areas of greatest need in Texas, in order to meet our requirements after 1985.

The Texas Water Plan recognizes the importance of the roles of local, State, and Federal agencies in the development of our water resources, and the need for the continuation of the cooperation and harmony that has been manifest in the preparation of the Plan.

Water is vital to sustaining the people of Texas and their economy. Full development and conservation of all our water resources is essential if Texans are to meet their responsibilities for a rapidly expanding population and for supplying the accompanying demands for water for domestic and municipal uses, industry, agriculture, mining, hydroelectric power, navigation, and recreation. If we are to meet these responsibilities and provide the water so essential to our well-being, we must begin now. To delay the full development of our water resources will place a burden upon the future of Texas from which it might never recover.

Respectfully submitted,

Texas Water Development Board

Mills Cox, Chairman

Marvin Shurbet, Vice Chairman

W. E. Tinsley, Member

Robert B. Gilmore, Member

Milton Potts, Member

Groner Pitts, Member

Howard B. Boswell, Executive Director

FOREWORD

NEED FOR ACTION

The preparation and release of the Texas Water Plan is only the beginning insofar as the effective protection, conservation, development, distribution, and utilization of Texas' water resources is concerned. The Texas Water Plan precipitates a moment of critical decision for the Legislature, for the people of Texas, and for the future of Texas. Similarly, immediate major decisions will be required of the Federal Government.

Action by and within the State of Texas alone, even on a large scale, is not enough, because the water resources now available to Texas are not sufficient to meet the economically justified future water needs of the entire State no matter how efficiently they may be conserved, distributed, and administered. Thus, the only solution for this shortage of water supply is the import of water into Texas from out-of-State sources, possible only through the coordinated efforts of Federal agencies, governmental agencies of other States, the State of Texas, and local Texas agencies. The urgent need for additional water will impose a time schedule which will be extremely difficult to meet even with the fullest effort. Delay by the State, or by any other concerned level of government, would have irreversible results.

Present water developments and those of the future will be extremely costly. Therefore, the maximum degree of efficiency in planning, financing, design, construction, and management is imperative. The State has a major responsibility for achieving this objective. By prompt effective action, whatever immediate costs may be involved will be returned many times to the State as a whole.

With the heavy demands on the Federal budget, it is completely unrealistic to expect that the United States would fully finance construction of all of the works needed to meet Texas' urgent water needs. The State of Texas, and its political subdivisions, must provide significant portions of the funds required. Further, in order that Texas may have full control over the development and utilization of its water resources, it is essential that the State be a major participant in financing and directing the Texas Water Plan into actuality and in its management once construction is completed.

The magnitude of the job and the tremendous long-range commitment of State resources involved must not be underestimated, nor the tragic consequence of delay. There is not a water resource plan of this magnitude or complexity in existence in the world today or even in the planning stage, yet Texas' water needs for the future can be met with nothing less sweeping.

STATUTORY AUTHORIZATION

Planning for long-range water resource development for Texas has been conducted by the Board in compliance with a series of statutory enactments. These Legislative and Executive directives have reflected the response by the State to the increasing complexity of its water problems.

Acting under the stimulus of prolonged drought, broken by heavy rains and flooding in the Spring of 1957, the Legislature in special session adopted the Water Planning Act of 1957. Complying with provisions of that Act, the Board prepared and submitted to the 56th Legislature a progress report titled "Texas Water Resources Planning at the End of the Year 1958."

In May 1960, Governor Price Daniel requested that the Board assume State leadership in coordinating water planning in Texas, and that it prepare a statewide plan to meet municipal and industrial water requirements. Cooperating with river authorities and cities, the Board prepared a report titled "A Plan for Meeting the 1980 Water Requirements of Texas," May 1961.

The 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 a defined area of study, which included only about 62% of Texas.

The Bureau of Reclamation and Corps of Engineers subsequently completed several reports on specific projects. The Corps of Engineers reports included multiple-purpose reservoir projects, local flood control, navigation primarily along the Texas Gulf Coast, hurricane protection, and comprehensive reports on the Sabine and Trinity River Basins. The Bureau completed its Preliminary Report on the Texas Basins Project in 1963.

Local entities—cities, river authorities, and water districts—were also suggesting projects in their areas, some of which conflicted with proposals of Federal agencies.

Governor John Connally recognized the need for a more orderly and longer range analysis of the State's water problems, water needs, and solutions to these problems on a Statewide basis, and by letter dated August 12, 1964, requested that a comprehensive State Water Plan be prepared. He said:

"I am increasingly concerned about drought conditions in Texas and progress of our efforts to develop adequate sources of water for all our State. I'm sure the members of the Texas Water Commission share this concern with all our citizens.

The Bureau of Reclamation and the Corps of Engineers have proposed broad water development projects for Texas far beyond the plans of the Texas Water Commission report, "A Plan for Meeting the 1980 Water Requirements of Texas." In my opinion, these plans fall short of satisfying the water needs for all of Texas.

Furthermore, the Congress is presently considering a Federal water pollution control bill which will supplant state authority in this field. I have long been concerned that the State exercise its responsibility in all areas of water conservation and development. The recently enacted Water Resources Act of 1964 does provide an opportunity for state participation in federal water research programs.

As you know, it is my responsibility, with the help of the Texas Water Commission, to review major federal projects and formally approve or disapprove them on behalf of the State. I cannot properly evaluate some proposed federal projects without a longer-range State Water Plan for Texas.

Therefore, by authority granted me under Article V, Section 22, House Bill 86, 58th Texas Legislature (The General Appropriations Act), I hereby request the Texas Water Commission to use any available moneys appropriated under the Act to begin at once to develop a comprehensive State Water Plan. In the public interest and to aid the economic growth and general welfare of the State, I urge *that you explore all reasonable alternatives for development and distribution of all our water resources to benefit the entire State, including proposals contained in preliminary reports of the federal agencies."*

The State's planning programs have been conducted in accordance with the Texas Water Planning Act of 1957 (V.A.C.S. 7472d-1) through August 1965, and in accordance with V.A.C.S. 8280.9(b) as amended by acts of the 59th Legislature since September 1, 1965.

Acceleration of the planning effort, and the development of a longer range Texas Water Plan, was begun with Governor Connally's authorization of August 12, 1964, under authority given the Governor in Acts 1963, 58th Legislature, Chapter 525, p. 1393, Article 5, Section 22.

Emergency funds were allocated for key planning staff for the accelerated program in October 1964 from appropriations to the Governor for the purpose of deficiency grants.

The 59th Legislature provided additional funds for the accelerated program in a special emergency appropriation in Acts 1965, Chapter 4, p. 7. In addition, the 59th Legislature realigned the functions of the several Texas water agencies. This realignment assigned planning for water development in Texas, including financing, as a responsibility of the Texas Water Development Board.

The 60th Legislature provided continuing support for the planning program in its regular appropriations to the Board.

ACKNOWLEDGEMENTS

Many individuals and organizations, both public and private, have participated in the formulation of the Texas Water Plan. It would be impossible to acknowledge the individual contribution of every person and every group playing a part in bringing Texas to the position of strength in managing its water resources that this Plan makes possible. With sincere appreciation, however, the Board recognizes this tremendous reservoir of support. The special and dedicated assistance of the following merit special mention:

The Governor of Texas
The Honorable John Connally

The Lieutenant-Governor of Texas
The Honorable Preston Smith

The Speaker of the House of Representatives
The Honorable Ben Barnes

The Legislature of the State of Texas

whose untiring support has made possible this Plan for sound water development in Texas.

The staff of the Board, both past and present, who have unstintingly worked toward the completion of the Texas Water Plan.

Members of the then Texas Water Commission, who provided initial direction for the planning program.

Joe D. Carter, Chairman
Otha F. Dent
H. A. Beckwith
William E. Berger

Consulting Advisory Panel, which performed an incalculable service to the Board and the State by setting the planning program on a firmly marked road of achievement.

Joe M. Kilgore, Chairman
Harvey O. Banks
William F. Guyton
Allen V. Kneese
Mason Lockwood

The U.S. Army Corps of Engineers and the Bureau of Reclamation for their very able and invaluable assistance in the Texas Water Plan, and to the U.S. Geological Survey for the very valuable studies it is making of ground waters.

Universities and colleges that have prepared reports and conducted studies vital to the development of the Plan.

University of Texas at Austin
Texas A&M University
Texas Technological College
University of Texas at El Paso

Leeds, Hill and Jewett, Inc., General Consultant to the Board, through guidance, assistance, direct participation, preparation of reports, and staff training, have played an essential part in every phase of the planning program.

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Raymond A. Hill

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The Texas Water Conservation Association and private organizations that have provided unfailing and generous encouragement and support.

All of those individuals and organizations who, through testimony at hearings held by the Board in 1966, contributed to the development of the Plan.

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Part I

The Texas Water Plan

THE TEXAS WATER PLAN

INTRODUCTION

Water planning is a means to an end and not an end in itself. Its objective is the development of water resources as effectively and economically as possible to meet man's needs while at the same time protecting him from flooding and periodic drought. The high dams and man-made rivers that stand as monuments to man's ingenuity and technical skills conserve and distribute the water which is vital to his life and well-being, and shield him from its detriments. These works are conceived and planned to overcome the sometimes severe disparities between water resources as provided by nature and the timing and places of man's needs for water supply.

In the past, Texas citizens generally have been able to live wherever they chose without concern for the availability of water. Where other resources were available, a water supply was also generally available, either in the immediate vicinity or at relatively short distances. People settled, developing these supplies where they were found; investments were made, economies developed, and social and cultural values accumulated to the benefit of all citizens of the State.

Texans now, however, are able to see the limits of the State's developable water resources. Seeing these limits, recognition has also come that wise use of the available water resources is vital to the continued expansion of Texas population, economy, and culture.

By far the bulk of the water resources remaining available for development in Texas occurs in the East Texas river basins. By contrast, large future water needs will occur in areas to the west and southwest, several hundred miles distant, and in some areas over 3,000 feet higher in elevation, where available water supplies are limited and diminishing. Cities and industries in many areas throughout the State will need more water or water of better quality than can be made available from local fresh water sources.

Furthermore, studies for the Texas Water Plan show conclusively that presently available water resources are grossly inadequate to meet Texas' future economically justified water needs. Importation of water from out-of-State sources will be essential. Without it, retrogression must inevitably occur in some sectors of the State's economy, particularly agriculture and associated agribusiness, with attendant severe social problems of unemployment and forced population relocation, and loss of financial investments.

As a result of the Texas Water Plan studies, the Congress has authorized the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation to investigate a possible import of water.

The Bureau of Reclamation is conducting studies of importing surplus water from the Mississippi River System into water-deficient areas in West Texas and eastern New Mexico. The Corps of Engineers is participating in these studies to determine the availability of water from the Mississippi in coordination with affected States, the locations and types of conveyance channels required for movement of water to these water-deficient areas, and the effects of such withdrawals and conveyance facilities. The Corps of Engineers was authorized in May 1966 also to determine, in cooperation with other Federal agencies, whether any modifications or additions should be made in proposed Federal projects in relation to the Texas Water Plan, and to determine the effects of upstream developments on pollution or changes in salinity in the bays and estuaries and to recommend such improvements as are necessary to maintain or improve the quality of water in the bays.

Concurrently, the U.S. Geological Survey is conducting a study of the Ogallala Aquifer in the High Plains of West Texas to determine the hydraulic and hydrologic conditions in the aquifer important to its effective utilization in conjunction with an imported water supply.

By 1972 the above Federal agencies, the Water Resources Council, and the Office of Water Resources Research will have spent several million dollars for studies and investigations including the potential import of water to Texas and eastern New Mexico, and the conditions of the Ogallala Aquifer of significance to continuing use.

Texas must continue to bear its full share of responsibility for developing and implementing plans for water import, and providing for the equitable distribution within Texas of waters now or potentially available for use. Since August 1964, the State has expended approximately $10 million in these planning activities. The time has now come to decide whether this investment in the future is to bear fruit or to be thrown away.

Statewide planning on a comprehensive long-range basis provides a guide for problem solving in advance of need; it is essential in a water-short area such as Texas. The Texas Water Plan has been prepared as

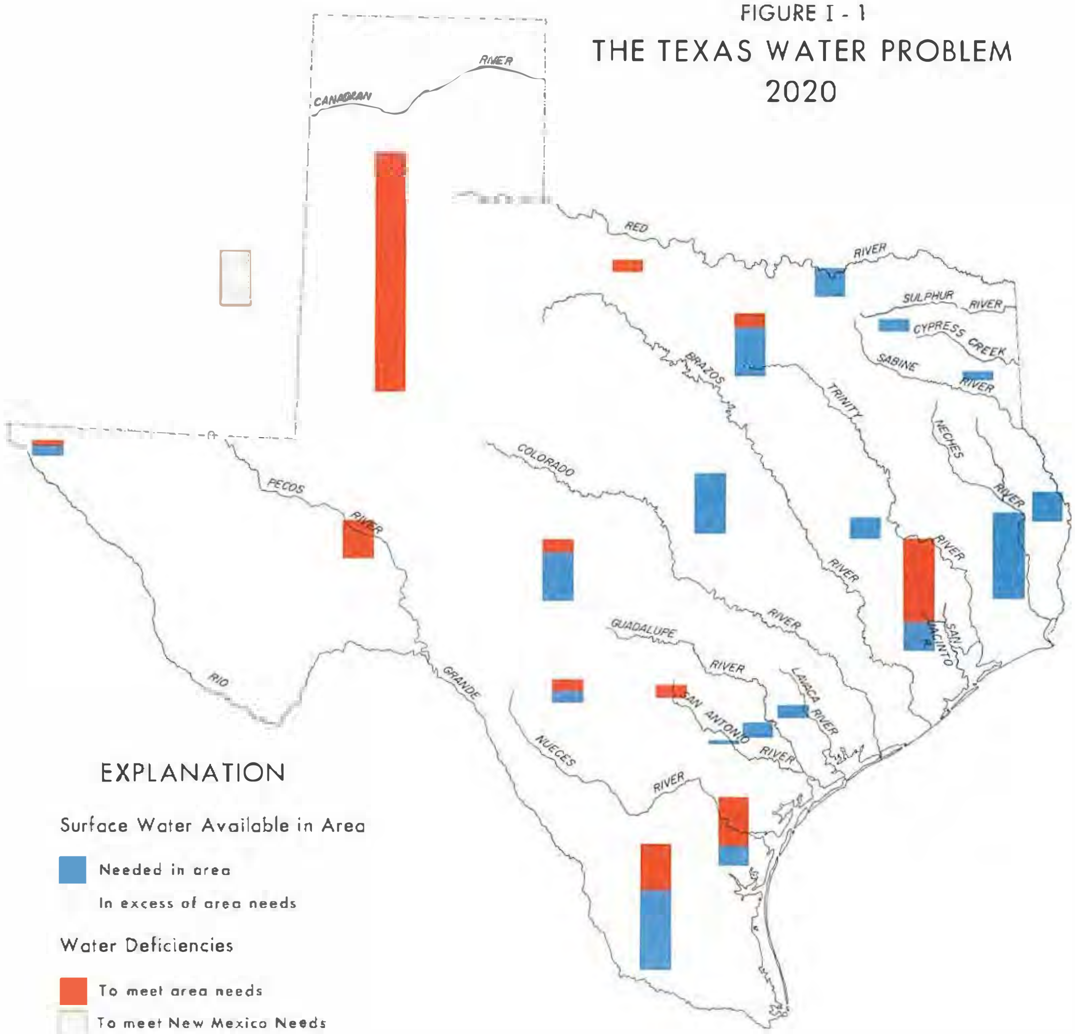


FIGURE I - 1
THE TEXAS WATER PROBLEM
2020

such a guide for water policies and development, and for intergovernmental relationships affected by or affecting water resource development. The coordinated progressive Statewide development proposed will enhance the effectiveness of the large investments of capital, labor, and materials and of water related land resources required to meet Texas' water needs. It will allow a thorough and systematic evaluation of those projects which are to receive State financial aid, and will provide a basis for selection of those which are in the Statewide interest.

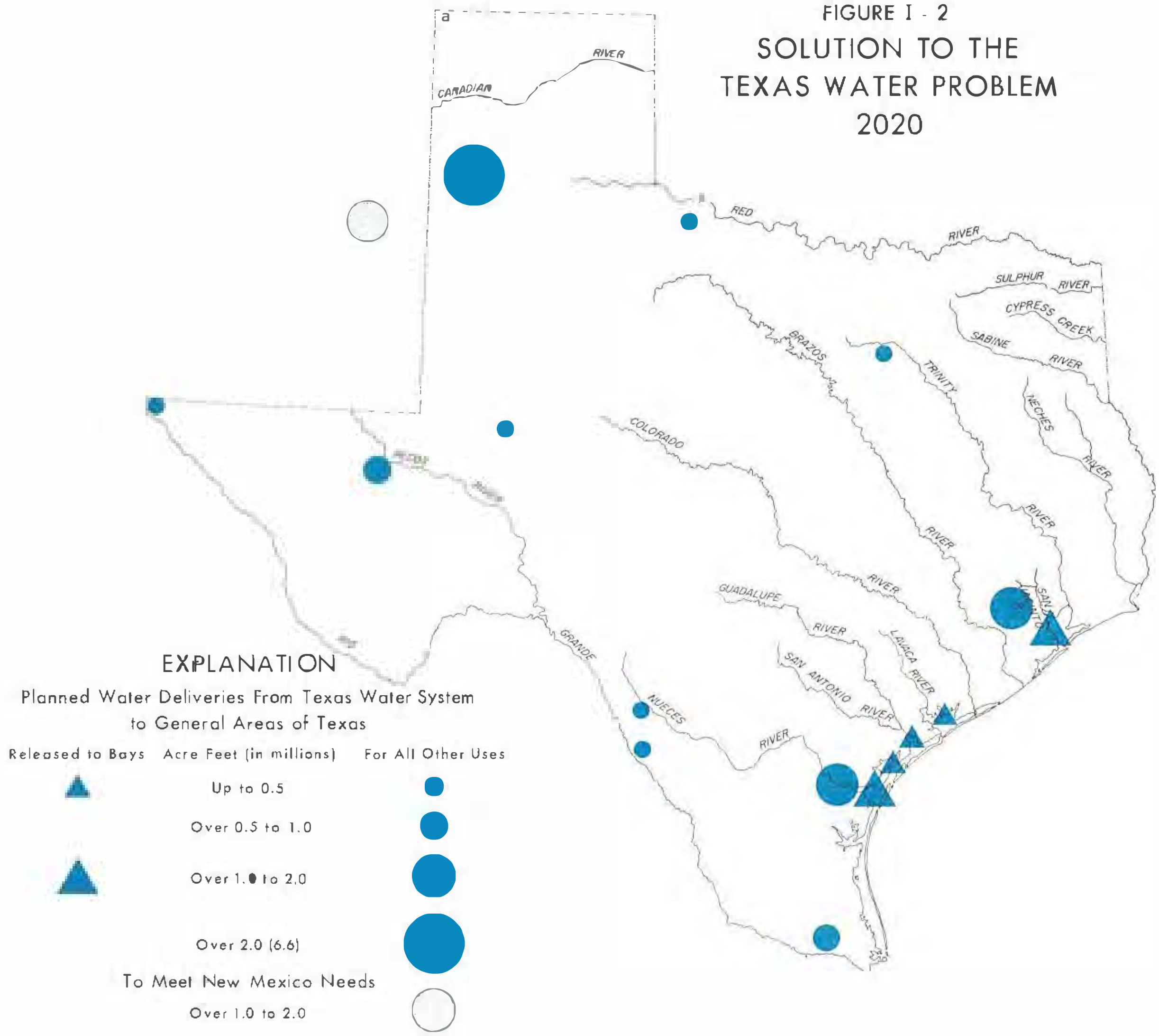
Water requirements have been projected for a 50-year period and means of satisfying these requirements are proposed. It is recognized that if this Plan for water development, completed in 1968, is to provide for water to meet people's needs to the year 2020, it must be subjected to continuing study, refinement, and alteration as changing needs, priorities, and wishes of the people of the State may dictate. Thus it is a Plan that is flexible, retaining freedom of choice as to future actions as long as possible.

In developing the Texas Water Plan, the Board has used all historical data that could be accumulated; the resources of a qualified and dedicated staff; and the advice of Federal and State agencies, universities, in-State and out-of-State consultants, river authorities, cities, water districts, and representatives of the various economic segments of the State, as well as the opinions of the citizens of the State expressed during the hearings held by the Board in the summer of 1966.

Recognizing that continuing study and investigation will be needed of future water needs and problems in Texas, the Board nonetheless believes that sufficient information is now available on which to base this comprehensive Statewide Water Plan.

The document has been organized to facilitate its use both by the general public and by technical readers. The supporting data are available in files of the Board, as are the reports prepared for the Board's use as a part of the planning document by universities, State agencies, and private consultants.

FIGURE I - 2
SOLUTION TO THE
TEXAS WATER PROBLEM
2020



RIVER BASIN DELINEATION

Article 8280-9, Section 3(b) specifically charges the Board with the duty to prepare, develop, and formulate a comprehensive State Water Plan, including a definition and designation of river basins and watersheds as separate units for purposes of water development and inter-watershed transfers.

The topography of Texas and the present network of more than 80 thousand miles of main streams and tributaries are the basis for the hydrologic delineation of Texas river basins. Topographic maps of varying scales and accuracy are available for all the State. As of August 31, 1968, detailed topography is available for 54.4% of the State and detailed mapping is in progress on an additional 20.7% of the area. First class topographic maps have been completed for the Gulf Coastal Plain from below Corpus Christi to the Sabine River.

The latest maps, obtained both through the continuing topographic mapping program conducted jointly with the Topographic Mapping Division of the U.S. Geological Survey and through the all-Federally financed mapping program, were used to delineate and measure the drainage areas of river basins.

During preparation of *A Plan for Meeting the 1980 Water Requirements of Texas* (May 1961), and using the then available topographic maps, the Board outlined the basin drainage boundaries so that a basin would include that area which drains to a stream above its mouth under usual runoff conditions. In the Gulf Coastal Plain major floods have flowed overland in the past from one basin to another, but the possibility of this occurrence was excluded from consideration. In the High Plains, some areas are essentially noncontributing to downstream flow. In these portions of the basins, the gross area between topographic divides was included.

Basin boundaries as shown on Plate 24 of the May 1961 report have been reviewed by the Board and the Texas Water Rights Commission using latest topographic maps, and minor alterations made in some basin boundaries. One delineated area was added, the closed basin in Hudspeth, Jeff Davis, Culberson, and Presidio Counties, which has no surface outlet to the Rio Grande Basin.

As mapping is completed in some of the central and western portions of the State, some further minor adjustments in basin boundaries may be required.

Intervening drainage areas on the Gulf Coastal Plain, between the topographic divides delineating the river basin boundaries, have been designated as Coastal Basins.

The Board defined the basin boundaries and their designations by Resolution No. 66-9 on May 17, 1966. The same delineations are used by the Texas Water Rights Commission and the Texas Water Quality Board. These basin boundaries and their designations are shown on Figure IV-11.

BASIN HEARINGS

The Board prepared a preliminary Plan, released in May 1966. During the summer of 1966, in compliance with the requirements of the Texas Water Development Board Act, the Board held 27 public hearings and three public meetings to assure the widest possible distribution of information concerning the Plan. Detailed summaries of the results of the planning studies were prepared for each of the river basins, forming the basis for the Board's presentation at the hearings. At each of the hearings, the Board presented the preliminary Plan for development of the river basin in which the hearing was held, and invited the views, comments, criticisms, and suggestions of those interested in water development in Texas. Testimony was recorded and an opportunity given for formal statements to be added to the official record until September 15, 1966, or 30 days after the hearing date, whichever was later.

The Legislature intended that through this process citizens might familiarize themselves with the proposals of the preliminary Plan, and that the Plan thereby might be subjected to the informed judgment of the people of Texas.

The Texas Water Development Board 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, general welfare, economy, and water requirements of the areas of such river basin" or "of the areas affected."

Each of the many valid suggestions, criticisms, and proposals for Plan modification, or alternatives to the proposed Plan submitted in the hearings, have been explored by the Board in continuing planning studies in as much detail as was feasible. These studies were conducted for the purpose of selecting the optimum technical and economic plan as a guide for development of Texas water resources.

Information contained in the detailed summaries which were prepared for each of the river basins is being revised as additional data become available. Information relating to these changes is available in the files of the Board. The Board will prepare and release revisions of these detailed summaries beginning about 1971, after obtaining the new census data to be taken in 1970, and periodically thereafter.

PLANNING CONCEPTS

Planning is the process by which a prudent society directs its activities to achieve goals it regards as important. It involves more, however, than the formulation of a physical plan—a means of implementation is necessary if planning is to be meaningful. The Board was directed to develop a comprehensive long-range flexible water plan for Texas. Recognizing the complexity of this task, the Board first defined the goals such a plan must achieve through the coordinated activities of Federal, State, and local levels of government. This conceptual framework has guided planning activities and formulation of the Texas Water Plan, and forms the basis for Plan implementation.

1. The Goal

The objective, or goal, of the Texas Water Plan is to provide in the most effective and economic manner the water supplies, and the other benefits to be derived from water development, necessary to meet the needs of Texans for all purposes throughout the State as the population grows and the economy expands. National, State, and local interests must be fully considered. Social, cultural, and economic values will be recognized. To the maximum extent possible, the Plan will assure that water supplies of good quality are made available so that the future of Texas will not be limited by lack of water.

2. The Plan to be a Flexible Guide

The Texas Water Plan is a guide for the extremely complex solution to the difficult problem of matching water development to demand. It has been designed to meet water needs for all purposes throughout the State, retaining options as to the proper course of action as long as possible. It must be progressively adapted to changing conditions, recognizing that all economically justified water demands throughout the State must be met as they develop if the Plan is to achieve optimum results.

Water requirements for all purposes must be frequently reviewed, updated, and revised as needed.

Feasibility studies of individual elements of the total Plan must be conducted in selected sequence. Design and construction of physical facilities for storage and conveyance of water must be staged at times that provide the optimal balance between water supply, needs for flood control and other purposes, and project economics. A time schedule for action must be adopted to meet Texas' water requirements in time to avoid economic detriment. This time schedule will be extremely difficult to meet.

A framework of project development to meet water needs is proposed in the Plan. All reasonable alternatives have been examined, and must continue to be evaluated with the objective of minimizing the costs of achieving the desired results.

Alternative intrabasin projects compatible with the long-range objectives of water development could be incorporated into the fabric of the Plan to meet local preferences or changing conditions.

Changes in water resource availability resulting from instream development, shifting land use patterns, changes in storage in ground-water bearing formations and effects on flow in streams, flood and drought incidence, and changes in water quality must all be continually analyzed within the context of the Plan. Maximum use must be made of waste waters which can be reclaimed and renovated for beneficial purposes.

The whole range of the State's economy—the effects of water availability and water pricing on location of industry, municipal development, and irrigation expansion—must be evaluated periodically so that water development can be phased to meet changing needs. Opportunities for water-oriented recreation must keep pace with the expanding population.

3. Water Rights

Formulation of the Texas Water Plan has been based upon the premise of no interference with vested rights under existing water right permits. The basin of origin provisions of the Texas Water Development Board Act provide legal bases for protection of intrabasin rights. There is no comparable legal protection in Federal laws or policies nor in other State statutes. Implementation of the Plan is to be based on these tenets of water rights administration:

(1) Intrabasin needs for all beneficial purposes developing within the ensuing 50-year period will have an absolute priority of right over exportation for out-of-basin demands, as to both water rights for locally sponsored projects and the right to purchase water from the facilities of the Texas Water System.

(2) Demands on the Texas Water System for reasonable intrabasin requirements will be met at any time on a 100% firm basis before any exportation.

(3) Water temporarily surplus to intrabasin requirements and to the satisfaction of existing rights at any time will be conserved and exported through the Texas Water System only under valid permit and contract arrangements, and subject to right of recapture when needed in the basin of origin.

(4) All rights under permits to be held by the Board will be obtained through full compliance with rules and procedures of the Texas Water Rights Commission.

(5) Where operation of the Texas Water System might conceivably interfere with beneficial uses under existing rights, appropriate protective terms and conditions will be imposed in water permits granted by the Texas Water Rights Commission.

(6) Agreements will be executed as necessary with holders of existing rights and with operators of other projects, defining such rights as against the Board, and specifying project operational criteria for the Texas Water System to protect usage under such rights, and its operation with that of other projects to maximize overall benefits.

4. Federal-State-Local Relationships

Implementation of the Texas Water Plan and the Texas Water System is proposed to be a coordinated and cooperative effort of the Federal Government, the State of Texas, political subdivisions of the State, and private interests, each acting within the scope of its authority and policies, and within the objectives and framework of the Plan. This arrangement is designed to further the interests of each to the maximum feasible extent. The State will be a major participant, on a partnership basis with the United States, in bringing the Texas Water System into being and in subsequent operation and management of the System.

5. Water Quality

Water quality management is an integral part of water resource development to enable maximum beneficial use, maximum reuse of waste waters, and to preserve the bays and estuaries. At the same time, the necessity to use streams, coastal waters, and ground waters for the final disposal of adequately treated waste effluents is recognized.

For purposes of planning, the achievement of the following goals of water quality management have been assumed: Pollution of Texas' water resources from both man's activities and natural sources will be abated as rapidly as possible, and future pollution prevented. Large-scale regional systems for the collection, treatment, and disposal of municipal sewage and industrial wastes will be planned and constructed where necessary to achieve quality control at reasonable cost. Control of wastes at the source may be necessary in some instances in order to maintain the quality of effluents discharged at levels that will permit reuse.

The principal factor in water quality control is the health and welfare of Texas citizens. Water quality criteria must be based upon the total use that will be made of the water resource. Low-flow augmentation for water quality management may be used to bring water quality to levels that will satisfy water uses of the stream on an interim basis, but not as a substitute for the highest technically and economically feasible treatment of wastes.

Reservoir storage space and water supplies will not be permanently and irrevocably allocated to stream quality control. However, under some circumstances water may be provided for low-flow augmentation, where such water can be used downstream to meet other requirements or to provide fresh water inflows to the bays and estuaries. Where so used, the necessity of continuance will be reviewed at intervals in the light of advances in waste treatment technology, economics, and the need for the storage and use of water for other purposes.

Control of natural sources of quality impairment will be diligently investigated and control measures undertaken where feasible as a means of enhancing usable water resources.

Water development will be undertaken so as to assist the Texas Water Quality Board in achieving effective pollution control, and in assuring maintenance of water quality standards.

6. Multipurpose Development

Dam and reservoir sites in Texas are becoming scarce and costly to develop, and must be preserved and developed to maximum advantage. In general, each water basin, source, site, and facility will be developed on a multipurpose basis, and to its optimum limits. In examining such multipurpose possibilities, all functions and problems related to the site and the requirements it is to meet will be considered. If it is not economical to build facilities to optimum limits initially, initial development will be planned so that subsequent enlargement will be possible.

7. Ground Water Use and Conjunctive Use With Surface Water

Whenever feasible, ground water resources will be developed and used on a safe-yield basis. In ground water aquifers subject to overdraft, ground water pumpage will be reduced to safe yield as rapidly as possible by substitution of surface water supplies. Where applicable and feasible, alteration in the pattern of excessive pumping will be considered.

The underground resources of natural ground water and of storage and transmission capacity will be utilized conjunctively with surface water supplies and facilities where such complementary operation will minimize the cost of providing adequate water supplies.

8. Progressive System Development and Coordinated Operation

The Texas Water System is considered as a single integrated unit to be planned, designed, constructed, and operated in such a manner as to minimize the costs of achieving the desired multipurpose results. To achieve this cost minimization objective, elements of the System will be staged and constructed progressively as water demands build up.

The most advanced techniques and automation will be used to operate the system of reservoirs, pumping plants, canals, powerplants, and other facilities in a coordinated manner to achieve optimum results.

9. Bays and Estuaries

The coastal bays and estuaries are of great importance to the State of Texas and to the Nation. Adequate fresh water inflows will be provided and other actions taken to preserve and enhance these resources. Comprehensive studies of all bays and estuaries are necessary to determine the proper actions.

10. Intangible Values

Future water development will have a profound impact on the State, politically, economically, socially, and culturally. The full range of impacts and benefits or detriments must be evaluated, even when not measurable in monetary terms. In planning and in project development, therefore, the benefits of esthetic and recreational enjoyment of the water resources of the State will be given full consideration, although these benefits cannot be quantified with precision. Sites of historic and archeological value will be examined, and measures taken to the fullest possible extent to minimize loss of any of these values as the result of water development. River reaches and springs of great scenic and scientific value will be preserved whenever possible and feasible. All feasible measures will be taken to mitigate any damage to fish and wildlife resources resulting from construction and operation of facilities of the Texas Water Plan, and wherever possible the enhancement of these resources will be included as a project purpose.

11. Need for Equity in Resolving Problems

The construction of the massive impoundment and conveyance facilities of the Texas Water System will have an adverse, although temporary, impact upon the civil functions and economic stability of some local areas. Schools, hospitals, police, fire protection, and other administrative functions will be affected by the large-scale influx of construction personnel. Offsetting these detriments and costs of local communities, to the extent they cannot be handled with local financial resources without hardship, and insofar as the costs are not borne as a Federal responsibility, will be an obligation of the State as part of the construction cost of the System.

12. Master Districts

The reimbursable costs of the facilities of the Texas Water System allocated to water supply will be repaid by income from water service contracts executed by the State with legally and financially viable local political subdivisions. Master districts must be formed in areas where no legally competent local agency presently exists. Contracting agencies must have adequate powers to raise sufficient revenue through water charges or taxation to assure that costs of providing water to the area through the System will be repaid. Where irrigation is to be served, a master agency or conservancy district will contract for the delivery of water to one or more wholesale delivery points within the area involved. Distribution of the water to retail consumers will be accomplished by the master agency or district or under ancillary contracts with other political subdivisions within the master agency.

Such agencies or districts will have adequate revenues, derived from executed water sales contracts, or tax revenues, or both, to assure that the Federal and State investment for capital costs and the annual costs will be repaid insofar as these costs are reimbursable under Federal and State laws and policies. It will be important to assure economically effective farm units within irrigation areas to meet the costs of water supply.

13. Master Plans and River Basin Comprehensive Plans

The Texas Water Plan has been formulated incorporating previous master plans and comprehensive plans for river basin development to the fullest possible advantage.

All elements of such plans not in conflict with the overall objectives of the Statewide comprehensive Plan can be developed as a part of the on-going development of water resources of the State.

In the resolution of any conflicts that may arise, consideration of means for enhancement of the economic and social well-being of the river basin will be a principal objective as well as consideration of the Statewide interest.

14. Interstate Compacts

The apportionment of water from sources flowing along or across the boundaries of Texas will be made on the basis of jointly conceived compacts between the States involved and approved by the United States where such compacts have been finalized. On streams where compacts have not yet been consummated, it is expected that continued efforts will be made to reach agreement on the equitable apportionment of the waters.

15. Energy for Pumping

Extremely large amounts of energy for pumping will be required for the Texas Water System, and costs for energy will be a major component of cost of supplying water under the System. New generating facilities and expanded transmission systems will be necessary, and should be the lowest cost facilities feasible for supplying these needs. These will be fully integrated with the regional power systems. Surplus capacity and energy available from the regional systems will be used where financially advantageous.

16. Water Service Contracts

The water service contracts to be executed between the State and local political subdivisions served by the Texas Water System will convey a contract right to a water supply of suitable quality for the intended use(s) without specifying the exact source or sources from which the water will be obtained. The contracts will specify the amounts, timing and places of delivery, and the amounts and manner of payment and will contain such other terms and conditions as necessary to protect the interests of the United States, the State, and the contracting agency.

17. Water Pricing and Repayment Policy

The formula for payments for water under water service contracts will be such as to assure the State, as operator of the Texas Water System, of sufficient revenues to meet its financial obligations to the United States to the extent these pertain to water supply, to repay the State's investment allocated to water supply, and to operate and maintain the water supply components of the System.

Pricing and repayment for water used for irrigation will be in accordance with the provisions of Federal Reclamation Law, as an investment by the United States. Other pertinent Federal laws and policies will apply with regard to reimbursement of the remainder of the Federal investment. The State's investment will be repaid with interest.

Pricing and repayment for municipal and industrial water supplies will be by zones, with the price for water increasing as the distance of conveyance increases.

THE TEXAS WATER PLAN

The Texas Water Plan is a flexible guide to the coordinated, long-range management, development, and redistribution of Texas' water resources, and for the importation of water from out-of-State for the benefit of Texans throughout the State.

The several regions of the State are interdependent economically, financially, and politically. One region with water surpluses cannot retain those surpluses in excess of its own needs to the detriment of other regions less fortunately endowed with water resources without loss to its own well-being and to the State as a whole. Concerted, aggressive action is required if adequate funds are to be available for the full development of water and facilities that will be necessary throughout the State. The Texas Water Plan will provide a sound basis for such action.

The Plan is based on the premise of the following accomplishments being achieved effectively and economically through cooperative coordinated action by the Federal agencies, State agencies, local political subdivisions, and private interests:

(1) Satisfy vested water rights with proper modes and procedures to be followed for the equitable adjustment of any water rights that might be affected by the program, including continuance of vested riparian rights now supplied by direct diversion from streams.

(2) Provide for the projected 2020 municipal and industrial water requirements throughout the State.

(3) In the first phase of import, provide for the importation of an estimated 12 to 13 million acre-feet per year from out-of-State sources by 2020 to meet Texas' water needs, and deliver 1.5 million acre-feet of imported water to New Mexico through joint use of facilities.

(4) Deliver about 7.5 million acre-feet of supplemental water annually for irrigation in North Central Texas, the High Plains, and the Trans-Pecos area. Planning will continue as to possible import of water to supply additional economically justified water needs throughout the State, as those needs arise.

(5) Deliver about 727 thousand acre-feet of water annually for irrigation in the Coastal Bend area and 700 thousand to the Lower Rio Grande Valley; and make a gross diversion from the Rio Grande of about 200 thousand acre-feet annually for irrigation in the Winter Garden area and a net depletion of Rio Grande flow of about 190 thousand acre-feet annually for additional irrigation in Webb and Maverick Counties using releases from Amistad Reservoir, with water supplied to the Lower Rio Grande Valley in replacement for these releases.

(6) Based on best available estimates of need, provide regulated fresh water inflows to the bays and estuaries, and participate as justified in other measures such as structural modifications to obtain better tidal circulation, with the objective of maintaining suitable quality conditions for fish and shellfish.

(7) Supply projected water requirements for wildlife management areas and refuges.

(8) Meet projected water requirements for secondary oil recovery programs.

(9) Fulfill interstate compact commitments.

(10) Use return flows and reclaimable waste waters to the maximum feasible extent.

(11) Through conjunctive use of surface and ground water and other measures, make possible a decrease in ground water extractions from aquifers to the safe yield, thus minimizing subsidence and other adverse effects of overdraft.

(12) Decrease loss of the State's water resources through control of phreatophytes and salvage of water from phreatic non-beneficial consumptive uses.

(13) Provide flood control through storage in proposed reservoirs, and by channel improvements and levees where necessary.

(14) Coordinate hurricane protection projects along the Gulf Coast with other actions in order to minimize the adverse effects of those projects.

(15) Support projects to provide drainage where feasible for land reclamation and where necessary for maintenance of agricultural productivity.

(16) Alleviate degradation of the State's fresh water resources from sources of naturally poor quality water, such as saline springs.

(17) Provide regional systems for the collection, treatment, and disposal of municipal sewage and industrial wastes that will be necessary to maintain the quality of the State's waters at requisite levels.

(18) Take other necessary measures for quality protection and management.

(19) Preserve and protect river reaches and springs of great scenic beauty or scientific value.

(20) Preserve and protect sites and natural phenomena of historic and archeological importance.

(21) Provide additional water-associated recreational opportunities.

(22) Integrate feasible navigation projects on Texas streams with other water development objectives, and provide necessary water requirements for navigation purposes.

(23) Provide for expanded upstream watershed programs for erosion control and land treatment, and additional floodwater-retarding structures and channel improvements.

(24) Generate electrical energy for pumping to the extent that energy cannot be made available from other sources at requisite prices.

(25) Develop hydroelectric power where feasible.

(26) Protect and enhance fish and wildlife resources to the maximum feasible extent.

(27) Provide increased financial assistance to qualified local agencies for necessary water facilities.

Surface water supplies which will be available for use and distribution to meet total future projected water requirements in the State include supplies from intrastate streams, and water from interstate streams where Texas' allocated share of water is already assured by river basin compact agreements. Additionally, in formulating the Texas Water Plan, two important assumptions were made:

(1) Under an equitable apportionment of the waters of the Red River Basin among the several States involved, the Texas' share would meet the demands on the Basin shown in this document; and

(2) A supply of water imported from an out-of-State source—tentatively projected to be the lower Mississippi River Basin—will be made available in time to prevent loss of the existing irrigated agricultural economy of West Texas and eastern New Mexico, and an Interstate System will be developed which will also provide benefits to the several States involved as well as to Texas.

Based upon projections of future in-State supplies, and these two important and critical assumptions, the Texas Water Plan has been designed to accomplish the following:

(1) Provide for efficient development and management of the total water resources of all river and coastal basins in the State to meet future beneficial intrabasin requirements to the year 2020, and redistribution of surpluses of water projected to be available in some of these basins to areas which will have deficiencies;

(2) Utilize to the fullest extent possible existing reservoirs and reservoirs already authorized for construction in order to reduce costs; and,

(3) Provide for water needs in areas of the State where deficits will occur by phasing in deliveries of both in-State supplies and water imported from out-of-State as requirements develop in these projected water-short areas.

The Texas Water System

The Texas Water System is designed to conserve waters in basins of surplus, and convey and distribute the surpluses and imported waters to areas of deficiency throughout the State, at the same time meeting future requirements in the basins of origin. It consists of an integrated, interconnected network of water storage, regulation, and conveyance facilities. It is comprised of the Trans-Texas Division, the Coastal Division, and the Eastern Division. The configuration of the System is shown on Plate 2 and illustrated schematically in Figure I-3. Present and proposed (including alternative) water development projects needed within the State by the year 2020 are shown on Plate 3. Pertinent data relating to existing, authorized, under-construction, and proposed reservoirs, including those designed to meet local requirements and those which would develop water resources as a part of the System, are given in Tables IV-52 and IV-53.

Sources of Water Supply

The principal Texas sources of water supply for the Texas Water System, designed to meet intrabasin requirements in water surplus areas and the needs in water deficient areas of the State, would be the lower Red, Sulphur, Cypress Creek, Sabine, and Neches River Basins. Some surplus water would also be available from the Trinity, Guadalupe, and San Antonio River Basins to the year 2020, and some additional surpluses from these basins on an interim basis as intrabasin requirements build up. These surpluses would be available for transfer to points of need through the Texas Water System after all requirements are met in these basins. In addition, some 12 to 13 million acre-feet of water would be imported annually from an out-of-State source.

After all projected local intrabasin water requirements are met, requirements under vested water rights

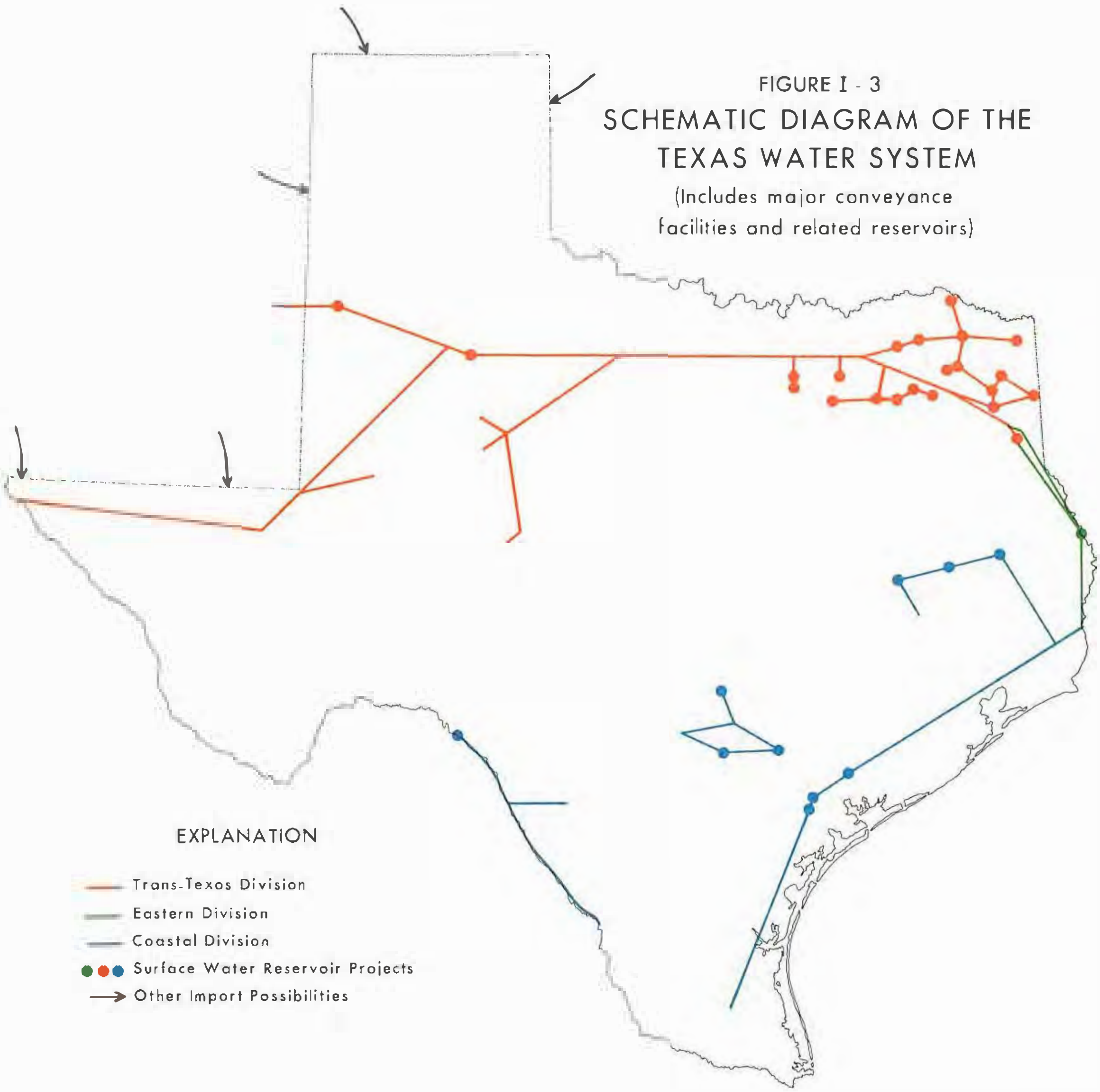


FIGURE I - 3
SCHEMATIC DIAGRAM OF THE TEXAS WATER SYSTEM
(Includes major conveyance facilities and related reservoirs)

met, interstate river basin compact obligations satisfied, and projected commitments under the draft compact on the Red River Basin met, surplus surface water supplies totaling at least 2.6 million acre-feet per year are estimated to be available annually in the year 2020 from the northeast Texas basins (the lower Red River, Sulphur River, Cypress Creek, and upper Sabine River Basins) for development and conveyance to areas of need in the State. Approximately 1.85 million acre-feet per year (or more) of water surplus to intrabasin requirements is also projected to be available for transfer from the lower Sabine, Neches, Trinity, Guadalupe, and San Antonio River Basins. These surplus supplies projected to be available for redistribution in the year 2020 are indicated on Figure IV-12.

Additional supplies, also projected to be available for early stages of interbasin transfer, could be obtained on an interim basis from water projected to be temporarily surplus in these and other river basins before the buildup of projected 2020 demands in the basins. Use of these temporarily surplus supplies for export would be gradually reduced as intrabasin requirements increase. The System would conserve and control these surplus waters, and transport them, together with water from other intrastate, interstate, and out-of-State sources, to areas of need throughout Texas. The System would also transport out-of-State supplies from the State line for New Mexico. By the year 2020, the Texas Water System would be capable of providing storage, regulation, and conveyance facilities for approximately 17.3 million acre-feet of water annually.

Physical Elements of the Texas Water System

The *Trans-Texas Division* of the Texas Water System would consist of storage and regulating reservoirs and the appurtenant interconnecting channels, canals, and pumping facilities in the northeast Texas basins; the

Trans-Texas Canal extending westerly to terminal storage and regulating facilities in the High Plains; canals and wholesale water distribution systems to serve the North Central Texas, High Plains, Trans-Pecos, and El Paso areas; and the facility to convey out-of-State supplies to the New Mexico State line. There are several possible alternate routes for movement of water—including supplies from an out-of-State source—into the Trans-Texas Canal. These alternate routes must receive additional study before selection of the location and optimum design of facilities of the Trans-Texas Division.

The *Coastal Division* would include storage and regulating reservoirs and diversion facilities in the lower Sabine, Neches, and Trinity River Basins; the Coastal Canal, which would extend from the lower Sabine River near Orange to the Lower Rio Grande Valley near Raymondville; facilities for supplying System water to the Houston area; the proposed reservoir and conveyance facilities in the Guadalupe and San Antonio River Basins to supply intrabasin and the San Antonio area needs; a conveyance system for transporting irrigation supplies from the Rio Grande below Amistad Reservoir to the Winter Garden area; and diversion facilities from the Rio Grande to serve irrigation areas in Maverick and Webb Counties.

The *Eastern Division* would consist of those facilities in the eastern part of Texas required to receive and transport water imported from an out-of-State source to the Trans-Texas Division and the Coastal Division. These facilities include the Sabine River—above and below Toledo Bend Reservoir—and Toledo Bend Reservoir, which might also be used for regulation.

Trans-Texas Division

The Trans-Texas Division would supply water for future municipal, industrial, and irrigation use in the northeast Texas basins, the Dallas-Fort Worth area, North Central Texas, the High Plains, the Trans-Pecos area, and El Paso, as well as convey out-of-State water to eastern New Mexico. The total annual deliveries of water which would be made from the Trans-Texas Canal when fully operational in or before the year 2020 outside the basins of origin are given in Table I-1.

The proposed diversion from the lower Red River into the Texas Water System is consistent with the terms of a proposed Red River Compact, a draft of which is presently under negotiation between the various States involved. A facility with a capacity capable of diverting an annual average of approximately 617 thousand acre-feet of water would be installed on the Red River a short distance above its confluence with Pecan Bayou. These diverted flows would be temporarily re-regulated in proposed Pecan Bayou Reservoir, and then conveyed to proposed Naples Reservoir in the Sulphur River Basin. This diversion from the Red River, plus the yield available from Pecan Bayou Reservoir, would provide a total of about 647 thousand acre-feet of water annually.

In the Cypress Creek Basin, existing Lake O' the Pines, Caddo Reservoir (Texas' share of the yield), and Franklin County Reservoir (which is presently under construction), plus construction of proposed Titus County, Marshall, and Black Cypress Reservoirs will yield about 842 thousand acre-feet of water annually. Approximately 641 thousand acre-feet of surplus water could be obtained for export through the Trans-Texas Canal. Additional supplies could be developed from an enlarged Caddo Reservoir if and when necessary.

Table I-1.—Proposed Annual Deliveries of Water by the Trans-Texas Canal by the Year 2020

(Exclusive of Deliveries in Basins of Origin)

AREA SERVED AND PRINCIPAL USE OF WATER	ANNUAL DELIVERY (ACRE-FEET)
Dallas-Fort Worth (Municipal and Industrial)	350,000
North Central and West Texas (Municipal and Industrial)	600,000
West Texas (Irrigation)	7,584,000
New Mexico (Out-of-State Import)	1,500,000
Subtotal	10,034,000
Estimated operational losses from canals and regulating reservoirs*	947,000
Total	10,981,000

* Principally losses from Trans-Texas Canal, terminal storage and regulating facilities, and distribution systems in North Central and West Texas.

These projected surpluses in the Cypress Creek Basin could be conveyed northward through Titus County Reservoir into Naples Reservoir in the Sulphur River Basin, for delivery through authorized Cooper Reservoir into the Trans-Texas Canal as illustrated in Figure I-3 and on Plate 2. Alternatively, after import supplies become available the total supply could be routed westward to the Trans-Texas Canal through a southerly canal (the "Sabine Ridge Canal") along the divide between the Cypress Creek and Sabine River Basins, also illustrated in Figure I-3 and on Plate 2. Possible alternative methods of conveying these supplies to the Trans-Texas Canal, including both routes described above, will require more detailed study, especially of the schedule of deliveries to West Texas during the initial years of project operation.

In the Sulphur River Basin, proposed Parkhouse Reservoir Stage 1, Naples Reservoir, and an enlarged Texarkana Reservoir will yield about 1,282,400 acre-feet of water annually, of which approximately 1,105,000 acre-feet would be surplus to projected 2020 intrabasin needs and available for export. The surplus yield of the Sulphur River Basin, plus the yield of Pecan Bayou Reservoir and water diverted from the main stem of the Red River, would be pumped westward through Cooper Reservoir for delivery through the Trans-Texas Canal.

After all projected 2020 requirements in the Sulphur River and Cypress Creek Basins are met, approximately 2,393,000 acre-feet of water would thus be available annually from these basins for delivery into the Trans-Texas Canal.

In the upper Sabine River Basin, proposed Lake Fork and Mineola Reservoirs will provide needed flood control and, together with proposed Big Sandy Reservoir, would yield sufficient supplies to meet all projected in-basin requirements and provide approximately 200 thousand acre-feet of surplus water annually for export. This surplus water could be pumped into Tawakoni Reservoir and thence directly to the Dallas-Fort Worth metropolitan area to provide a part of the total projected 2020 requirements of that area, or could be diverted from Tawakoni Reservoir into the Trans-Texas Canal, as illustrated on Plate 2. Final selection between these alternatives would require further study in cooperation with local agencies in the Dallas-Fort Worth area. Should this 200 thousand acre-feet per year of surplus water be pumped into the Trans-Texas Canal from Tawakoni Reservoir, then the total surplus from the northeast Texas basins delivered into the Canal would be about 2,593,000 acre-feet annually.

There are several potential routes for conveying water imported from out-of-State through the Eastern Division into the Trans-Texas Canal. These supplies, projected to total about 8.4 million acre-feet annually by the year 2020, could be routed into and through the system of reservoirs in the Cypress Creek Basin, thence into the Sabine Ridge Canal south of proposed Marshall Reservoir and into the Trans-Texas Canal. Black Cypress Reservoir could provide some of the required re-regulation under this routing. Alternatively, if imported supplies were conveyed northward through the Sabine River Basin, the most feasible route might also be into the Sabine Ridge Canal, joining the Trans-Texas Canal north of Tawakoni Reservoir in northern Hunt County. Under this alternative routing, some regulation might also be provided by reservoirs in the Cypress Creek Basin.

From "Northeast Texas Junction" at the Sulphur-Sabine Basin divide in northern Hunt County, the Trans-Texas Canal would convey water westerly—along an alignment generally paralleling the divide between the Red and Trinity and Brazos River Basins—to proposed Caprock Reservoir on the White River in Crosby County and to the Bull-Illusion-Yellow Lake Reservoir complex (hereafter termed Bull Lake Reservoir) in Lamb and Hockley Counties, which would collectively provide terminal storage and regulation. The Trans-Texas Canal has been designed, on a reconnaissance-level basis, for operation on an 11-month uniform flow basis for the conveyance of a total of approximately 10,981,000 acre-feet annually by the year 2020, including the 200 thousand acre-feet of water from the Sabine River Basin which might be delivered into the Canal by diversion northward from Tawakoni Reservoir.

From the Trans-Texas Canal, water would be diverted into Lavon Reservoir and through proposed Aubrey Reservoir into Garza-Little Elm Reservoir in the upper Trinity River Basin for municipal and industrial use in the Dallas-Fort Worth metropolitan area. The total amount of this diversion, either 150 thousand or 350 thousand acre-feet annually, would depend upon the final routing selected for export of surplus water from the upper Sabine River Basin as previously discussed.

Southwest of Wichita Falls, at a point herein defined as "Megargel Junction", a pipeline could divert approximately 95 thousand acre-feet annually from the Trans-Texas Canal for municipal and industrial use in the Abilene, Colorado City, San Angelo, Snyder, and Sweetwater areas, provided appropriate water sales contracts were negotiated. In the North Central Texas area, about 171 thousand acre-feet of water would also be available annually from the Canal for irrigation of about 95 thousand acres of irrigable lands in this region. Any part of the 95 thousand acre-feet of water allocated annually for municipal and industrial use in North Central Texas and not used for these purposes could supply additional irrigation requirements in this area.

From the remaining supplies delivered annually by the Trans-Texas Canal into Caprock and Bull Lake Reservoirs, approximately 6,480,000 acre-feet would be available annually for irrigation of about 3.8 million acres in the South High Plains; 933 thousand acre-feet would be delivered for irrigation of approximately 310 thousand acres in the Trans-Pecos area; and 505 thousand acre-feet would be available for municipal and industrial use in Lubbock, Big Spring, Midland, Odessa, Pecos, and El Paso areas. In addition, 1.5 million acre-feet of water delivered annually through the Trans-Texas Division from an out-of-State source would be conveyed from Bull Lake Reservoir to New Mexico.

The Trans-Texas Canal to Caprock Reservoir is the most complex single element of the Texas Water System. When operating at full capacity, the Canal could deliver water at a rate of more than 16,600 cfs (cubic feet per second). Regulating and terminal storage reservoirs in West Texas would allow the Canal and associated pump stations to be sized for minimum capacity to reduce costs, while providing storage for water as required during the peak irrigation season when as much as one-fourth of the annual irrigation requirement would have to be delivered to irrigators in one month or less.

The 78-mile-long main canal extending westward from Caprock Reservoir to Bull Lake Reservoir would convey water at a rate of about 22,200 cfs in its initial reach during the peak irrigation season. As illustrated on Plate 2, a principal canal would extend southward from the Caprock-Bull Lake canal with sufficient capacity to convey municipal and industrial supplies to Midland, Odessa, Big Spring, Pecos, and El Paso, as well as part of the irrigation supply for the South Plains and the water for the Trans-Pecos irrigation area. From this principal canal, water could be diverted to storage in a terminal regulating reservoir in the Pecos River watershed and part of the supplies conveyed for use in the Pecos area. A pipeline from this regulating reservoir would convey municipal and industrial water supplies to El Paso. If appropriate water sales contracts were negotiated with local interests, irrigation supplies for the El Paso-Hudspeth County areas could also be delivered through the System. Feasibility level studies will include evaluation of this possibility.

A preliminary design of the retail irrigation distribution system that would be supplied from the main canal between Caprock and Bull Lake Reservoirs, and directly from Bull Lake Reservoir, has been prepared for the purpose of estimating distribution costs. This preliminary design includes primary distribution canals extending north and south into irrigation service areas, as well as service to irrigation areas in the South Plains from the main canal extending southward to the Trans-Pecos area.

Coastal Division

The Coastal Division of the Texas Water System, when fully operational, would supply water for municipal, industrial, and irrigation use and for the preservation and enhancement of the bays, estuaries, and wildlife refuges in the coastal area of the State between the Sabine River and the Lower Rio Grande Valley. The Division also includes the reservoirs and conveyance systems required to supply future supplemental water needs of the Houston and San Antonio metropolitan areas.

The Coastal Canal would extend from a diversion site on the Sabine River north of Orange to a point near Anahuac in the Trinity River Basin, thence under Galveston Bay, and southwest through regulating and storage facilities along the Coast to a terminal facility near Raymondville in the Lower Rio Grande Valley.

The total projected annual deliveries of water which would be made by facilities of the Coastal Canal of the Texas Water System outside the basins of origin by the year 2020 are given in Table I-2, although more detailed planning studies, particularly comprehensive studies of bays and estuaries, may result in future modification of water requirements to be served by the Division.

Table I-2.—Proposed Annual Deliveries of Water by the Coastal Canal by the Year 2020

(Exclusive of Deliveries in Basins of Origin)

AREA SERVED AND PRINCIPAL USE OF WATER	ANNUAL DELIVERY (ACRE-FEET)
Houston Metropolitan Area (Municipal and Industrial)	774,300
San Antonio Metropolitan Area (Municipal and Industrial)	220,000
Subtotal	994,300
Bays and Estuaries	2,450,000
Fish and Wildlife Management Areas	60,000
Lower Colorado River Basin Replacement	85,000
Corpus Christi and Kingsville Areas (Industrial)	283,100
Coastal Bend (Irrigation)	727,000
Lower Rio Grande Valley	
(Municipal and Industrial)	150,000
(Irrigation)	1,090,000
Subtotal	4,845,100
Estimated Operational Losses from Canals and Regulating Reservoirs*	454,900
Total	6,294,300

* Does not include losses in Houston and San Antonio supply systems.

Supplemental fresh water requirements of the coastal bays and estuaries, following development of the major river basins presently contributing water to these areas, are tentatively estimated to be approximatley 1.5 million acre-feet annually for Galveston Bay and a total of 950 thousand acre-feet annually for the remaining bays and estuaries between the Brazos River and Corpus Christi. These bay and estuary requirements are described in greater detail in Part III.

The Coastal Division would supply approximately 85 thousand acre-feet annually to the lower Colorado River as replacement for the diminution of flow of the upper Colorado River as a result of construction of proposed Stacy Reservoir. By replacing this water in the lower part of the basin where most of the irrigation demand exists, necessary releases from the Highland Lakes to supply these demands would be reduced, and the effects of Stacy Reservoir on operating water levels of the Highland Lakes would correspondingly be diminished.

Approximately 1.09 million acre-feet would be provided annually from the Coastal Canal for irrigation in the Lower Rio Grande Valley. About 315 thousand acre-feet of this total would supply new irrigation development, and approximately 385 thousand acre-feet would supply existing irrigation projects in the Valley which it is expected will require a firm supply of new water following the adjudication of water rights in this area. The remaining 390 thousand acre-feet which would be delivered to the Lower Rio Grande Valley annually would replace water diverted from the Rio Grande below Amistad Reservoir for irrigation in the Winter Garden area (about 200 thousand acre-feet annually), and the consumptive use for additional irrigation development in Maverick and Webb Counties (tentatively estimated at 190 thousand acre-feet annually).

The Houston and San Antonio areas will require water served through the Coastal Division of the Texas Water System to meet total projected 2020 requirements. The System would provide an opportunity to arrive at a solution to the future water supply problems for both of these metropolitan areas through selection from alternative plans of development. Selection among these alternatives would be influenced by consideration of economics, water quality, adaptability to existing facilities (including distribution facilities), and the plans of local agencies involved. The Board has made preliminary studies of several possible solutions for each of these areas by its staff and through consultants, and the following discussion briefly outlines the problems, alternative solutions, and the relative merits of the alternatives based on these studies.

Future Water Supply for the Houston Metropolitan Area

The yields available from Conroe Reservoir and Lake Houston, and proposed Cleveland, Lake Creek, and Lower East Fork Reservoirs in the San Jacinto River Basin; existing Livingston and Wallisville Reservoirs in the Trinity River Basin; proposed diversions from the lower Brazos River Basin; and the safe yield of ground water aquifers in the area will provide additional future water supplies for the Houston area. These sources will not be sufficient, however, to supply the projected total requirement of the Houston metropolitan and industrial complex to the year 2020. These additional municipal and industrial water supplies would be provided through the Texas Water System by using (1) the yield of proposed Bedias Reservoir in the Trinity River Basin and (2) one or more of the alternatives described below and illustrated on Plate 2.

(a) Diversion of water stored by existing and proposed projects in the Neches River Basin through an enlargement and extension of the canal system presently operated by the Lower Neches Valley Authority, and possibly other existing canal systems in the Neches-Trinity Coastal Basin or diversion of these supplies directly into the Coastal Canal and purchase of water from the Canal for municipal and industrial water uses in the Houston area; or

(b) diversion of supplies developed in the Neches River Basin from proposed Rockland Reservoir to Bedias Reservoir and thence into the San Jacinto River Basin system; or

(c) diversion of additional supplies from the Trinity River, which may require more extensive treatment prior to municipal and many industrial uses. However, additional diversions of supplies projected to be available in the Trinity River Basin, in combination with the yield of Bedias Reservoir, would still not be sufficient to satisfy the total projected 2020 requirements in the Houston area.

The choice of alternatives used would be predicated in part on future decisions relating to the distribution system(s) within Harris County. However, long-range requirements of the area beyond the year 2020 indicate advantages to the area by obtaining at least a portion of its future supply from the Coastal Canal. Final decisions must necessarily involve more detailed studies by the Board in cooperation with the local agencies involved.

Future Water Supply for the San Antonio Area

The San Antonio area, as defined for purposes of this discussion, includes parts of the Nueces, San Antonio, and Guadalupe River Basins upstream from the northern boundaries of Zavala, La Salle, McMullen, and Karnes Counties and the Cuero damsite. Streamflows throughout much of the upper parts of these three river basins are strongly influenced by fluctuations in the amount of ground water in storage in the Edwards (Balcones Fault Zone) Aquifer and other limestone aquifers which underlie this area. Therefore, since these basins are essentially in hydraulic connection, there are significant advantages to planning for the development of the water resources of parts or all of these three river basins as a unit to meet projected water requirements of the area, while at the same time continuing to recognize the statutory individuality and needs of each basin.

Unless supplemental surface water supplies are made available to the San Antonio area for use at an early date, continuation of the historic rate of irrigation development and associated ground water pumpage, together with steadily increasing pumpage of ground water from the Edwards (Balcones Fault Zone) Aquifer for municipal and industrial use in the area, will result in:

(1) Marked seasonal fluctuations in water levels in the aquifer, as well as severe declines during drought periods;

(2) significant reduction in the quantity of ground water available to all users in the area on an annual dependable safe yield basis; and

(3) more frequent and probably prolonged periods of time during which little or no flow will occur from the numerous and important natural springs in the area, the largest of which are Comal Springs near New Braunfels and San Marcos Springs at San Marcos.

Although the volume of fresh water in storage in the Edwards (Balcones Fault Zone) Aquifer below an altitude of approximately 612 feet (the lowest altitude to which water levels have declined in the heavily pumped area) has not yet been precisely determined, saline water occurring in the Edwards and stratigraphically associated limestone beds south and southeast of the aquifer could be drawn into the aquifer locally if water levels were lowered significantly below this altitude. On the basis of studies of historical rates of recharge and the storage capacity and hydraulic characteristics of the Edwards (Balcones Fault Zone) Aquifer, it has been estimated that pumpage should not exceed approximately 400 thousand acre-feet annually if water levels in the aquifer are to recover following dry periods and the safe yield of the aquifer is to be maintained. However, studies performed thus far indicate that pumpage at this rate would eliminate flow from both Comal and San Marcos Springs part of the time. If adequate minimum springflows are to be insured in the future, these studies indicate that pumpage from the aquifer in the San Antonio area would have to be reduced somewhat below 400 thousand acre-feet annually. Maintenance of some springflows, which provide a part of downstream surface water supplies and enhance the natural waste-assimilative capacities of streams, as well as enhance the scenic, cultural, and recreational value of the area, is considered to be desirable by the Board. Much additional study, including mathematical and possible hydraulic modeling techniques, will be required to determine more precisely the optimum rate of pumpage and corresponding maintenance of springflow from the Edwards (Balcones Fault Zone) Aquifer.

The area of heaviest pumpage, and the area where projected future water requirements are the largest, is in Bexar County. To supply projected 2020 municipal and industrial requirements in Bexar County, a minimum surface water supply of about 220 thousand acre-feet annually will be required from outside the San Antonio River Basin to supplement ground water pumpage. Ground water pumpage would be maintained at a rate of about 215 thousand acre-feet annually within the basin for municipal and industrial use.

Projected future water requirements in the middle and lower Guadalupe River Basin, downstream from Comal and San Marcos Springs, will also require an additional firm annual surface water supply, but approximately 10 to 15 years later than the projected requirements for the San Antonio metropolitan area.

Three principal alternative methods for supplying supplemental surface water supplies in order to meet the total future water requirements of the San Antonio area have been evaluated by the Board:

1. Diversion of water from the Colorado River, with some supplies also obtained from the upper Guadalupe River Basin.

2. Diversion of water from proposed Cuero Reservoir in the Guadalupe River Basin and Cibolo Reservoir in the San Antonio River Basin.

3. Use of water from both Cuero and Cibolo Reservoirs, plus additional upstream flows of the Guadalupe River, including some releases from Canyon Reservoir.

In each alternative studied by the Board, the analyses included costs of replacing needed supplies of water to the basin of origin of potential export.

The most feasible alternative, on the basis of present data and studies, would be development of supplies from the San Antonio and Guadalupe River Basins. Projects could be constructed in time to meet the increasing requirements of the San Antonio metropolitan area, thus alleviating the competition for ground water supplies between irrigators and municipal and industrial users. Supplies from proposed Goliad Reservoir in the San Antonio River Basin would be available for replacement of water exported to the San Antonio metropolitan area when the need for these supplies develops in the lower Guadalupe River Basin. Surpluses projected to be available from Cuero, Cibolo, and Goliad Reservoirs (including return flows) under this water supply system would be released into the Coastal Canal for use elsewhere, resulting in a possible lower cost to water users in the Guadalupe and San Antonio River Basins by partial amortization of these facilities through use for the Coastal Canal supply. Use of these surpluses, proposed for diversion into the Texas Water System, would be gradually reduced over time as requirements in the basins of origin increase.

The following system of development is recommended to meet the requirements for the San Antonio area and Bexar County, and other requirements in the Guadalupe, San Antonio, and Nueces River Basins overlying the Edwards (Balcones Fault Zone) Aquifer:

1. Use of ground water in the Edwards (Balcones Fault Zone) Aquifer to supply projected 2020 municipal and industrial requirements in Kinney, Medina, Comal, Uvalde, and Hays Counties, and continued ground water pumpage sufficient to meet requirements for the San

Antonio metropolitan area and Bexar County until a supplemental surface water supply becomes available. Pumpage from the aquifer for municipal and industrial uses in the San Antonio area would be maintained at an average rate of about 215 thousand acre-feet annually after these additional surface water supplies become available.

2. Continued pumpage from the Edwards (Balcones Fault Zone) Aquifer for irrigation—with some increase in the five counties—with the rate of pumpage coordinated with the time of availability, amount, and method of use of imported surface water.

3. Development of a supplemental surface water supply for the Bexar County area through the staged construction of Cuero 1 and 2, Cibolo, and Goliad multiple-purpose reservoirs, and the appurtenant pipelines and pumping plants as elements of the Texas Water System. An alternative surface water supply system could include development of an operational plan involving diversion of water from the Guadalupe River in the vicinity of Seguin through a pipeline to San Antonio, using some flows from the upper Guadalupe River Basin and releases from Canyon Reservoir, and pump-back facilities from Cuero Reservoir to the Seguin area, as illustrated on Plate 2.

4. Use of ground water in conjunction with the surface supply, with the objective of developing a management program optimizing the use of water from the Edwards (Balcones Fault Zone) Aquifer for all beneficial purposes while maintaining optimum minimum flows from Comal and San Marcos Springs.

5. Construction of Concan and Sabinal Reservoirs on the Frio and Sabinal Rivers, respectively, and possibly Montell Reservoir on the Nueces River, for additional recharge to the Edwards (Balcones Fault Zone) Aquifer as well as flood control and recreation purposes. These reservoirs would facilitate the conjunctive use of surface and ground water resources, and although not considered an integral part of the Texas Water System, they are potential projects which can be developed as a part of the Texas Water Plan. They would be constructed by the Corps of Engineers, with participation by the Edwards Underground Water District, and the City of San Antonio.

A longer-range possibility, which might provide for expanded irrigation west of the San Antonio area as well as additional surface supplies for the San Antonio metropolitan area, could involve importation of water from the Trans-Texas Canal into the upper Colorado River Basin and diversion of these supplies in the vicinity of Austin to the San Antonio area for municipal and industrial use.

The development of Cuero, Cibolo, and Goliad Reservoirs, and the appurtenant pumping plants and pipelines as recommended under the Texas Water System would necessitate joint participation by the Guadalupe-Blanco River Authority, San Antonio River Authority, City of San Antonio, Edwards Underground Water District, the Board, and the U.S. Bureau of Reclamation. The facilities would be constructed by the U.S. Bureau of Reclamation, and could be operated by the Board and/or local entities. Under this proposed system development, these facilities would have to be constructed as rapidly as possible.

Implementation of the total water supply system outlined above would require that proper organizational, institutional, and financial arrangements be instituted encompassing the entire area which would benefit. This is essential if the area is to have an assured adequate future water supply at minimum cost. Formulas for equitable cost sharing among the beneficiaries would have to be developed and implemented.

Eastern Division

The Eastern Division of the Texas Water System includes those in-State facilities required to receive, regulate, and transport water imported from the Mississippi River to the Trans-Texas and Coastal Divisions of the Texas Water System. Since selection of the most feasible delivery route of imported water to the State is contingent upon the results of further studies, decisions as to the most feasible components of the Eastern Division are less advanced than for the other units of the Texas Water System.

With a coastal delivery point, import water would be routed into the lower Sabine River Basin. This import water, plus projected intrabasin surpluses in the lower Sabine River Basin, would be conveyed to the Coastal Division and northward to the Trans-Texas Division. Toledo Bend Reservoir, and perhaps other proposed reservoirs in the Sabine River Basin, could provide regulating storage capacity and transfer facilities for these supplies. Imported water moved northward through Toledo Bend Reservoir could enter facilities of the Trans-Texas Division by one or more routes as illustrated on Plate 2.

If imported water should be conveyed by a northern route directly into the Cypress Creek Basin in Texas, necessary storage and regulation could be partially provided by an enlarged Black Cypress Reservoir in the Trans-Texas Division. From regulating storage in Black Cypress Reservoir, water would be conveyed west to the Trans-Texas Canal by one or more of several possible alternative routes, and south to the Coastal Division through Toledo Bend Reservoir and the lower Sabine River channel.

Determination of the most feasible and economic system of regulating reservoirs and conveyance routes for transporting out-of-State supplies either south or north in the Eastern Division of the Texas Water System will require detailed studies utilizing data unavailable at the present.

Quality of Water Supplies Delivered By the Texas Water System

Preliminary studies of the quality of the water resources proposed for development and delivery by the Texas Water System indicate that under present conditions these supplies are of suitable quality for the intended uses, with appropriate conventional pretreatment where necessary. In several river basins of the State which would supply water to the System, projections of stream quality to and beyond the year 2020 have been completed by Federal agencies and/or the Board. Additional intensive study must be given to water quality aspects of the Texas Water Plan, however, including examination of numerous water quality parameters as they relate to specific water uses. Methodology must be developed for operational water quality control of water deliveries through the Texas Water System, to include the complete range of physical, chemical, and biological water quality parameters. Preliminary studies thus far have dealt primarily with inorganic water quality parameters, principally concentrations of total dissolved solids.

As discussed in more detail in Part III, it has been presumed as the basis for long-range water development planning that under the comprehensive water-quality control program in the State, municipal and industrial waste waters will minimally be provided secondary treatment, including removal of biostimulants and toxic materials, and chlorination (disinfection) where appropriate. Municipal waste water treatment levels on the order of 95 to 98% removal of biochemical oxygen demand (BOD) and correspondingly high degrees of biostimulant and toxicant removal may be mandatory in some areas where such waste waters are to be discharged to streams or other receiving waters proposed to supply the Texas Water System, as well as meet local requirements. Industrial wastes discharged to streams or reservoirs must likewise receive the highest technically and economically feasible levels of waste treatment consistent with the character of the wastes and the intended uses of the receiving waters. Controlled releases from reservoirs (where such releases would serve other beneficial purposes downstream), or other means of providing high quality water to maintain desired water quality in streams and reservoirs proposed to supply the System, may be utilized to provide for necessary additional in-stream treatment of degradable wastes and also, where necessary, for possible dilution of conservative constituents to maintain the appropriate use-concentration spectrum. It is therefore presumed that with proper quality-control measures, the organic quality of the water supplies delivered by the System will be suitable for all intended uses with conventional pretreatment methods.

Trans-Texas Division

Under present conditions, supplies developed by existing and proposed reservoirs in the Sulphur River Basin would contain an average of about 100 to 125 mg/l (milligrams per liter) of dissolved solids. Future municipal and industrial return flows within the basin are not expected to significantly alter the chemical quality of these supplies, and the average concentration of dissolved solids in supplies available for export through the Texas Water System should not exceed about 150 mg/l under 2020 conditions.

Supplies developed by proposed reservoirs in the Cypress Creek Basin should contain an average of not more than about 125 mg/l of dissolved solids, and the surpluses from these two basins which would be available for initial delivery westward through the Trans-Texas Canal should contain an average of not more than approximately 140 mg/l of total dissolved solids.

The flow of the Red River below Denison Dam presently varies widely in chemical quality, and although long-term water quality data are not available in the vicinity of the proposed diversion site, short-term records and synthesis of long-term data from available records of flow and quality indicate that dissolved solids concentrations in the lower Red River in Texas generally range between 500 and 1,000 mg/l, averaging about 800 mg/l. The salinity of the lower Red River is largely the result of water released or spilled from Lake Texoma, which impounds river flows degraded in quality by natural brines originating in the upper Red River Basin.

Construction of Federally authorized and proposed natural salt-control projects and other salinity alleviation measures in the upper Red River Basin will significantly improve the quality of the Red River, however. Proposed criteria for operation of Federally authorized and proposed reservoirs in the basin would also result in flows of a more uniform quality in the main stem of the river below Denison Dam. Studies by the Federal Water Pollution Control Administration in connection with the recently completed *Comprehensive Basin Study of the Red River Basin below Denison Dam* indicate that following implementation of the proposed upper basin salinity control measures the dissolved solids concentration of the river below Denison Dam would seldom exceed 600 mg/l, even during a recurrence of the critical drought period 1953 through 1956. These studies further indicate that monthly discharge-weighted average dissolved solids concentrations of the Red River in the vicinity of the proposed site for diversion of water into the Texas Water System should average not more than about 500 mg/l. Selective pumping of flood flows could possibly provide water averaging about 300 to 400 mg/l of dissolved solids during some years.

The yield of proposed Pecan Bayou Reservoir should contain an average of not more than about 100 mg/l of dissolved solids. Based on the assumption that supplies diverted from the Red River would contain an average of not more than 500 mg/l of dissolved solids, and that supplies from the lower Red River Basin would be brought into the Texas Water System after all proposed facilities of the System in the Sulphur River and Cypress Creek Basins are operational, the approximately 2.4 million acre-feet of water delivered to the Trans-Texas Canal from these East Texas basins should contain an average of about 230 mg/l. The additional 200 thousand acre-feet of supplies proposed to be developed in the upper Sabine River Basin for export under the Texas Water System should contain an average of not more than about 175 mg/l of dissolved solids. If these supplies are routed into the Trans-Texas Canal, the approximately 2.6 million acre-feet of intrastate supplies delivered westward through the Canal would therefore contain an average of slightly less than 230 mg/l of dissolved solids.

Flows of the lower Mississippi River under existing conditions of development within that basin are comparatively low in dissolved solids concentrations. At Luling Ferry, Louisiana, approximately 17 miles west of New Orleans, concentrations in flows of the river during the period 1960 through 1965 ranged from 126 to 336 mg/l, and were less than 250 mg/l about 50% of the time. Chloride concentrations in these flows ranged from 12 to 52 mg/l, and were less than about 25 mg/l 50% of the time. Concentrations of sulfate ranged from 29 to 89 mg/l, being less than 50 mg/l 50% of the time during the period. The lower ranges of dissolved solids concentrations generally coincided with flood flows of the river.

Upstream in the vicinity of St. Francisville, Louisiana, during the concurrent period, monthly average concentrations of dissolved solids in the Mississippi River ranged between 123 and 343 mg/l. Dissolved solids were less than about 230 mg/l 50% of the time, and concentrations of chloride and sulfate occurred within similar ranges and with similar frequencies of duration as compared with river flows at the Luling Ferry sampling station.

Although the biological quality and the concentrations of various organic materials presently varies widely throughout the Mississippi River Basin, it is presumed that with the accelerated National water quality control program now in progress, organic quality, including biostimulants and toxic materials, will not present a problem to the importation of potentially surplus waters of the basin to Texas and eastern New Mexico.

Although further development within the Mississippi River Basin will influence the quality of the river flows in the lower basin, on the basis of presently available data the potentially surplus flood flows of the Mississippi River which may be available for diversion and importation to Texas and eastern New Mexico presently contain dissolved solids concentrations generally ranging upward to about 250 mg/l, perhaps averaging not more than approximately 250 mg/l under future conditions in the basin. On the basis of these data, when fully operational the Trans-Texas Canal would therefore deliver import water and intrastate supplies from Northeast Texas Junction which, when combined, would contain not more than about 245 mg/l of total dissolved solids on an average annual basis.

Coastal Division

The quality of water supplies delivered by the Coastal Canal will vary widely with the stage of development of facilities and as the use of interim surpluses from the various river basins progressively decreases. When fully operational, and with out-of-State supplies brought into the Texas Water System, the quality of water delivered by the Canal would become more uniform.

In the Guadalupe and San Antonio River Basins, supplies developed by proposed Cuero and Cibolo Reservoirs should average about 300 and 275 mg/l of dissolved solids respectively. These supplies, proposed to supplement ground water supplies used in the San Antonio metropolitan area, would generally be of similar similar chemical quality to supplies available to the City of San Antonio from the Edwards (Balcones Fault Zone) Aquifer. However, possible chemical incompatibility with respect to calcium carbonate equilibrium should these two sources of water supply be mixed needs further study to determine whether corrective measures are necessary.

Surpluses from the Guadalupe and San Antonio River Basins proposed for diversion into the Coastal Canal, projected to total about 267 thousand acre-feet annually in the year 2020, would result largely from increased return flows in the San Antonio River Basin from the San Antonio metropolitan area and return flows in the Guadalupe River Basin below proposed Cuero Reservoir. Under 2020 conditions, controlled releases from Cuero Reservoir, plus reservoir spills, unregulated runoff below the reservoir, and projected return flows from the Victoria area should result in flows of the Guadalupe River containing an average of about 375 to 400 mg/l of dissolved solids, although the quality of the river water could vary widely depending upon the amount and seasonal distribution of runoff below Cuero Reservoir. Preliminary estimates of the chemical quality of projected municipal and industrial return flows from the San Antonio area indicate that by the year 2020 water stored in proposed Goliad Reservoir should contain an average of about 600 mg/l of dissolved solids. Controlled releases from the reservoir, plus projected reservoir spills, return flows, and intervening runoff below the reservoir should result in surpluses from the San Antonio River Basin containing an average of about 580 mg/l of dissolved solids. Therefore, in the year 2020 surpluses from these basins proposed for diversion into the Coastal Canal should contain an average of about 475 to 500 mg/l of dissolved solids.

In the Neches River Basin, proposed releases and projected spills from Ponta Reservoir shorld contain an average of about 150 mg/l of dissolved solids, and with projected return flows to the Angelina River below the reservoir, water supplies stored in existing Sam Rayburn Reservoir should average about 160 to 170 mg/l of dissolved solids under 2020 conditions of development in the basin. Proposed Palestine Enlargement Reservoir on the Neches River should store water averaging about 150 mg/l of dissolved solids, and considering projected return flows to the river below this reservoir, water stored and released from proposed Rockland Reservoir should contain an average of about 160 mg/l of dissolved solids under 2020 conditions.

Thus, B. A. Steinhagen Lake on the main stem of the Neches River should store, release, and spill supplies averaging about 160 mg/l of dissolved solids. However, industrial return flows to the lower Neches River Basin are projected to increase substantially by the year 2020. Surpluses projected to be available for diversion into the Coastal Canal, including the proposed supplemental water supplies for the Houston metropolitan area, are expected to contain an average of about 200 mg/l of dissolved solids under projected 2020 conditions of economic development in the basin.

With all existing and proposed reservoirs operating in the upper Sabine River Basin, inflows to Toledo Bend Reservoir resulting from intervening runoff and from spills and controlled releases from upstream reservoirs are projected to average about 175 mg/l of dissolved solids. Under 2020 conditions, however, return flows, principally from the Longview and Kilgore areas, are expected to increase the average concentration of dissolved solids in water stored in Toledo Bend Reservoir to about 200 mg/l. Controlled releases and spills from this reservoir and return flows to the Sabine River Basin below the reservoir (above the Orange metropolitan and industrial complex) should result in surpluses available to the Coastal Canal averaging about 225 to 250 mg/l of dissolved solids.

When fully operational, in-State supplies delivered by the Coastal Canal should therefore average about 260 mg/l of dissolved solids, and when combined with water imported from the Mississippi River brought into the Coastal Canal, the supplies delivered by the Canal should contain less than about 255 mg/l of dissolved solids on an average annual basis.

System Design, Operation, and Management

The construction, operation, and management of the Texas Water System in the most cost-efficient manner will require the application of the most sophisticated concepts and methods of analysis and design, and a very high degree of automation in operation. With the mass of data involved, advanced techniques of machine data processing and data transmission will be essential in the planning, design, and construction of this complex system of dams, reservoirs, powerplants, diversion facilities, pumping plants, and navigation conveyance works.

The key to the ultimate proper operation and management of the Texas Water System is the development of a fully automated control center, capable of receiving—as it happens—"operational information" from all critical points within the System, and able to process this information and issue instructions quickly enough to properly respond to normal operation changes as well as catastrophic events. The time from receipt of this information in the control center to the time that the information is processed must be very short, in order that the information center may issue appropriate instructions to all critical points within the System quickly enough for proper action.

It is estimated that the time from the receipt of information indicating the occurrence of a catastrophic event to the time of issuing instructions for appropriate corrective action must, at a maximum, be on the order of 5 to 10 minutes. During normal operation of the storage reservoirs, transfer canals, and distribution systems of the Texas Water System, a new operational plan would be issued at least on a daily basis, as dictated by projected weather conditions, daily runoff rates and water demands, available supplies in storage, and economic considerations.

Considering this reponse-time requirement, the amount of information being received, and the necessary complex computational procedures involved in developing new operational plans, the only solution to the operation of the Texas Water System would be through the use of (a) automated data collecting and transmission facilities, (b) automated data storage and retrieval facilities, (c) operational plan development programs, (d) computerized data analysis, (e) automated information generation and control facilities, and (f) automated control of reservoir outlet works, control structures in canals, pumping plants, and all facilities for the control and conveyance of water supplies.

Final design criteria for all facilities of the Texas Water System must consider the necessity of this high degree of automated operation of the System as an integrated unit.

In order to cope with a task of this magnitude, the Board has initiated the first of many studies which will ultimately provide solutions to the problem of how to:

(1) Simulate the operation of various combinations of reservoirs and transfer canal links of various capacities and under varying conditions of available streamflow and water requirements;

(2) optimally size and stage the sequence of construction of the various facilities of the proposed Texas Water System;

(3) properly design these facilities for automated operation;

(4) optimally operate the System, both during the installation of various facilities and after completion of construction;

(5) optimally develop the legal and financial framework by which the System can be operated and financed;

(6) integrate the results of research and development activities of the Board and of other State and Federal agencies applicable to the goals of the Board, such as integrating the results of possible technological advances in long-range weather forecasting capabilities, and more accurate predictions of runoff rates; and

(7) implement the results of all of the above studies in a well organized manner for the System to deliver water at minimum cost.

Although the solutions to all of these design and operational problems will not be found immediately, the Board recognizes that the application of advanced techniques will be an essential factor in the efficient utilization and management of the labor, capital, and water resources which will be required to satisfy Texas water needs in the future.

Energy Requirements

A tremendous amount of energy will be required for operation of the Texas Water System. While natural gas could supply some of the smaller pump stations in the System, the projected power requirements generally would dictate the use of electrical power.

On the basis of preliminary design criteria, it is estimated that the Trans-Texas Division, when fully operational and operating at peak capacity in 2020, would require approximately 6.5 million kilowatts of electrical power. Pumping facilities in the northeast Texas basins and the Trans-Texas Canal would require about 5.5 million kilowatts in pumping to Caprock Reservoir, and an additional 0.8 million kilowatts for conveyance of water to Bull Lake Reservoir. Requirements for transporting water from the Canal to municipal and industrial water users in North Central Texas and for the conveyance of water from the Pecos area to El Paso will require an estimated additional 0.1 million kilowatts.

The Coastal Division, when fully operational, would require an estimated 0.27 million kilowatts of electrical power. The Coastal Canal, when fully completed from the Sabine River to the Lower Rio Grande Valley and including the Houston supply, would require about 0.23 million kilowatts of this total. A separate system to convey water from the Neches River Basin to the Houston area via the route through Bedias Reservoir would require approximately 0.04 million kilowatts additional. The proposed San Antonio supply system from Cuero and Cibolo Reservoirs would require about 0.043 million kilowatts of the total power requirements of the Coastal Division.

With out-of-State supplies brought in to the Cypress Creek Basin through an upper import route, approximately 0.014 million kilowatts of electrical power would be required for pumping from Eastern Division facilities to the Sabine Ridge Canal of the Trans-Texas Division. Should water from out-of-State be delivered into the lower Sabine River Basin, estimated power requirements for conveying these supplies northward through the Eastern Division into the Trans-Texas Division would be about 0.5 million kilowatts.

Thus, the Texas Water System would require a total of approximately 6.9 million kilowatts of electrical power when fully operational. These estimated power requirements for various segments of the System are given in Table I-3. This projected total requirement for the System represents about 37% of the present (1967) electrical power generating capacity of the State.

Staging of Facilities

Before construction of any conveyance unit of the Texas Water System can be initiated, there must be assurance of an available import water supply. This is essential to avoid committing in-State water supplies surplus on an interim basis in some river basins to meet needs in water deficient areas for which there would not be a sufficient assured long-term water supply without an out-of-State source of supply.

Once a supply of water imported from the Mississippi River has been assured through appropriate agreements and Congressional authorization and funding, maximum efficiency at minimum cost can be achieved by staging construction of storage, conveyance, and distribution facilities as water requirements increase. Constraints of design and construction capability, and the availability of funds, are key factors in determining the rate at which facilities could become operational.

Table I-3.--Estimated Energy Requirements of the Texas Water System When Fully Operational Under 2020 Conditions

Because of uncertainties as to the final configuration of the Interstate Water Supply System, and the numerous alternative operational and conveyance systems within various segments of the Texas Water System—as well as timing of water requirements—only one configuration of the Trans-Texas and Eastern Divisions is indicated as an example of the magnitude of energy requirements. Analysis of the various alternative routings indicates, however, that total energy requirements do not vary significantly among the alternatives studied.

GATHERING SYSTEM OR CONVEYANCE REACH	TOTAL ANNUAL DELIVERY (ACRE-FEET)	TOTAL DYNAMIC HEAD (LIFT) (FEET)	POWER REQUIREMENT (KILOWATTS)
TRANS-TEXAS DIVISION (Potential Upper Import Route into Cypress Creek Basin)			
Lower Red River diversion point to Naples Reservoir	647,00	98	18,600
Cypress Creek Basin reservoirs to Naples Reservoir	641,000 a/	b/	41,000
Sulphur River Basin reservoirs to Trans-Texas Canal (includes supplies from lower Red River and Cypress Creek Basins)	2,393,000	b/	161,000
Marshall Reservoir to Sabine Ridge Canal (import water)	8,388,000 c/	168	284,000
Sabine Ridge Canal from near Marshall Reservoir to Trans-Texas Canal	8,388,000	338	453,800
Upper Sabine River Basin reservoirs to Trans-Texas Canal	200,000	b/	11,800
	Subtotal		970,200
Trans-Texas Canal—Northeast Texas Junction to Aubrey Reservoir diversion point	10,981,000	492	865,100
Trans-Texas Canal—Aubrey Reservoir diversion point to Megargel Junction	10,631,000	329	1,560,400
Trans-Texas Canal—Megargel Junction to North Central Texas irrigation area turnout	10,534,000	852	1,437,400
Conveyance facility—Trans-Texas Canal to North Central Texas cities (municipal and industrial supplies)	95,000	b/	32,300
Trans-Texas Canal—North Central Texas turnout to Caprock Reservoir	10,359,000	1,014	1,682,700
	Subtotal		4,577,900
Main canal—Caprock Reservoir to Bull Lake Reservoir takeoff	d/	335	554,000 e/
Main canal—Bull Lake Reservoir takeoff to Bull Lake Reservoir	d/	158	262,400 e/
	Subtotal		816,400
Conveyance facility—Pecos area to El Paso	200,000	3,000	96,000
	Total, Trans-Texas Division (with import water brought into Cypress Creek Basin)		6,460,500

Table I-3.--Estimated Energy Requirements of the Texas Water System When Fully Operational Under 2020 Contitions--Continued

GATHERING SYSTEM OR CONVEYANCE REACH	TOTAL ANNUAL DELIVERY (ACRE-FEET)	TOTAL DYNAMIC HEAD (LIFT) (FEET)	POWER REQUIREMENT (KILOWATTS)
EASTERN DIVISION (Potential Upper Import Route into Cypress Creek Basin)			
Marshall Reservoir to Sabine Ridge Canal (within Trans-Texas Division)	4,109,000 f/	168	139,300
	Total, Eastern Division		139,300
COASTAL DIVISION			
Coastal Canal—Sabine River diversion to Guadalupe River Basin (including supplemental supply for Houston from Canal)	g/	191	142,900
Coastal Canal—Guadalupe River Basin to Lower Rio Grande Valley terminal storage facility	g/	97	55,000
Rio Grande diversion and conveyance facilities to supply irrigation water to Winter Garden and Webb and Maverick Counties	390,000	b/	28,600 e/
	Subtotal		226,500
San Antonio Supply System h/	220,000	b/	42,900
	Total, Coastal Division (with Houston supplied from Coastal Canal) i/		269,400

a/ As out-of-State supplies become available, part or all of these supplies could be routed to Sabine Ridge Canal and thence to Trans-Texas Canal along with import water.

b/ Where water would be collected from several sources of supply, or distributed to various points of use, amounts of water conveyed and dynamic head between conveyance reaches vary.

c/ Includes only that part of potential out-of-State supply for Trans-Texas Division.

d/ Rate of water delivery would vary widely during year due to regimen of irrigation demand—this canal would also serve numerous distribution systems which would receive varying amounts of water.

e/ Energy requirements for delivering water at maximum design capacity during peak irrigation season.

f/ Includes only that part of the potential out-of-State supply for Coastal Division.

g/ Supply conveyed within various segments of Coastal Canal would vary as diversions into and releases from the Canal are made.

h/ Requirement reflects system for conveying 205,000 acre-feet annually from Cuero Reservoir to Cibolo Reservoir and a total of 220,000 acre-feet annually thence to San Antonio.

i/ Should Houston be supplied by alternative system of routing surplus supplies from the Neches River Basin through Bedias Reservoir in the Trinity River Basin, total energy requirement of the Coastal Division would be increased by approximately 40,000 kilowatts.

Subject to possible alterations as a result of feasibility level studies, the Board proposes that detailed design and construction of the Texas Water System begin and proceed concurrently on the following schedule:

A. (1) Storage facilities in southwest Texas and the Coastal Canal from the Guadalupe River Basin to the Lower Rio Grande Valley, utilizing temporary surplus supplies in and west of the Guadalupe River on an interim basis, then building eastward immediately toward the Sabine River Basin as intrabasin demands and requirements of service areas continually increase and absorb these temporary surpluses. Construction on the Coastal Canal would continue progressively eastward from the Guadalupe River as rapidly as possible to assure delivery of sufficient water supplies through the Canal to meet the projected buildup in demands in the areas to be served.

(2) Storage and conveyance facilities in the northeast Texas basins.

B. The Trans-Texas Canal and storage projects and municipal, industrial, and irrigation distribution facilities in the High Plains and North Central Texas areas.

Construction of irrigation distribution systems in the High Plains would have to be initiated before completion of the Trans-Texas Canal and Caprock and Bull Lake Reservoirs. As the construction of the Trans-Texas Canal to Caprock Reservoir and the canal to Bull Lake Reservoir is completed and construction begins on the main canal southward toward the Pecos River watershed, construction would have to begin on the irrigation distribution system in the Trans-Pecos area.

C. The conveyance facility from the Mississippi River to the State line.

In the Trans-Texas Division, surplus water supplies from the northeast Texas basins would be conveyed westward first, initiating deliveries through the Trans-Texas Canal to North Central and West Texas, and supplying the projected requirements in the Dallas-Fort Worth area as needed.

As conveyance facilities from the Mississippi River are completed, the imported water, including the 1.5 million acre-feet annually for New Mexico, would be moved through the Trans-Texas Division facilities as rapidly as municipal demands increase and as irrigation distribution facilities are constructed to serve the areas.

When the Coastal Canal is completed east to the Sabine River, Mississippi River water would be brought directly into the Coastal Division to supplement in-State supplies transported through the Canal, thus supplying all projected 2020 requirements in the areas to be supplied by the Coastal Division.

At this phase the Texas Water System would be fully operational.

Estimated Capital Costs of Major Facilities, and Related Expenditures

Estimated first costs of facilities of the Texas Water System, based on December 1967 prices and excluding the effects of escalation and interest during construction, are given in Table I-4. Estimated costs of retail distribution systems, not actually a part of the Texas Water System, are also shown, as these computations were necessary in the total benefit-cost analysis of the System. These cost estimates for the Texas Water System were based on the following criteria and assumptions:

1. Estimated first costs for conveyance facilities, including pipelines, were developed principally from the following engineering reports prepared for the Board:

   (a) *Cost of Transporting Water by Pipeline,* Lockwood, Andrews and Newnam, Inc., 1965 (Data published in Board Report 42).

   (b) *Sulphur River Basin and Red River and Tributaries in Texas Below Denison Dam,* Forrest and Cotton, February 1966.

   (c) *Interbasin Transfer of Water—Comparison of Costs of Transportation,* Freese, Nichols and Endress, April 1966.

   (d) *Interbasin Canals and Pipelines, 1967,* Freese, Nichols and Endress, March 1967.

   (e) *East Texas Water Transportation Cost Study,* Forrest and Cotton, April 1967.

   (f) *Preliminary Engineering Study of Alternative Conveyance Systems, Lake Austin to San Antonio and Cuero-Cibolo to San Antonio,* Turner, Collie and Braden, March 1967.

   (g) *Transportation of Water in Southeast Texas,* Turner, Collie and Braden, October 1967.

   Published and unpublished data furnished the Board by the U.S. Bureau of Reclamation, and additional reports prepared for the Board by the consulting firm of Leeds, Hill and Jewett, Inc., were also used.

2. The amounts of water proposed to be supplied to various points of use throughout the State were based on requirements and proposed deliveries previously discussed and which are also described in Parts III and IV. Seepage losses from unlined conveyance canals and evaporation losses in canals and terminal storage and regulating reservoirs were considered, as indicated in Tables I-1 and I-2, with the exception that seepage losses were not estimated for facilities in the Sulphur, Cypress Creek, Sabine, Neches, and Red River Basins.

3. Capital costs were based on cost-capacity curves derived from the above mentioned reports, although in some cases allowances for engineering and administrative costs and for contingencies were modified to insure consistency. In the final estimates of cost, U.S. Bureau of Reclamation cost indices were used to bring all capital cost figures to a December 1967 cost base.

4. In the Coastal Division, peaking requirements of 1.5 times the average rate of delivery of irrigation supplies were used where appropriate, and a peaking requirement of 0.8 was used for delivering supplies to the bays and estuaries from the Coastal Canal. Deliveries of

water for municipal and industrial supply were assumed to have no peaking requirement.

5. The costs given in Table I-4 indicate the estimated December 1967 dollar cost of the System when fully completed by or before the year 2020, with facilities staged concomitant with increasing water demands. In most of the studies, it was assumed that major canals would be initially constructed at maximum design capacity, with staged installation of pumps, pumping energy, and necessary miscellaneous and accessory equipment, including discharge piping. These criteria are of major significance in the Interstate Water Supply System involving a potential northern route into the State, and in the Trans-Texas Division. In the case of a possible coastal conveyance route from the Mississippi River through the lower Sabine River to the Lower Rio Grande Valley, the total dynamic head is only about 428 feet, which is about one-tenth of the total dynamic head involved in pumping from the Mississippi River northward into the Trans-Texas Division and to Caprock Reservoir in the High Plains.

6. Estimated costs of the smaller municipal and industrial supply systems were based on staged construction of these facilities as requirements develop, with the assumption that initial capacities of the facilities would be sufficient to supply demands for water projected to develop at least 10 to 15 years hence.

7. In the preliminary design of the wholesale and retail distribution system for the High Plains, a peaking requirement of one-fourth the total annual supply for irrigation in the maximum month of demand (August) was assumed. Canals and pumping plants in these facilities were designed with a capacity approximately 1.8 times the proposed annual delivery rate.

8. As there are presently no storage facilities available for regulating proposed deliveries of water to the North Central Texas irrigation areas, a diversion from the Trans-Texas Canal was designed with a capacity to deliver one-fourth of the total projected annual demand in one month.

9. Estimated costs for the El Paso supply system from the Pecos area did not consider a schedule of increase in demand for water or staging of construction of facilities for this segment of the Trans-Texas Division.

10. In most of the major conveyance facilities studied, the discharge pipe between a pump station and canal is a relatively small part of the project cost, and therefore was assumed as part of the cost of the pump station. However, in estimating project costs where a large amount of water is proposed to be transported by pipeline, the pipe cost is a major factor.

Although no estimates are made of the rate at which estimated costs given in Table I-4 will escalate, it must be recognized that during the past two decades rising costs of both materials and labor have resulted in a progressive increase in total construction costs.

Table I-4.--Estimated Costs of the Intrastate Facilities in the Texas Water Plan for Full 2020 Development

The final routing for importation of water from out-of-State sources to Texas has not been decided at this time. Costs for various alternatives for import routes have been estimated by the Board, as well as various alternatives for the intrastate facilities to accompany the different import routes. The estimated costs for one configuration are shown in the following tabulation. Import water would be delivered to regulatory storage in Marshall Reservoir in the Cypress Creek Basin and thence routed to Marshall Junction on a Sabine Ridge Canal between the Cypress Creek and Sabine River Basins, and from that point to the Trans-Texas Canal and the Coastal Canal.

In addition to the costs of the Texas Water System allocated to water supply as shown below, the investments from the Texas Water Development Fund for storage in Toledo Bend, Palestine Enlargement, and Franklin County Reservoirs (estimated at $25,748,950 as of 1970) will be recouped from revenues from sale of water delivered by the System. Costs for purchase of surplus water from Tennessee Colony Reservoir and Texarkana Reservoir Enlargement, and use of storage or purchase of surplus water from Cooper and Palmetto Bend Reservoirs for the System, all now authorized as Federal projects, will likewise be repaid from water sales revenues.

Capital Costs for facilities to deliver water from out-of-State sources to Marshall Reservoir are not shown.

Conveyance facility capital costs include pump station costs where applicable.

THE TEXAS WATER PLAN
Costs based on December 1967 prices
(millions of dollars)

TEXAS WATER SYSTEM	ALLOCATED WATER SUPPLY COSTS	
TRANS-TEXAS DIVISION		
RESERVOIRS		
Marshall	32.6	
Black Cypress	29.2	
Titus County	10.6	
Naples	105.7	
Parkhouse 1	38.4	
Pecan Bayou	19.8	
	236.3	
Mineola	20.2	
Lake Fork	31.4	
Big Sandy	5.3	
	56.9	
Caprock	43.7	
Bull Lake	45.2	
	88.9	
TOTAL COST FOR NEW RESERVOIRS ALLOCATED TO WATER SUPPLY, TRANS-TEXAS DIVISION		382.1
CONVEYANCE FACILITIES—Northeast Texas Basins Reservoir Interconnections		
Marshall to Lake O' the Pines	3.1	
Black Cypress to Lake O' the Pines	2.8	
Lake O' the Pines to Titus County	14.9	
Titus County to Naples	8.8	
Texarkana Enlargement to Naples	4.2	
Pecan Bayou to Naples	24.8	
Naples to Parkhouse 1	28.1	
Parkhouse 1 to Cooper	14.6	
Cooper to Northeast Texas Junction	38.4	
Lake Fork to Mineola	2.5	
Mineola to Tawakoni	1.7	
Tawakoni to Northeast Texas Junction	10.4	
	154.3	
CONVEYANCE FACILITIES—Northeast Texas Junction Westward		
Northeast Texas Junction to Megargel Junction	734.6	
Megargel Junction to Paducah	475.9	
Paducah to Caprock Reservoir	506.5	
Caprock Reservoir to Bull Lake	334.4	
Bull Lake Takeoff to Midland-Odessa Takeoff	93.8	
Midland-Odessa Takeoff to Pecos	24.3	
Pecos to El Paso	167.7	
	2,337.2	

Table I-4.--Estimated Costs of the Intrastate Facilites in the Texas Water Plan for Full 2020 Development--Continued

		ALLOCATED WATER SUPPLY COSTS	
CONVEYANCE FACILITIES—Imported Water From Marshall Reservoir			
Marshall Reservoir to Marshall Junction, Trans-Texas Division Allocation		136.9	
Marshall Junction to Northeast Texas Junction		274.4	
		411.3	
LOCAL DELIVERY CONVEYANCE FACILITIES			
To Lavon Reservoir		Natural Channel	
To Aubrey Reservoir		Natural Channel	
To North Central Texas Cities		68.6	
To North Central Texas Irrigation Areas		9.6	
To Midland-Odessa-Big Spring		30.1	
		108.3	
TOTAL CONVEYANCE FACILITIES COST, TRANS-TEXAS DIVISION			3,011.1

The above total conveyance facilities costs include the costs allocable to New Mexico. None of the costs of Caprock and Bull Lake Reservoirs are allocated to New Mexico. The conveyance cost allocated to New Mexico varies from reach to reach along the Trans-Texas Canal because of the variation in capacity required for Texas deliveries; overall it is 20% of the total cost of the joint-use conveyance facilities.

CONVEYANCE FACILITIES—Allocation of Costs of Joint-Use Facilities (Texas-New Mexico)			
Marshall Reservoir to Northeast Texas Junction		411.3	
Northeast Texas Junction to Megargel Junction		734.6	
Megargel Junction to Paducah		475.9	
Paducah to Caprock Reservoir		506.5	
Caprock Reservoir to Bull Lake Reservoir		334.4	
		2,462.7	
New Mexico Allocation	20%		492.5
Texas Allocation	80%		1,970.2

COASTAL DIVISION

RESERVOIRS			
Ponta		31.1	
Rockland		50.3	
Confluence		68.2	
Cuero 1 and 2		80.2	
Goliad		30.7	
Cibolo		12.6	
Bedias		27.3	
TOTAL COST FOR NEW RESERVOIRS ALLOCATED TO WATER SUPPLY, COASTAL DIVISION		300.4	300.4
CONVEYANCE FACILITIES—Imported Water From Marshall Reservoir			
Marshall Reservoir to Marshall Junction, Coastal Division Allocation		49.3	
Sabine Ridge Canal to Carthage Site (Sabine River)		10.0	
Carthage Site to Sabine Diversion		Natural Channel	
		59.3	
CONVEYANCE FACILITIES—Coastal Canal, Sabine River to Rio Grande			
Sabine River to Neches River		28.4	
Neches River to Galveston Bay:			
Allocated to Houston Delivery	5.2 (See Local Delivery Conveyance Facilities below.)		
Allocated to Coastal Canal Delivery	69.6	69.6	
Galveston Bay Crossing		126.0	
Galveston Bay to Pearland		49.8	
Pearland to Guadalupe River		156.6	
Guadalupe River to Nueces River		98.3	
Nueces River to Raymondville		87.3	
		616.0	

Table I-4.--Estimated Costs of the Intrastate Facilities in the Texas Water Plan for Full 2020 Development--Continued

	ALLOCATED WATER SUPPLY COSTS	
CONVEYANCE FACILITIES—Diversions from Rio Grande Upstream from International Falcon Reservoir		
Diversion Canal to Winter Garden area	22.3	
Diversion Canal to Webb-Maverick Counties	28.4	
	50.7	
LOCAL DELIVERY CONVEYANCE FACILITIES		
City of Houston—Coastal Canal Alternative:		
Coastal Canal, Neches River to Houston Takeoff	5.2	
Houston Takeoff to Lake Houston	12.6	
	17.8	
Guadalupe and San Antonio Rivers to City of San Antonio—Cuero-Cibolo Alternative:		
Cuero 1 & 2 Reservoirs to Cibolo Reservoir	42.6	
Cibolo Reservoir to San Antonio	39.6	
	[illegible]	
TOTAL CONVEYANCE FACILITIES COST, COASTAL DIVISION		826.0
TEXAS WATER SYSTEM TOTAL COSTS ALLOCATED TO WATER SUPPLY		
TRANS-TEXAS DIVISION		
Reservoir Costs Allocated to Water Supply	382.1	
Reservoir Interconnections	154.3	
Trans-Texas Division Local Delivery Conveyance Facilities	108.3	
Texas Allocation—Joint-Use Facilities (Texas and New Mexico)	1,970.2	
Bull Lake to El Paso Conveyance Facility	285.8	
Total Allocated to Water Supply	2,900.7	
COASTAL DIVISION		
Reservoir Costs Allocated to Water Supply	300.4	
Coastal Canal	675.3	
Rio Grande Projects above International Falcon Reservoir	50.7	
Houston delivery conduit	17.8	
San Antonio delivery conduit	82.2	
Total Allocated to Water Supply	1,126.4	
POWER COSTS		
Power Plants	914.0	
Power Distribution System	214.0	
	1,128.0	
TEXAS WATER SYSTEM WATER SUPPLY COST, INTRASTATE FACILITIES		5,155.1
COST ALLOCATED TO FLOOD CONTROL (Reservoirs in Texas Water System)		270.0
TOTAL TEXAS WATER SYSTEM COST		5,425.1
IRRIGATION DISTRIBUTION SYSTEMS COST		
North Central Texas	28.5	
High Plains	1,143.6	
Trans-Pecos	93.3	
Lower Rio Grande Valley—New Irrigation	61.9	
Winter Garden	16.0	
Webb-Maverick Counties	12.0	
Coastal Bend	87.0	
Total Distribution System Cost	1,442.3	1,442.3
IRRIGATION SYSTEM REHABILITATION		102.0
TOTAL IRRIGATION DISTRIBUTION SYSTEMS COST		1,544.3

Table I-4.--Estimated Costs of the Intrastate Facilities in the Texas Water Plan for Full 2020 Development--Continued

ADDITIONAL TEXAS WATER PLAN COSTS		
Local Reservoirs	1,369.4	
Additional Flood Control	494.0	
Salinity Control Projects	163.2	
Total Additional Texas Water Plan Cost	2,026.6	2,026.6
TOTAL TEXAS WATER PLAN COST		8,996.0

Economic Analysis

Purposes of Analysis

The purposes of the economic studies of the Texas Water System were to analyze the several alternative configurations of the System and to determine whether the interdependent units of the Texas Water System are economically justified; i.e., whether total economic benefits exceed total economic costs, and whether the benefits attributable to municipal and industrial water supply, to irrigation, and to enhancement of the estuarial environments along the Gulf Coast for fish and wildlife equal or exceed the costs allocated to each of those functions.

Methods of analysis used are less rigorous than those to be applied in subsequent feasibility level studies since the primary objective was to establish which of the alternatives should be studied further and in more detail, rather than to determine precisely how beneficial each unit would be. It was necessary only to show that individual components of the System have a benefit-cost ratio equal to or greater than one. However, the assumptions concerning hydrology, losses, costs, and benefits are more conservative than those normally used in feasibility level studies.

Components of the Texas Water System

The System and its relation to the overall Texas Water Plan have been described above. However, because a number of alternative System configurations in the northeast Texas basins were analyzed in the economic studies, the major components of the System were grouped somewhat differently for purposes of economic analysis than the three major System Divisions. The Trans-Texas Canal west of Northeast Texas Junction, the Coastal Canal west from the Sabine River, the Interstate System (import), and the supply and conveyance facilities in the northeast Texas basins, namely the lower Red River, Sulphur River, Neches River, Sabine River, and Cypress Creek Basins, were treated as separate components.

The alternative configurations studied for the northeast Texas basins included a ridgeline transfer system and reservoir pumpback systems which would utilize existing and proposed reservoirs in the basins for transfer of both intrastate and imported waters. Several combinations of reservoir yields and of division of northeast Texas basins water between the Coastal Canal and the Trans-Texas Canal were analyzed. Alternative transfer routes outside the northeast Texas basins were studied; for example, transfer of water to the upper Trinity River Basin and utilization of the natural channel of the Trinity River to convey water to the Coastal Canal. In the final stages of the economic analyses, the Coastal Canal and supply facilities west of the Sabine diversion and the Trans-Texas Canal west of the Northeast Texas Junction were common to each of the alternatives considered.

Assumptions and Methods of Analysis

Benefits were derived only for functions served by the Texas Water System within Texas. Costs for transfer of water to New Mexico have been included as part of the total costs of transfer facilities in the northeast Texas basins and the Trans-Texas Canal. To determine the timing of capital costs and the rate of increase in annual costs, it was assumed that the rate of buildup in water demand in New Mexico would be similar to the anticipated demand buildup in West Texas. The present worth of energy cost was computed separately for New Mexico water, as a direct function of the quantity delivered. Costs were apportioned to New Mexico by the "use of facilities" method on a reach by reach basis, and were subtracted from total System costs. Costs so apportioned to New Mexico are not included in the benefit-cost ratio.

By law, the reasonably foreseeable intrabasin water demands within the ensuing 50-year period have a priority over interbasin transfers. Therefore, in the economic analyses, these intrabasin demands have not been included. The evaluations of benefits and costs encompass only those properly allocable to purposes to be served by interbasin transfers and importation from out-of-State sources; i.e., municipal and industrial water supply, irrigation, and enhancement of the bay and estuarial environments for fish and wildlife. The benefits attributable to flood control, navigation, reservoir associated recreation, and quality improvement have not been included.

The proposed water supply for the Texas Water System includes water imported from the Mississippi River. The several possible import configurations east of the Texas border have not been studied in depth. The analyses presented herein encompass only two of the possible import routings, (a) with delivery of import water to Marshall Reservoir in the Cypress Creek Basin and (b) with delivery to the Sabine River Basin at the point of diversion to the Coastal Canal.

A unit cost of $3.50 per acre-foot has been estimated as a reasonable cost of import water from the Mississippi River delivered at the eastern border of Texas. No multipurpose advantages, with resulting sharing of costs and economies of scale, were assumed for such potential project purposes in Louisiana as flood control, water supply, and enhancement of bay and estuary environment. Transfer capacity and costs were determined on the basis of delivering the full System yearly import demand in seven months.

In determining the present worth of the Mississippi River import water cost, it was recognized that a substantial portion would be capital costs incurred before initial import of water into the System. It was deemed feasible to stage installation of pumping and mechanical equipment, but not construction of conduit or canal capacity. Therefore, installation of the basic canal with the capacity required to meet the ultimate project 2020 requirements was assumed to be completed prior to initial import of Mississippi River water.

Estimated future project costs and benefits were discounted to present worth values as of January 1, 1970. This index date was selected as a common base of comparison for the various planning studies. The assumed date of first water delivery was 1985.

In accordance with Federal practice, a 100-year period for economic analysis was used, extending from January 1, 1985, through December 31, 2084. Since future demands for water and the facilities required to meet these demands were projected only through the year 2020, all annual costs and benefits accruing to the System were assumed to remain constant at the 2020 level during the period January 1, 2021, through December 31, 2084.

Both costs and benefits were measured in current prices, and these prices were assumed to remain constant over time. The analysis was conducted in terms of constant relative prices rather than financial or monetary value. No attempt was made to project the rate of inflation or deflation in monetary terms, as would be appropriate for a financial feasibility study, nor to determine differences in the rate of change in value of the resources relative to each other, which would be appropriate in a more rigorous economic analysis.

Most of the reconnaissance level analyses were conducted using an interest rate or discount factor of 3-1/2%. These studies used primary benefits only, generally in accordance with past practices of the Federal agencies involved in the analysis of water resource projects.

In July 1968, pursuant to a directive of the President in his budget message, the Water Resources Council placed in the Federal Register a proposal for an executive order changing the procedures used in computing discount rates appropriate to project analyses. If such an executive order is issued it will become effective on January 1, 1969, and the discount rate recommended for use in project analysis will be established at 4-5/8% for use in 1969. Therefore, in later analyses of the Texas Water System, computations were also made with an interest rate of 4-5/8%. The Water Resources Council proposal does not define the types of benefits which should be included for water resources project analysis using the higher discount rate. If the discount rate is increased, discussion among members of Congress and Congressional committee staffs indicates a prevailing sentiment that pertinent benefits over and above primary benefits should be included directly in future economic analyses. It was assumed in the Board's analyses that as a matter of public policy, the inclusion of such benefits will be required in future evaluations. Therefore, for the analyses using a 4-5/8% discount rate, the national secondary benefits stemming from agricultural production as well as primary benefits have been included.

Benefits

Irrigation

Primary Benefits.—Primary benefits from project irrigation are measured by the additional net farm income derived therefrom. Farmers choose to irrigate because it is profitable to do so. Benefits accruing due to irrigation are measured by the difference between net farm income with irrigation and net farm income if the land were dry-farmed. In deciding on the feasibility of irrigation, costs of irrigation must be weighed against the increment of return, with allowance for a return to management. The primary benefits so derived represent reasonable estimates of the average return due to irrigation.

In deriving primary benefits, current levels of unit prices received by farmers were assumed to remain constant. Irrigated and dryland crop yields, irrigated and dryland cropping patterns, and irrigated and dryland costs by crop were projected to the year 2020. Primary benefits per acre were determined by comparing costs and returns on a composite or typical irrigated acre to costs and returns on a composite dryland acre. The composite acre contains all the applicable crops in relative proportions estimated to represent the overall cropping pattern for the study area under both dry-farmed and irrigated conditions.

In some cases, additional primary benefits will accrue because of an irrigation project. When lack of water would force a reduction in irrigated acreage from present levels, a reduction would be felt in local income. Lack of water would force the farmer to reduce his labor force and lose returns on his invested capital. Loss of returns to labor and capital resources may be looked upon as a *cost* to the economy, an "opportunity cost" that would be "foregone" with availability of adequate supplemental water for irrigation. If labor and capital resources presently employed in irrigated agriculture could not be reemployed elsewhere to generate other types of income or are relatively immobile, the full or partial reduction in income without supplemental water would be a net loss. If these labor and capital resources could be fully reemployed elsewhere to generate an equivalent income stream, the reduction in agricultural income would be offset by other types of income, and there would be no *net* loss.

It is unlikely, however, that both labor and capital resources could be reemployed immediately. A part of the agricultural income reduction that would occur without water delivery through the Texas Water System will constitute a *net* loss in income, or an "opportunity cost" to the economy which could be "foregone" by water resource development. This opportunity cost foregone is an additional benefit that will accrue due to the Texas Water System.

Although opportunity costs are expected to occur in a portion of the Lower Rio Grande Valley area, these costs were not included because of the changing amounts of irrigation water available from the Rio Grande in any one year.

Opportunity costs foregone have been included as a project benefit for those portions of the West Texas area currently irrigated from depleting ground water supplies, namely the High Plains and Trans-Pecos areas.

Secondary Benefits.—In addition to primary benefits, national secondary irrigation benefits were calculated, based on net national coefficients which have been derived by the U.S. Bureau of Reclamation. The resulting estimate of secondary benefits is limited to the increment in net income of all enterprises between the farmer and the final consumer from handling, processing, and marketing the increased farm production due to irrigation. Only that portion of irrigation-induced value added by processing and marketing establishments which constitutes profit and proprietor income is defined as national secondary benefits. Compensation of employees, capital consumption allowances, etc., are excluded from this concept.

Irrigation Economic Impact

In many ways irrigation is more important to the economy, particularly regional, through its induced effects than is indicated by measurable primary or secondary benefits. Even before the irrigated crops are marketed, the impact of irrigation is felt throughout the economy. The farmer invests in pumps, irrigation equipment, land levelling, and other improvements. These investments usually require credit availability for financing. The irrigator applies increased amounts of fertilizer to heavier seedings of improved seed, invests in chemicals for insect and weed control, purchases additional machinery for more efficiently raising and harvesting higher yields, uses additional labor, and provides better farm handling.

The increase in production resulting from irrigation goes through a series of transportation, manufacturing, and marketing stages—first of the bulk, raw commodity, then of partially finished goods to secondary types of processing, and finally of the final product to consumer markets. The value of the additional output due to irrigation increases with each act of processing as additional labor and capital resources are employed. Induced investments in labor and capital resources add tax base for public financing.

The additional local income generated by irrigation is spent on goods and services demanded for consumption (more cars, new housing, clothes, recreation, insurance, health, etc.). The consumer retailing and service sectors employ additional resources to meet increased consumption demands.

For the purposes of this analysis, economic impact is defined as economic *value* which is *added* or induced by irrigation. This value is measured by the additional payments to labor and capital resources (the sum of compensation of employees, profits and proprietors income, capital consumption allowances, etc.). Types of impact evaluated include local secondary impact, national secondary impact, agricultural inputs, tertiary impact, and consumption tertiary impact. A distinction must be made between benefits attributable to irrigation and impact, since the economist assumes that alternate uses of labor and capital resources would produce substantially equivalent impact. Nevertheless, and especially from a regional point of view, the positive impact of irrigation made possible by the Texas Water System on the economy will be very substantial. For example, total national impact resulting from the Texas Water System is estimated to be $51.2 billion present worth 1970 at 3-1/2% and $31.7 billion present worth 1970 at 4-5/8%. Corresponding local impact is $14.2 billion at 3-1/2% and $8.8 billion at 4-5/8%, both present worth 1970.

Municipal and Industrial Benefits

It is assumed that municipal and industrial water supply benefits equal the cost of the least costly single purpose alternative project. However, this approach was not applied in two cases, specifically in West Texas and for those municipalities to be served from the Coastal Canal. For the 10 cities in West Texas to be served by the Texas Water System, a joint single purpose project serving all of the cities was used as the measure of benefit for supplemental water. The economies of scale inherent in a single purpose project serving all 10 cities with municipal and industrial water produce a conservative estimate of benefits. For cities served by the Coastal Canal a conservative approach was also adopted. A joint-use project was used to measure the cost of an alternative supply for Corpus Christi and Kingsville industrial requirements. A more rigorous approach of using independent, alternate, single purpose projects as a measure of benefit was not warranted for the reconnaissance level analysis.

Fish and Wildlife Benefits

Capacity is included in the Texas Water System for provision of supplemental inflows of fresh water to protect the estuarial environment in Galveston, Matagorda, San Antonio, Aransas, and Corpus Christi Bays. Even with future upstream water development and use, a firm fresh water supply will be provided for bays and estuaries. This supply of supplemental inflows, together with measures to improve the circulation of seawater from the Gulf of Mexico and other means to protect the bay water quality, will improve the salinity gradients and general environmental conditions in these bays, enabling increased production of sport and commercial fish, and the enhancement of water-associated recreation.

Provision of supplemental fresh water inflows constitutes enhancement of the environment in Galveston, Matagorda, Aransas, and Corpus Christi Bays, since no reductions of the tributary inflows to these bays are contemplated as a specific consequence of operation of the Texas Water System. Supplemental fresh water inflow to San Antonio Bay would be required for mitigation purposes, since facilities of the Coastal Division of the Texas Water System would regulate and divert for upstream use much of the natural tributary dry-year inflows to this bay from the Guadalupe and San Antonio River Basins.

Adequate data are not now available to estimate the probable full dollar value of enhancement of the fishery environment in the coastal bays and estuaries through provision of supplemental fresh water inflows during periods when the natural tributary inflows would be limited due to either climatic conditions or upstream water development and use. The best seasonal timing of fresh water releases, and optimum coordination with facilities for improved Gulf water circulation and with other quality control measures, will be better understood as a result of studies currently underway. Conservative unit values, measured in dollars per acre-foot, for benefits at Galveston, Matagorda, Aransas, and Corpus Christi Bays were developed for inflows provided in excess of those that would occur in the absence of the Coastal Canal. These per acre-foot benefits, derived by the U.S. Fish and Wildlife Service, were used to provide an estimate of the average annual fish and wildlife benefits accruing to the Texas Water System.

A project water supply of 300 thousand acre-feet per year for San Antonio Bay is assumed in the reconnaissance level project design and costs. This supply is for mitigation, and no project benefits are claimed. An additional supply of 60 thousand acre-feet per year is included in the Coastal Canal design and cost estimates for wildlife refuges, also as mitigation for which no project benefits are claimed.

Cost Allocation

The recommended method of cost allocation for a rigorous feasibility level economic analysis is the Separable Costs-Remaining Benefits (SCRB) method. Properly applied, this method will determine the economic justification of incremental features of a multipurpose project. This procedure, together with reliable cost and benefit functions over the range of demands for any resource use, will indicate that scale of use which maximizes net benefits for any given function.

The SCRB method requires the derivation of benefits for each function of a multipurpose project. The specific cost or cost functions for each feature are also required. Specific cost is cost for those items which are associated directly with a given function, and which would occur only if that function were included in the project. An example of a project specific cost is the cost of an irrigation distribution system beyond the point of diversion from a multipurpose main conveyance facility.

Rigorous application of the SCRB method in project economic analysis provides a technique useful to the efficient allocation of costs. The major problem with the use of the SCRB method of incremental analysis is the assumption that all benefits are quantifiable. As with any method, careful judgement must be exercised in its application. Final decisions must always result from a broader range of analysis and considerations. The framework of the economic analysis and the assumptions with regard to the future should be clearly defined for use in decision making.

Although the Separable Costs-Remaining Benefit method of cost allocation could not be applied rigorously here because of the limits of available data and the necessary simplifying assumptions, the philosophy and theoretical framework of the method were adopted for this analysis.

The Alternate Justifiable Expenditures (AJE) method was used in allocating System joint transfer costs among the purposes and functions served by the Trans-Texas and Coastal Canals. This method is similar to the SCRB procedure in that alternate and specific costs are estimated. However, separable or incremental costs for each function are not calculated.

In the AJE method, total project costs less specific costs (total joint costs) are allocated among functions in proportion to the remaining justifiable expenditure for each function; i.e., the lesser of benefit or alternate cost less specific cost. Although the separable cost of each function was not computed for the final series of reconnaissance level studies, costs were allocated similarly to allocation by the SCRB method.

Results

The present worth values, as of 1970, of the benefits and costs of the proposed Texas Water System through 2084 for each of the three principal functions to be served by the Trans-Texas and Coastal Canals are summarized in Tables I-5 and I-6. The tables show the effect on the analysis of using two different discount rates, 3-1/2% and 4-5/8%, over the period of analysis. For the 3-1/2% rate, only primary benefits due to irrigation were used in the analysis, while at 4-5/8% both primary and national secondary irrigation benefits were included. For both analyses only primary benefits were included for municipal and industrial use and for fresh water inflows into the bays and estuaries.

Table I-5.—Benefit-Cost Ratios for Functions Within Texas Served by the Coastal and Trans-Texas Canals[1]

3½% Discount Rate

(Benefits and Costs are Present Worth 1970 Values in Millions of Dollars)

		MISSISSIPPI RIVER IMPORT TO MARSHALL RESERVOIR		MISSISSIPPI RIVER IMPORT TO SABINE DIVERSION	
	BENEFITS	COSTS	B/C RATIO	COSTS	B/C RATIO
Coastal Canal					
Lower Rio Grande Valley Irrigation	499.2	318.5	1.57	305.7	1.63
Coastal Bend Irrigation	503.1	403.8	1.25	386.8	1.30
Webb and Maverick Counties Irrigation	144.9	126.4	1.15	122.9	1.18
Winter Garden Irrigation	109.7	105.2	1.04	101.7	1.08
Lower Rio Grande Valley Municipal and Industrial	88.3	88.2	1.00	83.9	1.05
Corpus Christi and Kingsville Municipal and Industrial	57.0	57.0	1.00	54.0	1.06
Houston Municipal and Industrial	88.3	88.0	1.00	78.5	1.12
Bay and Estuary Enhancement	120.0	118.8	1.01	108.2	1.11
Total, Coastal Canal	1,610.5	1,305.9	1.23	1,241.7	1.30
Trans-Texas Canal (Texas Functions)					
Trans-Pecos Irrigation	395.7	375.9	1.05	381.5	1.04
High Plains Irrigation	4,083.3	3,833.7	1.07	3,906.3	1.05
North Central Texas Irrigation	79.3	75.7	1.05	77.0	1.03
Municipal and Industrial					
El Paso	253.2	239.8	1.06	243.7	1.04
Pecos	37.7	34.4	1.10	35.3	1.07
Midland-Odessa	92.5	84.2	1.10	86.4	1.07
Big Spring	29.2	27.1	1.08	27.8	1.05
Lubbock	50.9	47.0	1.08	48.4	1.05
At Megargel Junction [2]	106.9	100.6	1.06	102.2	1.05
Dallas-Fort Worth	44.8	39.9	1.12	41.3	1.08
Total, Trans-Texas Canal	5,173.5	4,858.3	1.06	4,949.9	1.05
Total, Coastal and Trans-Texas Canals	6,784.0	6,164.2	1.10	6,191.6	1.10
Costs for Delivery to New Mexico	[3]	750.2	—	774.0	—

[1] Based on Primary Benefits only.

[2] Serving municipal and industrial requirements of Abilene, Colorado City, San Angelo, Snyder, and Sweetwater.

[3] Benefits not computed.

Table I-6.—Benefit-Cost Ratios for Functions Within Texas Served by the Coastal and Trans-Texas Canals 1/

4-5/8% Discount Rate

(Benefits and Costs are Present Worth 1970 Values in Millions of Dollars)

		MISSISSIPPI RIVER IMPORT TO MARSHALL RESERVOIR		MISSISSIPPI RIVER IMPORT TO SABINE DIVERSION	
	BENEFITS	COSTS	B/C RATIO	COSTS	B/C RATIO
Coastal Canal					
Lower Rio Grande Valley Irrigation	570.5	270.3	2.11	254.8	2.24
Coastal Bend Irrigation	469.8	339.5	1.38	323.9	1.45
Webb and Maverick Counties Irrigation	170.1	96.5	1.76	93.4	1.82
Winter Garden Irrigation	131.7	88.5	1.49	85.4	1.54
Lower Rio Grande Valley Municipal and Industrial	53.0	53.0	1.00	50.8	1.04
Corpus Christi and Kingsville Municipal and Industrial	33.8	33.8	1.00	32.5	1.04
Houston Municipal and Industrial	66.2	66.2	1.00	63.0	1.05
Bay and Estuary Enhancement	78.9	78.9	1.00	74.8	1.05
Total, Coastal Canal	1,574.0	1,026.7	1.53	978.6	1.61
Trans-Texas Canal (Texas Functions)					
Trans-Pecos Irrigation	639.0	345.5	1.85	352.1	1.81
High Plains Irrigation	5,571.7	2,930.5	1.90	2,990.0	1.86
North Central Texas Irrigation	116.4	63.5	1.83	64.7	1.80
Municipal and Industrial					
El Paso	186.2	122.9	1.52	124.3	1.50
Pecos	28.8	14.3	2.01	14.6	1.97
Midland-Odessa	70.7	33.9	2.09	34.7	2.04
Big Spring	22.5	11.4	1.97	11.7	1.92
Lubbock	38.6	17.8	2.17	18.2	2.12
At Megargel Junction 2/	84.5	61.7	1.37	62.2	1.36
Dallas-Fort Worth	30.8	16.9	1.82	17.2	1.79
Total, Trans-Texas Canal	6,789.2	3,618.4	1.88	3,689.7	1.84
Total, Coastal and Trans-Texas Canals	8,363.2	4,645.1	1.80	4,668.3	1.79
Costs for Delivery to New Mexico	3/	609.0	—	630.6	—

1/ Based on Primary Benefits plus National Secondary Irrigation Benefits.

2/ Serving municipal and industrial requirements of Abilene, Colorado City, San Angelo, Snyder, and Sweetwater.

3/ Benefits not computed.

Specific costs for irrigation distribution systems and for single purpose facilities beyond the main canal for delivery of municipal and industrial water are included.

The usefulness of these tables transcends results of the benefit-cost analysis in that the differences in the values, because of the two discount rates, emphasize relationships over time rather than absolute values. They show that discounted benefits are greater than discounted costs at 3-1/2% and 4-5/8%, but do not indicate actual benefits or costs which will accrue under the System. The financial analysis to be associated with the subsequent feasibility level study and its resulting cash flows will give a meaningful picture of cost and repayment values by year.

Use of the Alternate Justifiable Expenditure method of cost allocation and the varying present worth factors produced some anomalies in the values shown in Tables I-5 and I-6.

Examination of the tables shows that the benefit-cost ratios for municipal and industrial water served by the Trans-Texas Canal increase substantially at the 4-5/8% discount rate. This increase is due directly to the method of cost allocation and to the inclusion of national secondary irrigation benefits. In the Alternate Justifiable Expenditures method each purpose is assigned its specific cost, as well as a share of remaining costs proportionate to the remainders obtained by deducting specific costs of each function from the lesser of the benefits or that functions's alternative cost. Addition of national secondary irrigation benefits increases the proportion of joint costs allocated to agriculture and reduces those allocated to municipal and industrial water supply. Since joint costs are reduced for municipal and industrial beneficiaries at a rate greater than the reduction of the benefit stream because of the higher interest rate (4-5/8%), benefits relative to costs are increased. This results in a higher benefit-cost ratio at 4-5/8% than at 3-1/2% for municipal and industrial beneficiaries of the Trans-Texas Canal.

Another anomaly concerns the Coastal Canal and also involves municipal and industrial beneficiaries. At 4-5/8% certain functions show 1:1 benefit-cost ratios with Mississippi River import to Marshall Reservoir. Benefit-cost ratios for municipal and industrial water as well as bay and estuary releases from the Coastal Canal at 4-5/8% react to the present worth factors as well as to the conservative estimate of benefits. Capital costs incurred in 1985 which are associated with the transfer of water from Marshall Reservoir to the Sabine River have been discounted to 1970. The 15-year benefit stream from 2070 through 2084 was subject to a discount factor of 4-5/8% which is only 58% of that at 3-1/2%. The capital costs which will be incurred by 1985 are subject to a discount factor at 4-5/8% which is 90% of that factor for a comparable period of time at 3-1/2%. Therefore, the cost of transfer from Marshall Reservoir to the Sabine River at 4-5/8% interest, when added to remaining joint costs and allocated among functions, is greater than the additional benefits which are added at the end of the project's economic life. Feasibility level studies are expected to yield benefit-cost ratios at 4-5/8% for those functions greater than one because: (1) the SCRB method of cost allocation will require the calculation of separable or incremental costs for each function, and these costs are expected to result in marginally lower allocated costs for the above mentioned functions; and (2) rigorous attention has not been accorded to detail in the reconnaissance level studies. The margin of error of the estimated benefits and costs, when added to possible rounding errors, can result in adjusted figures varying 5% or more from those used in the tables. The reconnaissance level analysis used estimates of costs and benefits which were quite conservative for planning purposes; i.e., the assumptions underlying their derivation would normally yield higher costs and lower benefits than those expected from a feasibility level analysis. Thus, the margin of error in the reconnaissance studies is expected to undergo a positive response in the feasibility studies resulting in a benefit-cost ratio greater than one for the affected functions.

Summary

Economic analyses of the Texas Water System were conducted with sufficient rigor and based on sufficiently conservative assumptions to conclude that the System is economically justified in that benefits exceed costs and warrants continued and more detailed investigation at feasibility level. Benefits resulting from each function served exceed the costs attributable to each such function.

Considering water supply benefits accruing through deliveries from the Trans-Texas and Coastal Canals only, including those to the bays and estuaries, the benefit-cost ratio for the System was determined to be 1.1, using 3-1/2% discount rate and primary benefits only. Using a 4-5/8% discount rate and primary benefits plus national secondary irrigation benefits, the benefit-cost ratio of the Texas Water System was estimated to be 1.8.

At the discount rate of 3-1/2%, present worth 1970 total System benefits amount to $6.8 billion, and total System costs to $6.2 billion, for a total net benefit due to the System of $0.6 billion. At the 4-5/8% discount rate, present worth 1970 total System benefits are $8.4 billion, and total System costs $4.7 billion, for a total net benefit of the System of $3.7 billion.

The project benefit-cost ratios include only that portion of East Texas reservoir and inter-reservoir conveyance costs allocated to out-of-basin water supply. Benefits are not included for flood control, recreation, navigation, quality improvement, nor for conservation for local in-basin use, which would result from the construction of supply reservoirs for the Texas Water System. Since substantial benefits accruing to purposes other than out-of-basin water supply are not included in System benefits, and since the allocation procedure used in the reconnaissance level economic analysis is conservative, it is expected that more detailed feasibility analysis will show substantially higher System benefit-cost ratios.

Substantail additional local or secondary impact would accrue as a result of the System. Studies indicate that the beneficial impact on the local economy due to provision of a water supply from the System for irrigation is at least twice the benefits shown.

Detailed feasibility studies are needed to determine the final System configuration, particularly in the northeast Texas basins. The import configuration east of the Texas border is uncertain, and alternative routes, and regimen of diversion need further study. Also, the optimum seasonal distribution and locations of supplemental fresh water inflows for bay and estuary needs, as well as other measures to protect the estuarial environments, require a more detailed investigation.

Feasibility level studies may indicate advantages to both New Mexico and Texas of delivering to New Mexico water which is regulated to meet a seasonal demand pattern. Future investigations should explore potential terminal re-regulation storage, and conjunctive use of the Ogallala Formation for re-regulation of surface import and for provision of seasonal peaking requirements.

Hydraulic analyses of the complex alternatives of System operation and coordination with local projects will be an integral part of future feasibility studies. The economic and hydrologic "economies of scale" which are possible with coordinated operation of the System components could reduce costs substantially below current estimates.

Without the Texas Water System, the decline in irrigated acreage in Texas will reduce the State's share of national agricultural production and result in substantial unemployment of labor and capital resources. The Texas Water System will permit Texas to maintain its share of national agricultural production at current levels.

Financial Feasibility

On the basis of preliminary evaluations, the financial resources of the areas to be served by the Texas Water System appear to be adequate to repay the costs under current Federal and State repayment policies, either through water charges, or through a combination of water charges and general taxation, which is discussed in more detail in Part V of this document.

Interstate Water Supply System

In the preliminary Texas Water Plan released early in 1966, the Board described the imperative need for importation of out-of-State sources of water if a major loss of irrigated agriculture is to be avoided in the West Texas area, notably in the High Plains. With the support of the Board, local interests, and the Texas Congressional delegation, as well as widespread support throughout Texas, in 1966 the Congress of the United States authorized preliminary studies by the U.S. Bureau of Reclamation of potential sources of import water to augment the natural supplies of West Texas and eastern New Mexico. In late 1967 the Congress authorized the Mississippi River Commission and the Lower Mississippi Valley Division of the U.S. Army Crops of Engineers to participate with the U.S. Bureau of Reclamation in further studies of potentially surplus waters in the Mississippi River System and alternative routes for conveying waters from the Mississippi River to these water deficient areas.

Extremely preliminary indications, plus reconnaissance level water studies and economic analyses made by the Board, suggest that feasibility studies of an import routing to Texas and eastern New Mexico from the lower Mississippi River are warranted. The route through Louisiana for such an import might follow the channel of the Red River, entering Texas in the Cypress Creek Basin, or might be a part of a fresh water coastal channel constructed westward to the lower Sabine River from the Mississippi River, or a combination of these two or other routings.

No decision as to the relative merits of the two routes, or a combination thereof, is possible at this time, and the Texas Water Plan is therefore designed to be compatible with either route, as well as other possible routes.

Projects to Meet Local Requirements

Facilities to meet local requirements are included in Tables IV-52 and IV-53 and are shown on Plate 3. Inclusion of these projects in the Texas Water Plan is based on the premise that the ground and surface water resources of each river basin of the State would be developed to the maximum practicable extent by the year 2020, that exports of water from basins having surpluses would be limited to those quantities of water available above projected 50-year intrabasin needs (except where surplus supplies might be exported on an interim basis), and that importation to areas of deficiency would be limited to the amount of water needed to supplement locally available supplies of suitable quality for the intended uses. Throughout the planning studies, the Board examined many potentially feasible alternative projects, including studies of new alternatives proposed by various local interests. Proposed development of the water resources of each river and coastal basin is described in more detail in Part IV.

The ommision from Plate 3 or Tables IV-52 and IV-53 of a previously studied or potential project to meet local needs does not preclude the possibility that such a project may ultimately be constructed, and the inclusion of a project in the Plan does not imply that it is the only feasible project worthy of study. Rather, each project designed specifically to meet local needs must be examined in more detail on the basis of its potential for meeting these needs and from the standpoint of the basic objectives of the Texas Water Plan, that is, the optimum development of the total water resources of the State.

Most of these projects will probably be constructed under local sponsorship, either by one of the Federal agencies or by a local agency, possibly with financial assistance when necessary from the Texas Water Development Fund.

Projects Other Than for Water Supply

These projects include navigation, both along the Coast and on inland rivers, flood control facilities other than reservoirs also providing water supply storage, hydroelectric power generation, hurricane protection projects, upstream watershed protection programs, drainage facilities for wetlands, natural salinity alleviation projects, and phreatophyte control and grassland restoration programs. These projects and programs are discussed more fully in Parts III and IV.

CONCLUSIONS

1. Texas' Potential for Growth

Texas has the capability for great population growth and industrial and agricultural expansion, provided adequate water supplies of suitable quality can be made available at reasonable and equitable costs. With ample supplies of water, it is anticipated that the population of Texas in 2020 will have grown to 30,500,000, more than 3 times the population in 1960. Corresponding industrial and agricultural expansion to support this growth is expected to occur.

If adequate water supplies are not available in time, however, this future population growth and economic development will be severely curtailed. Agricultural production in the western half of the State must inevitably decline, with Statewide adverse economic impact, particularly to the associated agribusiness and financial interests in the major metropolitan centers.

For example, supplemental water supplies must be made available in the following areas no later than the dates shown:

San Antonio area (municipal and industrial)—1985
Corpus Christi area (municipal and industrial)—1987
El Paso area (municipal, industrial, and irrigation)—2000*
High Plains (irrigation)—1985
Trans-Pecos area (irrigation)—1990
Lower Rio Grande Valley (municipal, industrial, and irrigation)—1980

If this time schedule can be met, water needs in other areas of the State can and will be adequately met. To meet this schedule, however, coordinated and cooperative action in planning, feasibility studies, authorization, financing, design, and construction among all levels of government is essential.

2. Water Resources Now Available to Texas

Water supplies can be developed to meet all reasonably foreseeable long-term intrabasin needs and provide supluses for interbasin transfers under the Texas Water Plan in the lower Red, Sulphur, Cypress Creek, Sabine, and Neches River Basin. Some surpluses will exist in the Guadalupe-San Antonio River Basins and in the Trinity River Basin. Pending full development of the intrabasin needs, the surpluses available for interbasin transfers on an interim basis will be substantially larger.

These water resources available to Texas from intrastate sources and from interstate sources flowing along or across the State boundaries are grossly inadequate to meet the future water needs of the State.

3. Importation From Out-of-State

Importation of water from out-of-State sources is essential to the future development of Texas, and must begin no later than 1988. By 2020 as much as 12 to 13 million acre-feet per year may need to be imported. Planning estimates indicate that water of suitable quality, in these quantities, can be made available from the lower Mississippi River.

Such estimates are based on full consideration of the needs of the Mississippi River Basin States now, and in the future, including maintenance of quality and navigation. It is also planned that any project for exportation of Mississippi River water would yield benefits to the exporting State(s), as well as to Texas and New Mexico. Further, this source appears to offer the most economic benefits. In light of these factors the assumption has been made that water could be made available to meet Texas' requirements, and planning has continued on this basis.

It is probable that additional importation of water from some source may be required by 2020, and possibly before.

4. The Texas Water Plan

The Plan, the most extensive and complex water resource system yet conceived, is the most effective and economic means for meeting the future water needs of Texas for all purposes on a Statewide basis.

5. Participation by the State of Texas

The State must be a major participant with Federal and local agencies in planning, feasibility studies, financing and design, and in operation, maintenance, and management of the Texas Water System in order that the State's interest in its resources may be fully protected.

6. Cost

The costs of facilities of the Texas Water Plan are shown in Table I-4. These expenditures will be spread over a period of 50 years, with most of the capital costs incurred between fiscal years 1975 and 1990. The anticipated rate of cost escalation will be a significant factor in long-range financing planning.

7. Acreage Limitation

The present acreage limitation provisions of Federal Reclamation Law will need to be revised if the State is to have an economically viable agriculture in Texas under Reclamation projects.

8. Economic Justification and Financial Feasibility

The Texas Water System, including import from out-of-State sources, is economically justified on the basis of reconnaissance level studies. The financial resources of the irrigation areas to be served appear to be adequate to repay their share of the costs under current Federal repayment policies through water charges or a combination of water charges and general taxation.

* Needed whenever can be made available. Year 2000 projected in present planning as earliest feasible date for delivery.

RECOMMENDATIONS

The Board recommends that the following actions be taken by the Governor and Legislature of the State of Texas, the President and the Congress of the United States, and local governmental agencies:

THAT THE GOVERNOR AND THE LEGISLATURE OF THE STATE OF TEXAS:

1. Adopt a plan for financing the State's share of the cost of the Texas Water System as a joint Federal, State, and local partnership undertaking and to provide additional financial assistance to local political subdivisions for water supply projects; such plan to be submitted for approval by the voters at the 1970 general election.

2. Amend the Texas Water Development Fund Act to:

   (1) Eliminate the present provision for termination in 1982 of Texas Water Development Fund investments.

   (2) Remove the present limitation on the total amount of the Water Development Fund, the limitation on the permissible investment in a single project, and the limitation on the maximum aggregate investment in reservoir conservation storage facilities.

   (3) Remove the limitation on the coupon interest rate for Water Development Fund bonds from the present maximum of 4%.

3. Empower the Board to implement the Texas Water Plan, including authority to:

   (1) Participate in partnership with the United States Government, pursuant to appropriate statutory and contractual arrangements, in the design, construction, operation and maintenance, and management of the Texas Water System; such participation to be on the basis of ownership by the State of an undivided interest in the total System.

   (2) Enter into contracts with Federal, or with Federal-State agencies, to purchase water from out-of-State sources delivered at the State line.

   (3) Enter into cooperative agreements with the United States, local public agencies, and investor-owned utilities for financing, constructing, and operating facilities to generate and deliver pumping energy required for the Texas Water System.

   (4) Acquire by eminent domain lands necessarily required for water development project purposes proposed in the Texas Water Plan.

   (5) Preserve lands necessarily required for water development project purposes proposed in the Texas Water Plan under terms providing equitable return to the landowner.

   (6) Use lands necessarily acquired for project purposes prior to initiation of construction, and on an interim basis. Purpose of use would include leasing for agricultural use, leasing for recreational development, or development cooperatively with the Parks and Wildlife Department for wildlife and fishery management, or for other purposes not inconsistent with ultimate reservoir development. Since acquisition of lands by the State removes the tract from local tax rolls, lease contracts may contain provision for contribution by the lessee to units of local government, of an amount equivalent to former ad valorem taxes or special assessments.

   (7) Act as sponsor of water development projects proposed for Federal authorization when the Board is acquiring storage in a reservoir project as a part of the Texas Water System, or when a local sponsor is not available for a needed water development project, whether or not it is a part of the Texas Water System.

4. Amend Article 7470 which lists the purposes for which water may be appropriated, by adding a provision to authorize the appropriation of water for other beneficial uses which may be defined from time to time in Rules and Regulations of the Texas Water Rights Commission, to enable the Commission to consider the allocation of waters of the State for water quality control purposes, mosquito control, fish and wildlife, maintenance of fresh water inflows to the bays and estuaries, and such other purposes as it may deem beneficial to the State. Many of these uses are already specifically included as project purposes in the Federal reservoirs in Texas.

5. Provide additional funds to the Texas Water Quality Board, under its authorized program of State grants for planning and constructing sewage collection and treatment systems, by establishing a Texas Clean Water Fund to complement the construction grant provisions of the Federal Water Pollution Control Act as amended.

6. Establish a Texas Water Projects Recreation Fund, to be administered by the Parks and Wildlife Department as a part of its long-range recreation plan for Texas, to provide the funds in excess of those available from user fees necessary to repay the reimbursable Federal investment allocated to recreation, and to enhancement of fish and wildlife resources under the Federal Water Project Recreation Act, to provide on-shore facilities and to operate and maintain such facilities for elements of the Texas Water System.

7. Provide adequate funds for the concerned State agencies, designating specific inter-agency responsibilities, to complete comprehensive studies of the bays and estuaries and to prepare recommendations for Legislative consideration for long-range conservation of these resources.

8. Establish State policy as to the degree of State responsibility for the costs associated with providing fresh water inflows to the bays and estuaries to complement Federal policy when established; appropriate funds, or establish other funding procedures for payment of those costs; and designate the responsible State agency for administering such funds.

9. Mitigate the effects of the influx of workers for construction of the facilities of the Texas Water System upon communities which must provide school, police, fire, hospital, and other services for those workers during the period of construction; adopt a formula for assessing those effects; and make funds available to assist such communities in defraying the short-term costs of providing these additional local services where such mitigation is not a Federal responsibility.

10. Authorize creation of master districts for purposes of contracting for purchase of water under the Texas Water System; such districts to be created where needed and as local interests reach agreements on the areas to be encompassed.

11. Establish and fund a program to be administered by the Texas Parks and Wildlife Department to designate and preserve river reaches and springs of historic, scenic, and scientific value to complement and supplement Federal legislation.

12. Appropriate to the Board adequate funds to carry out its duties and responsibilities for future water development in Texas in a timely manner as shown on Plate 1.

THAT THE PRESIDENT AND THE CONGRESS OF THE UNITED STATES:

1. Continue to fund the feasibility level studies now being conducted by the U.S. Bureau of Reclamation and U.S. Corps of Engineers of the import to Texas of surplus water from the Mississippi River and its conveyance to points of need within Texas and adjacent States, and approve the concept of such importation as soon as agreement has been reached among the non-Federal interests involved.

2. Accept and implement the concept of Federal-State relationships with responsibilities at both levels of government generally as defined in this Plan for the planning, design, financing, construction, operation, maintenance, and administration of the Texas Water System and other projects of the Texas Water Plan.

3. Recognize the Texas Water Plan and subsequent modifications as the general guide for future water and related land resource development in Texas.

4. Authorize the Texas Water System and its projects, and appropriate funds for engineering and construction of elements of the Texas Water System upon submission of feasibility and survey reports, so that the time schedule presented herein for the Texas Water Plan may be met.

5. Authorize the Corps of Engineers and the Bureau of Reclamation to enter into contracts with the State of Texas as the principal contracting agent for repayment to the United States of the reimbursable Federal costs allocated to water supply incurred in the design and construction of the facilities of the Texas Water System, with the State of Texas securing its obligations under such contracts through ancillary repayment contracts executed by the State with local political subdivisions.

6. Amend the provisions of Federal Reclamation Law relating to acreage limitations so that economically productive farming units can be developed or sustained under Reclamation projects.

7. Establish policy as to the national interest in protection of the coastal bays and estuaries and the criteria for evaluating benefits and detriments to the bays and estuaries from water and related land resource development.

8. Empower Federal construction agencies, for reservoir and water conveyance projects authorized now or in the future, to:

   (1) Immediately acquire necessary interests in project lands and take necessary actions to preserve the future project sites from encroachment.

   (2) Enter into agreements with the State of Texas and local agencies to provide for credit or reimbursement for the costs of lands acquired, land-taking surveys made, or other project costs incurred by the State or local agencies when such expenditures are sound contributions to the projects.

THAT LOCAL INTERESTS:

1. Take steps immediately to form master districts, where necessary, covering the areas which desire to be supplied with water for irrigation and other purposes under the Texas Water System, with adequate powers to contract with the State of Texas or the United States for a water supply and other purposes; to raise the revenues necessary to repay the reimbursable costs involved; and to accomplish the other actions necessary to put the water to beneficial use in the most effective manner.

2. Examine the desirability of forming, and form where feasible, regional organizations or entities such as a metropolitan water district covering major metropolitan areas in order to minimize the cost of treating and distributing water supplied through the Texas Water System.

3. Examine the legal authority of the local and regional agencies to participate in the Texas Water Plan with the Federal and State agencies, and where such authority is lacking, seek authorization from the Legislature.

4. Immediately undertake studies of the amounts and timing of supplemental water to be contracted for under the Texas Water System, the point(s) of delivery, and the necessary legal and financial arrangements to assure the capability of meeting the contractual repayment obligations. Initiation of these studies should not await the formation of master districts or regional organizations.

5. Expand, in cooperation with Federal and State agencies, programs of basic data collection and planning.

6. Cooperate in further planning for the Texas Water Plan and in preparation of feasibility reports for elements of the Plan.

7. Cooperate with the Board in preparing and presenting unified programs to the Federal agencies and the Congress for Federal authorization and appropriations.

Part II

Water Resources And Water Rights

WATER RESOURCES AND WATER RIGHTS

WATER RESOURCES

The water resources evaluated in developing the Texas Water Plan include (1) fresh water contained in the saturated zones of underground formations (ground water), (2) surface waters of the interstate and intrastate streams of the State, (3) waste waters discharged to streams or coastal waters (return flows), (4) saline ground and surface waters suitable for demineralization, or directly for use in mining operations, (5) atmospheric water which might be made available in additional quantities at the earth's surface by weather modification techniques, (6) water supplies which might be salvaged by the eradication and control of phreatophytes (water wasting vegetation of little or no economic value), and (7) surface waters from out-of-State sources which might be surplus to existing and projected needs of those areas and feasible for import to Texas.

The studies conducted by the Board since the initiation of accelerated planning activities in 1964 have resulted in the development of a proposed balance between the quantities of water estimated to be available and the projected future water requirements throughout the State as of the year 2020. Under the Texas Water Plan, construction of reservoirs and conveyance facilities is proposed to develop fully the available supplies from intrastate sources, from interstate and international streams bordering or crossing Texas, and for storage and regulation of water proposed for importation from out-of-State sources to meet projected requirements. Where ground water of suitable quality is available to meet projected local water supply needs, and can be developed and used at total costs comparable to or less than the total cost of an alternative surface water supply, this resource constitutes an important source of supply in the water balance.

The water resources presently existing and projected to be available for development in the State are described herein. Described also are climatic and physiographic conditions which determine to a very large degree the availability for use of these water resources.

Climate

The climate of Texas is marked by extremes in temperature, precipitation rates, and the variation and extent of catastrophic weather events which affect all regions of the State. The climatic patterns of the State are determined primarily by the interaction of moisture-laden Gulf air masses moving northwestward over the State and dryer, relatively cooler air masses moving southeasterly from the continental interior.

Frequent occurrences of hail, floods, tornadoes, occasional hurricanes, and recurrent droughts combine to make climate and weather a compelling consideration in any water resource development program in the State. Rates of precipitation and evaporation and variations in temperature are of primary importance.

Precipitation

Although an average of about 413 million acre-feet of water falls in Texas each year in the form of precipitation, the occurrence of rain and snow is poorly distributed both in space and time. Average annual precipitation at Lubbock in the High Plains is about 18 inches, while at Texarkana in East Texas the normal annual precipitation is a little more than 49 inches. This is an average increase from west to east of about 1 inch of precipitation every 15½ miles. There is a difference of 47 inches between El Paso's 8 inches and Port Arthur's 55 inches.

Texas experiences abnormally wet and abnormally dry years. Based on climatic division averages, during 7 wet years (1940-1946) an average of about 33 inches of precipitation fell annually in Texas. During 7 dry years (1950-1956) an annual average of about 22 inches fell. The 1931-1960 average annual precipitation for Texas was about 28 inches. Figure II-1 shows the 10 climatological divisions of the State for which Table II-1 indicates average annual precipitation records for the period 1931-1960.

Temperature

Table II-2 illustrates the variations in average January and July temperatures in the 10 climatological divisions of Texas (Figure II-1). January and July are on the average the coolest and warmest months, respectively, in most areas of Texas. The moderating influence of air masses from the Gulf of Mexico and the effect of latitude are evident in the tabular values of temperature—that is, both the range between daily maximum and minimum temperatures and the temper-

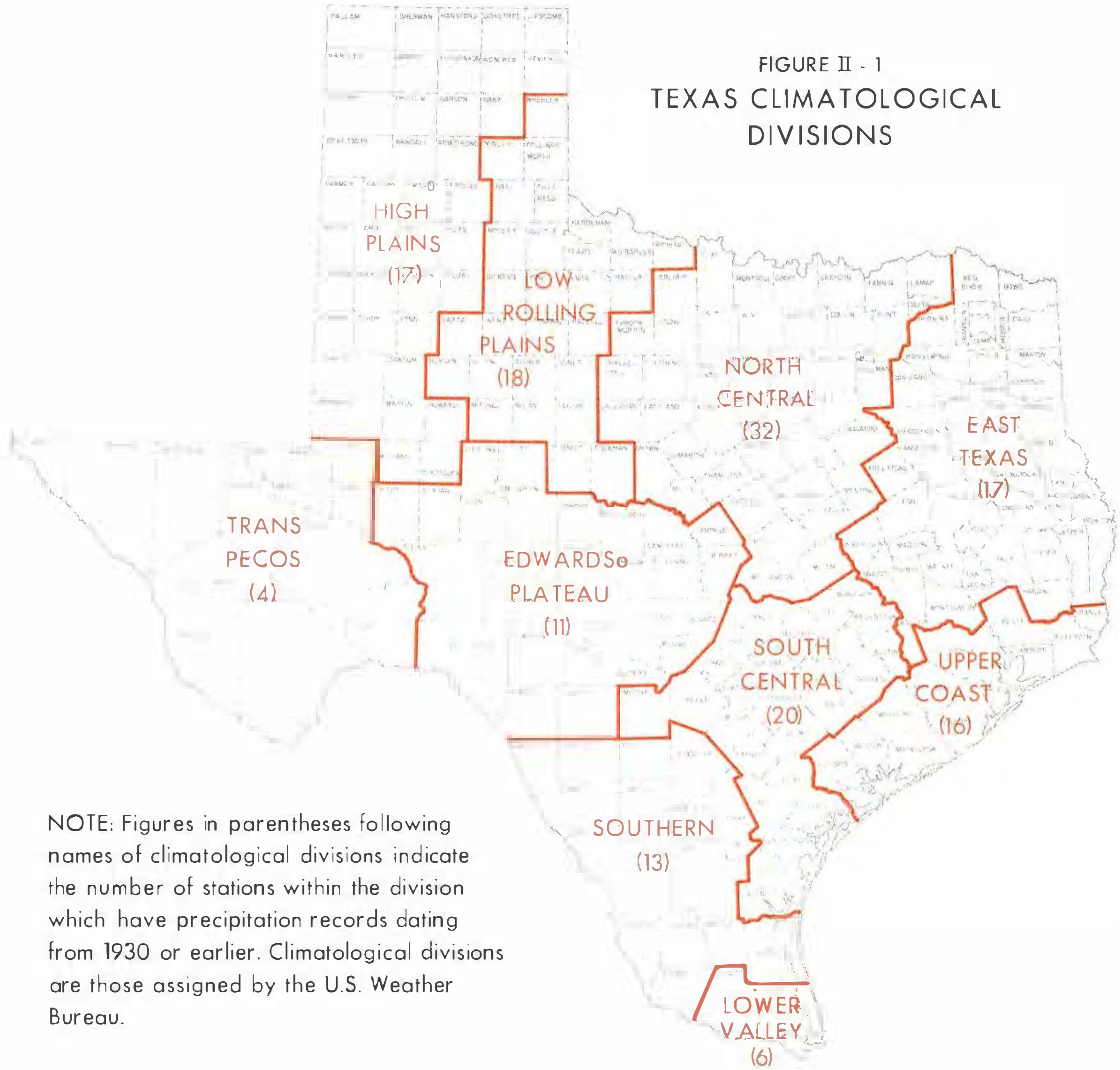


FIGURE II - 1
TEXAS CLIMATOLOGICAL DIVISIONS

NOTE: Figures in parentheses following names of climatological divisions indicate the number of stations within the division which have precipitation records dating from 1930 or earlier. Climatological divisions are those assigned by the U.S. Weather Bureau.

atuœ spread between the coldest and warmest month generally increase with distance from the Gulf of Mexico and with latitude.

In addition to the influence of latitude and proximity to the Gulf of Mexico, physiography exerts an important influence on average annual temperature in Texas, with higher elevations having lower average annual temperatures. This effect is particularly striking in far West Texas.

Evaporation

Lake surface evaporation is influenced by such factors as air and water temperature and wind movement, and generally increases across the State from east to west. While rainfall offsets evaporation to a large extent in East Texas, the western part of the State has high rates of evaporation, with only a low rainfall to help in reducing its effect. This results in lake evaporative losses which are low to moderate in East Texas, but high to very high in West Texas.

As shown in Figure II-8, for the period 1940-1965 the average annual net lake surface evaporation rate was between 0 and 20 inches along the eastern edge of the State, and more than 80 inches in the Big Bend area of West Texas.

Droughts

During the period 1891 to 1960, Texas experienced 11 significant drought periods of varying severity and areal extent, which are shown below:

Most Severe	1954-1956	Seventh	1950-1952
Second	1916-1918	Eighth	1924-1925
Third	1909-1912	Ninth	1891a1893
Fourth	1901	Tenth	1937-1939
Fifth	1953	Eleventh	1896-1899
Sixth	1933-1934		

Table II-1o-Average Annual Precipitation in Texas By Climatological Divisions

CLIMATOLOGICAL DIVISION	AVERAGE ANNUAL PRECIPITATION 1/
High Plains	18.51
Low Rolling Plains	22.99
North Central	32.93
East Texas	45.96
Trans-Pecos	12.03
Edwards Plateau	25.91
South Central	33.24
Upper Coast	46.19
Southern	22.33
Lower Valley	24.27

1/ From "Decennial Census of United States Climate 1931-1960," U.S. Weather Bureau, 1963.

As the 1954-1956 drought was the most severe, and since it was immediately preceded by the fifth and seventh ranked droughts comprising a continuous series of years of rainfall deficiencies, this series—1950 through 1956—comprises the most intense 7-year drought period that the State as a whole has experienced within the 70-year period of rainfall records. Dendrochronological studies in the southwestern part of the United States suggest that the 1950-1956 drought period ranks among the most severe droughts of the past 400 years.

Records of streamflows during the 1950-1956 period provide a basis for evaluation of the dependable amounts of water which can be obtained from existing and proposed reservoirs.

Physiography

The wide range in physical conditions influencing 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 Plains, the Great Western Lower Plains, the Great Western High Plains, and the Rocky Mountain Region.

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

The Staked Plains, reaching an elevation of about 4 thousand feet above sea level in the Panhandle, is a part of the Great Western High Plains, an alluvial mantle extending east from the Rocky Mountains. In the Panhandle, and to a line marked by the caprock escarpment, the Staked Plains is known as the High Plains of Texas, characteristically level in land surface, relatively treeless, and semiarid. Below the caprock escarpment delineating the High Plains is the Edwards Plateau, roughly 35 thousand square miles of limestone, deeply dissected and rapidly drained, and ranging in elevation from about 2,600 feet above sea level in the west to about 700 feet in the east.

North and eastward from the Edwards Plateau, and southwest of the North Central Plains, is the Central Texas hill country, and the Llano area, marked by a turbulent geologic past.

The Balcones fault system strikes across Central Texas from Del Rio on the Rio Grande eastward to San Antonio, then northeastward, intersecting the Colorado River at Austin. This fault trend is of major significance in Texas, marking the boundary between lowland coastal plains and upland plains and plateaus. Above the fault system, on the Edwards Plateau and through Central Texas, streams are characteristically eroding and cutting through the land surface, while below the fault escarpment deep soils are deposited as sediment loads are released.

The North Central Plains is the southern extension of the Great Plains, and includes the West Texas Rolling Prairies, Grand Prairie, and East and West Cross Timbers regions. Level to rolling topographically, the area is a typically prairie environment, with the occurrence of timber increasing to the east.

The Balcones fault system marks the western edge of the Texas Gulf Coastal Plain, a part of the Coastal Plains extending along the Gulf from the Atlantic to beyond the Rio Grande. Rising from sea level at the Coast to around 550 feet above sea level below the fault system, the area is topographically rolling to hilly. It is marked by a heavy growth of pine and hardwood in East Texas, while in the more arid west, vegetation consists largely of post oak, and still further west, of treeless prairies.

Ground Water Resources and Development

Ground water aquifers presently supply about 75% of the water used in Texas. In the past, municipalities, industry, and irrigators, as well as rural inhabitants, have generally turned to this resource to satisfy their demands because of: (1) the widespread geographical occurrence of aquifers, (2) the absence of sufficient surface water supplies or lack of facilities for storing and distributing available supplies, and (3) the economic incentive—the relatively low costs of developing and pumping this resource in some areas as compared to the costs of construction of storage and treatment facilities for surface water supplies.

Table II-2.--Temperature Ranges Within U.S. Weather Bureau Climatological Divisions of Texas

(Degrees Fahrenheit)

STATION	JANUARY AVERAGE MINIMUM	JANUARY AVERAGE MAXIMUM	JANUARY AVERAGE	JULY AVERAGE MINIMUM	JULY AVERAGE MAXIMUM	JULY AVERAGE
			High Plains Division			
Amarillo*	23.5	49.8	36.7	67.0	94.2	80.6
Lubbock*	25.4	53.0	39.2	66.5	92.4	79.5
Midland*	30.9	57.1	44.0	71.2	94.5	82.9
			Low Rolling Plains Division			
Abilene*	32.8	56.4	44.6	72.1	94.3	83.2
Wichita Falls*	30.6	52.9	41.8	73.3	96.9	85.1
			North Central Division			
Dallas*	36.0	55.8	45.9	75.3	94.5	84.9
Fort Worth*	34.9	56.0	45.5	74.9	95.9	85.4
Waco*	37.8	58.2	48.0	74.3	96.6	85.5
			East Texas Division			
Nacogdoches	38.4	58.5	48.5	71.5	93.0	82.3
			Trans-Pecos Division			
El Paso*	29.5	56.3	42.9	68.9	94.9	81.9
			Edwards Plateau Division			
San Angelo*	34.3	59.4	46.9	72.7	96.9	84.8
			South Central Division			
Austin*	40.5	60.3	50.4	73.9	95.1	84.5
San Antonio*	41.6	62.3	52.0	73.9	94.0	84.0
Victoria*	46.0	64.8	55.4	74.6	91.7	83.2
			Upper Coast Division			
Galveston*	48.4	60.4	54.4	78.6	88.6	83.6
Houston*	43.6	63.6	53.6	73.8	92.1	83.0
Port Arthur*	43.7	62.5	53.1	72.7	91.0	81.9
			Southern Division			
Laredo*	47.0	68.4	57.7	76.0	99.0	87.5
			Lower Valley Division			
Brownsville*	52.2	70.5	61.4	75.5	92.5	84.0

* Airport Station.
Source: U.S. Weather Bureau—based on records for 1931-1960.

In projecting future water requirements in Texas and evaluating sources of supply for these future demands, there are, however, several major constraints on ground water as a firm, long-range supply:

1. More ground water is being removed in many areas of the State than is being replaced by natural recharge. In effect, the resource is being mined. This is particularly critical in areas where ground water constitutes the only source of suitable water supply.

2. Lack of adequate quantitative information on the maximum safe yields and recharge potentials of aquifers has handicapped the development of effective management programs for many important aquifers.

3. Ground water quality is threatened by the discharge of wastes, by increases in mineralization as a result of recycling of irrigation return flows and seepage losses, and saline water intrusion caused by modification, through pumping, of the natural hydrodynamics of aquifers.

4. **Under present Texas statutes dealing with water law, potential developers of ground water have no legal protection with respect to continued availability and use of these supplies.**

Without properly planned, positive management programs, aquifers may be over-developed or improperly developed, resulting in possible general economic decline and losses of businesses, premature depletion of supplies locally, and loss of capital investments in wells, pumps, and distribution facilities.

Ground water will nonetheless continue to constitute an important part of the total future water supply of the State. Proper management of aquifers and optimum conjunctive use of ground and surface water resources will be essential in many areas if the total future water requirements of these areas are to be met most economically.

Major Aquifers

During the period 1957 through 1962, the Board, in cooperation with the U.S. Geological Survey, conducted reconnaissance investigations and studies of the ground water resources of the State. Data collected from these studies, as well as previous and subsequent investigations, resulted in the delineation of the major and minor ground water aquifers in Texas, the locations and extent of which are illustrated in Figures II-2 and II-7.

A major aquifer is herein defined as one which yields large quantities of water in a comparatively large area of the State. Major aquifers from which ground water is withdrawn include the Ogallala Aquifer, Alluvium Aquifer, Edwards-Trinity (Plateau) Aquifer, Edwards (Balcones Fault Zone) Aquifer, Trinity Group Aquifer, Carrizo-Wilcox Aquifer, and the Gulf Coast

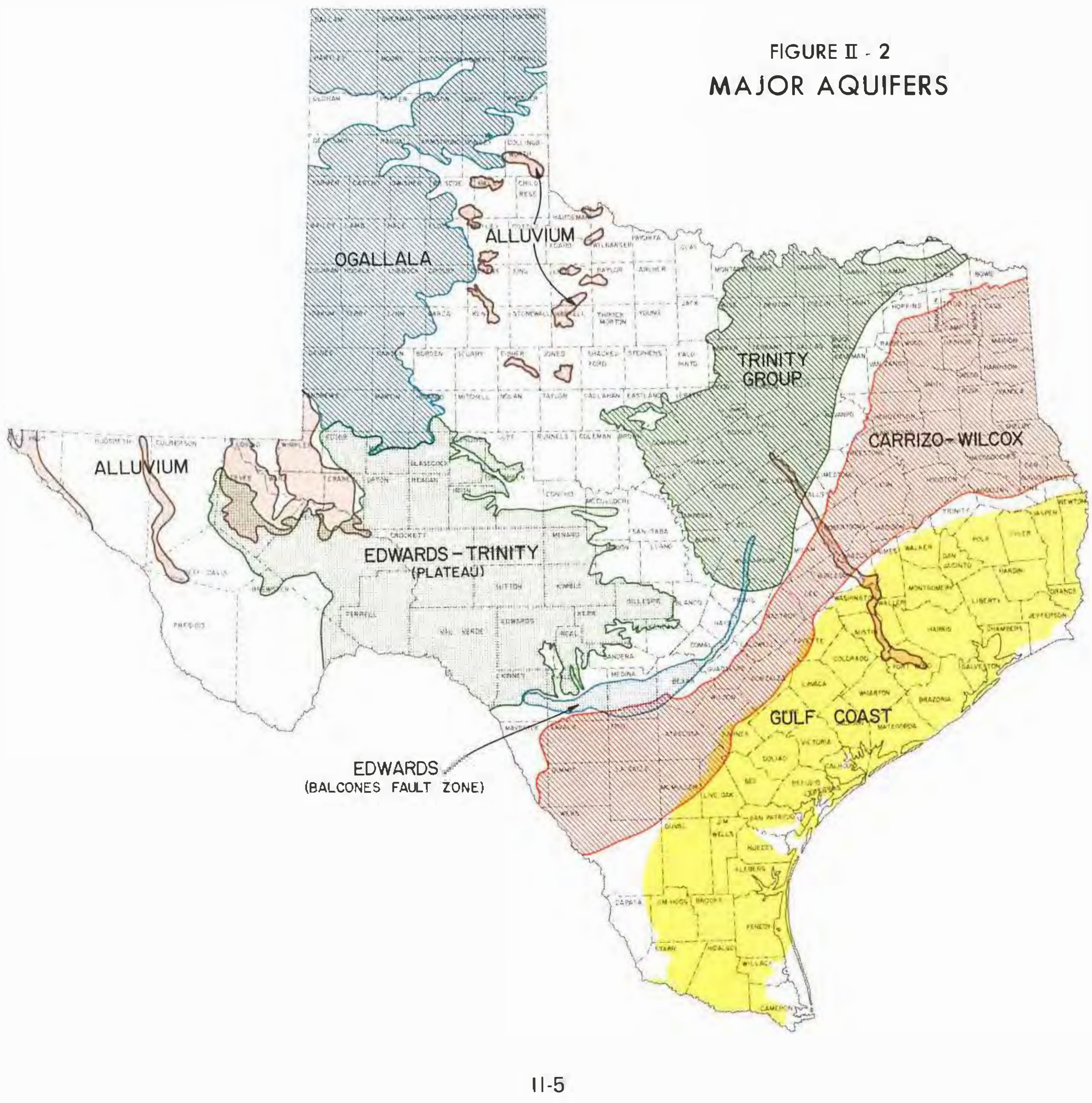


FIGURE II - 2
MAJOR AQUIFERS

Aquifer. Collectively, these aquifers supply most of the ground water used in the State.

Ogallala Aquifer

The Ogallala Formation of Pliocene age occurs at or near the surface over much of the High Plains area of northwest Texas. The formation consists of alternating, commonly lenticular beds of silt, clay, sand, gravel, and caliche, reaching a maximum known thickness of more than 900 feet in southwestern Ochiltree County.

For the most part, water-bearing areas of the Ogallala Formation are hydraulically connected, except where the Canadian River has separated the formation in the North Plains from that part in the South Plains.

The zone of ground water saturation in the aquifer ranges in thickness from only a few feet to more than 400 feet. The thickest saturated sections of the aquifer occur in the northeastern part of the South Plains, principally in southern Carson County. In the large irrigation area north and west of Lubbock, the saturated interval generally ranges between 100 and 300 feet. In areas south of Lubbock, this saturated zone is generally between 50 and 150 feet thick.

Depth to water in the aquifer ranges between 100 and 200 feet throughout much of the South Plains; however, in heavily pumped areas of the South Plains and in parts of the essentially undeveloped areas of the North Plains, depths to water commonly exceed 300 feet. Yields of wells range from less than 100 gpm (gallons per minute) to more than 2,000 gpm, averaging about 500 gpm.

Natural recharge to the Ogallala Aquifer results from precipitation on the land surface and underflow from that part of the aquifer in New Mexico. The ground water moves slowly through the formation in a generally southeasterly direction toward the eastern escarpment of the High Plains.

Ground water in the Ogallala Aquifer generally contains between 300 and 1,000 mg/l of dissolved solids, of which calcium, magnesium, and bicarbonate are the principal constituents. The water is hard but suitable for most uses. Comparatively small, widely distributed areas of saline water occur, however, principally in and around large saline playa lakes and in the southeastern part of the South Plains where the water table is shallow. In these areas, solution of salt deposits (in and adjacent to large playas) and evaporation are largely responsible for the increase in the salinity of the ground water.

The Ogallala Aquifer in Texas is one of the most intensely developed ground water aquifers in the United States, presently furnishing water to more than 800 municipal wells, 400 industrial wells, and 63,000 irrigation wells. Pumpage for irrigation alone ranges from about 4 to almost 8 million acre-feet annually, depending on the amount of precipitation occurring during the irrigation season. The average annual depletion of ground water by pumpage in the South High Plains is considerably greater than the estimated average annual natural recharge to the aquifer in this area. Figure II-3, a hydrograph of a well in one of the heavily pumped irrigation areas of the South Plains, illustrates the magnitude of historical water level declines typical of such areas of heavy pumpage.

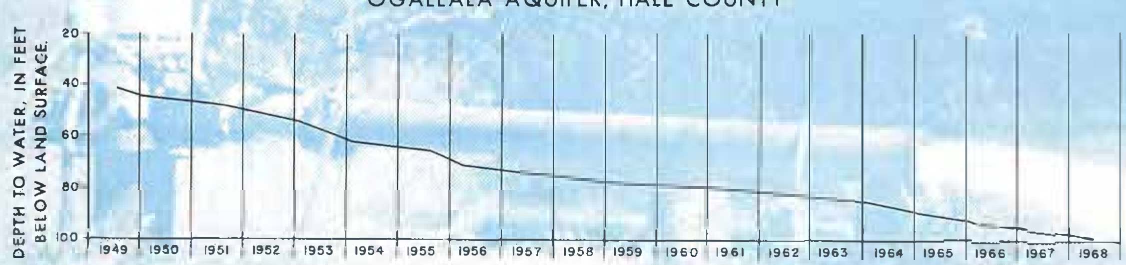
On the basis of preliminary studies of the hydrology and hydraulic characteristics of the aquifer, there is estimated to be on the order of 280 million acre-feet of water remaining in the aquifer which is economically recoverable from storage. However, at least one-third of this water occurs in the rugged breaks along and principally north of the Canadian River, where large-scale irrigation is not feasible; part occurs in the South Plains in areas where soils are not irrigable; and a small part is too saline for irrigation use.

Detailed investigations of the Ogallala Formation being conducted by the Board, Federal agencies, universities, and local ground water districts centered in the High Plains are principally oriented toward more

FIGURE II - 3

WATER LEVEL DECLINE

OGALLALA AQUIFER, HALE COUNTY



efficient use and management of existing supplies and increasing recharge to the aquifer. These investigations must be enlarged to provide information adequate to develop operational criteria for a program of conjunctive use of residual ground water supplies and supplemental surface water proposed for importation to the High Plains through the Texas Water System.

Alluvium Aquifer

Deposits of alluvium, both stream deposited sediments and windblown materials, occur in many parts of Texas. They generally consist of alternating and discontinuous beds of silt, clay, sand, and gravel of recent geologic age. In some areas, these deposits contain comparatively large volumes of ground water, and the five largest and most productive of these local aquifers collectively make up a major aquifer in Texas.

In the El Paso area and the El Paso Valley, alluvium and bolson deposits ranging to more than 5,000 feet thick contain fresh ground water to depths of about 1,400 feet. Large-capacity wells completed in this aquifer commonly yield between 1,000 and 1,500 gpm and supply large volumes of water for irrigation and municipal use. Preliminary studies indicate that water from the aquifer, and the limited surface water supplies locally available, are not sufficient to supply projected future fresh water needs in the El Paso Valley.

Alluvium and bolson deposits extending from northeastern Hudspeth County to northern Presidio County supply large volumes of water for irrigation. Large-capacity wells completed in the aquifer yield up to 2,500 gpm. At the present rate of pumpage, however, it is projected that these supplies will be largely depleted before the year 2020.

In the upper part of the Pecos River drainage system in Texas, deposits of alluvium ranging up to 1,500 feet or more in thickness yield large volumes of water used principally for irrigation. This aquifer also supplies municipal and industrial water needs in this region, including supplies for the cities of Monahans and Pecos. Legal rights to the ground water in a large area of the aquifer in northwestern Winkler and northeastern Loving Counties have been acquired by the City of Midland as a potential source of future supply for that city; however, these supplies will furnish only a part of Midland's projected future water needs.

In parts of this aquifer in the Trans-Pecos area, the ground water is highly saline, and most of the water contains between 1,000 and 4,000 mg/l of dissolved solids. Salinity of the ground water has increased in some of the heavily pumped areas, and water quality may be a future constraint upon the full development of the aquifer.

Scattered, isolated areas of alluvium (principally erosional remnants of the Seymour Formation) furnish domestic, municipal, and irrigation supplies to areas of North and West Central Texas. These local aquifers in the upper Red and Brazos River Basins vary greatly in thickness, but in most areas the saturated interval is less than 100 feet. Pumpage at times and in local areas has exceeded the rate of natural recharge. Yields of large-capacity wells range from less than 100 gpm to as much as 1,300 gpm, with the average being about 300 gpm.

The quality of ground water in these local aquifers in North Central Texas varies widely from place to place but generally ranges from less than 500 to more than 2,500 mg/l of dissolved solids, and salinity has increased in many heavily pumped areas to the point that the water has become unsuitable for domestic and municipal use. Ground water in these areas also contains relatively high concentrations of nitrate, which are considered to be undesirable for human consumption.

Along the Brazos River between northern McLennan County and central Fort Bend County, stream deposited alluvial material ranging from less than 1 to about 7 miles wide supplies comparatively large volumes of ground water used principally for irrigation. Thickness of the saturated interval in the aquifer ranges to 85 feet or more, with the maximum thickness of saturation occurring in the central and southeastern part of the aquifer.

The chemical quality of ground water in the Brazos River alluvium varies widely, even within short distances, and in many areas concentrations of dissolved solids exceed 1,000 mg/l. The soils of the Brazos River Valley which are irrigated with the ground water are generally sufficiently permeable, however, so that soil salinity problems have not developed from use of the water.

Edwards-Trinity (Plateau) Aquifer

The Edwards-Trinity (Plateau) Aquifer underlies the Edwards Plateau and extends westward into the eastern part of the Trans-Pecos region of Texas. The aquifer consists of water-saturated sand and sandstone of the Trinity Group and limestone of the overlying Fredericksburg and Washita Groups of Cretaceous age.

These water-bearing units range to more than 1,000 feet in thickness, and large-capacity wells completed in fractured and cavernous limestone locally yield as much as 3,000 gpm. Concentrations of dissolved solids in the ground water vary widely, although calcium, magnesium, and bicarbonate are commonly the principal constituents, and the water is generally hard. The salinity of the ground water generally increases toward the west, where the aquifer is overlain by younger geologic formations.

The Edwards-Trinity (Plateau) Aquifer supplies numerous small cities and communities with water. Industrial supplies are also obtained from the aquifer locally, principally for petroleum processing. Natural discharge of ground water from the aquifer constitutes a substantial part of the base flow of several streams, including the Pecos, Devils, Nueces, Frio, and Llano Rivers.

Ground water supplies of the Edwards-Trinity (Plateau) Aquifer have proved difficult to develop, however, because of the irregular distribution of permeability in the limestone beds and the variable thickness of the lowermost sand and sandstone beds. In heavily pumped areas, water levels have declined significantly. Sustained heavy pumpage over long periods would result in substantial depletion of the base flows of streams draining the plateau, thus reducing somewhat the surface water supplies of these river basins.

Edwards (Balcones Fault Zone) Aquifer

The Edwards (Balcones Fault Zone) Aquifer extends from central Kinney County east and northeast into southern Bell County. It includes the Edwards Limestone and stratigraphically associated limestone beds of Cretaceous age. Conditions favorable for the development of extensive solution channels and cavities and the consequent accumulation of large volumes of ground water in these formations have resulted from faulting along the Balcones fault zone.

The Edwards (Balcones Fault Zone) Aquifer supplies municipal and industrial water to numerous cities and towns, including the total municipal water supply for the City of San Antonio. Capacities of wells operated by the city are among the largest in the world, some wells yielding over 16 thousand gpm each. Large industrial and irrigation supplies are also pumped from the aquifer. Water pumped from the aquifer in Bexar County for municipal and industrial use contains an average of about 300 mg/l of dissolved solids. Toward the west, the water is generally somewhat more mineralized. The water contains principally calcium, magnesium, and bicarbonate, and consequently is hard.

Some of the largest springs in the State result from natural discharge of ground water from the aquifer. These include Leona Springs at Uvalde, San Pedro and San Antonio Springs in San Antonio, Comal Springs at New Braunfels, San Marcos Springs at San Marcos, and Barton Springs at Austin.

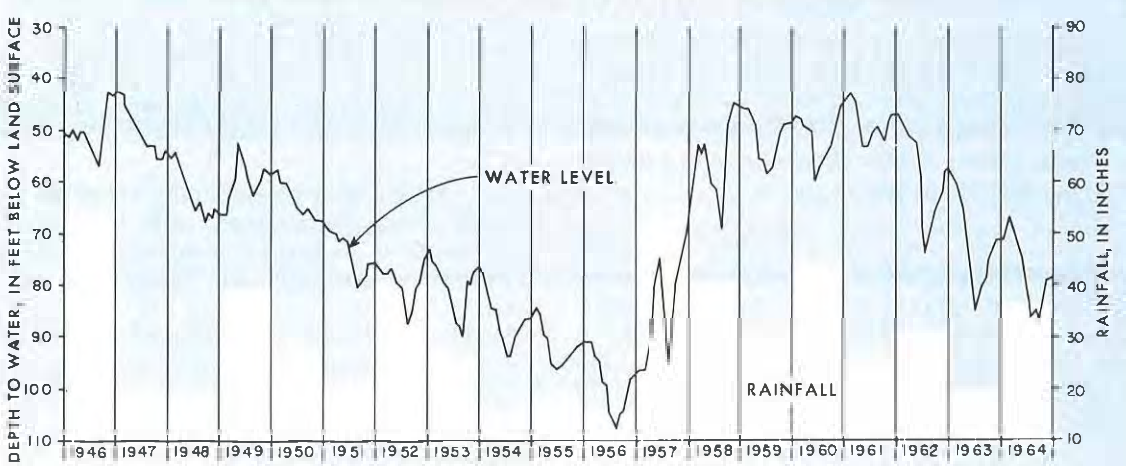
The aquifer is recharged partly by spring-fed streams. The West Nueces, Nueces, Frio, Sabinal, Medina, and Blanco Rivers and Seco, Hondo, and Cibolo Creeks, which head in the Edwards Plateau, flow across the Balcones fault zone, losing water into the extensive fracture system of the aquifer. Ground water moves rapidly through the aquifer, and the volume of water in storage and the rate of springflow change rapidly in response to precipitation. For example, the depletion of water in storage resulting from continuous heavy pumpage during the drought years 1948-1956 was almost completely restored during the wet years 1957 and 1958 (Figure II-4).

Highly saline water, also containing hydrogen sulfide gas, occurs in the Edwards and associated limestone beds south of the heavily pumped areas, and

FIGURE II - 4

RECOVERY OF WATER LEVEL WITH PLENTIFUL PRECIPITATION FOLLOWING 1948-56 DROUGHT

EDWARDS(BALCONES FAULT ZONE) AQUIFER, BEXAR COUNTY



the possibility of saline water intrusion and the necessity to maintain adequate minimum springflow are constraints against continued intensive pumping from the aquifer, particularly during drought periods.

Trinity Group Aquifer

The Trinity Group Aquifer extends over a large area of North and Central Texas. The Trinity Group of Cretaceous age, which ranges from only a few feet in thickness along the western edge of the quifer to more than 1,200 feet in the eastern part of the aquifer, furnishes most of the water produced by wells in this area.

Yields of large-capacity wells in the aquifer range up to several thousand gpm, but in thinner sections of the aquifer, where it supplies water principally for irrigation and domestic use, most wells yield less than 100 gpm.

Concentrations of dissolved solids generally do not exceed 500 mg/l throughout the western extent of the aquifer. Toward the east, where the water-bearing zones become deeply buried, usable quality water occurs to depths of about 3,500 feet, and dissolved solids concentrations range from 500 mg/l to about 1,500 mg/l near the fresh water-saline water interface. In some areas, improper well-completion methods and failure of well casings has allowed saline water in overlying beds to enter the fresh water-bearing zones.

The Trinity Group Aquifer has been intensively developed for municipal and industrial supply in the Dallas-Fort Worth area and formerly provided much of the municipal water supply for the City of Waco. In these heavily pumped areas, significant reduction in artesian head has occurred, thus lowering pumping levels and increasing pumping costs. Detailed studies of the aquifer presently being conducted by the Board will include the development of a mathematical model designed to predict the behavior of the aquifer under alternative management programs.

Carrizo-Wilcox Aquifer

The Carrizo-Wilcox Aquifer, one of the most extensive aquifers in Texas geographically, furnishes water to wells in a wide belt extending from the Rio Grande northeastward into Arkansas and Louisiana. The aquifer consists of hydrologically connected water-bearing sand, sandstone, and gravel of the Wilcox Group and overlying Carrizo Formation.

The Carrizo-Wilcox Aquifer is exposed at the surface along the northern and western edge of its extent, where it is recharged by precipitation and streams crossing the outcrop area. The water-bearing beds dip beneath the land surface toward the Gulf, except in the East Texas structural basin where the formations form a trough and are exposed at the surface on both sides of the trough's axis. The net thickness of the aquifer ranges from a few feet in the outcrop to more than 3 thousand feet in areas downdip.

Ground water in the aquifer is generally under artesian head downdip from the outcrop, and flowing wells are common in areas of low elevation. However, in heavily pumped irrigation areas, such as the Winter Garden area, and in municipal and industrial well fields, such as those north of Lufkin, water levels have declined and pumping costs have correspondingly increased significantly.

Yields of wells vary widely, but yields of more than 1,000 gpm from large-capacity wells are common, and some wells yield as much as 3,000 gpm. Usable quality water occurs at greater depths (up to about 5,300 feet) than in any other aquifer in the State.

Ground water in the deeper, heavily pumped areas of the aquifer contains principally sodium and bicarbonate and is therefore comparatively soft. However, hydrogen sulfide and methane gas occur locally, and iron, frequently in objectionable quantities, is common throughout much of the northeastern extent of the aquifer.

Where geologic formations overlying the aquifer contain saline water, as in the Winter Garden area, improper water well completion practices and failure of well casings from corrosion together with decline in the artesian head of the aquifer have resulted in interformational leakage of saline water.

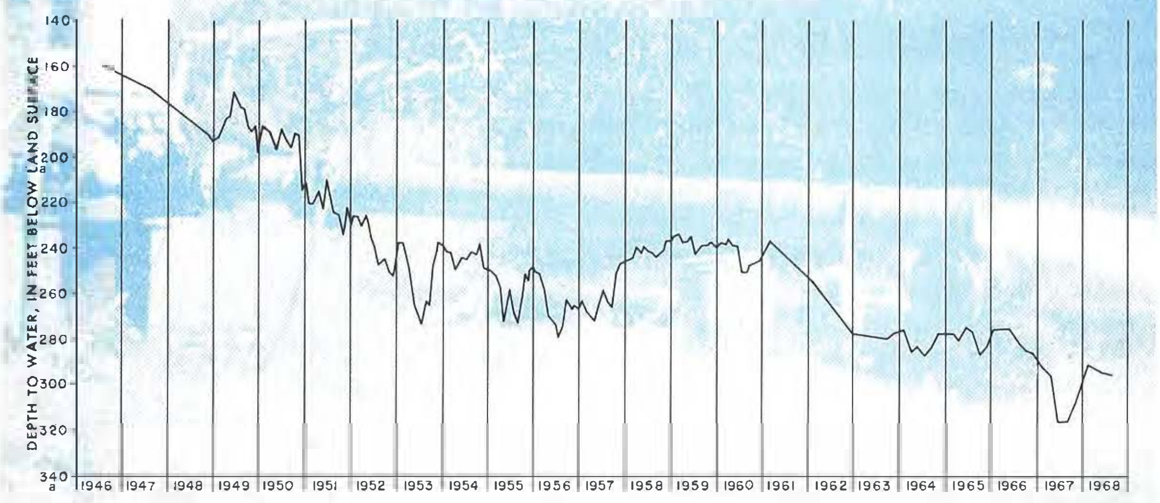
Ground water from the Carrizo-Wilcox Aquifer is used for irrigation in the Winter Garden area and for municipal and industrial use in Angelina and Nacogdoches Counties. The municipal and industrial use in these two counties has exceeded 20 million gallons of water per day.

The aquifer will not support the present irrigation development in the Winter Garden area in the future. In 1964, more than 360 thousand acre-feet of water was pumped from the aquifer for irrigation in this area, greatly exceeding the estimated average annual natural recharge. Declining water levels, as illustrated in Figure II-5, in the heavily pumped area, and the associated economic liability of escalating pumping costs, will result in substantial reductions in pumpage for irrigation in the Winter Garden area in the future. The potential for artificial recharge of the aquifer is planned to be evaluated by the Board. The potential for prolonging the productive capacity of the Carrizo-Wilcox by a management program of ground water recharge and pumpage in conjunction with the supplemental imported surface water supply proposed under the Texas Water Plan will also be evaluated.

FIGURE II - 5

WATER LEVEL DECLINE

CARRIZO-WILCOX AQUIFER, ZAVALA COUNTY



Gulf Coast Aquifer

The Gulf Coast Aquifer covers most of the Coastal Plain from the Lower Rio Grande Valley northeastward into Lousiana, extending about 100 miles inland from the Gulf. The aquifer consists of alternating clay, silt, sand, and gravel beds belonging to the Catahoula, Oakville, Lagarto, Goliad, Willis, Lissie, and Beaumont Formation, which collectively form a regional, hydrologically connected unit.

Fresh water occurs in the aquifer to depths of more than 3 thousand feet, and tremendous quantities of water are pumped for municipal, industrial, and irrigation use. In the Houston metropolitan area, including the Pasadena and Baytown areas and the associated industrial complex, on the order of 300 million to 350 million gallons is pumped daily for municipal and industrial use. Large-capacity wells yield individually as much as 4,500 gpm in this area. In the central and southern parts of the Coast, the net thickness of water-bearing zones in the aquifer decreases and yields of wells are somewhat less, although locally wells may yield as much as 3 thousand gpm.

The aquifer is recharged by precipitation on the surface and seepage from streams crossing the outcrop area. The rate of natural recharge is estimated to be sufficient to sustain the present level of pumpage from the aquifer. In some areas where the ground water is essentially undeveloped, substantial volumes of potential recharge are rejected. Probably the principal factor restricting maximum development of this resource is the limited capability of the aquifer to transmit water from areas of recharge to areas of pumpage.

Throughout most of the eastern part of the aquifer the ground water is low in dissolved solids, generally containing less than 500 mg/l. Sodium and bicarbonate are commonly the principal constituents, and the water is comparatively soft. The presence of iron and dissolved gases and slight acidity of the water are local problems that frequently require appropriate pretreatment prior to use.

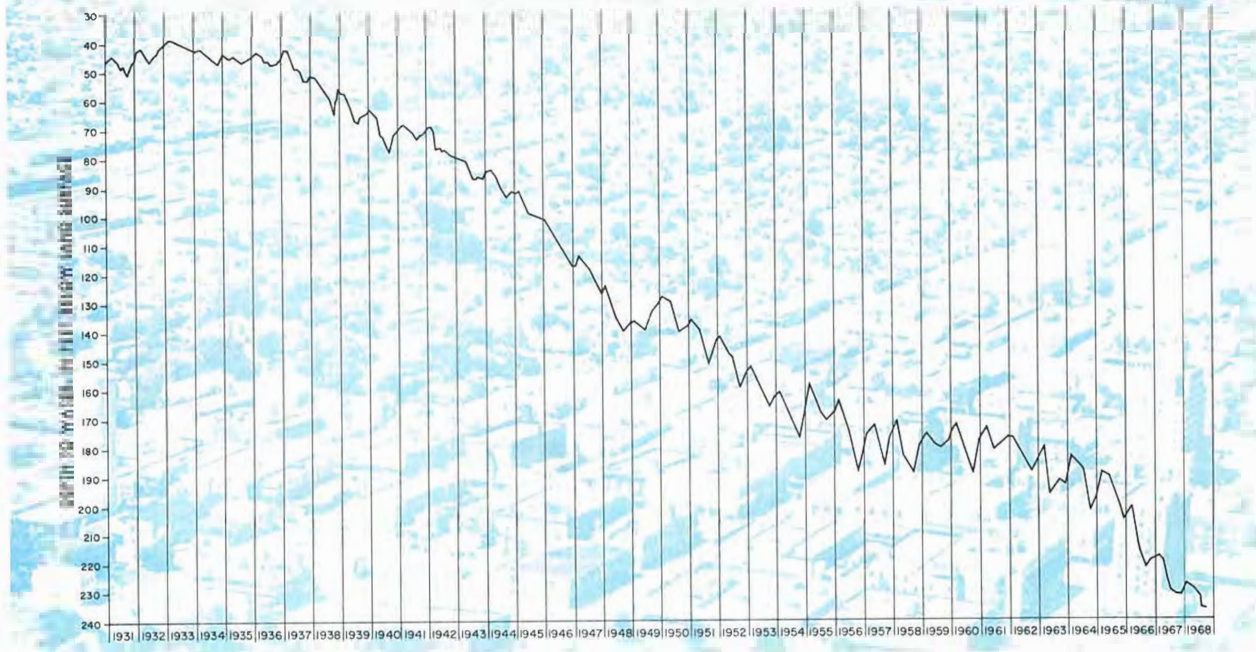
The ground water generally becomes more saline in the southern part of the aquifer, and in some areas highly saline water overlies the fresh water and also underlies the aquifer at relatively shallow depth. In the Lower Rio Grande Valley, ground water pumped from the aquifer for irrigation and municipal use contains between 1,000 and 1,500 mg/l of dissolved solids in most areas.

Sustained heavy pumpage in local areas has caused several serious problems, and there is a probability of more widespread problems in the future unless the aquifer is properly managed. Declining water levels (Figure II-6) have increased pumping lifts, required the installation of larger pumps in many wells, and increased overall pumping costs. In addition, it has been necessary to reconstruct many wells and replace pumps at greater depths to accommodate the declining pumping levels. Intrusion of saline water into the aquifer has occurred in the Galveston, Baytown, and Texas City areas and threatens other areas of concentrated pumpage along the Coast. Subsidence of the land surface, which is at least partly the result of ground water pumpage, has become a serious problem in the Baytown-Pasadena area and along the Houston Ship Channel.

FIGURE II - 6

STEADY WATER LEVEL DECLINE FROM CONTINUED HEAVY MUNICIPAL AND INDUSTRIAL PUMPING

GULF COAST AQUIFER, HARRIS COUNTY



The Gulf Coast Aquifer will continue to furnish large volumes of municipal, industrial, and irrigation supplies in the future. Proper management of the aquifer will be essential, however, to prevent excessive local declines in pumping levels, saline water intrusion, and land subsidence.

Minor Aquifers

The minor aquifers in Texas are important and in some areas the only sources of water supply. The location and general extent of some of these aquifers are shown in Figure II-7. Others, not shown, are described below and are significant in the areas they supply with ground water.

Edwards-Trinity (High Plains) Aquifer

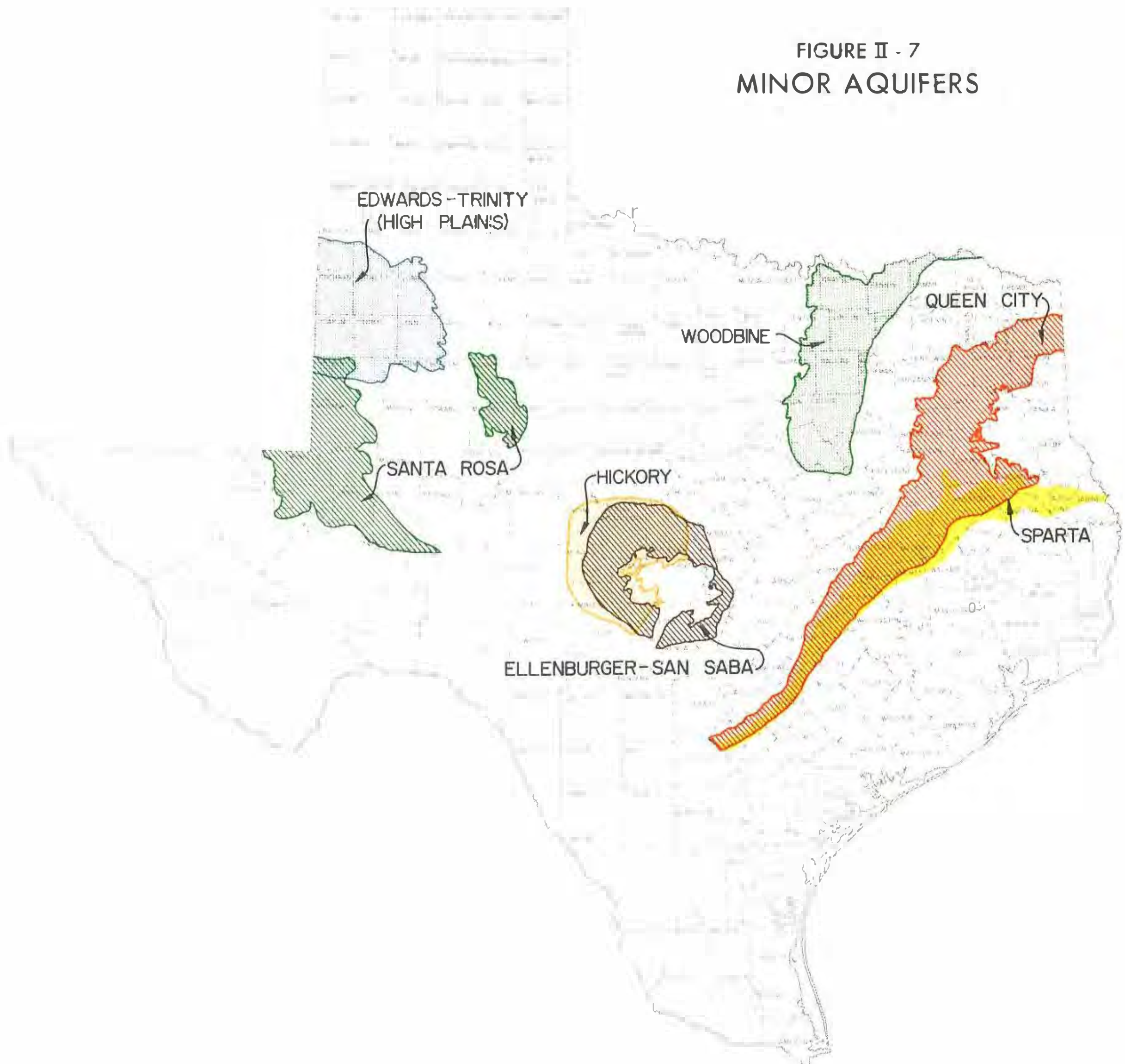
The Edwards-Trinity (High Plains) Aquifer underlies the Ogallala Formation in the southern part of the South Plains. The aquifer is composed of thin, locally discontinuous sand and sandstone of the Trinity Group and overlying shale and limestone of the Fredericksburg Group of Cretaceous age.

Small quantities of water are produced from the aquifer for irrigation, principally in Lynn and Borden Counties, and for mining (secondary oil recovery). The quality of the water varies widely from place to place, and in some areas the ground water is too saline for most uses other than mining. The aquifer probably cannot be relied upon to furnish any significant future ground water supplies in the High Plains.

Santa Rosa Aquifer

The Santa Rosa Formation of Triassic age consists principally of interbedded shale, sand, sandstone, and conglomerate. It underlies the Ogallala Formation throughout much of the High Plains, is exposed at the surface east of the Plains escarpment, and underlies alluvium in the upper Pecos River drainage area. Its maximum thickness occurs in the central part of the South Plains, but in this area the water is highly saline.

Ground water from the formation is used for domestic and livestock supply, municipal, industrial, and mining (principally for secondary oil recovery) supplies, and for irrigation. In Scurry, Mitchell, and western Nolan Counties, the aquifer supplies municipal, indus-



trial, and irrigation water to wells as much as 450 feet deep. Yields of wells in this area generally range between 200 and 300 gpm. In the southwestern part of the aquifer, ground water is pumped for municipal use in Winkler County, and for mining use (principally for secondary oil recovery) from wells up to 1,200 feet or more in depth in other areas. Yields of wells generally do not exceed about 300 gpm, and concentrations of dissolved solids range from less than 100 to more than 4,000 mg/l in the areas where the resource has been developed.

Comparatively recent exploratory drilling in the northern part of the South High Plains has led to the development of irrigation and municipal supplies from the aquifer in localized areas. Although the water is comparatively low in dissolved solids, the sodium content is high and continued use of the water for irrigation may therefore be limited.

Bone Spring-Victorio Peak Aquifer

The Bone Spring Limestone and the Victorio Peak Limestone of Permian age underlie a narrow north-trending topographic basin between the Guadalupe Mountains on the east and the Diablo Plateau on the west, in the northeastern part of Hudspeth County in the Trans-Pecos area of Texas. Ground water has collected in joints, fractures, and solution cavities in these limestone beds. The distribution of permeability is erratic, and yields of wells vary widely, ranging from about 150 to more than 2,200 gpm.

Large-scale irrigation supplied by the aquifer developed in the Dell City area about 1948. Water levels in wells in that area have declined substantially in recent years as the result of irrigation pumpage. The water generally contains between 1,000 and 8,000 mg/l of dissolved solids, and although suitable for irrigation under the irrigation methods practiced, it is undesirable for municipal and domestic use. In 1967, the community of Dell City constructed a small desalt plant which now provides a high quality municipal supply using this ground water source as feedwater.

Blaine Aquifer

The Blaine Aquifer comprises usable quality water-bearing zones of the Blaine Formation of Permian age in Collingsworth, Childress, Hardeman, Cottle, and King Counties. Ground water occurs principally in fractured and cavernous gypsum and dolomite beds.

Most of the water produced from the aquifer is used for irrigation and livestock, and yields of wells vary from only a few gpm to more than 1,500 gpm. The ground water presently being pumped generally contains between 2,000 and 4,000 mg/l of dissolved solids, of which calcium and sulfate are commonly the principal constituents. Salinity of the water sometimes increases during sustained pumpage as saline waters underlying the fresh water-bearing sections are drawn into wells through the extensive fractures and solution channels.

Use of the water for irrigation is generally restricted to salt-tolerant crops and to areas where soils are permeable, drainage is adequate, and water can be applied in large quantities to prevent a buildup of salinity in the soils.

Ellenburger-San Saba Aquifer

The Ellenburger-San Saba Aquifer, made up of limestone and dolomite of the San Saba Member of the Wilberns Formation of Cambrian age and the Ellenburger Group of Ordovician age, yields domestic, municipal, industrial, and minor irrigation supplies in the middle Colorado River Basin. The formations are exposed at the surface within a circular area surrounding the Llano Uplift, where fresh water from precipitation and streams crossing the outcrop migrates downdip through fractures and solution channels. The aquifer reaches a thickness of more than 1,000 feet.

Ground water occurring in the aquifer is commonly under artesian head. Natural discharge by springs supports the base flows of streams, including the Llano, San Saba, Pedernales, and the main stem of the Colorado River. Yields of wells range to as much as 1,000 gpm. In most places, the water is comparatively low in dissolved solids, but hard.

The Ellenburger-San Saba Aquifer will support additional pumpage in the future without depleting storage and significantly affecting springflow.

Hickory Aquifer

The Hickory Aquifer underlies the Ellenburger-San Saba Aquifer in the Llano Uplift region and presently furnishes most of the ground water used in this area. The aquifer is made up principally of sand and sandstone of the Hickory Sandstone Member of the Riley Formation of Cambrian age, and ranges to more than 400 feet in thickness.

Yields of wells completed in the aquifer generally range between 200 and 500 gpm, although a few wells have yielded more than 1,000 gpm. Irrigation within the area is supplied by water from the Hickory Aquifer, as are municipal needs for the cities of Mason and Brady and the communities of Melvin and Eden. Eden is supplied by a well more than 4 thousand feet deep. Except in the Brady area where municipal pumpage has lowered water levels slightly, there has been little, if any, net decline in water levels since development of these supplies. If properly managed, the aquifer is capable of supporting considerable future development.

Dissolved solids concentrations of water pumped from the aquifer commonly range from about 300 to 500 mg/l.

Woodbine Aquifer

Water occurring in sand and sandstone beds of the Woodbine Aquifer furnishes municipal, industrial, and small irrigation supplies throughout a relatively extensive area of the State from northern McLennan County northward to the Red River. The aquifer is exposed at the surface within a narrow belt from McLennan County to southeastern Cooke County, dips eastward, and reaches a maximum thickness of about 600 feet.

Yields of wells completed in the aquifer range from less than 100 gpm to about 700 gpm. The quality of the water varies widely from place to place, although throughout much of the downdip extent of the aquifer sodium and bicarbonate are the principal constituents and the water is comparativelv soft. Locally, relatively high iron concentrations limit the full potential development of the supplies available. The aquifer will support additional pumpage if properly planned and managed; however, variations in quality may limit development.

Queen City Aquifer

The Queen City Aquifer extends from southwestern Wilson County in the Nueces River Basin northeastward into the Sulphur River Basin. The aquifer consists principally of sand and loosely cemented sandstone. It is exposed at the surface throughout much of its extent in northeast Texas and dips gently toward the southeast beneath younger geologic formations.

The aquifer supplies water for domestic, livestock, municipal, and industrial use in East Texas and provides irrigation supplies in Wilson County in the San Antonio River Basin. Yields of wells are generally low, few exceeding 400 gpm. Concentrations of dissolved solids are generally low; however, throughout parts of the aquifer in northeast Texas the ground water is acid and locally contains excessive concentrations of iron. Additional supplies are available for future development provided pretreatment, where required, is economically feasible for the intended use.

Sparta Aquifer

The Sparta Aquifer, which underlies the Queen City Aquifer, extends from southeastern Wilson County northeastward to the Texas-Louisiana line in Sabine County. Sand beds of the Sparta Formation, which make up the aquifer, dip south and southeast from their area of outcrop and range in thickness to approximately 300 feet.

Water from the Sparta Aquifer supplies numerous towns, communities, State correctional institutions, irrigated areas, and several industrial firms, as well as domestic and livestock purposes, and additional supplies could be developed. Large-capacity wells, producing principally from thick sand beds near the base of the formation, generally yield 400 to 500 gpm, some as much as 1,200 gpm. Ground water produced from the aquifer is generally low in concentrations of dissolved solids.

Effective Utilization of Ground Water Supplies

The term *ground water management* has been used increasingly in the field of water resources and represents one of the measures offering potential value for successful operation of major Texas aquifers either independently or conjunctively with surface water supplies.

The underground resources of concern encompass not only the ground water itself but also the storage capacity underground and the capability of aquifers to transmit water from areas of recharge to points of extraction for use.

The objective of such management is the operation of underground resources by carefully calculated procedures: to produce water at minimum cost; to protect the usability of the aquifer; to extend the life of a ground water basin; or to maintain water quality at a desirable level. Once the objectives have been defined, the procedures and criteria of operation necessary to produce that result must be determined. This requires detailed knowledge of the nature of the ground water basin involved, its hydraulic characteristics, sources of water, recharge areas and amounts, the amounts and rate of water extraction, pattern of extraction, standards of well construction, pollution hazards, waste possibilities, cost of ground water and alternative supplies, authority to insure successful management, economics, and water rights and legal constraints. In short, it is necessary to establish definitively all those factors which make it possible to predict the performance of the aquifer under varying conditions.

A successful ground water management program may require that each water user be faced with the need to give up one or more of his avenues of totally independent action in order to effect a common benefit. If the users of a ground water basin recognize a need for a management program of an integrated water supply, they must be willing to accept an alternative to the philosophy of ground water capture. The incentive is generally in the area of economics.

In the San Antonio, Houston, and High Plains areas, with a firm surface water supply, the advantages inherent in a management program utilizing the ground and surface water resources are very great. The legal complexities of instituting such a system are formidable, but an objective appraisal of these opportunities is essential.

Surface Water Resources and Development

Surface water resources in Texas as used herein include those waters flowing in intrastate streams, those waters in interstate streams assured to Texas under compacts and treaties, and the water allocated to Texas under the terms of the draft compact on the Red River. These surface water resources are summarized below, and are described in more detail by river and coastal basins in Part IV.

Availability and Variability

During the period 1931-1960, Texas received an average of about 413 million acre-feet of precipitation annually—principally in the form of rain. If this were evenly distributed over the State's land area, it would amount to an average annual precipitation of approximately 28 inches. In reality, however, average annual precipitation ranges from about 55 inches at the eastern edge of the State to less than 8 inches at El Paso. Some of this precipitation is evaporated or transpired by vegetation, some enters the surface drainageways as

runoff, and some enters the subsurface where it moves downward into ground water bearing formations.

Runoff

The average annual runoff from the State (1924-1956 average) is about 39 million acre-feet, about three-fourths of which originates in the eastern one-fourth of the State. Average annual runoff decreases from about 1,100 acre-feet per square mile at the eastern boundary of the State to practically zero in large areas of extreme West Texas. Figure II-8 illustrates the long-term average annual streamflows of the major rivers of the State, which indicates the geographic variation of runoff.

Runoff varies sharply not only areawise but timewise. During the wet period 1940-1946, the average annual runoff was about 59 million acre-feet, whereas during the dry period 1950-1956, the average was about 24 million acre-feet.

About 10% of the total runoff from Texas comes from the coastal areas, where possibilities for capture and use of the water are limited because reservoir sites are unavailable. This runoff contributes essential fresh water inflows to coastal bays and estuaries in many areas, however.

Quality

The quality of water is generally defined in terms of its chemical, physical, and biological characteristics. To these principal measurable water quality parameters may be added physiological and esthetic properties, such as taste, color, and odor, which may frequently result from the interrelationship of two or more of the major water quality characteristics.

Chemical materials are present to some degree in all natural waters, either in inorganic or organic form, or both. The presence of inorganic chemicals results largely from the solution of soluble minerals in geologic material through or over which water flows. The principal inorganic constituents most common in natural surface waters include silica, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, and nitrate. Other constituents which may be present, usually in very small concentrations, include iron, fluoride, manganese, boron, and phosphate. Lead, lithium, strontium, beryllium, iodide, bromide, chromium, zinc, copper, barium, aluminum, among others, may also be present but generally only in trace quantities. Dissolved gases, usually carbon dioxide and occasionally hydrogen sulfide, may also be present.

The sum of these dissolved constituents makes up the total dissolved solids content of the water, and the relative concentrations of several of these and the state of chemical equilibrium among the dissolved constituents largely determines the alkalinity or acidity of the water. Hardness of water is generally due to the presence of calcium and magnesium.

Most natural waters unaffected by the presence of municipal, industrial, or agricultural pollutants do not contain organic chemicals, although natural organic material may be present due to decaying vegetation. Natural organic materials may impart coloration, and the utilization of oxygen by biological organisms during their digestion (decomposition) of natural organic matter may deplete the supply of dissolved oxygen in a stream. Natural organic acids sometimes produced by decaying vegetation may also contribute to the acidity of a stream.

The concentration of dissolved solids in water may be expressed in a variety of terms, but is most commonly expressed on the basis of weight per unit volume, generally in milligrams per liter.

Physical characteristics of water include color, temperature, turbidity, suspended solids (including floating material), and radioactivity. Color, although not necessarily harmful unless caused by the presence of toxic pollutants, is undesirable in water supplies for human consumption and for certain industrial uses. Turbidity, or the degree of clarity of water, results from the presence of colloidal or fine-grained suspended material. The erosion of soils and other geologic material and the decay and decomposition of vegetation contribute to the load of suspended material carried by a stream. The temperature of water in part controls the dissolved oxygen content, as the solubility of oxygen in water decreases with increasing temperature.

Objectionable taste results from excessive natural mineral concentrations, particularly sulfate and chloride; and objectionable taste and odor may result from the presence of decomposed biological organisms, particularly algae. However, the presence of wastes (particularly nutrients) and their effects on the biological balance of a stream or reservoir are usually principally responsible for taste and odor problems.

The quality of the surface water resources of Texas varies widely across the State. The concentrations and proportional relationships of the various dissolved and suspended constituents in streams are the result of geographic variations in: geology; rates, frequency, and intensity of precipitation; evaporation; the quality of ground waters and the hydrodynamics of aquifers which contribute to the base flow of streams; vegetation; land use and land-management practices; and, of course, pollution resulting from the activities of man.

Plate 4 illustrates the chemical quality of water in existing major reservoirs, and the general range of quality of the major rivers and tributary streams of the State in terms of the discharge-weighted average concentrations of total dissolved solids. A discharge-weighted average represents the average concentration of dissolved solids in all flows of a stream over an extended period of time, and thus provides an indication of the quality of water which will be impounded in proposed and potential reservoirs included in the Texas Water Plan. Complete mixing of water in such reservoirs is inherently implied in such an approximation, although such conditions are rare.

Stream quality characteristics portrayed on Plate 4 illustrate the effects of both natural and man-made pollution in some areas, which are briefly described in Part IV. Abatement of man-made pollution over time and construction of authorized and proposed salinity alleviation projects, as well as local salinity control measures, will improve stream quality in many areas (Plate 4). On the other hand, increasing volumes of municipal, industrial, and agricultural return flows in the future will alter the present chemical quality of streams in some areas, as will construction of reservoirs. In streams where natural salinity problems exist, properly treated return flows may have beneficial effects locally.

Information upon which Plate 4 is based results from a long-term comprehensive basic data gathering program under a cooperative agreement between the Board and the U.S. Geological Survey, and from data collected by the State Department of Health, Federal Water Pollution Control Administration (formerly a part of the U.S. Public Health Service), the International Boundary and Water Commission, as well as independent studies by the Board. In some areas for which long-term streamflow and water quality data are not available, stream quality has been computed on the basis of data collectecd periodically, knowledge of the geology and climate of the drainage area, and comparison of these periodic data with long-term data available from nearby streams influenced by similar geologic and climatic factors. Sufficient data are not yet available in some areas with which to accurately define stream quality characteristics.

In addition, sufficient data are not available to define accurately the effects of recently completed major reservoirs. In most cases, the effect of these newly constructed reservoirs on the weighted average chemical quality of downstream flows is not believed to be sufficient to alter the general ranges shown on Plate 4. One notable exception, however, is the upper Colorado River Basin. Prior to construction of Robert Lee Reservoir, the discharge-weighted average concentration of dissolved solids in the river exceeded 500 mg/l as far downstream as Mills County. The quality of the river should improve as a result of this project, and this projected improvement in quality is approximated on Plate 4.

The discharge-weighted average quality of major streams and principal tributaries as illustrated on Plate 4 is not necessarily indicative of the time-weighted average quality, which reflects the frequency or percentage of days of flow during which a particular concentration of dissolved solids is equaled or exceeded. For example, in western areas of the State where much of the total annual streamflow of unregulated streams may result largely from infrequent floodflows, which are generally low in dissolved solids concentrations, the discharge-weighted average for the historical period of record may have been exceeded most of the time during the intervening periods of more saline low flow. Conversely, however, throughout much of the eastern half of the State, the indicated ranges in discharge-weighted average quality of most major streams are rarely, if ever, exceeded.

When considering diversion of water from a stream for specific uses on a day-to-day basis, and in managing stream quality for fish and wildlife, recreation, or other beneficial uses, it is essential to know the quality duration characteristics. Stream quality criteria promulgated by the Texas Water Quality Board are established on this basis; thus, the discharge-weighted average stream quality characteristics for many streams illustrated on Plate 4 are not necessarily consistent with existing State stream quality criteria, nor are they intended to be.

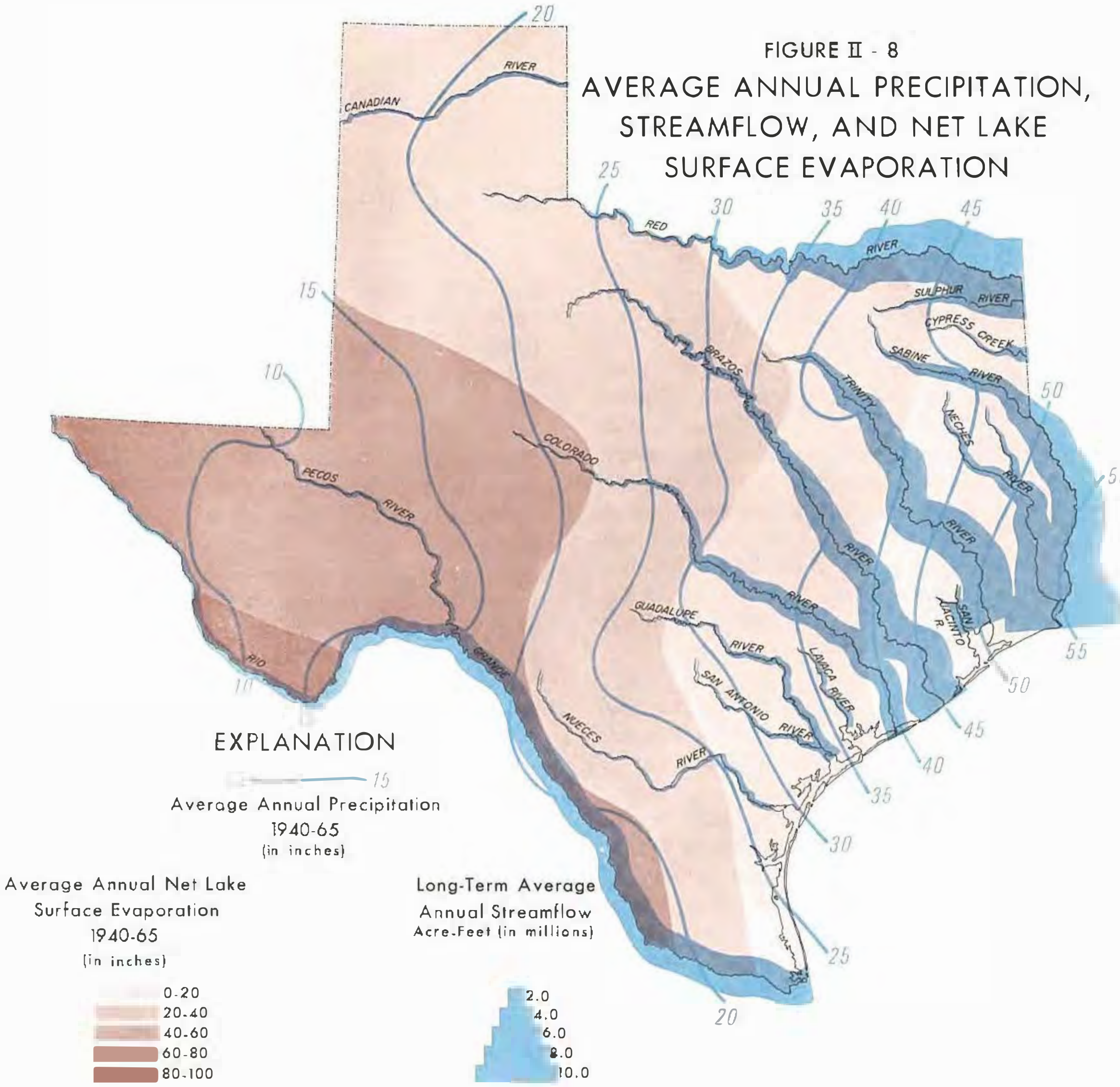
Evaporation and Sedimentation

Surface water stored in reservoirs is depleted by evaporation, and storage capacity is gradually reduced through the accumulation of sediment. Analyses of evaporation rates and sediment loads are important, therefore, to reservoir design and staging studies.

Evaporation losses from reservoirs are particularly significant in Central and West Texas, as shown on Figure II-8. The Board has developed indices of the monthly evaporation rates for each one-degree quadrangle in Texas for the period 1940 through 1965. A continuing program of data collection of evaporation rates and analysis of these data is underway. In addition to an expanded program of measuring evaporation rates, research has been conducted into the possible methods of retarding evaporation from reservoir surfaces.

Many streams in Texas carry very large volumes of sediment produced by erosion from contributing watersheds, particularly during periods of heavy rainfall. These sediments are trapped in the first downstream reservoir, thus progressively reducing its storage capacity. Storage capacity for sediment is specifically included in the design of new reservoirs, but improvement in overall basin systems of development may be effected by construction of catchment basins for sediment above water supply reservoirs, channel improvement, reforestation, and land management practices.

FIGURE II - 8
AVERAGE ANNUAL PRECIPITATION, STREAMFLOW, AND NET LAKE SURFACE EVAPORATION



Waste-Water Reuse and Reclamation

Proper management and maximum possible reuse of municipal, industrial, and agricultural waste water is an integral concept of the Texas Water Plan. The magnitude of the future water requirements of Texas requires that return flows be recognized as an essential and valuable water resource that should be managed and administered conjunctively with other water resources.

Ratio of Return Flow to Water Use in Texas

The ratio of municipal return flow to water use varies widely across the State, depending upon such factors as total population, population density, economic base, and costs and quality of the supply, with climate the most important single factor. The ratio decreases generally from east to west, ranging from more than 0.8 in southeast Texas to about 0.13 in the El Paso area. In general, present return flow-water use ratios in most municipalities of the State range between 0.4 and 0.7, the weighted mean being 0.6.

Industrial return flow-water use ratios vary over a much wider range of values than do municipal ratios. They are somewhat lower in areas of the State where water supplies are limited; frequently the cost of water to the industry is the controlling factor. The present average industrial return flow-water use ratio in the State is about 0.88, which includes those industries using large quantities of saline water. The Statewide average for industries not using saline water is about 0.69.

Future return flow-water use ratios are projected to decrease for both municipalities and industry. The ratio for a city generally declines as the population increases. Declining supplies and increasing costs of municipal supplies will result in increased efficiency of municipal water use in the future. Industrial water supplies will also be used more efficiently as readily available supplies decline and costs of these supplies increase. In projecting future return flows for the State, municipal and industrial return flow-water use ratios were adjusted for this assumed increase in efficiency of water use.

Present Distribution of Municipal and Industrial Waste Waters

Municipal and industrial return flows in Texas presently total more than 0.8 and 1.3 million acre-feet per year, respectively. Saline water makes up about 64% of the present total industrial water intake; consequently, about 0.5 million acre-feet of the approximately 1.3 million acre-feet of industrial return flow is saline. These saline return flows are for the most part discharged into the coastal bays and the Gulf of Mexico. Non-saline municipal and industrial return flows in the State therefore total about 1.6 million acre-feet annually.

About 29% of the total municipal and industrial return flow derived from the use of fresh water originates in the Houston metropolitan area, most of which is discharged into the Galveston Bay System. Approximately 15% of the total originates in the Dallas-Fort Worth area and is discharged into the Trinity River. These return flows also provide inflow to Galveston Bay. About 10% enters Sabine Lake from the Sabine River and the Orange area. The Neches River, which also discharges into Sabine Lake, presently receives about 8% of the total return flow, and the Brazos, Colorado, San Antonio, and Canadian River Basins collectively receive approximately 18% of the total. The remaining 20% of the 1.6 million acre-feet of annual total return flow is distributed throughout the other drainage basins of the State.

Of the 0.8 million acre-feet of municipal return flow presently discharged to natural watercourses of the State, about 27% enters the Trinity River from the Dallas and Fort Worth metropolitan areas, while about 19% of the total is derived from the Houston metropolitan area. The San Antonio and Brazos River Basins receive approximately 10 and 9%, respectively, followed by the Colorado and the Rio Grande Basins with 7 and 4%, respectively. The remaining 24% is distributed throughout the other major drainage areas of the State, with no single basin receiving more than 3% of the remaining municipal return flows.

About 37% of the non-saline industrial return flow originates in the Houston area, and is discharged into Galveston Bay. Approximately 15% originates in the Orange-Port Arthur industrial complex, and is discharged into Sabine Lake. The Neches River Basin receives about 13% of the total, principally from the Beaumont area, and this also enters Sabine Lake. Approximately 4% of the total industrial return flow is discharged into the Trinity River Basin, primarily from the Dallas-Fort Worth area, and the remaining 30% is distributed among the other basins of the State.

Direct Reuse of Waste Waters

Water reuse by industry in Texas is potentially a significant factor in long-range industrial water requirements and in projections of waste water returned to streams. The Board compiled detailed data from 3,100 industries in the State which during 1964 were using water at a rate of 10 thousand gallons per day or more. These industries, summarized by Standard Industrial Classification (SIC) groups in Table II-3, indicated that reuse was already being practiced to a significant degree, particularly in the natural gas products, paper and paper products, chemicals, petroleum and coal products, rubber and plastic products, and primary metal industries. Except in severely water-short areas, the present extent of industrial water reuse is dictated chiefly by economic considerations—the relative costs of reuse versus alternative supplies, and the costs of required waste treatment.

Municipal waste water is used for industrial purposes in several areas of the State. The large petrochemical complex at Odessa has utilized secondary treated municipal waste water from the City of Odessa for industrial purposes for a number of years. Additional extensive treatment is given the municipal waste water to remove phosphates and reduce suspended solids, hardness, silica, and alkalinity. After use by the industrial complex, part of the waste water is then used for secondary oil recovery.

Between 1944 and 1966, a large refinery and petrochemical plant at Big Spring used secondary treated municipal waste water from the city for boiler feedwater, and prior to 1955 also for cooling water. Rates of use ranged from about 75 million to more than 475 million gallons yearly. Discontinuance of use of this source resulted from development of a new source of fresh water supply in the area, which proved to be more economical.

Municipal waste water from the City of Andrews is also presently being reclaimed by oil companies for secondary oil recovery.

The use of municipal effluents for irrigation is an accepted practice in many parts of the United States and is also widely practiced in Texas, particularly in the western part of the State. A survey of 1,200 Texas cities, conducted by Texas Technological College for the Board, indicated that part or all of the sewage effluent from 135 towns and cities in the State was being used for irrigation of an agricultural crop in 1965. Large municipalities putting their effluent to such

Table II-3.--Recirculation of Industrial Water in Texas During 1964

STANDARD INDUSTRIAL CLASSIFICATION GROUP (SIC)	PERCENTAGE OF INDUSTRIES IN GROUP REPORTING RECIRCULATION	PERCENTAGE OF TOTAL WATER REQUIREMENTS SERVED BY RECIRCULATION
Natural Gas Products	17.0	98.6
Ordinance	0.2	12.3
Food and Kindred Products	10.8	65.8
Tobacco	0.0	0.0
Textile Mill Products	0.5	3.4
Apparel	0.0	0.0
Lumber and Wood Products	10.7	82.7
Furniture and Fixtures	0.0	0.0
Paper and Paper Products	9.6	42.2
Printing and Publishing	10.8	29.1
Chemical and Chemical Products	8.0	55.2
Petroleum and Coal Products	7.0	92.1
Rubber and Plastic Products	10.7	93.3
Leather and Leather Products	0.0	0.0
Stone, Clay, and Glass Products	4.6	75.2
Primary Metals	5.7	76.6
Fabricated Metals	1.3	73.7
Machinery	1.7	95.0
Electrical Machinery	0.9	90.6
Transportation Equipment	1.0	65.6
Instruments	0.2	86.5
Miscellaneous Manufacturing	0.1	1.6
Nonmanufacturing Industries	3.2	84.1

beneficial use include San Antonio (up to 28 million gallons per day for irrigation of grass and cotton), Lubbock (2,100 acres of grain sorghum, wheat, and cotton irrigated with treated effluent), Amarillo, and Abilene. Other cities and towns supplying municipal waste water for irrigation include New Braunfels, Hale Center, Edinburg, Snyder, Muleshoe, Midland, Brownfield, Llano, and Fredericksburg.

Eight other towns were using municipal waste water for irrigation of parks, golf courses, or cemeteries, and several were using effluents for recreational purposes. In addition, the survey indicated that a number of municipalities were considering use of effluents for some type of irrigation in the near future.

The generally high nutrient content (nitrogen, phosphorous, potassium, etc.) of these effluents contributes to agricultural yields which are generally greater than those realized from conventional irrigation without fertilization. No known incidence of disease directly related to these projects has been documented, although detailed epidemiological studies have not been conducted.

The use of return flows specifically for recharge of ground water aquifers is not practiced in Texas, although practiced on a large scale in California and on Long Island, New York. Deep percolation of a part of the applied irrigation waters probably occurs in municipal projects, however, and recharge to aquifers may result.

Indirect Reuse of Waste Waters

In reality, indirect reuse of municipal, industrial,

Table II-4.--Percentage of Annual Municipal and Industrial Return Flows Projected to Originate in River and Coastal Basins of Texas by the Year 2020

BASIN	INDUSTRIAL	MUNICIPAL	TOTAL (EXCLUDING IRRIGATION)
Canadian	2.6	1.3	2.0
Red	1.0	3.1	2.1
Sulphur	1.0	1.0	1.1
Cypress	1.4	0.5	0.9
Sabine	13.0	3.5	8.2
Neches	12.3	3.7	8.0
Neches-Trinity	13.1	2.9	8.1
Trinity	3.9	25.1	14.4
Trinity-San Jacinto	1.9	0.7	1.2
San Jacinto	24.4	18.7	21.5
San Jacinto-Brazos	6.6	4.4	5.5
Brazos	3.4	9.6	6.4
Brazos-Colorado	1.3	0.6	1.0
Colorado	2.1	6.0	3.9
Colorado-Lavaca	1.2	0.2	0.8
Lavaca	0.2	0.3	0.2
Lavaca-Guadalupe	5.1	0.2	2.8
Guadalupe	1.2	1.6	1.4
San Antonio	0.9	7.2	3.9
San Antonio-Nueces	0.2	0.3	0.3
Nueces	0.3	0.8	0.6
Nueces-Rio Grande	2.2	4.9	3.6
Rio Grande	0.7	3.4	2.1
	100	100	100

Total projected industrial return flow:	3,065,000 acre-feet per year
Total projected municipal return flow:	3,031,000 acre-feet per year
Total:	6,096,000 acre-feet per year

and agricultural waste waters has long been practiced in the State. Waste waters discharged into streams and rivers by municipalities and industry commonly make up a part of the water supply for downstream cities, industries, and irrigators. In large streams, dilution, natural decay, and biological decomposition of remaining pollutants in these return flows is generally sufficient to allow downstream reuse of these diluted waste waters, including municipal use, with conventional treatment commonly provided raw water supplies. In smaller streams, however, treated effluent from cities and/or industry may presently comprise a substantial part of the water supply for a downstream city. Consequently, as existing natural water supplies become fully developed and return flows continue to increase in volume, standards for effluent quality will become more stringent and in some areas advanced waste treatment will become mandatory.

Waste-Water Reuse and Reclamation in the Texas Water Plan

Total municipal and industrial return flows in the State are expected to exceed 3.6 million acre-feet per year by 1990 and 6.1 million acre-feet per year by 2020. Table II-4 shows the projected percentage of municipal, industrial, and total return flows (exclusive of irrigation return flows) for each of the river and coastal basins of the State by the year 2020.

These return flows, adequately treated and properly managed, will be a part of the total water resource available to supply downstream demands, including fresh water inflows for Texas' bays and estuaries. The potential for waste-water reclamation projects will still be great, however, and incentives for greater direct use of reclaimed water will increase due to increasing demands for water and higher costs of alternative supplies. Also, as waste-treatment requirements become more stringent and costs of such treatment increase, waste waters may become too valuable to discard in some areas.

Waste-water reclamation by industry will increase substantially, especially in water-short areas. Industrial use of reclaimed municipal waste waters has already been proven to be both feasible and economical. It is not unlikely that as regional municipal waste-treatment facilities become realities, planned industrial complexes can be developed to which treated municipal waste waters could be supplied through special distribution systems for renovation and reuse. It is probable that waste waters from these industrial complexes would again be reclaimed and further used beneficially, possibly for irrigation.

Properly controlled irrigation with treated waste waters offers great potential to agriculture in the State. Recharge of ground water aquifers with treated municipal and industrial waste waters, particularly those aquifers supplying irrigation water, can be expected to occur in the State. However, appropriate geologic conditions, adequate pretreatment, and proper management of such projects will be mandatory to prevent degradation of the quality of ground water supplies.

Renovation of municipal and industrial waste waters for direct municipal reuse presently is technically feasible, and may be economically practical in the future. A high degree of removal of presently known water-borne viruses can be attained by conventional waste-treatment processes followed by chlorination, and extensive studies of the effectiveness of virus removal by advanced treatment processes are underway. However, much additional investigation of the potential health hazard from direct reuse of waste waters for municipal purposes is needed. In Texas, as elsewhere throughout the Nation, extensive reuse for such purposes is improbable in the near future.

Desalting

Texas has significant saline water resources in some areas, some of which are amenable to desalting for the production of additional water supplies.

Municipally owned desalting plants are now in operation at Dell City in West Texas and Port Mansfield in the Lower Rio Grande Valley. In addition to these plants, the Office of Saline Water presently operates a one million gallon per day test facility at Freeport on the Gulf Coast, from which the City of Freeport obtains part of its water supply. The City of Plains in West Texas is installing a plant which should be in operation by early 1969. Also, there are numerous small desalt plants located throughout the State which are owned by private industry. Total desalting plant capacity in Texas for plants producing 25 thousand or more gallons per day presently totals more than 5.7 million gallons per day.

Statewide Studies of the Potential for Desalting

In May 1965, the Board, as a part of the comprehensive water planning program, entered into a contract with the U.S. Department of Interior, Office of Saline Water, to study the potential contribution of saline water conversion to future water supply in Texas.

Present and potential municipal and industrial water supplies for each of the 586 communities in the State with a population of 1,000 or more in 1960 were examined and screened on the basis of criteria designed to identify those communities for which desalting might be a feasible solution to their water needs. After screening, 37 cities were selected for detailed study, representing a cross section of the State with respect to population, economic base, geographic location, and degree and intensity of present and future water supply and water quality problems.

A uniform procedure was developed to calculate the relative costs of water supply produced by saline water conversion and supplies obtained from conventional fresh water sources to provide a base for cost studies in each of the study cities. Evaluation of the problems and costs of disposing of saline effluents associated with the conversion process was also made for each city studied.

The major conclusions resulting from this initial study were:

1. The unit cost of water is less or about the same for desalting as the cost of developing the most feasible alternative fresh water supply for 11 of the 37 cities studied: Beeville, Freer, Hebbronville, Italy, Kingsville, Port Mansfield, Rankin, Refugio, Dell City, El Paso, and Fort Stockton. The lower initial capital investment required for desalting compared to capital investments necessary to develop fresh water resources potentially available to these 11 cities was largely responsible for the economic advantage of desalting.

2. In the remaining 26 cities studied, the calculated unit cost of desalted water was found to exceed costs of developing conventional supplies for the cities.

3. Nine of the 37 cities studied are in the Lower Rio Grande Valley, and these cities warranted additional study because of their geographic proximity, the similarity of water problems in the area, and the possibility of providing economical water supplies through construction of one or more large desalting plants instead of smaller plants.

4. The cost of desalted water for each case studied ranged upward from a minimum of 30 cents per thousand gallons, or $98 per acre-foot. These costs would appear to make economically infeasible the development of irrigation supplies by the desalting methods considered in these studies.

Lower Rio Grande Valley Study

Following completion of the statewide study, the Board conducted a preliminary study of the economic feasibility of desalting sea water or saline ground water to supply projected future municipal and industrial water needs throughout the Lower Rio Grande Valley. Nine cases including various types and combinations of systems were studied in detail, capable of delivering 62.5

million gallons per day containing not more than 500 mg/l of dissolved solids. These cases considered combinations of: a single-purpose plant for producing desalted water only; a dual-purpose water-electric power system; and a triple-purpose system producing water, electric power, and anhydrous ammonia. Powerplants were sized at 113 and 120 megawatts, respectively, and for the triple-purpose facility, the anhydrous ammonia plant was sized at 500 tons per day production rate.

The results of the study indicate that:

1. Large-scale desalting plants offer an early interim solution for supplying additional municipal water to the Lower Rio Grande Valley, pending delivery of a firm long-term supply through the Texas Water System.

2. The cost of desalted water as calculated in the study, using the Gulf of Mexico as a source of supply, ranges from about 27 to 31 cents per thousand gallons delivered at the cities. The lowest unit cost of water is from the triple-purpose plant, which requires the largest initial capital investment.

3. The least expensive desalted water was about 27 cents per thousand gallons, or $88 per acre-foot, which would apparently preclude development of economically feasible irrigation supplies by desalting techniques.

West Texas Study

In June 1967, the Board entered into a second contract with the Office of Saline Water to make a preliminary evaluation of the feasibility of producing municipal and industrial water from desalting plants in the 2 to 20 million gallon per day size range for areas of West Texas.

Seven candidate areas in West Texas were selected for study on the basis of data developed in the earlier statewide study of the potential of desalted water supply for various Texas communities, and of data resulting from further planning studies by the Board. The areas studied were El Paso County; Reeves-Ward-Winkler Counties; Ector-Midland Counties; Crane-Reagan-Upton Counties; Taylor County; Childress-Hardeman Counties, including the City of Vernon and the areas served by the Greenbelt Municipal and Industrial Water Authority; and a combined eight-county area centered by the Ector-Midland Counties area. These study areas were subjected to preliminary engineering and economic evaluations of scale of plant capacity and cost of desalted water supplies as compared to alternative fresh water supplies. One or more cases for study were developed in each area, utilizing a variety of desalting systems capable of delivering water containing not more than 500 mg/l of dissolved solids.

The results of the West Texas study indicate that saline ground water in several regions of West Texas can be desalted at reasonable costs to partially fulfill future needs for additional municipal and industrial water supplies in the area. The calculated cost of desalted water ranged from 36 cents per thousand gallons in El Paso County to a high of $1o15 per thousand gallons in the Childress-Hardeman Counties area. A major cost in the production of desalted water is the disposal of the effluent resulting from the conversion process.

The study concluded that calculated costs of desalting inland saline waters on a large scale for municipal and industrial use in some West Texas regions may be economically competitive with the cost of importing fresh water from more distant sources. However, the availability and quality of saline water required to support operation of large scale desalting plants for their assumed economic lives of 30 years is uncertain. The study also showed that certain specific dissolved minerals and gases in water from one of the largest saline aquifers in the West Texas region, the Capitan Reef, may require extensive chemical pretreatment, including the removal of sulfur, before the water can be desalted. The cost of such pretreatment, even after considering economic benefits from the recovery of sulfur as a by-product, is so significant that the economic feasibility of desalting this water for municipal and industrial use could be adversely affected.

The Waste Problem

Methods and costs of disposal of the waste effluents resulting from various desalting processes have proven to be critical factors in evaluating the economic feasibility of potential desalting projects in the State. Alternative methods considered by the Board in the desalting studies for disposal of this effluent included the use of evaporation ponds, lined to prevent leakage; injection into underground formations containing natural saline water; discharge directly into the Gulf, or into estuaries, navigation canals, and land drainage channels emptying into the Gulf; sale of the effluent to the petroleum industry for secondary recovery; and mixing with treated municipal waste waters.

Direct discharge into streams of desalting waste effluent mixed with municipal waste water may be feasible in special cases, but will require detailed study of pollution hazards. Sale of the effluent to the petroleum industry is probably the optimum method of disposition, but the market is lacking in many areas, and is subject to the life of oil reserves recoverable by secondary recovery in other areas.

Costs of properly designed and constructed evaporation ponds generally exceed the cost of subsurface injection. Deep well disposal of desalting effluents was considered the most desirable method of waste disposition during the Board's studies, and calculated costs of injection wells and related facilities in each of the candidate areas studied were generally used in economic evaluation of desalting projects.

Future Studies

Future studies by the Board will also include the evaluation of desalting as a treatment process for the renovation of municipal and industrial waste waters. As conventional sources of water become limited and more expensive to develop, it will become necessary to look to new supplies that might be developed by these processes.

Costs of desalting presently are too high to consider this process for producing irrigation water; however, in some areas of the State the use of saline irrigation return flows and ground water for irrigation water is causing salinity problems in soils. Plans are being made by the Board to study the application of desalting to the reclamation of saline irrigation return flows to determine the costs of such a program and the benefits that might accrue to the agricultural economy of an area.

Technological advances in desalting processes will be evaluated by the Board, and desalting projects supported where and when feasible. Studies by the Board and Federal agencies are continuing in various areas of West Texas to define more accurately the availability of saline water resources amenable to desalting techniques.

Weather Modification

Recurrent droughts alternating with periods of excessive rainfall common to Texas have generated a sustained interest in the possibilities offered by weather modification. Among the many weather modification efforts was an effort in the late 1950's to suppress hail in West Texas. An injunction was brought in that case against the experimenters. The Court ruled that the landowner has "natural rights" to the moisture in clouds, and can prevent a cloud seeder's efforts to dissipate the clouds. Prior and subsequent to this legal decision, many States promulgated legislation permitting, encouraging, controlling, and in some instances enjoining against weather modification operation activities within the respective States.

In 1967, Texas joined the group of States which had enacted weather modification statutes with enactment of the Texas Weather Modification Act. Under provisions of this Act, the Board is charged with the Act's administration. It may establish advisory committees and regulate or order such standards and instructions as necessary to carry out research, projects, or cooperative agreements with public or private agencies in weather modification. It further may control, obtain information, make such regulations, studies, investigations, and hold such hearings as necessary in the performance of the Board's powers and duties.

Two projects underway are related directly to weather modification activities in Texas. Texas A&M University under an agreement with the Board has initiated a quantitative study of the precipitable water available in the atmosphere in the area of Texas and adjacent States. The University of Texas under contract with the Board is conducting a census of cloud types and sky coverage at selected stations in West Texas, west of the 100th meridian, to determine the suitability of clouds in this region for cloud modification and precipitation control activities.

A third study, under an agreement between Texas A&M University and the Board, has as its objective a determination as to whether precipitation may be artificially induced to fall to the ground from warm clouds, the most common clouds in Texas. These investigations are in East Texas.

Texas has the statutory authority and potential for examining methods of producing additional water supplies through weather modification and precipitation management programs, and increased participation in weather modification operations is anticipated.

Out-of-State Sources of Supply

Maintenance of the State's present economy will depend largely on the future availability of a water supply imported into the State from out-of-State. Areas of eastern New Mexico also face the need for future supplemental water supplies, principally to maintain the irrigation potential of these areas.

To prevent possible overcommitment of intrastate supplies, and water assured the State under interstate compacts, no conveyance facility of the Texas Water System will be constructed without assurance that sufficient water supplies will be available to serve permanently the water requirements which the facility is designed to meet. Consequently, timing of negotiations required to obtain an imported supply is of critical importance in the Texas Water Plan.

Culmination of the Board's studies of future water resources projected to be available from interstate and intrastate sources and estimated total future requirements in the State indicate that at least 12 million to 13 million acre-feet of water from out-of-State sources will be required annually before the year 2020 to meet Texas' water needs. About 1.5 million acre-feet will be needed annually for areas of eastern New Mexico by 2020. A part of this total projected need will be required before 1990.

Potential Sources Studied

Preliminary studies by consultants to the Board included consideration of the Columbia River, the Missouri River, and the Mississippi River as potential sources of supply. It was recognized in these preliminary studies that any potential importation of water must be considered within the context of a regional plan for conservation and redistribution of water to serve needs in areas of several States.

The Western States Water Council, which includes the 11 western States, has reviewed several such regional plans. Although Texas is not a member of this organization, representatives of the Board have regularly attended meetings as observers. The Conference considers the water requirements of the 11 States and has studied possible means of meeting these requirements through regional action. Sources of water considered include the Columbia River, streams in Canada, and supplies from Alaska. Although it is apparently engineeringly feasible to develop such massive systems for transporting water, early detailed planning of such facilities does not appear probable. It is important to Texas, however, that such planning be initiated at an early date and the need for water in parts of Texas be considered in such planning, principally to meet the needs of the State beyond 2020.

From the standpoint of meeting needs for water in Texas and eastern New Mexico, which will develop in less than two decades, reconnaissance studies indicate that under present conditions the lower Mississippi River Basin is the most feasible possibility, with the point of diversion below most diversions for consumptive use in the Mississippi River Basin States.

Potential diversions from the lower Mississippi River will by necessity come from surplus flood waters in excess of the total future requirements of the Mississippi River Basin States, including requirements for navigation and control of salinity in the Mississippi River estuary, and maintenance of a desirable environment in all coastal bays of the region.

Construction of projects in the Mississippi River System have modified both the magnitude and seasonal regimen of flows of the main stem in the lower basin, and further development of the basin will result in additional regulation of Mississippi River flows. A comprehensive study of the Mississippi River Basin by the Corps of Engineers has been initiated and is scheduled for completion in 1972. Among other things, this study will (1) project total future water requirements in the basin to the year 2020 and beyond, (2) determine the magnitude of modifications of future river flows in the lower basin as a result of proposed upstream development, and (3) define potentially surplus water of the lower Mississippi River above all projected future in-basin needs.

On the basis of published data and information developed by the Corps of Engineers and Mississippi River Commission, the Board has made preliminary studies of potentially surplus flows of the Mississippi River below New Orleans. These studies suggest that surplus water would probably be available during only part of the year, thus necessitating storage of surplus flows available seasonally as well as surpluses from year to year.

WATER RIGHTS

Surface Water Law in Texas

Sources of water generally are categorized as surface or underground. Surface water may be classified either as diffused surface water or as water within a defined watercourse. Diffused surface waters are those which occur in a natural state in places on the earth's surface other than in a watercourse, lake, or pond. A watercourse is defined as an identifiable natural stream having a definite natural channel and originating from a definite source of supply; waters present in a watercourse may be subclassified as (a) ordinary or normal flow, (b) underflow, and (c) storm and flood water.

(a) The ordinary or normal flow of a watercourse has been judicially defined as a flow below the line "which the stream reaches and maintains for a sufficient length of time to become characteristic when its waters are in their ordinary, normal and usual conditions, uninfluenced by recent rainfall or surface runoff" [*Motl* v. *Boyd,* 116 Tex. 82,i286 S.W. 458 (1926)]i.

(b) The underflow consists of water in the sand, soil, and gravel immediately below the bed of an open stream, which supports the surface stream in its natural state or feeds it directly, together with the water in the lateral extensions of the subterranean water bearing material on each side of the surface channel.

(c) The storm and flood water is primarily the collected diffused surface water from recent precipitation.

The legal distinction between ordinary flow, underflow, and storm and flood flow is particularly significant in reconciling conflicting claims to the same water supply, which sometimes arise because of the dual recognition in Texas of both riparian and appropriation doctrines. The riparian right relates to and is concerned only with the ordinary flow and underflow of a stream. A riparian right does not attach to that portion of stream discharge comprised of storm and flood flow, and therefore generally will not attach to flood waters impounded by large reservoirs.

Diffused surface waters are considered to be private waters and are subject to capture and use by the owners of the surface estate. No State regulation of use is exercised with respect to diffused surface water until it reaches a watercourse.

Two basic doctrines of surface water rights are recognized in Texas, the prior appropriation doctrine and the riparian doctrine. The corresponding water rights perfected thereunder are commonly referred to respectively as appropriative rights and riparian rights. The riparian right arises by operation of common law concepts as an incident to the ownership of land abutting a stream or watercourse, requiring no act other than the acquisition of title to the land (but see the Water Rights Adjudication Act of 1967, discussed later). The appropriative right, on the other hand, is regulated by statute. It is not necessarily related to the land ownership and is today acquired by compliance with statutory requirements implemented by the rules and regulations of the Texas Water Rights Commission.

The Riparian Doctrine

Although not defined in Texas statutes, riparian rights are mentioned in legislative Acts. Some of these statutory references appear contradictory.

In 1840 the Republic of Texas adopted the Common Law of England as the rule of decision insofar as it was not inconsistent with the Constitution and Acts then in force. The judicial application and recognition of the riparian right concept in Texas began in 1856 with what appears to be the first reported Texas court decision involving any phase of water law (See *Haas* v. *Choussard,* 17 Tex. 588). In this case, the court quoted with approval the classic common law riparian doctrine that, except for his natural wants, a riparian user could not diminish the quantity of water in a stream that would otherwise flow past downstream riparian owners.

A subsequent series of court decisions created considerable contradiction and confusion. Initially, the courts held that irrigation was a natural use and that downstream riparian owners could not complain if upstream riparian owners consumed the entire water supply for irrigation. This was followed by contradictory decisions that irrigation was not a natural use of water, but was an artificial use. Still later, the courts held that if a particular stream was sufficiently large to permit irrigation without unreasonable impairment of the rights of downstream riparian owners, the use of water for irrigation would be lawful. In 1926 the entire subject of riparian and appropriative rights was considered by the Supreme Court of Texas in the case of *Motl* v. *Boyd,* 116 Tex. 82, 286 S.W. 458 (1926). The court concluded that since the Mexican Colonization Law of 1823 (1 Gammel, p. 28), all of the several governments which had been sovereign in the State had recognized the right of the riparian owner to use water, not only for his domestic and household use, but for irrigation as well. The riparian right was held to attach to the ordinary or normal flow of a watercourse.

However, in 1962 the State Supreme Court, in the case of *Valmount Plantations et al.* v. *The State of Texas,* 163 Tex. 381, 355 S.W. 2d 502, held that Spanish and Mexican grants do not have appurtenant riparian rights in the absence of specific grants of irrigation water.

The Prior Appropriation Doctrine

Historical Origin

The Prior Appropriation Doctrine evolved in the arid western States of the United States, from whence Texas water statutes were largely borrowed. Nevada, Colorado, and particularly Nebraska, contributed substantially to the text of early Texas water law.

With the exception of Texas and the comparatively small areas included in Spanish and Mexican land grants, the Western United States was a part of a vast public domain administered and distributed by the United States government. In those vast areas, the Federal government did not assert the same ownership of public water as it did of public land. Hence, the land was disposed of without regard to available water. Rights to streams were not acquired by any orderly or systematic administrative procedure.

The failure of the Federal and State governments to assert control over streams and dispose of them as a great public resource left water to be treated as though it belonged to no one, and could be appropriated in a manner similar to that of a gold claim. In the absence of public control, men took water from streams and used it; that is, they *appropriated* it—using the word *appropriate* in its ordinary sense—to take for one's own use. When water laws were enacted, this appropriation practice was legalized and the basis of such laws became known as the Doctrine of Appropriation. This concept is contrary on the one hand to the common law doctrine of riparian right (which strictly construed demands that water must not be taken from the stream unless it can be returned undiminished in volume), and on the other hand, to a public policy of permanent governmental control under a system whereby all water is disposed of by license, which had been adopted in some European countries, the British Colonies, and a few of the arid States.

Originally the Prior Appropriation Doctrine was simply that any one needing water had the right to take it. Changed conditions in the West, resulting from population growth, and the consequent increase in demand for water, produced many limitations and modifications. Early definitions of appropriations contained in court decisions do not agree. The following is a synopsis of early equitable concepts and/or doctrines which, in combination, form the basis of the Prior Appropriation Doctrine:

Doctrine of Priority.—Justice seemed to demand that when there was not water enough for all, those who first used water from a stream should have the superior right to continue that use, and the Doctrine of Priority resulted. The doctrine originated with the belief of the first settlers that their claims were superior to those of later comers, and they insisted that the owner of the last ditch or facility built should be the first to suffer when a stream failed to supply the needs of all. The first builders of water facilities could not anticipate how many were to follow. Unless protected by some such principle, the greater their success, the sooner they would be injured by the attempts of others to benefit by their experience. The general principle that among appropriators the first in time is the first in right is now a recognized rule in the water laws of the arid region and was so recognized by the end of the last century.

Doctrine of Relation.—Since many ditches were built about the same time, it became necessary to prescribe rules in determining when a right should attach. If the right should date from the time of actual use of the water, a premium would be placed upon poor construction. It might happen that during the construction of a large canal, smaller canals or those more easily built might be begun and completed and appropriate all water, leaving the large canal a total loss to its builders. To avoid this, the Doctrine of Relation was adopted; that is, the right does not date from the time the water is used but relates back to the time of the beginning of the work.

Modification As to Due Diligence.—To prevent abuse, the Doctrine of Relation, above, was modified by the provision that the work of construction must be carried on with "due diligence". Under the Doctrine of Relation, a water right is *initiated* when the work of construction begins, and dates from that time, but is not *perfected* until the water has been actually diverted and used. The question of "What is due diligence?" is a question of fact to be determined in each particular case, and when such diligence is not exercised, the right dates from the time of use.

Beneficial Use—Limit As To Quantity.—As scarcity of water led to the adoption of the Doctrine of Priority, the two led to the necessity of defining the quantity of water to which an appropriator should be entitled. While the early appropriators were entitled to protection in their use of water, the later comers had equal claim to protection from an enlargement of those uses. The first appropriator had the first right, but he did not have the right to take all the water he might want at any future time. His rights must, in justice to others, be defined as to quantity as well as to time. In theory, "beneficial use" has been made the measure of a right as to quantity. What constitutes "beneficial use," and the determination of the quantity of water so used, is left to the courts in most States.

Notice.—With the adoption of the Doctrine of Priority, the need to provide notice of the extent of rights already acquired became apparent. Such notice was needed both for the protection of the rights already in existence, and as a warning to intending investors of the extent to which the stream had already been adsorbed.

Initially, most western States, except Colorado and Texas, required the actual physical posting of a written notice at the intended point of diversion. While this procedure was undoubtedly an adaptation of the system of "posting" a gold or mineral claim with a physical monument containing a written description of the claim, there is little similarity between a stationary gold claim and the fluid movement of water on its way to the sea.

The diversion of water without any official record of the time or place of use produced much confusion and hardship when it became necessary to determine the priorities and amounts of appropriations. In early years, the absence of official records meant that facts which governed rights in the stream had to be established by testimony. Often this determination was required many years after the irrigation appropriation had begun and continued for several generations. Eyewitnesses to the early development frequently were unavailable. The memory of those actually present was often faulty. Wide discrepancies regarding the dates of beginning the work, the size of the ditches, and the amounts of water used were the rule rather than the exception.

To achieve greater permanence, and to afford something approaching actual notice, most state statutes eventually required public registration of the claim in the office of the county clerk. Inadequate supervision coupled with poor understanding of the law by appropriators resulted in a "system" whereby all one need do to claim his own stream or river was present a proper fee to the registry official with a document setting forth his claim.

For many streams appropriations have been initiated which aggregate to many times the available yield. Sometimes cities have claimed entire rivers without regard to earlier established concepts requiring "beneficial use." Disregard, carelessness, and misunderstanding of the law and its requirements evolved into habit; habit into community accepted custom; and custom in some instances became generally but erroneously accepted as law. Throughout the arid western States, it is today common for holders of these early filings to flaunt them as superior vested rights—absolute and secure against the State—when there exists no relation between "beneficial use" and the appropriation claimed, and the requirement of "due diligence" has been completely disregarded.

Development of Appropriative Rights in Texas

Prior to the 1870's, Texas water legislation was limited to a number of special laws granting franchises to particular canal companies and individuals for the construction of dams and canals to utilize specified quantities of water for beneficial purposes, and to an 1852 Act giving each County Commissioners Court administrative control over water distribution systems within the county.

Acts were passed in 1875 and 1876 which authorized the donation of public lands to canal companies for canal construction. These Acts were later construed to mean that the act of incorporating a canal company authorized the company to acquire a right to use water, but did not actually confer the perfected right.

The first effort to establish the Doctrine of Prior Appropriation within the State was made in the Irrigation Act of 1889. This statute was rewritten and reenacted in 1895. Both Acts declared that the unappropriated waters of every river or natural stream, within the arid areas of the State where irrigation was necessary for agricultural purposes, were the property of the public and subject to appropriation. A system of registration was established which required the filing of a sworn statement describing the proposed appropriation of water with a county clerk in the county where the point of diversion was to be located. As between appropriators, the first in time was to have a prior claim to a given water supply.

In 1913, the Texas Legislature rewrote the laws relating to the use of water. The new Act extended the classical system of prior appropriation to the entire State whereas the Acts of 1889 and 1895 had applied only to the arid portions of the State. A most important feature of the new Act was the establishment of a Board of Water Engineers with original jurisdiction over all applications to appropriate water. That agency has functioned since 1913, having been renamed the Texas Water Commission in January 1962 and the Texas Water Rights Commission effective September 1, 1965.

Certified Filings.—The 1913 Irrigation Act required everyone who had constructed or partially constructed a system for the diversion and use of water to file a sworn statement describing the system with the county clerk of the county where the point of diversion was located, if they had not previously done so in accordance with the Acts of 1889 and 1895. The Act also required anyone who had actually taken or diverted water for beneficial use prior to January 1, 1913, to file a certified copy of the previous statement describing the system and the amount and purpose for which water was diverted and used. An initial time limit of one year for compliance with the provision was later extended to 1916. The Act provided that those who filed with the Board "shall, as against the State, have the right to take and divert such water to the amount or volume thus being actually used and applied."

Together, the two statements filed with the Board came to be known as "certified filings" and are now so defined by statutes. Many of these filings declared an intent to irrigate several hundred thousand acres of land. Many of these large filings were never developed in accordance with the sworn statement describing the irrigation system, nor have the vast acreages been irrigated. Some of these undeveloped certified filings have been cancelled by subsequent action of the Texas Water Rights Commission. The extent to which other undeveloped certified filings should be recognized as vested rights to water use remains one of the several unresolved questions affecting optimum development of the water resources within the State. It is a matter of conjecture as to how many of these early rights could be maintained in litigation today since many declared appropriations (1) never *attached* by virtue of lack of due diligence, or (2) were never *limited* as to quantity measured by "beneficial use," or (3) have been *abandoned*.

Appropriation Permits.—The Irrigation Act of 1913 was revised and reenacted in 1917. A principal feature of the Act of 1917 authorized the Texas Board of Water Engineers to adjudicate water rights. This provision of the Act was held unconstitutional in 1921. The Act of 1917, without the adjudicative provision, was reported in the 1925 revision of the Texas Civil Statutes and, with numerous amendments, remains the statutory basis for appropriative right concepts in the State today.

Present-day statutes retain the cornerstone of the Doctrine of Prior Appropriation in that "as between appropriators, the first in time is the first in right." To this cornerstone, the statutes add the following concept of actual beneficial use as a limit to the measure and extent of a perfected water right: "Rights to the use of water acquired under the provisions of this chapter shall be limited and restricted to so much thereof as may be necessarily required when beneficially used for the purposes stated in this chapter, irrespective of the capacity of the ditch or other works, and all the water not so applied shall not be considered as appropriated." Beneficial use is defined as "the use of such a quantity of water, when reasonable intelligence and reasonable diligence are exercised in its application for a lawful purpose, as is economically necessary for that purpose." (Article 7476, V.A.C.S.)

In 1931, a proviso was added that all appropriations of water for any purpose other than domestic and municipal purposes "shall be granted subject to the right of any city, town, or municipality. . . to make further appropriations of said water thereafter without the necessity of condemnation or paying therefor, for domestic and municipal purposes. . . ." The Rio Grande waters are specifically excluded.

In Texas today, anyone who desires to appropriate water must make an application in writing to the Texas Water Rights Commission. The Commission, as a regulatory agency with broad discretionary powers, is charged with the administration of rights to the surface water resources of the State. The Commission consists of three members appointed by the Governor for six-year terms, with the consent of the Senate. The Chairman is designated by the Governor.

The Rules, Regulations, and Modes of Procedure of the Texas Water Rights Commission prescribe the procedures for applying for a water permit. The Commission will consider an application for approval if the application is in proper form, complies with statutory provisions, contemplates an authorized use of water, does not impair existing water rights or vested riparian rights, and is not detrimental to the public welfare.

After approval of an application, the Commission issues a permit giving the applicant the right to take and use water only to the extent stated. Permits may be "regular," "seasonal," "temporary," or "contract" in nature. A "regular" permit is permanent in nature and does not limit the appropriator to the taking of water during a particular season or between certain dates. A "seasonal" permit is also permanent in nature, but the taking of water is limited to certain months or days during the year. A "temporary" permit is granted for a period of time not exceeding three years and does not vest in the holder any permanent right to the use of water. A "contract" permit is granted for a stated duration and governs the use of water to be obtained from the storage facilities owned by another person or entity. A "contract" permit requires a written consent agreement or "contract" with the owner of the facility.

The Texas Water Rights Commission may also grant permits for the impoundment and storage of water with the use of the impounded water to be determined at a later date by the Commission.

Once the right to the use of water has been perfected by (1) issuance of a permit from the Texas Water Rights Commission and (2) subsequent beneficial use of the water by the permittee, the water authorized to be appropriated under the terms of the particular permit is not subject to further appropriation until the permit is cancelled. Formal cancellation of unused permits and certified filings is possible by administrative action initiated by the Commission or by judicial proceedings to adjudicate water rights between claimants. Cancellation by administrative action has, in the past, been difficult in the typical situation because of inadequacies in cancellation statutes. However, the recently enacted Water Rights Adjudication Act of 1967 is expected to facilitate the administrative process. Adjudication by the courts frequently does not provide the flexibility of action, the geographic coverage, or the inclusion of all parties desirable from the State's view.

Article 7500a allows a landowner to construct a small reservoir on his own property to impound not to exceed 200 acre-feet of water for domestic and livestock purposes only, without securing a permit. A simplified, short-form application for a permit to appropriate water for other than domestic and livestock purposes is available to the owner of a small reservoir of this size. Permits granted by the Texas Water Rights Commission pursuant to this statute may be for a period of years.

After considering the practical difficulties encountered by pioneer water appropriators in perfecting their claim, and analyzing the concepts they evolved as necessary aids to determine water rights—which concepts Texas Legislatures have codified as appropriation statutes—it is apparent that certain conditions or qualifications are inevitably present in every perfected water right under the nonriparian concept of appropriation, i.e., under the Prior Appropriation Doctrine. These elements are:

1. A definite point in *time* at which the claimed right can be said to have *attached*, i.e., time of attachment.

2. A definite *limitation as to quantity*. The "declared" appropriation must be considered with and governed by the "actual" appropriation, as measured by actual beneficial use.

3. Adequate *notice* to subsequent appropriators in accordance with prescribed customary procedure.

The absence of any one or more of these conditions must cause an asserted claim or right to fail. The Doctrine of Abandonment results in forfeiture or loss, as would estoppel (*Motl v. Boyd*, mentioned above) and prescription. The procedure by which an agency of the State issues a permit to appropriate public waters is a mere extension of the concepts underlying and embodied within earlier appropriative processes, and the later certified filings. Time of attachment, limitation (both declared and actual, i.e., the appropriative limit *declared* within the permit document, and *actual* appropriation as measured or limited by actual "beneficial use"), and *notice* are current requirements for the perfection of a water right by means of a statutory permit.

The Water Rights Adjudication Act of 1967

This recent statute modifies claims of right to public water under the riparian doctrine or water impounded under Article 7500a for other than domestic or livestock purposes. It is incumbent upon the user to file a statement, including the nature of right claimed and volume of water used, with the Texas Water Rights Commission before September 1969. Failure to file such a sworn statement will result in an extinguishment of such right, and bar any claim thereon. The Act further provides for adjudication of rights in any stream upon the Texas Water Rights Commission's own motion, or upon petition by 10 or more claimants of rights, or by the Texas Water Development Board.

Ground Water Law in Texas

As a prelude to any discussion of the ground water law of Texas, it is desirable to understand the term "ground water" as defined by statute and case law. A more accurate term would probably be "percolating water."

Percolating waters are defined as those waters below the surface of the ground not flowing through the earth in known and defined channels, but are waters percolating, oozing, or filtrating through the earth. Percolating waters are distinguished from (1) "subterranean streams flowing in well defined beds and having ascertainable channels" and (2) "the ordinary underflow of every river and natural stream of the state."

The state of the law with respect to ownership of subterranean streams flowing in well defined channels is not well settled in Texas. However, "stream underflow" (the water that flows beneath and alongside of a surface stream channel) is the property of the State (Article 7467). Both stream underflow and subterranean streams have been expressly excluded from the definition of underground water in Article 7880-3c, which article recognizes the ownership and rights of Texas landowners to underground water (Section D).

There exists a legal presumption in Texas that all sources of ground water are percolating waters as opposed to subterranean streams. The courts in the past have been reluctant to accept testimony of engineers and hydrologists as conclusively rebutting this presumption. Consequently, the surface landowner is presumed to own underground water until it is conclusively rebutted by a showing that the source of such supply is a subterranean stream or stream underflow, a burden of proof that may be very difficult to carry.

Texas courts have followed unequivocally the "English" or "common law" rule that the landowner has a right to take for use or sale all the water he can capture from beneath his land. The judiciary early chose not to adopt the "American rule" with respect to ground water, which is based on "reasonable use" and correlative rights. Consequently, neither an injured neighbor nor the State can effectively exercise control over water use practices involving ground water. This is in contrast with the extensive and direct involvement of the State in conserving and controlling surface water supplies. The situation is paradoxical when one realizes the actual interrelationship of ground and surface water, and even more so when one realizes the necessary interrelationship of ground and surface water development for future State needs and the necessity of adequate ground water supplies to meet future municipal and domestic requirements in certain areas.

Owners of land overlying defined ground water reservoirs may adopt voluntary well regulation through mutual association in underground water conservation districts; Article 7880-3c provides the framework for these districts, and to date, eight have been formed.

Impairment of a landowner's right in the percolating waters under his land, when this impairment is the result of a trespass on the land is, of course, actionable. To date there are only three legal actions available to a landowner in Texas for outside interference with his percolating water rights. The first is the common law right recognized in jurisdictions which apply the English rule. This right arises when there is malice or wanton conduct which results in a taking for the sole purpose of injuring a neighbor. The second action recognized in Texas arises when artesian flow results in no beneficial use, and as such, is defined as "waste." Article 7602 of the Civil Statutes and Article 846 of the Penal Code defines "waste" in relation to artesian wells, and provides, among other exceptions, that waste will not exist if the water is "used for the purposes and in the manner in which it may be lawfully used on the premises of the owner of such well." The third action arises as a result of contamination of the quality of water in a landowner's well. Cases within the third category have arisen mostly in areas where it can be conclusively shown that oil and gas operations have allowed brines, oil, and other substances to escape into the percolating fresh water bearing strata (*Continental Oil Company v. Berry,* 52 S. W. 2nd 953; Tex. Civ. App., 1932, error refused).

Water Rights Considerations in Plan Formulation

During the early phases of the planning investigations, the listings of water permits and certified filings were reviewed, and pertinent permit data were extracted for guidance in planning. Although all permits and filings were considered individually, they are discussed as used in planning in the five following general groupings:

1. Permits and filings for existing or under-construction reservoirs with capacities in excess

of 5 thousand acre-feet, used for water supply purposes.

2. Applications for permits and permits for proposed reservoirs with capacities in excess of 5 thousand acre-feet not yet under construction and permits for modifications of existing reservoirs.

3. Permits for supplying municipal, industrial, and irrigation water in the coastal region through existing canal systems.

4. Permits and filings of individuals or public entities for use of relatively small quantities of water, by direct diversion from streams or from small reservoirs to irrigate individual farms and fields, for recreational use, or for smaller towns for water supply and other purposes.

5. Federally constructed reservoirs for which permits may have been obtained by local interests for a portion of the conservation storage, or no permit obtained.

The provisions of the permits applicable to each reservoir in group (1) above were reviewed to ascertain for each the conservation storage capacity, the upper elevation of conservation storage, the maximum annual use of water permitted, the intended water use, and the places for use. Consideration was also given to specific permission within a permit for conjunctive use of water from a particular reservoir with water from other sources, or for the operation of two or more reservoirs. In addition, various permit provisions pertaining to subsequent upstream development, and express limitations on reservoir minimum conservation pools were reviewed.

Reservoir conservation capacities for existing reservoirs were checked to determine usable conservation storage with silting to 1960. Drainage areas upstream from dams, or between dams, were determined using the most current U.S. Geological Survey drainage area determinations and the most current topographic maps. Historical runoff from these drainage areas determined by the U.S. Study Commission-Texas was adjusted for future depletions due to projected watershed land treatment programs and floodwater-retarding structures. Sediment rates established by the Soil Conservation Service applicable to each drainage area were used in computing future sediment inflows to each reservoir. Using these data, reservoir yield studies were made for each existing reservoir for 1975 and 2010 conditions. These two yield determinations were interpolated and extrapolated to establish yields for each decade 1970 to 2020. These yields indicate the annual firm supplies of water which could be obtained from existing reservoirs.

Similar criteria were used to determine the probable firm yields of proposed and alternative reservoirs included in the Texas Water Plan. The probable effects of these proposed and alternative reservoirs on the permitted storage of downstream reservoirs was then computed.

For reservoirs with drawdown limitations, the yields were determined for only that portion of the reservoir above the specified storage elevation, such as power pools.

In a few instances, reservoir yield determinations were indicated to be slightly larger than the annual diversions allowed in the permits. Reservoir yields were used as the governing parameter in these cases. Usually, the safe yield was less than the permitted annual use, due to the effects of sedimentation to the year 2020, and the lesser amount was used for planning purposes.

For existing reservoirs, the amounts of water shown to be available under future conditions were used to supply the requirements of the permittees for the purposes described in the permits.

The second grouping of permits, including those applications for permits approved by the Commission but for which a permit has not been issued, related to proposed reservoirs, or modifications to existing reservoirs. Where permits had been issued, or applications for permits approved, the planning procedures generally utilized the proposed reservoir capacities and locations. In an effort to establish hydrologic optimum of reservoir yields in the basin, reservoirs of larger and/or smaller capacities than those proposed were also analyzed, together with the possibility of alternative reservoir sites in the same vicinity.

The amounts of water permitted and the purpose described were considered to serve future water requirements. However, the lack of inclusion of a particular project purpose in a water permit—for example, flood control—was construed as not precluding the inclusion of such purpose.

The third grouping of permits and certified filings pertained to water needs in the coastal region supplied primarily through existing canal systems. Many of these systems were constructed initially to supply irrigation water to rice growers with subsequent amendments to the permits to authorize municipal and industrial uses also.

Water requirements for rice irrigation were determined from projections of rice production and acreage requirements to the year 2020, shown in the analysis of future agricultural needs made for water planning purposes by Texas A&M University. The 1964 total of

465 thousand acres of rice, by this analysis, is expected to be increased to 552 thousand acres by 2020, after allowances for increased crop yields that are expected to result from improved agricultural technology. Although many permits for rice irrigation limit use of water to 2 acre-feet per acre per year, the total diversion requirements for rice used in the planning on the basis of U.S. Study Commission data were 4.23 acre-feet per acre per year in the coastal area from the Sabine River Basin to (but not including) the Trinity River Basin; 4.57 acre-feet per acre per year for the area from the Trinity River Basin to (but not including) the Colorado River Basin; and 4.81 acre-feet per acre per year for the area southwest of the Colorado River Basin and including the Guadalupe River Basin.

Although consideration was given to the future encroachment of urban, industrial, and public developments on agricultural lands in determining the future distribution of rice acreage in the coastal area, relocations of actual production are permitted by present allotment policies providing for the movement of acreage within the State. It is not possible to firmly estimate the timing or location of such intrabasin transfers, the total acreage allotments by years, or the conversions of water from rice irrigation use to municipal and industrial purposes. However, present outstanding certified filings and water permits, and most existing distribution facilities, appear to be sufficiently large to accommodate the projected rice acreage wherever it may shift along the Gulf Coast.

The permits for municipal and industrial water from existing coastal canal systems, the areas to be served by these permits, and the amounts of water for each purpose were used as guides in planning to meet future requirements. Projections of future water requirements for municipal and industrial purposes were met either under existing permits or from the Coastal Canal of the Texas Water System or both. In most instances these projected future requirements exceed present water permit quantities.

With reference to water permits and certified filings for canal systems diverting from the Rio Grande below Falcon Dam, data and studies prepared by the State of Texas during the recent water rights litigation were utilized. These studies established that more land was being irrigated from the Rio Grande waters than the river could supply with reasonable periodic shortages. Water requirements for existing and new irrigation in Starr, Hidalgo, Cameron, and Willacy Counties were determined in planning studies on the basis of the total acreage which could be served from the Rio Grande (using the studies presented in the court proceedings) but without attempting to determine which lands would actually be served from the Rio Grande. The acreage that could be served from the Rio Grande within this four-county area, assuming reasonable periodic water shortages, was determined to be not more than 650 thousand acres. Additional lands to be served in this four-county area will require supplemental water delivered through the Coastal Canal of the Texas Water System.

The fourth grouping, consisting of permits and certified filings for use of relatively small quantities of water by direct diversion from streams, or from small reservoirs, all held by small users such as individuals and the smaller towns, were generally considered and evaluated in the same manner as those from the preceding group (3). Many of the permits and certified filings are for relatively small quantities of water for irrigation and were included as part of the total of non-project irrigated areas to be served with water in the future. These consumptive use requirements were totaled and assigned to reaches of the river between reservoirs. In addition, these estimated non-project type irrigation requirements were computed to include riparian uses along the river reaches.

A few of the smaller reservoirs for municipal purposes were reviewed to determine future condition yields. All reservoirs under these permits were assumed to continue operation. Reservoirs for single purpose recreation use under present permits were assumed to continue in operation for that purpose.

A number of reservoirs have been constructed by Federal agencies for which permits have been obtained by local interests for a portion of the conservation storage, or no permit obtained for the Federal project purpose. These reservoirs include Benbrook, Whitney, Grapevine, Texoma, Sam Rayburn, International Falcon, and Amistad. The conservation storage in Benbrook Reservoir and a portion of the storage in Grapevine Reservoir are allocated to navigation purposes for which no permits have been issued.

The conservation storage in Whitney Reservoir is allocated for hydroelectric power development for which no permit has been issued. The yield of Whitney Reservoir was used to serve a portion of the downstream water requirements.

Most of the conservation storage in Lake Texoma is for hydroelectric power generation, with authorized storage allocations and water permits for Sherman, Denison, and the Texas Power and Light Company. These storage allocations were utilized in meeting water requirements of Sherman and Denison. A portion of future storage allocations as now included in the Red River Compact draft were designated for irrigation use in Texas below Lake Texoma.

The yield of Sam Rayburn Reservoir operated above the minimum power pool elevation is included in water use requirements of the Lower Neches Valley Authority, while the yield from the remaining storage below the power pool is reserved as a basin resource.

Although no water permits have been issued for the United States portion of the conservation storage in International Falcon and Amistad Reservoirs, it has been assumed that future operations will be similar to the present method of operation. Present releases of water for downstream users are made at the request of a water master.

Although numerous statutes refer to the riparian right of a landowner abutting the bed of a stream to utilize the water flowing past his land and several court decisions speak to this subject, it is not possible to quantify the amounts of water needed for riparian uses exactly. Estimated riparian needs were categorized as non-project type irrigation requirements on stream reaches between major reservoir projects to be met as part of the overall basin requirements.

During the planning process, it was necessary to make numerous analytical studies of information contained in permits and certified filings, and apply such data in the manner herein described. Numerous older permits and certified filings contain only sufficient information for an approximation of the amount of water that could be involved. It appears from the limited number of reported riparian uses that many possible users have not reported a use of water. The implementation of the Water Rights Adjudication Act, coupled with the aggressive program of the Texas Water Rights Commission in partial or full cancellation of unused permits and certified filings, will provide in the immediate future firmer values for the detailed planning and consideration of individual project units.

Listings of water permits and certified filings as of April 1, 1966, for each basin are contained in the preliminary basin plan reports distributed and used at public hearings in 1966.

PROTECTION OF THE BASINS OF ORIGIN

In 1965, legislation authorizing the preparation of the State Water Plan forbade the formulation of any plan " which contemplates or results in the removal from the basin of origin of any surface water to some other river basin...if the water supply involved...will be required to supply the reasonably foreseeable future water supply requirements for the next ensuing fifty-year period within the basin of origin except on a temporary basis...." The concept was generally termed the "statutory fifty-year limitation on planning." A companion concept, incorporated into constitutional amendments authorizing the increase in available Texas Water Development Bonds needed to finance projects, applied a similar fifty-year limitation on the use of State funds by prohibiting their investment in a project "which contemplates or results in the removal from the basin of origin of any surface water necessary to supply the reasonably foreseeable future water requirements for the next ensuing fifty-year period within the river basin of origin, except on a temporary, interim basis." This constitutional prohibition restricting the use of State funds is commonly known as the "constitutional fifty-year limitation."

Local interests favoring enactment of these limitation concepts understandably feared that appropriative rights to the use of water originating in surplus basins would vest in users situated in deficient basins, thereby depriving for all time the basin of origin of water necessary for that potential growth which it might otherwise have enjoyed had its waters remained uncommitted to a water deficient area. When legislative proposals were advanced that trans-basin diversions should never result in the vesting of a permanent appropriative right, local interests from water deficient areas were quick to point out that a water supply, once committed to a metropolitan area, could never in fact be withdrawn from household faucets or critical industries.

Thus, in an effort to effect compromise between water deficient areas and those seeking to protect the potential economic development of basins of surplus, the specific texts of the "fifty-year limitations" were adopted, and incorporated as amendments to draft legislation.

Previous to the enactment of the statutory fifty-year limitation, the bulwark of protection for basins of origin against the depletion of surplus reserves by interbasin transport lay primarily in the statutory provisions of Article 7589-91, prohibiting interbasin transfers when such exports operate to the prejudice of any person or property situated within the basin of origin. However, in *City of San Antonio* v. *Texas Water Commission*, the Supreme Court of Texas construed the provisions of Article 7589 and following Articles as prohibiting trans-basin diversions only to the extent of prejudice with respect to those rights then in existence, without regard to future potential for economic development within the basin of origin. In upholding the broad discretionary powers of the Texas Water Rights Commission with respect to the administration of the State's water resources, the Court declared that considerations for trans-basin diversion must be based upon three positive considerations: (1) purpose of use, (2) existing rights, and (3) the public welfare. And while Article 7589 relating to trans-basin diversion and prejudice does not require and/or involve the projection of possible future development within the basin of origin, nevertheless the effects on probable future development within a basin of origin are necessarily inherent within public welfare considerations, and are therefore properly considered by the Commission in exercising administrative discretion in granting permit applications.

In preparing the Plan, however, the Board followed the guidelines prescribed by the statutory fifty-year limitation, and projected the reasonably foreseeable in-basin requirements for basins of origin for that fifty-year period next ensuing the proposed date of the Plan's adoption. The prior water rights of those users within the basin of origin, at such time as they may choose to exert such rights, were assumed. The Texas Water System was then formulated on the further assumption that basins of origin will be accorded by the Texas Water Rights Commission the prior right to purchase water from the System, at such time as it may be needed. Concepts implementing these assumptions will be incorporated in all future Texas Water System water service contracts.

The Texas Water Plan, and the statutory and constitutional limitations under which it has been formulated as a flexible guide to the Commission in permitting development and use of Statewide water resources, will operate as a stalwart defense, in fact the only certain defense, against the unwise depletion of in-basin water reserves; there are no similar provisions in Federal laws or policies. The preservation of these reserves will assure the development of available economic potential within basins of origin.

COMPACTS AND TREATIES

A plan for distributing water in Texas is subject to legal agreements entered into between Texas and other States as well as agreements reached between the United States and foreign countries when such agreements govern the right to use waters otherwise available to the State. In this regard, Texas has entered into four compacts with other States—the Rio Grande Compact, the Pecos River Compact, the Canadian River Compact, and the Sabine River Compact—and is currently negotiating a fifth, the Red River Compact; and the United States has entered into two treaties with the United States of Mexico, which govern international waters.

The Compacts

Rio Grande Compact.—The Rio Grande Compact, Article 7466e-1, Vernon's Revised Civil Statutes, was entered into by the States of Colorado, New Mexico, and Texas on March 18, 1938. The Compact was ratified by all three States and, pursuant to Constitutional requirements, the United States in 1939.

With this Compact, the three States purported to resolve all interstate controversies with respect to the use of waters of the Rio Grande above Fort Quitman, Texas. Detailed water delivery schedules, constituting obligations of the States of Colorado and New Mexico, are established in the Compact.

The Compact provides that the water delivery schedules contained therein and the quantity of waters allocated thereby shall never be increased nor diminished because of an increase or diminution in the delivery or loss of water to Mexico.

Pecos River Compact.—On December 3, 1948, the States of New Mexico and Texas entered into the Pecos River Compact. This Compact relates to the uses, apportionment, and deliveries of the water of the Pecos River and was ratified in 1949 by the two State Legislatures and Congress, Article 7466f, Vernon's Revised Civil Statutes.

Pursuant to the Compact, the following allocation agreements were reached between New Mexico and Texas:

(1) New Mexico is not to deplete the flow of the Pecos River at the New Mexico-Texas State line so as to give Texas a quantity of water less than that available to Texas in 1947 and as described in the Report of the Engineering Advisory Committee;

(2) the beneficial consumptive use of the waters of the Delaware River is allocated to Texas;

(3) the beneficial consumptive use of water salvaged in New Mexico through the construction and operation of a project or projects by the United States or by the joint undertakings of Texas and New Mexico is apportioned 43% to Texas and 57% to New Mexico;

(4) the beneficial consumptive use of water which is to be nonbeneficially consumed and which is recovered is apportioned to New Mexico;

(5) water salvaged in Texas is apportioned to Texas; and

(6) beneficial consumptive use of unappropriated flood waters, as defined herein, is apportioned 50% to Texas and 50% to New Mexico.

New Mexico and Texas further contracted to support legislation for the construction of projects to eliminate nonbeneficial consumption of water and to cooperate with agencies in the United States in devising remedial means to ameliorate salinity conditions of the Pecos River. For the purpose of administering the Compact, the Pecos River Commission was created.

The Compact further provides that in the event of water importation to the Pecos River Basin from any other river basin, the State making importation shall have the exclusive use of such imported water. Finally, the failure of either State to use the water as apportioned under the terms of the Compact shall not constitute a relinquishment of the right to such use nor shall it constitute a forfeiture or abandonment of the right to such use.

Canadian River Compact.—This Compact was entered into by the States of New Mexico, Texas, and Oklahoma on December 6, 1950, was approved by Congress in 1952, and was ratified by the Texas Legislature in 1951, Article 7466h, Vernon's Revised Civil Statutes. The avowed purposes of the Compact were to promote interstate comity, to remove causes of present and future controversy, to make secure and protect present developments within the States, and to provide for the construction of additional conservation works. For the purpose of administering the Canadian River Compact, the Canadian River Commission was established.

The Compact expressly recognized those rights to waters previously perfected by beneficial use. New Mexico was accorded free and unrestricted use of all waters originating in the drainage basin of the Canadian River above Conchas Dam, and free and unrestricted use of all waters originating in the drainage basin of the Canadian River in New Mexico below Conchas Dam, provided that the amount of conservation storage in New Mexico available for impounding the waters originating in the drainage basin of the Canadian River below Conchas Dam is limited to an aggregate of 500 thousand acre-feet. Texas was accorded the free and unrestricted use of all Canadian River waters in Texas, subject to the following limitations upon storage of water:

(1) Impoundment of the waters of the North Canadian River by Texas is limited to storage on tributaries of the River in Texas and for municipal, household, domestic, livestock watering, and irrigation uses; and

(2) following the development of 300 thousand acre-feet of conservation storage in Oklahoma, the right of Texas to impound and retain waters in storage is limited to an aggregate quantity equal to 200 thousand acre-feet plus whatever amount of water shall be at the same time in conservation storage in reservoirs in the drainage basin of the Canadian River in Oklahoma, exclusive of reservoirs in the drainage basin of the North Canadian River and exclusive of reservoirs east of the 97th meridian.

Sabine River Compact.—On January 26, 1953, the States of Louisiana and Texas entered into the Sabine River Compact which was ratified in 1953 by the 53rd Legislature of Texas, Article 7466, Vernon's Revised Civil Statutes, and approved by the Louisiana Legislature and Congress in 1954.

The purposes of the Compact were to provide for an equitable apportionment of the waters of the Sabine River and its tributaries between the States of Louisiana and Texas; to encourage the development, conservation, and utilization of the water resources of the Sabine River and its tributaries; and to establish a basis for cooperative planning and action by the States for the construction, operation, and maintenance of conservation projects. Pursuant to the covenant, Texas and Louisiana agreed that, concerning the point on the Sabine River where its waters in downstream flow first touch the States of both Louisiana and Texas, all Sabine River water lying between this point and Sabine Lake should be divided equally between the two States, the division to be made without reference to the origin. The parties recognized the necessity and provided for the maintenance of a minimum flow at that point on the Sabine River where its waters in downstream flow first touch both States. The parties of the Compact further provided, subject to some exception, that Texas was accorded the unrestricted use of all waters of the Sabine River and its tributaries above that point on the Sabine River where its waters in downstream flow first touch both States. Expressly excluded from the apportionment of the Sabine River waters are those waters consumed in either State for domestic and livestock uses. Finally, for the purpose of administering the Sabine River Compact, the Sabine River Compact Administration was created.

Red River Compact.—Pursuant to a legislative mandate, recorded in Article 7466g, Vernon's Revised Civil Statutes, negotiations for a compact governing the waters of the Red River Basin were commenced in 1956 among the States of Texas, Arkansas, Oklahoma, and Louisiana. As of the present time no final agreement has been reached among these States, although a draft of the Compact is under review.

The Treaties

On May 21, 1906, the United States of America and the United States of Mexico entered into a Treaty providing for the equitable distribution of the waters of the Rio Grande for irrigation purposes, 34 Stat. 2953. This Treaty was ratified by the United States in 1906 and by the United States of Mexico in 1907. Pursuant to the Treaty the United States agreed to deliver to Mexico a total of 60 thousand acre-feet of water annually at the point in the Rio Grande streambed where the headworks of the Old Mexican Canal exist above the City of Juarez, Mexico, and according to a schedule set out in the Treaty. In consideration of such delivery, the United States of Mexico waived any and all claims to the Rio Grande between the head of the Mexican Canal and Fort Quitman, Texas, and also declared fully settled and disposed of all claims theretofore asserted or existing or that may thereafter arise or be asserted against the United States on account of any damage alleged to have been sustained by the owners of Mexican land by reason of the diversion by citizens of the United States of waters of the Rio Grande.

A second Treaty between the United States of America and the United States of Mexico was signed on February 3, 1944, and ratified by both Nations in 1945, 59 Stat. 1219. The purpose of the Treaty was to fix and to limit the rights of the two countries with respect to the waters of the Colorado and Tijuana Rivers and of the Rio Grande from Fort Quitman, Texas, to the Gulf of Mexico, in order to obtain the most complete and satisfactory utilization thereof. The International Boundary Commission was designated as the agency to administer the Treaty.

In the Treaty, the countries agreed that when the joint use of international waters was required, the following order would serve as a guide for use priority: (1) domestic and municipal uses, (2) agriculture and livestock raising, (3) electrical power, (4) other industrial uses, (5) navigation, (6) fishing and hunting, and (7) any other beneficial uses which may be determined by the Commission.

Pursuant to the Treaty and to delivery schedules found therein, the waters of the Rio Grande between Fort Quitman, Texas, and the Gulf of Mexico were allocated in part to Mexico and in part to the United States. Mexico became entitled to all waters reaching the main channel of the Rio Grande from the San Juan and Alamo Rivers including the return flow from the lands irrigated by the latter two rivers. In addition, Mexico received one-half of the flow of the main channel of the Rio Grande below the lowest major international storage dam; two-thirds of the flow reaching the main channel of the Rio Grande from the Conchos, San Diego, San Rodrigo, Escondido, and Salado Rivers, and the Las Vacas Arroyo; and one-half of all other flows not otherwise alloted occurring in the main channel of the Rio Grande between Fort Quitman and the lowest major international storage dam. In return the United States received all the waters reaching the main channel of the Rio Grande from the Pecos and Devils Rivers, Goodenough Springs, and Alamito, Terlingua, San Felipe, and Pinto Creeks. In addition the United States received, subject to certain contingencies, one-half of the flow in the main channel of the Rio Grande below the lowest major international storage dam, one-third of the flow reaching the main channel of the Rio Grande from the Conchos, San Diego, San Rodrigo, Escondido, and Salado Rivers and the Las Vacas Arroyo, and one-half of all other flows not otherwise alloted occurring in the main channel of the Rio Grande between Fort Quitman and the lowest major international storage dam.

In the Treaty, provisions were made for the construction of several dams for the purposes of conservation, storage, regulation of annual flow, and for diversion of flow, and provision was also made for ownership of water and storage.

Part III

Water Uses And Requirements, And Related Water Development Considerations

WATER USES AND REQUIREMENTS, AND RELATED WATER DEVELOPMENT CONSIDERATIONS

WATER USE AND REQUIREMENTS IN TEXAS

Population Growth and Industrial Expansion

Since World War II, Texas has experienced tremendous economic growth; agricultural, industrial, and urban expansion will soon reach the point where the available water resource base necessary for a viable economic environment will be inadequate. In order to maintain Texas' rate of growth and to avoid economic retrogression, development of the State's remaining resources must be carefully planned and carried out to serve the entire State. Importation from out-of-State sources will be required. The Texas Water Plan is a set of coordinated solutions to water supply problems which stem from water supply needs throughout the State. The methods and criteria used in projecting future water needs and the projected future water requirements in the State are described below.

Population Trends

The population of Texas has grown substantially during the past century, and centers of concentration have shifted from a predominantly agricultural economy to a more balanced agricultural, industrial, and commercial economy. Historically, the State's population was centered around rural marketing and agricultural trading areas. However, as trade and commerce in Texas increased in importance, the population began to grow and shift to urban centers. This change was accelerated during the first three decades of this century by the discovery of vast oil reserves, which produced the "boom town" growth typically associated with mineral speculation and development.

Between 1880 and 1960, the population of Texas grew from about 1.5 million to 9.5 million—an increase of more than six times—while the national population for the same period increased by only three and one-half times. In 1940, only 45.4% of the State's population lived in urban areas as compared to 56.5% throughout

Table III-1.--Projected Trends in Urban Population Growth in Texas

STANDARD METROPOLITAN STATISTICAL AREA	YEAR 1960	1990	2020
Abilene	120,377	187,601	276,285
Amarillo	149,493	350,542	487,450
Austin	212,136	534,728	1,091,837
Beaumont-Port Arthur	306,016	560,632	1,109,565
Brownsville, Harlingen, and San Benito	151,098	239,855	368,160
Corpus Christi	266,594	535,704	1,198,227
Dallas	1,083,601	2,478,824	4,019,830
El Paso	314,070	573,048	1,013,960
Fort Worth	573,205	1,043,850	1,948,685
Galveston and Texas City	140,364	291,621	620,008
Houston	1,418,323	3,263,640	6,373,677
Laredo	64,791	98,627	147,314
Lubbock	156,271	284,320	464,262
McAllen, Pharr, and Edinburg	18,706	38,213	62,001
Midland	67,717	103,815	150,770
Odessa	90,995	140,783	200,362
San Angelo	64,630	116,686	202,160
San Antonio	716,168	1,322,918	1,937,895
Texarkana	59,971	89,895	145,327
Tyler	86,350	217,643	466,246
Waco	150,091	325,250	624,100
Wichita Falls	129,638	207,666	310,004
Sherman-Dension	73,043	110,826	187,100
Total	6,413,658	13,116,687	23,504,725
Total Projected for State	9,579,677	17,758,380	30,546,378

the Nation. By 1960, about 75% of the people of Texas lived in urban areas compared to about 70% for the Nation as a whole. By the year 2020, it is estimated that 84% of the State's population will be concentrated in urban areas.

The 1960 Census indicated a total State population of 9,579,677. The State's population is projected to reach over 14.9 million by 1980, more than 21.2 million by 2000, and in excess of 30.5 million by the year 2020.

Table III-1 indicates the projected future population growth within the 23 Standard Metropolitan Statistical Areas of the State shown in Figure III-1, and Figure III-2 illustrates the trend toward urbanization in relation to this projected population growth throughout the State. In 1960, these 23 principal urban areas had approximately 67% of the State's population. By 2020, about 77% of the projected total population of the State is expected to be centered in these areas.

A further indication of the trend toward population concentration is the fact that between 1940 and 1960 the number of cities and towns having a population of more than 2,500 increased from 196 to 320. It is projected that by 2020 the number of cities and towns with a population of more than 2,500 each will increase to 374.

Industrial Growth

Industry in Texas was originally based largely upon the production of goods in self-sufficient frontier communities, related to the agricultural nature of the economy. Production of soap, leather, candles, flour,

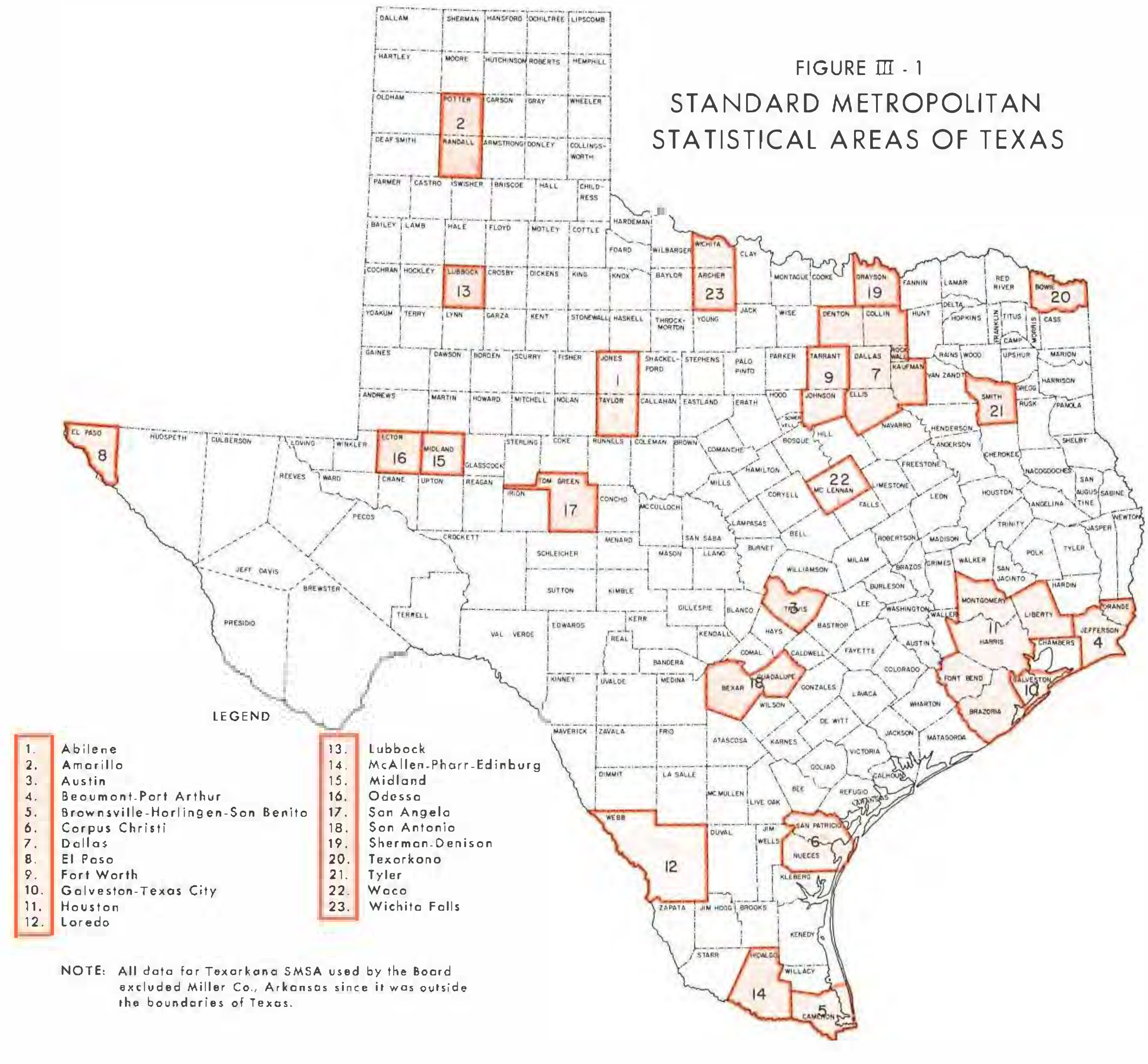


FIGURE III - 1
STANDARD METROPOLITAN STATISTICAL AREAS OF TEXAS

cottonseed oil, and lumber was important. Around 1870, processing of cotton and cottonseed and lumber milling were leading Texas manufactures, retaining their preeminence until the early 1900's when the rapid expansion in petroleum production began.

Texas is presently first in the Nation in value of minerals produced, and the State's economy has been broadened by the vast expansion of the petroleum products industry. The production of petrochemicals has become the fastest growing of all Texas' industries.

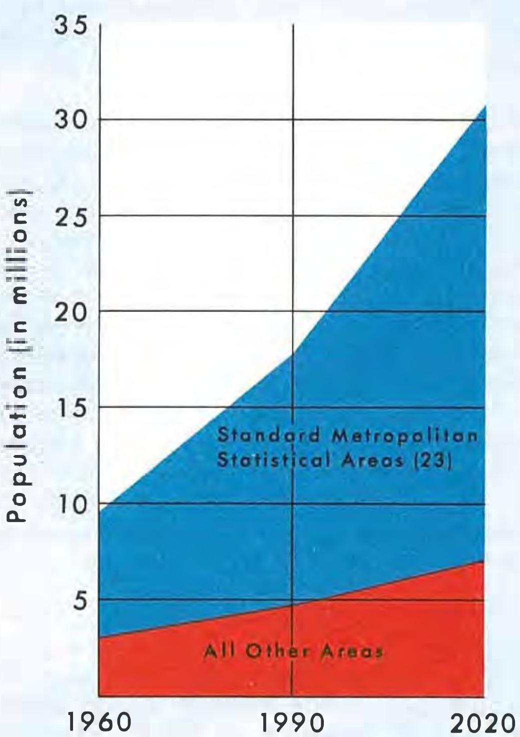
Petroleum production and refining remain important, particularly along the Gulf Coast and in West Texas. At the end of 1964, the State was estimated to have 42.3% of the proved natural gas reserves and 47.1% of the total liquid hydrocarbon reserves of the Nation.

Petroleum exploration and production have also led to rapid growth in the manufacture of oil field tools and other related equipment. The world's largest oil field supply and refinery equipment industries are concentrated in the Houston area. Demands for steel in the petroleum industry also encouraged the development of two steel mills presently operating in Texas.

Although the Texas mineral industry is dominated by petroleum and associated products, 18 non-petroleum minerals were being produced in the State in 1964, with a value equal to 7% of all mineral production. The production of portland cement led in value with a total of more than $94 million. Other minerals produced include stone (second in value), sulfur, sand and gravel, salt, clay, oyster shell (for producing lime), gypsum, iron ore, and lignite.

FIGURE III - 2

TEXAS POPULATION GROWTH



The chemical industry in Texas began on a large scale with the production of inorganic chemicals in the Corpus Christi area. After 1940, the organic chemical industry developed rapidly because conditions during World War II made it necessary to develop synthetic substitutes for raw materials which were in short supply or unavailable. Hundreds of organic compounds were discovered which have useful commercial applications. The expanded use of chemicals in agriculture and the substantial increase in irrigated acreage in recent years have greatly increased demands upon producers of chemicals.

The scale of manufacturing in Texas has increased rapidly. In 1949, value to the economy added by manufacturing was $1.8 billion, while in 1963 it totaled $7 billion. The total number of employees in manufacturing increased during this period from 319 thousand to 508 thousand. Important gains were registered during the same period by chemicals and allied products, primary metal industries, fabricated metal products, machinery, and transportation equipment. Food and kindred products also maintained their importance. Employment in manufacturing is expected to reach 745 thousand by 1975 and 1.16 million by 1990. Value added by manufacturing is expected to total $40.9 billion by 1990.

The recent broad-based industrial development in Texas has demanded the rapid expansion of trades and services in the last 10 years to support employees as well as plants. Retail trade, wholesale trade, and selected service sales which totaled over $26.5 billion and employed over 738 thousand in 1958 had sales of almost $33 billion and employed nearly 798 thousand by 1963. As basic employment increases, the growth of dependent employment in trades and service industries is expected to increase at a slightly faster rate in the future.

Governmental Activities

An important source of wages and salaries in Texas is government, military, aerospace, and other Federal installations. Together with State and local governmental payrolls, in 1964 the total governmental payrolls amounted to $2.3 billion, compared with the $2.9 billion payroll resulting from manufacturing during that year.

Transportation, Utilities, and Construction Activities

Vast transportation facilities, communications, public utilities, finance, insurance, real estate, and construction activities have developed in the State since the close of World War II. These sectors of the economy are expected to maintain their importance and expand to meet the demands of increased industrialization and a growing population.

Municipal, Industrial, and Mining Water Requirements

Requirements for Municipalities and Industry

An adequate municipal and industrial water supply does not necessarily insure economic development, but an inadequate supply certainly inhibits it. Therefore, an essential element of water planning is the determination of the level of municipal and industrial water use, the quality of water necessary to meet these uses, and projection of the magnitude of use into the foreseeable future.

The frequently close relationship between municipal and industrial supply requires that the analytical processes for projecting future municipal and industrial water needs be combined to some extent. Criteria used in making municipal and industrial projections included: (1) smaller industries and commercial establishments presently obtaining or projected to obtain their water supplies from municipal systems were included in municipal requirements; and (2) large-scale industrial users—10 thousand gallons per day or more—who purchase their supplies from municipal systems were separated into the industrial category.

In the analysis, it was assumed that necessary water supplies of suitable quality would be available to each area at a reasonable cost. A reasonable cost was assumed to be on the order of prices experienced in each area over the recent historical period. Therefore, since the availability of water supplies influences cost and ultimate use, some limit on development was implicit in the analysis. An area where historical water prices have limited industrial development is not expected to attract large water-using industries. Industrial development was thus projected in accordance with what has been feasible in the past at the experienced price of water and the resources available.

Population and industrial water requirements used in formulating the Texas Water Plan were developed under a cooperative agreement by the Bureau of Business Research of The University of Texas at Austin, with some modification by the Board after further planning studies. Criteria and methodology used by the Bureau were developed through similar studies conducted over the past 17 years.

Water use data upon which future water requirements were partially based were collected and compiled by the Board. These data were accumulated in a continuing program initiated by the Board in 1955. For the planning studies, municipal water use data were rechecked with each municipality and cross-checked with data collected by the State Department of Health.

In early 1965, the Board, in cooperation with the Bureau of Business Research and with assistance from the Water Supply Committee of the Houston Chamber of Commerce, inventoried water use by industrial users in Texas. Data were obtained on the quantity of water used, the sources of supply, the extent of water reuse, and the users' projections of their future requirements. These data served as the basis for developing an industrial water use summary questionnaire, used in an annual inventory to collect data on industrial water use. These data, with other information collected by the Board, are used in continuing evaluation and refinement of projections of future industrial water requirements in Texas.

While short-term changes in population may be forecast accurately using birth and death rates, long-term population projections must rely heavily on assumptions of changing migration patterns due to income and employment opportunities for the more mobile urban labor force. The normal changes in population for the different areas in Texas were projected using the difference between births and deaths, but migration patterns were projected as being a result of employment in each area.

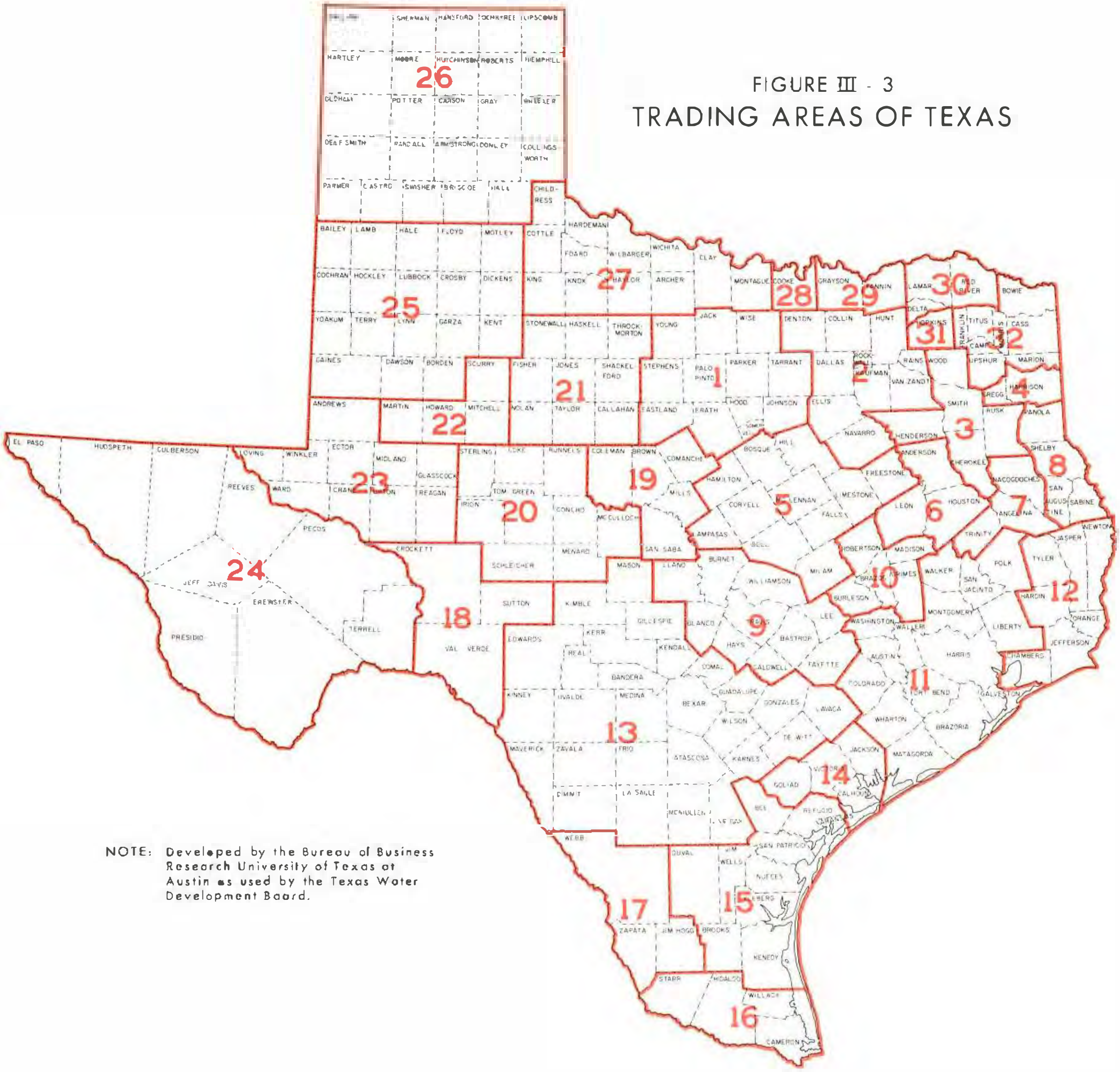
Projections of employment were based on area resource evaluations and the probable expansion of basic local industries. Resources include raw materials and services which are expected to prove valuable to people outside the local area. Their purchase of those resources brings income into the area and forms a firm base for economic expansion.

Population and employment projections were first made for the State as a whole and then allocated to the 32 major trading areas of Texas shown in Figure III-3. The Statewide projections served as both a practical limit for regional and river basin projections and for comparison with similar projections made by various Federal agencies. Each trading area consists of a major urban center and its area of immediate economic influence. A trading area, although influenced by a number of factors outside its boundaries, was considered a homogeneous, self-sufficient, economic unit. Growth was projected if the resource base can be expected to attract additional employment. The magnitude of population growth was assumed to be limited by labor force participation rates, which indicate the number of people supportable by a given industrial employment.

Trading area population projections were then separated into county and city totals. After projecting population for workable specific areas, these smaller areas were aggregated to conform to river basins and basin zones as defined by the Board. The population

FIGURE III - 3

TRADING AREAS OF TEXAS



NOTE: Developed by the Bureau of Business Research University of Texas at Austin as used by the Texas Water Development Board.

which would need to be supported by water supplies within the various basins was determined through this aggregating analysis.

Municipal water requirements were projected for each city by using computed per-capita water use data developed from information collected by the Board between 1960 and 1964. This per-capita base was compared with similar data collected by the State Department of Health between 1956 and 1962 in order to study geographic trends in the per-capita use of water. The stage of urban development was also considered for each area so that emerging urban centers were not penalized by the use of criteria applicable to mature urban areas.

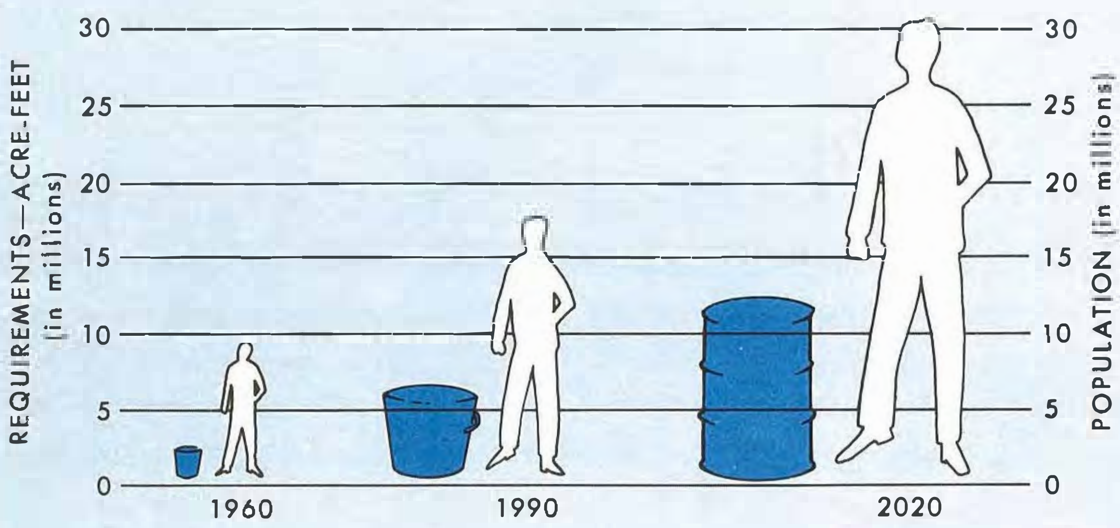
The projected per-capita use of water, when multiplied by future projected basin and basin zone populations, provided projections of municipal water requirements within river basins and basin zones. Industrial requirements were developed by comparing projected employment in basic industrial sectors with current and projected water requirements for those sectors. Both projections were then added together to arrive at total projected municipal and industrial water requirements for each river basin of the State.

Total municipal and industrial water requirements in the State are projected to increase from the 2.6 million acre-feet per year used in 1960 to about 6.5 million acre-feet per year by 1990, and to reach more than 12 million acre-feet annually by 2020. These projected increases in population and the demand for water in the State through the year 2020 are illustrated in Figures III-4 and III-8.

Projections of future populations and water requirements are subject to many variables, and must be

FIGURE III - 4

COMPARATIVE GROWTH OF TEXAS MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS AND POPULATION



reviewed as new data become available. Continuing planning studies will use current census information, annual water use inventories, and periodic industrial and agricultural surveys as the base for maintaining flexibility in water development programs and staging construction of water supply facilities.

Requirements for Mining

The principal use of water for mining purposes is the recovery of petroleum by fluid injection, commonly known as secondary recovery. The development of sand and gravel resources and the recovery of minerals other than petroleum also require water; however, consumptive use of water in these operations is small in comparison to requirements of the petroleum industry.

The growing importance of secondary petroleum recovery and maintenance of pressures in hydrocarbon reservoirs by the injection of fluids is demonstrated by the increase in oil production from this method from about 20% of the total State oil production in 1953 to about 30% in 1965. Within the next 15 years, it is projected that about one-half of the oil produced in Texas will result from secondary recovery operations.

Both saline and fresh water can be used for secondary oil recovery and reservoir pressure maintenance, and the choice is generally dictated by the costs of alternative water supplies and operation and maintenance costs of the supply system. Much of the total water requirement for secondary oil recovery can be satisfied by saline water commonly produced with oil and gas in the State, by the recycling of water used in secondary recovery projects, or by locally available brackish or saline waters, principally from ground water souoces.

Studies of future water requirements of the petroleum industry were conducted for the Board by the Texas Mid-Continent Oil and Gas Association and by Dr. Paul D. Torrey, Consulting Petroleum Engineer. These projections were developed through evaluations of the amount of petroleum potentially recoverable by water injection. The study by Dr. Torrey included estimates of proven oil reserves recoverable by fluid injection plus oil reserves estimated to be discovered in the future.

Water requirements, both fresh and saline, for the petroleum industry in Texas are projected to total about 15 million acre-feet through the year 2020. These requirements are calculated to peak about 1980, when approximately 584 thousand acre-feet per year of water will be needed, but will decline to about 293 thousand acre-feet per year by 1990 and approximately 52 thousand acre-feet by 2020. Average annual requirements for the decades 1981-1990 and 2011-2020 are illustrated in Figure III-8.

There are many technical and economic variables which strongly influence petroleum production in the State; therefore, continuing study and refinement of these projected requirements will be necessary to assure that future demands can be met. Continued close coordination between the Board, the Texas Railroad

Commission, and the petroleum industry will be essential in these continuing studies.

Water Requirements for Agriculture

Agricultural Development

Early Texas settlers found the climate, soils, and vast expanses of level land in Texas favorable for agriculture. Cattle, cotton, and feed crops were major contributors to this early agricultural growth.

A rapidly expanding lumber industry in East Texas late in the last century modified the early largely livestock-crop agriculture. The substantial lumber production in this area has been supplemented more recently by woodpulp, paper, and other pulp products.

Texas ranks first among the States in the production of cotton and cottonseed, grain sorghum, rice, and cowpeas, and leads in total numbers of cattle, sheep, and goats and in wool and mohair production. The State ranks second in forage sorghum production, production of sorghum for silage, and production of pecans. It is also second in total value of all farm land and buildings.

Texas is currently third among the States in the farm value of crops and in the combined value of crops and livestock, in harvested crop acreage, and in the production of peanuts and citrus fruit. It is fourth in the production of commercial vegetables and melons, and supports an important part of the Nation's production of wheat. Cash receipts from farm marketings totaled $2.0 billion in 1955, $2.5 billion in 1964, and are expected to increase to $9.3 billion by 1990.

Much of the industrial economy and employment of people in Texas' cities is wholly or partially dependent upon agriculture. These industrial sectors include the food and allied products industries, agricultural supplies, materials, equipment and services, food and other agricultural crops and livestock product processing, agricultural chemicals, transportation, and marketing. These agriculturally oriented segments of the economy constitute a multibillion dollar contribution annually to the total economy of the State.

Despite the trend toward urbanization, farms and commercial forest holdings in 1965 occupied over 90% of the total surface area of Texas, or about 161 million acres. Urbanization, industrialization, highway development, reservoirs, and other uses of land are encroaching on this farm and forest area, however. In the next 50 years, these non-agricultural uses of land are estimated to require an additional 11 to 12 million acres presently in farms and forest. This encroachment means new pressures on agricultural production capabilities.

Direct employment in agriculture has declined in Texas, as in the rest of the Nation, from 446 thousand persons in 1950 to 292 thousand in 1960. By 1970, the total number of people employed in agriculture is expected to decline further to about 187 thousand.

Growth and Trends in Irrigation

Early settlers, particularly those of Spanish origin, brought irrigation to southern, southwestern, and western areas of Texas. Irrigation expanded rapidly in the Rio Grande Valley and began to develop in the Winter Garden area during and following World War I. Irrigation of rice began along the Texas Gulf Coast in about 1910.

The most rapid expansion of irrigation came with the development of extensive ground water supplies in the Texas High Plains prior to World War II. By 1964, approximately 5.d million acres was being irrigated in the High Plains, representing two-thirds of the total irrigated acreage in the State.

Nearly 83% of all present irrigation in Texas is supplied by ground water. Storage and diversion of streamflow for irrigation has remained relatively constant.

Crops grown under irrigation account for more than one-half of the cash receipts from farm marketing of Texas crops during most years. The percentage of the contribution of irrigated agriculture is commonly much greater during years of climatic drought, when dry-farmed crop production is usually reduced. Cotton is presently the most valuable irrigated crop in Texas, although rice, irrigated grain sorghum, fruits (including citrus), fresh and processed vegetables, and wheat are also of major importance.

About 85% of the irrigated lands in Texas produces cotton, grain sorghum, wheat, pasture, hay, and other feed crops. Although in the past some of these crops have been in surplus nationally, many reserves are now in short supply. The remaining 15% of irrigated acreage in the State produces higher value crops such as fruits, vegetables of all kinds, peanuts, pecans, nursery and other specialty crops, and rice. Irrigation of pasture grasses, hay, and feed crops for dairy and livestock farming and feedlot operations is increasing.

As the practice of irrigation has become of increasing importance in the production of crops, dryland farming practices have changed in the State. Small cash-crop farms common in East and Central Texas in the past have largely been replaced by the development of larger units engaged in livestock production. Cotton production has shifted to irrigated areas. Trends toward larger farming units and a greater dependence on livestock in dryland farming areas are likely to continue.

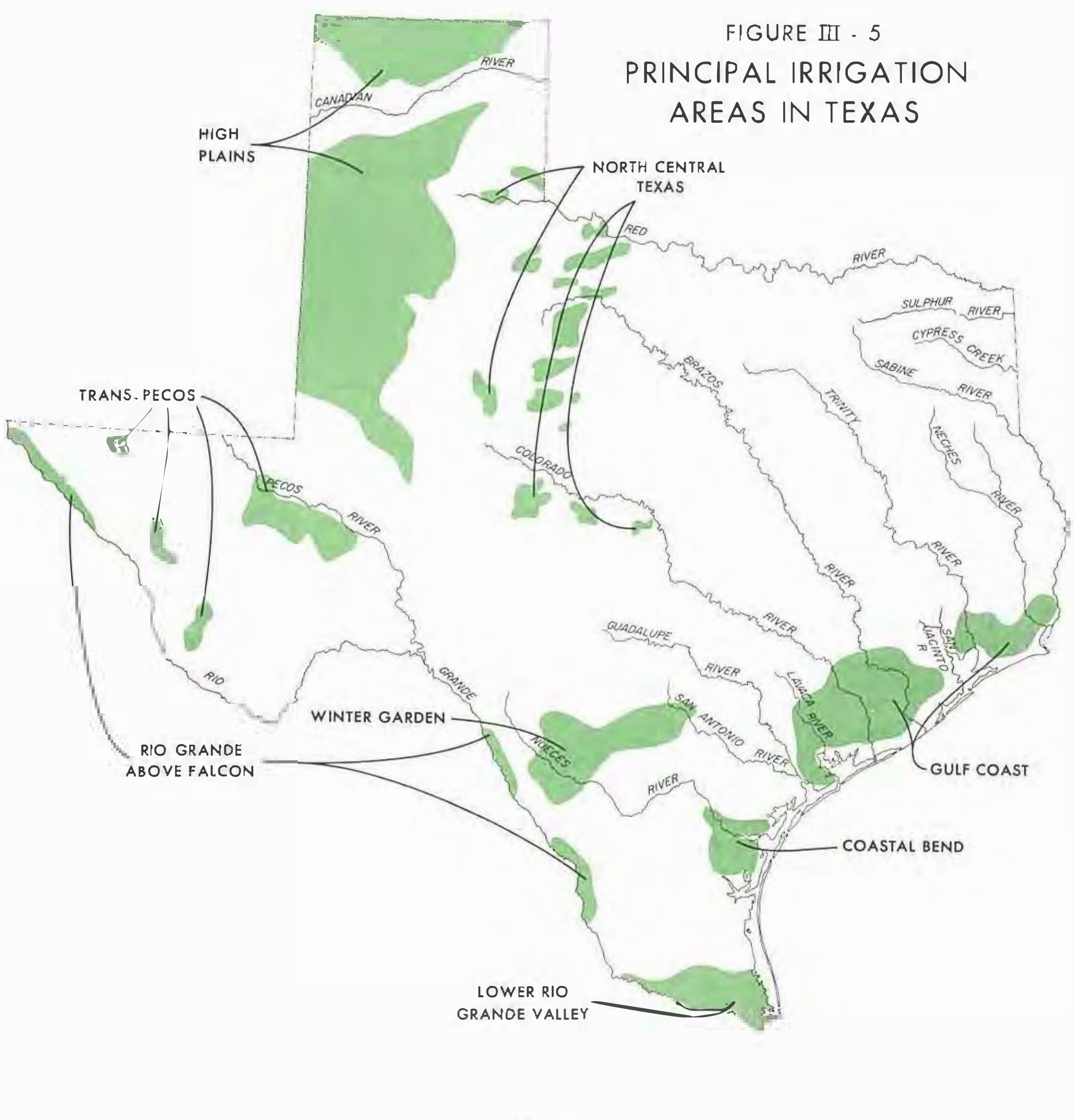
Irrigation in Texas is largely concentrated in eight areas: (1) High Plains, (2) Lower Rio Grande Valley, (3) Coastal Bend, (4) Gulf Coast (above Coastal Bend), (5) Winter Garden and vicinity, (6) Trans-Pecos (in West Texas), (7) North Central Texas, and (8) Rio Grande above Falcon (alluvium from the New Mexico-Texas line to Falcon Reservoir). These principal irrigation areas are shown in Figure III-5. Areas covered by alluvium and floodplain deposits along parts of the Brazos River, Colorado River, and other major streams, plus several widely scattered and generally small areas using ground water for irrigation, make up the remaining irrigated acreage in the State.

Water Requirements for Irrigation

A team of specialists at Texas A&M University prepared a detailed study for the Board of future needs for irrigated agriculture in the State, based on future needs for agricultural products and the resources available in Texas to meet these needs. Consideration was given to market trends, soils, water resources, and the future importance of agriculture to the total economy of Texas.

The results of the study indicate that approximately 37 million acres of lands in Texas are physically suitable for growing crops under irrigation. These lands are distributed over much of the State, but are concentrated principally in the High Plains, the Lower Rio Grande Valley, the Winter Garden, along the Gulf Coast, in the alluvium-filled valleys of the major streams, and inland from the Coastal Bend. The Pecos River Valley, the El Paso Valley, and areas in North Central and West Central Texas also have important irrigable lands. These 37 million acres of irrigable areas were defined without consideration of economic constraints on the development of irrigation, availability of irrigation water, or need for resulting produce.

FIGURE III - 5
PRINCIPAL IRRIGATION AREAS IN TEXAS



A detailed analysis was made in this study of the future need for agricultural products in the Nation, and Texas' probable share in providing these food and fiber requirements for both domestic consumption and export. These potential requirements for Texas farm products to the year 2020 are shown in Table III-2. In these projections, consideration was given to future advances in agricultural technology, and constraints on crop production were introduced in recognition of market limitations. These constraints were based on:

(1) Texas' share of national markets over the past quarter century;

(2) estimates of national food and fiber requirements for the years 1980, 2000, and 2020; and

(3) prospective changes in the competitive position of Texas in production of some crops, which will add to—or subtract from—the shares of markets previously claimed.

Table III-2.--Projected Requirements for Production of Major Farm Products in Texas

(Units in Thousands)

COMMODITY	UNIT	YEAR 1980	YEAR 2000	YEAR 2020
Livestock Products: 1/				
Beef and Veal	lbs.	4,676,000	6,471,000	8,805,000
Lamb and Mutton	lbs.	188,000	250,000	330,000
Pork	lbs.	289,000	358,000	433,000
Chickens	lbs.	745,000	996,000	1,317,000
Turkeys	lbs.	205,000	299,000	426,000
Milk	lbs.	3,309,000	4,243,000	5,370,000
Eggs	doz.	239,583	354,500	477,250
Crops, Non-Feed:				
Wheat	bu.	78,608	109,114	149,403
Cotton	bales	4,784	6,356	8,465
Rice (Rough)	cwt.	22,770	27,725	34,123
Peanuts	lbs.	292,005	456,909	692,403
Other Oil Crops	bu.	13,886	26,232	44,206
Sugar Beets	tons	1,203	2,836	5,547
Potatoes	cwt.	5,447	8,556	13,001
Sweet Potatoes	cwt.	1,347	2,043	3,021
Vegetables	cwt.	70,008	106,124	156,879
Grapefruit	tons	981	1,465	2,144
Other Citrus	tons	449	821	1,374
Fruits, Non-Citrus	tons	30	52	84
Tree Nuts	lbs.	39,488	58,587	85,092
Crops, Feed: 2/				
Corn for Grain	bu.	8,916	14,572	21,475
Oats	bu.	1,773	2,700	3,984
Barley	bu.	1,764	1,932	2,467
Sorghum for Grain	bu.	85,168	89,900	94,631

1/ Live weight requirements.

2/ Requirements only for human foods and exports; livestock needs reflected in requirements for livestock products.

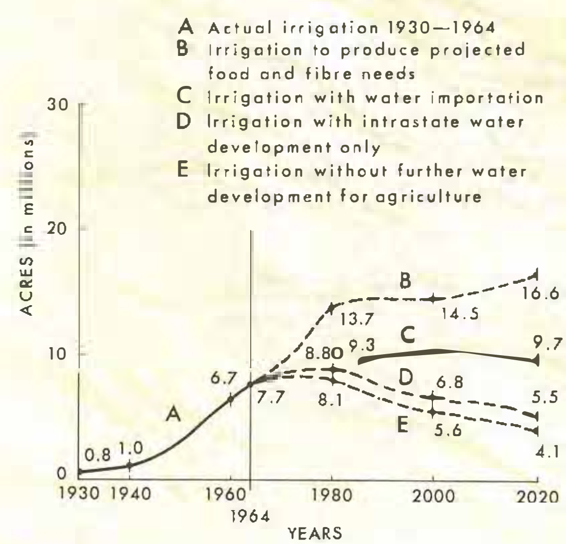
By the year 2020, these studies by Texas A&M University indicate that economic incentives for the development of irrigated agriculture on about 16.6 million acres of the 37 million acres of irrigable lands in Texas are possible, provided water could be made available for irrigation and water and associated irrigation costs would be sufficiently low to maintain or improve the competitive position of Texas irrigators.

Of the 16.6 million acres, based on the assumption that sufficient supplies of water could be made available at reasonable cost, over one-half would be in the High Plains; 1.6 million acres in North Central Texas; 0.7 million acres in the Coastal Prairie along the upper Gulf Coast above the Coastal Bend; 0.5 million acres in the Trans-Pecos region in West Texas; and 3.5 million acres in the Rio Grande Plain, including the Coastal Bend, Winter Garden, and Lower Rio Grande Valley. The remaining 1.8 million acres is distributed along the alluvium-covered valleys of the major river basins and in small, scattered areas of Central and East Texas.

The anticipated limited availability of water, however, combined with urban and industrial encroachment on irrigable lands, create the prospect of a 2020 level of irrigation in Texas short of the 16.6 million acres considered as possible by the Texas A&M University studies. Projected declines in existing ground water supplies which presently sustain the irrigation economies of several areas, notably the High Plains, Trans-Pecos, and Winter Garden areas, will result in a substantial reduction of irrigated acreage in the State during the next decade and beyond unless water is imported. Additional importation beyond that presently contemplated may be found justified later. Figure III-6 illustrates potential irrigated acreage in the State.

FIGURE III - 6

TEXAS IRRIGATION WITH FOUR PROJECTIONS



Irrigation Potential of Principal Irrigable Areas

High Plains

Virtually all of the water presently used for irrigation of approximately 5.1 million acres annually in the High Plains comes from a declining ground water supply in the underlying Ogallala Formation. Cotton, grain sorghum, wheat, and vegetables are the principal crops grown. Although irrigated acreage in the High Plains is still increasing markedly, much of the new irrigation is in the northern part of the area where existing ground water supplies have not yet been fully developed. Some formerly irrigated areas have been returned to dry farming or lie idle because of exhaustion of the ground water supply.

With presently available water supplies, irrigated acreage in the High Plains is expected to reach a peak of approximately 6 million acres by about 1980. Up to that time, expansion of irrigated acreage in some portions of the South High Plains and in the North Plains (north of the Canadian River) will proceed at a higher rate than projected reductions in irrigated acreage due to lack of water in parts of the South Plains. After about 1980, a gradual overall reduction in irrigated acreage will ensue, and by 2020 only about 2.2 million acres can be expected to be irrigated annually from the remaining ground water supply, largely in the more recently developed northern part of the High Plains. Thus, importation of a supplemental irrigation water supply will be necessary if the present level of irrigation is to be maintained.

North Central Texas

Based upon preliminary studies by the Board of potentially irrigable land in North Central Texas, a total of as much as 1.6 million acres could be irrigated in this region of the State provided water were available at reasonable cost. Approximately 350 thousand acres is irrigated annually in this area, supplied principally by ground water. Ground water supplies of the area are limited, however, and water quality in some scattered local areas is not suitable for irrigation. Surface water provides a minor part of the supply for irrigation in the area.

It is projected that by 2020 ground water in North Central Texas will support irrigation of only about 108 thousand acres annually, and locally available surface water supplies will only support an additional 60 thousand acres. Importation of water to those areas suitable for project-type irrigation will be needed to supplement supplies locally available if future irrigation is to be maintained reasonably near present levels.

Lower Rio Grande Valley

This semitropical area includes Cameron, Willacy, Hidalgo, and Starr Counties. Citrus, other fruits, and vegetables, as well as cotton and grain sorghum are the principal crops grown. Most of the 824 thousand acres irrigated in 1964 in the Valley was supplied with water from the Rio Grande, but a supplemental supply of import water is needed to maintain adequately this irrigation level.

Texas Water Commission Bulletin 6413, *Water-Supply Limitations on Irrigation from the Rio Grande in Starr, Hidalgo, Cameron, and Willacy Counties, Texas,* was prepared on request of the Attorney General of Texas to assist the Court in reaching a decision on the issues. Results of the studies conducted in preparing Bulletin 6413 indicate that water from the Rio Grande would be available to meet projected annual demands of 124 thousand acre-feet for domestic, municipal, and industrial uses, and to meet irrigation requirements of an estimated 650 thousand to 680 thousand acres with tolerable shortages of irrigation water in critical drought years.

The adjudication and litigation of rights to water above and below International Falcon Reservoir from the Rio Grande is currently in process; thus, allocation among water users of a firm supply from this source is uncertain at this time. There is, however, a dependable water supply for no more than the equivalent of approximately 650 thousand acres of irrigation annually below Falcon Dam from the operation of Amistad and International Falcon Reservoirs. Serving any acreage greater than the 650 thousand acres that can be dependably supplied annually from the Rio Grande will require importation of irrigation water.

Some increase in the level of irrigation would enhance the Valley economy, and import water is planned to supply a moderate increase. Importation of about 700 thousand acre-feet of water annually to the area is needed to supply a total of about 966 thousand acres a year (including the 824 thousand presently irrigated by Rio Grande water).

Coastal Bend

Less than 50 thousand acres is now irrigated in this part of the Lower Gulf Coast. Fertile lands in the area are well suited for the irrigation of vegetables, cotton, grain sorghum, and other crops, but water supplies of suitable quality are not locally available to support large-scale irrigation development. About 0.8 million acres of the 16.6 million acres of the potential 2020 irrigation development in the State is in the Coastal Bend area.

One of the largest blocks of potentially irrigable land in the Coastal Bend area is in eastern Nueces County, south and west of Corpus Christi. At least 300 thousand acres could be effectively and efficiently served in this area with project facilities for delivery of about 453 thousand acre-feet of water annually.

Another large block of irrigable land in the Coastal Bend area is located north of Corpus Christi. In this area, at least 200 thousand acres could be efficiently irrigated by project water-delivery systems, requiring a supply of about 274 thousand acre-feet of water annually.

Winter Garden and Vicinity

Vegetables, fruit, peanuts, cotton, and other crops are grown in this area annually under irrigation, supplied principally by ground water and secondarily by diversions from spring-fed streams.

More than 900 thousand acres of irrigation could be developed by the year 2020 in this broad area if adequate water supplies were available. Existing ground water supplies are being depleted, however, and locally available surface water supplies are inadequate. The present rate of ground water pumpage from the principal aquifer serving the area exceeds the projected rate of dependable recharge to the aquifer. **This area can maintain a stable irrigated agriculture by properly planned conjunctive use of remaining ground water supplies, locally available surface water, and 200 thousand acre-feet of water which would be imported to the area from Amistad Reservoir on the Rio Grande through the Texas Water System, with replacement water furnished to the Lower Rio Grande Valley through the System.**

Gulf Coast

Irrigation in this area, with over 500 thousand acres irrigated in 1964, is largely for the production of rice. About one-third of the irrigation in this area is presently supplied with ground water from coastal aquifers, and the remaining two-thirds is supplied by surface water delivered through public and private distribution systems. The permeable, friable soils common in the deltas of the Colorado and Brazos Rivers and deposits along meander cutoffs of former river channels are suitable for the production of a variety of crops, mostly without irrigation. On the heavier, clayey soils, pasture lands are rapidly developing.

According to the studies by Texas A&M University, the annual irrigation need in this area by 2020 will be nearly one million acres, principally for rice production. **Several million acres of land in this area is suitable for irrigation, particularly for growing rice, but urban and industrial encroachment around metropolitan areas and the need for crop rotation are limiting factors in some areas. As much as 700 thousand acres has been irrigated annually in this area, including about 600 thousand acres of rice, from available surface water supplies. Ground water can be expected to supply some of the anticipated increase in irrigated acreage; however, potential saline water intrusion in aquifers may limit full development of this source of supply locally.**

Rio Grande Above Falcon

About 126 thousand acres of land on the United States side of the Rio Grande is presently being irrigated each year in this area. Water supplies are from diversion of streamflow of the Rio Grande and pumpage of ground water from shallow wells in the Rio Grande alluvium. Irrigated acreage is concentrated along the river between El Paso and Fort Quitman (the El Paso Valley) and in areas of Maverick, Webb, and Zapata Counties. If dependable water supplies were available to serve these areas, about 270 thousand acres could be irrigated in this region. Without a supplemental water supply for the El Paso Valley, there is not enough water available to maintain more than about 65 thousand acres of irrigation, and continued use of municipal and industrial waste waters discharged into the Rio Grande above Fort Quitman is necessary to maintain present levels of irrigation. The excessive salinity of present irrigation supplies and the methods of irrigation used, which are necessitated by the limited supply, have created an unfavorable salt balance in the soils locally.

Irrigation in areas of Webb and Maverick Counties between Amistad and Falcon Reservoirs can be expanded with the availability of dependable, regulated releases from Amistad Reservoir. Replacement of the Rio Grande streamflow thus used, however, would be required to maintain the supply to Lower Rio Grande Valley water users. It is estimated that as much as 190 thousand acre-feet of diverted water from Rio Grande streamflow might be consumed annually to supply the potential demands for irrigation water in areas of Webb and Maverick Counties. It will be essential to clarify all rights to the use of Rio Grande water as a basis for accurately determining permissible diversions in this area and the amounts of replacement water required to be furnished the Lower Rio Grande Valley.

Trans-Pecos

Irrigated lands in the Trans-Pecos region of Texas are centered largely along the Pecos River in Reeves, Pecos, and Ward Counties; near Dell City in Hudspeth County; near Van Horn in southern Culberson and western Jeff Davis Counties; and in the Marfa area, Presidio County. A frequently limited and usually saline supply of surface water from Red Bluff Reservoir on the Pecos River is used in Reeves, Pecos, and Ward Counties, but ground water is the principal source of irrigation water supply in this region.

The supply of ground water in the Trans-Pecos region is declining, however, as pumpage exceeds natural recharge to the aquifers in most areas. The ground water pumped for irrigation is also becoming more saline as the result of natural saline water encroachment in the aquifer, and possibly as a result of the recycling of irrigation seepage. No additional surface water supplies are presently available for irrigation in the region, and by 2020 only about 56 thousand acres can be irrigated from local water supplies projected to be available.

If sufficient water of suitable quality were available in the Trans-Pecos area, about 500 thousand acres could be irrigated annually by the year 2020. Planned importation of about 933 thousand acre-feet of water annually to supply about 311 thousand acres will maintain a total of 367 thousand acres of irrigated lands in the Trans-Pecos region.

Other Areas

In addition to the eight principal areas of irrigable lands described above, comparatively small areas in various parts of Texas are also under irrigation. These areas are widely scattered in individual fields and farms in Central and East Texas, below small impoundments, adjacent to streams, or where suitable ground water supplies and favorable soil and climatic conditions exist. In 1964, nearly 100 thousand acres was irrigated along the Brazos River below Waco, and about 70 thousand acres distributed throughout other Central and East Texas areas.

About 1.6 million acres of the potential 2020 irrigation development, if irrigation water were available at reasonable cost, is located in the Blackland and East Texas Timber land resource areas and along major streams of Central and East Texas. Most of these irrigable areas are not readily adaptable to large-scale project irrigation because they are relatively small and scattered. It would be physically difficult to provide some of the areas with irrigation water from water supply projects, and the economic feasibility would be questionable. The agricultural trend in these land resource areas, however, is toward livestock raising and development of lands for grazing, for which irrigation is generally not required.

Summary

Nearly 83% of all present irrigation is supplied with ground water. However, many presently irrigated areas—the High Plains, Lower Rio Grande Valley, Winter Garden, Trans-Pecos, and elsewhere—face the prospect of returning to dryland farming as available water supplies are exhausted. There is not enough water in Texas available, even through redistribution, to avoid this occurring. These needs for water for irrigation in excess of available supplies do not occur in eastern and central river basins of the State where present and projected irrigation will be supplied by direct diversion or under existing water rights.

By 1985, if a supplemental surface supply of water has not reached the High Plains, this vast area will have begun an area-wide retrogression to dryland farming which will have profound economic consequences throughout the State. The North Central Texas, Trans-

Table III-3.--Planned Program of Texas Irrigation by 2020 (Annual Amounts, in Thousands of Acres and Thousands of Acre-Feet)

MAJOR IRRIGATION AREA	SOURCE OF WATER SUPPLY: GROUND WATER		LOCAL SURFACE WATER		IMPORTED WATER		ALL SOURCES	
	ACRES	AC-FT	ACRES	AC-FT	ACRES	AC-FT	ACRES	AC-FT
High Plains	2,191	1,527	—	—	3,812	6,480	6,003	8,007
North Central Texas	108	205	60	126	95	171	263	502
Trans-Pecos	34	119	22	70	311	933	367	1,122
Rio Grande Above Falcon Reservoir	5	12	130	366	74	190	209	568
Lower Rio Grande Valley	—	—	650	1,500	316	700	966	2,200
Coastal Bend	29	41	8	8	500	727	537	776
Winter Garden and Vicinity	112	185	62	85	80	200	254	470
Gulf Coast	221	782	449	1,814	—	—	670	2,596
Other	105	123	393	558	—	—	498	681
Texas	2,805	2,994	1,774	4,527	5,188	9,401	9,767	16,922

Pecos, Lower Rio Grande Valley, and Winter Garden areas face equally crucial time-phasing problems. The 5.1 million acres of land irrigated in the High Plains is supplied by water from the Ogallala Formation, where water levels are declining as the result of prolonged pumping at rates far exceeding the rates of replenishment. Studies by Texas A&M University indicate a potential economic demand of 6.7 million irrigated acres in the South High Plains if water can be made available at costs which would leave irrigators an economic incentive to irrigate their lands rather than dry farm. Without an import of water from outside the area, however, irrigation will have begun a severe decline by 1985, to a predicted 2.2 million acres supportable by ground water in 2020. Present irrigation of 350 thousand acres in North Central Texas will decline to about 168 thousand acres supportable by local water supplies in 2020. Planning studies by the Board indicate that only about 650 thousand acres of the 824 thousand acres historically irrigated in the Lower Rio Grande Valley can be supported by Rio Grande water, and there is an irrigation potential of 1.4 million acres in the area with an adequate water supply. An added complexity in providing an adequate irrigation water supply in the Lower Valley area results from the as yet unresolved legal questions relating to allocation of Rio Grande water. In the Winter Garden about 200 thousand acres of the present irrigated acreage will be dry farmed or out of production by 2020 without additional water supplies, and this is an area where economic incentives are projected to create an irrigation potential of more than 900 thousand acres. Declines in irrigated acreage will occur elsewhere throughout the State without a systematic program for supplying supplemental water.

The reimbursable costs of water supply to these areas will have to be borne by the areas. The cumulative cost to the entire State of their loss as irrigation areas will be formidable if it is not possible to supplement their locally available supplies through the Texas Water Plan.

Agriculture generates more of Texas' wealth, supporting a related annual $6 billion to $7 billion commerce and industry, than any other factor in the economy with the exception of petroleum and petrochemicals. One yardstick of this contribution is in cash receipts from farm marketings which reached $2.5 billion in 1964, and under the Texas Water Plan are expected to reach $9.3 billion by 1990. Irrigation accounts for over half of this agricultural wealth.

The contribution of irrigated agriculture to the economy of the entire State, however, goes far beyound the direct returns for the value of crops. Utilities, gas pipelines, transportation, navigation, investments through loans and mortgages, bank deposits, canneries, food processing plants, livestock and poultry production, fertilizer and pesticide manufacturers, farm equipment manufacturers and distributors, and wholesale and retail commerce are all direct beneficiaries of a healthy and expanding irrigated economy.

The development of major irrigation areas in the State by the year 2020 with an import of water from out-of-State as envisioned under the Texas Water Plan is summarized in Table III-3, and shown graphically in Figure III-7. The Plan provides for irrigation of about 9,767,000 acres of land by 2020, which would be

FIGURE III - 7
TEXAS IRRIGATION
PRESENT AND PROJECTED

supplied by approximately 16,922,000 acre-feet of water annually. Ground and surface water resources projected to be available locally in the irrigable areas will be sufficient to sustain annual irrigation on only about 4,579,000 acres of this total.

Of the 12 to 13 million acre-feet of water which the Board's studies have indicated can be imported from out-of-State sources and distributed for use throughout the State in an economically feasible manner, approximately 7.6 million acre-feet is proposed to be made available for irrigation of about 4.2 million acres of land. Interbasin importations from in-State sources will furnish 1.8 million acre-feet annually for irrigating about 1 million acres. These imported supplies, when added to in-basin supplies projected to be available for irrigation in the year 2020, will not be sufficient, however, to meet the total need for irrigated agriculture in the State by 2020 as projected by the Texas A&M University studies.

Water Requirements For Navigation

Navigation was important to exploration, colonization, and early economic development in Texas. The major rivers of the State, most of which flow along parallel courses from northwest to southeast, provided routes from the Coast to the interior. Settlers depended upon these rivers for transportation. Gradually, as other means of transport to the interior of Texas developed and early networks of highways and railroads emerged, overland transport became important and navigation on the streams diminished. Navigation facilities in the tidewater area along the Gulf, however, have been steadily expanding, keeping pace with and contributing to the growth of this highly industrialized region of the State.

Navigation Facilities

Today, Texas has 12 ports for deep-draft (30-40 feet) vessels and 13 shallow draft (6-14 feet) ports. The Houston Ship Channel has enabled this inland area to receive and ship the third largest tonnage of all U.S. seaports. The intracoastal waterway connects the entire coastal area with a protected, shallow draft route between Texas and other Gulf and Atlantic ports. Harbor and port facilities have been improved to accomodate shipping and to expedite the handling of cargo. A number of extensions of this canal connect important industrial areas with tidewater, coastal shipping routes, and the sea lanes.

Water Requirements

Existing and potential navigation facilities on major streams were considered during the planning studies. The volumes of water required to operate shallow barge transportation were determined for all major basins from the Red River Basin to the San Antonio River Basin, with the exception of the Sulphur, San Jacinto, and Lavaca Rivers.

Data developed by the Corps of Engineers were used for the Trinity River and Cypress Creek. Lockage heights were estimated from channel profiles of the Red, Sabine, Neches, Colorado, Brazos, and San Antonio Rivers, and amounts of water required for 12 lockages per day were computed. Leakage and evaporation losses were also estimated. The navigation water requirements for the Guadalupe River were assumed to be the amount of water presently diverted to the Victoria Channel Barge Canal for operation and maintenance purposes.

Navigation water requirements are commonly large in the middle and upper part of a river basin where it may be necessary to provide locks around an existing or proposed dam. In most instances, navigation water requirements will be provided by flows released from upstream reservoirs for various downstream uses. While large navigation requirements generally occur in the upper and middle parts of river basins, the net basin navigation water requirement is the requirement for the lowermost lockage. Navigation facilities should be designed so that excess lockage water from upstream lockages can be diverted for other uses downstream.

It has been assumed for planning purposes that all navigation water requirements in Texas will be provided as needed and justified. Staging of construction of navigation facilities throughout the State cannot be predicted with reasonable certainty; therefore, the requirements given in Table IIb4 represent the possible projected total needs by the year 2020. Requirements for navigation on the Trinity, Guadalupe, and Neches Rivers are included in the projected 1990 demands as shown on Figure III-8 to assure that water is available as navigation projects develop.

Water Requirements of Texas' Bays and Estuaries

The impact of the development of the rivers of the State and of municipal, industrial, and irrigation return flows on Texas' bays and estuaries is of vital concern to the State and Nation. Therefore, strong planning emphasis has been placed on seeking a reasonable and constructive management program for the bay areas.

The complexity of the Texas estuaries and bay systems and the lack of sufficent data to define with reliable accuracy the physical, hydraulic, and water quality characteristics and future fresh water needs for these areas present a tremendous challenge in attempting to preserve this valuable resource of the State. The bays and estuaries lie in a broad arc along the Texas Coast extending from Brownsville to Orange, a distance of

Table III-4.--Projected Navigation Water Requirements by 2020

RIVER BASIN	REQUIREMENTS, IN ACRE-FEET
Red	74,100
Cypress	70,800
Sabine (Upper Basin)	155,600
Sabine (Lower lock)	34,300
Neches (Lower lock)	34,500
Trinity (Livingston Dam)	375,700
Trinity (Wallisville Dam)	63,900
Brazos (Lower lock)	36,700
Colorado (Matagorda Dam)	40,700
Guadalupe (For sea level channel)	7,000
San Antonio	1/
Total requirements at lower lock	362,000

1/ If navigation is determined to be feasible at some future time, design studies at that time will necessarily involve consideration of pumpback of some lockage water, together with available return flows.

approximately 400 miles. This area encompasses several climatic regions, which, together with varying tidal interchange and circulation patterns, result in wide variations in bay water salinities.

Inflows of fresh water to the bays and estuaries are subject to wide seasonal variations, and the bay areas are affected by severe drought and major floods. Extreme changes in the environments of the bays and estuaries caused by these uncontrolled hydrologic events have frequently resulted in serious damage to the ecology of several of the bay systems.

Estuaries important as nursery areas commonly possess a well defined salinity gradient between the river mouth and tidal pass, thus providing desirable habitat for several species of aquatic life. River inflow supports this salinity gradient to a large extent, and without it the entire estuary may become hypersaline, as has occurred in some areas. These inflows also provide nutrients, both in dissolved and suspended form, necessary for the growth of plankton, which in turn constitutes the basic food for many marine species. Excessive fresh water inflow, by contrast, may cause the entire estuary to become fresh or near-fresh and destroy the salinity gradient so necessary for species diversity.

The quality of waters in the estuaries and bays of the Texas Coast is also influenced by navigation developments. Each of the major estuaries and bay systems has navigation facilities which require periodic maintenance. New navigation facilities will be required, or existing channels enlarged, as industrial development proceeds in these areas. In places, navigation development may contribute to the pollution of the bays as spoil from dredging operations increases the turbidity of the bay waters. Serious blocking or modification of bay water circulation and tidal interchange can also result from spoil disposal.

The threat of further reduction of Gulf water inflow by hurricane-protection works and the rapidly rising demand for coastal recreation are significant factors which must be considered in planning for the preservation and enhancement of the bays and estuaries.

In 1967, the Board and the U.S. Geological Survey began a three-year comprehensive data collection program designed to aid in defining the quality and hydraulic characteristics of the bays. The total cost of this program is in the order of $400 thousand.

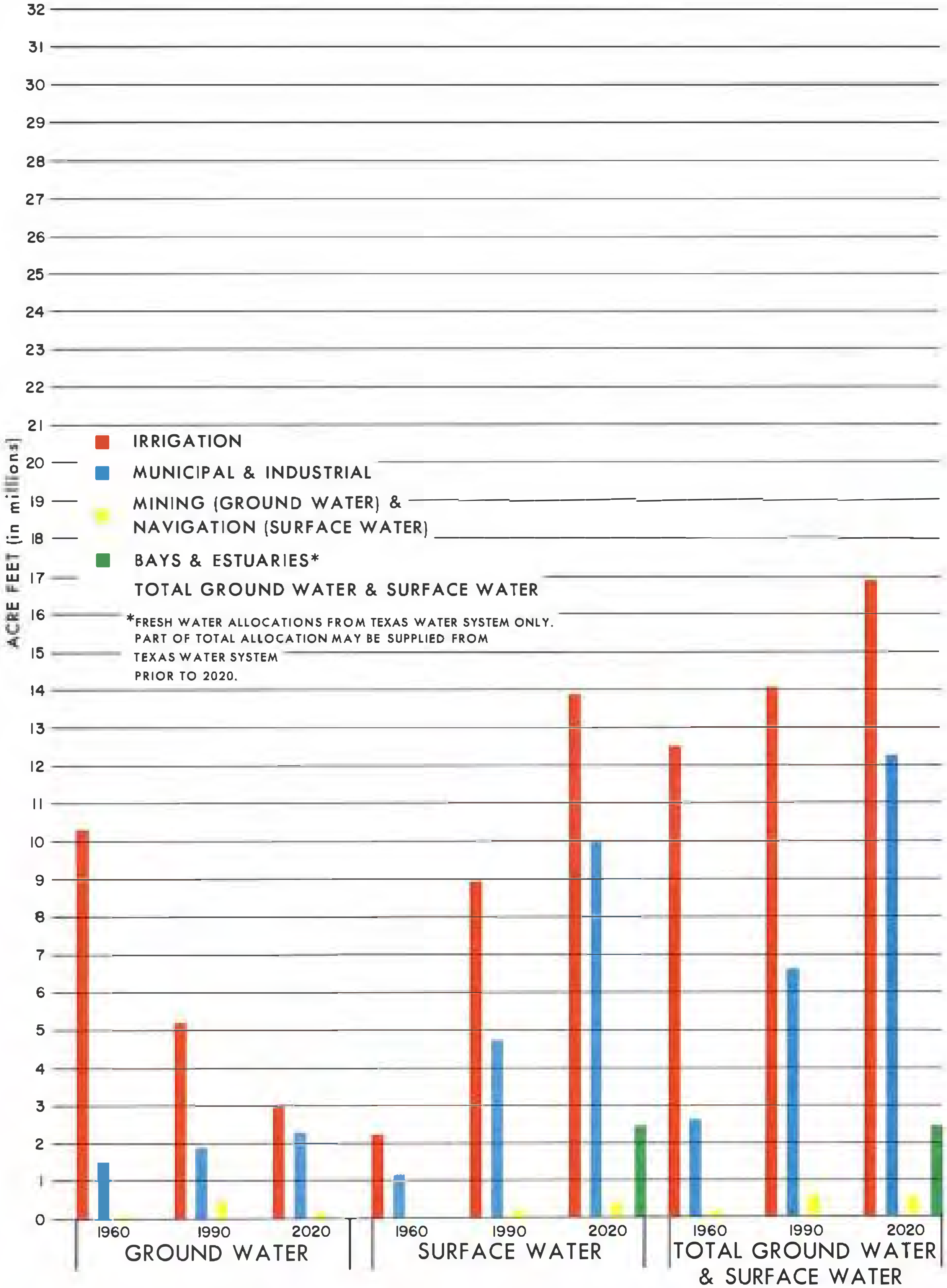
At present, there is insufficient information on the bays and estuaries to predict with reasonable accuracy the impact of continued discharges of municipal and industrial wastes and runoff from urban areas and agricultural lands to these areas, but there seems little doubt that these factors are significant. Data collected thus far by State and Federal agencies suggest that accumulation of pesticides in many of the bays is already approaching serious proportions.

Maintenance of Salinity Gradients

Maintenance of optimum salinity gradients in the bays and estuaries is essential for the propagation of important aquatic life. At the present stage of planning,

FIGURE III - 8

TOTAL WATER REQUIREMENTS



the Board proposes maintenance of desirable salinity gradients through managed fresh water inflows and modified distribution of, and in some cases increased, Gulf water inflow. Thus, those bays which are presently receiving an overabundance of fresh water might be enhanced by additional tidal interchange, and those which are becoming hypersaline might be benefitted by improved Gulf-water circulation.

The Board has made reconnaissance hydrologic studies of the principal bay systems for the purpose of estimating those quantities of controlled inflow needed to avoid the losses of these resources to the State. Table III-5 presents data developed from these preliminary studies, and the volumes of fresh water to be provided each of the principal bay systems from the Texas Water System on an annual basis by the year 2020, subject to completion of detailed studies of each of the bay systems to determine the optimum management program for each.

These preliminary allocations of fresh water for the bays and estuaries under the Texas Water Plan will result from controlled releases from various components of the Texas Water System, reservoir spills, and properly treated and managed return flows. The proportion of this total allocated supply available prior to 2020 will depend upon the staging of construction of the various components of the Texas Water System.

The characteristics of each of the principal bay systems considered in the Texas Water Plan and the problems associated with these areas are briefly described below.

Galveston Bay

The Galveston Bay System, with about 341 thousand acres of water surface, is the largest inland bay system of the Texas Coast. It consists of Galveston Bay, Trinity Bay, and East and West Bays. Rainfall in the area has averaged about 50 inches per year, and the mean annual temperature is about 69° F.

Galveston Bay is probably the most important bay, economically and ecologically, of all bays on the Texas Coast. Its large acreage and its wide range of depth, temperature, and salinity conditions make Galveston Bay the nursery grounds for over 80% of the poundage taken as fishery products in the Gulf of Mexico adjacent to the Texas Coast.

Inflow of fresh water to the Galveston Bay System during the period 1941 through 1957 averaged about 10.2 million acre-feet annually, although total yearly inflows varied from as little as 1.4 million to more than 20 million acre-feet. Approximately 2.1 million acre-feet of the average annual fresh water inflow consisted of runoff from adjacent coastal basins. An average of about 1.4 million acre-feet of precipitation falls directly on the bay annually; therefore, in the past the total volume of fresh water available to the bay on an average annual basis has been about 11.6 million acre-feet.

Projections indicate that under 2020 conditions of land use and water resources development annual fresh water inflow (exclusive of return flows) will average about 6.0 million acre-feet per year. Assuming average annual precipitation on the bay system will remain on the order of 1.4 million acre-feet per year, a total average annual fresh water inflow of about 7.4 million acre-feet would be available to the area plus uncontrolled return flows from the Houston metropolitan and industrial complex.

On the basis of the preliminary studies and present knowledge of the characteristics of the Galveston Bay System, approximately 1.5 million acre-feet of additional fresh water will be provided the bay annually from the Texas Water System. The Texas Water Quality Board, coordinating with Federal and State agencies, universities, and private consultants, has begun a study designed to predict the impact of urban, agricultural, and industrial developments in the State on the quality of water in the bay system. This study will also be oriented toward more reliably defining the fresh water inflows needed to sustain a desirable aquatic environment and the optimum management program for the bay system. The results of this study will be helpful in developing similar comprehensive studies of the other bay areas.

East Matagorda Bay

East Matagorda Bay, a relatively small bay with about 35 thousand surface acres, has been separated from Matagorda Bay by the development of the Colorado River delta, and also is now completely isolated from the Gulf.

Annual fresh water inflow to East Matagorda Bay during the 1941 through 1957 period averaged about 0.2 million acre-feet, which included a small volume of return flow. Precipitation in the area has averaged about 42 inches per year; thus approximately 0.1 million acre-feet of precipitation falls on the bay annually. A total of about 0.3 million acre-feet of fresh water has therefore been available to East Matagorda Bay on an average annual basis. These historical conditions of available fresh water inflow are not projected to change significantly in the future. However, in order to prevent the development of hypersaline conditions in East Matagorda Bay, reestablishment of Gulf-water inflow may be needed in the future.

Matagorda Bay

Matagorda Bay, with about 238 thousand surface acres, is the second largest inland bay on the Texas

Table III-5.--Fresh Water Contributions to Major Texas Bays and Estuaries

(Million Acre-Feet per Year)

BAY	SURFACE AREA (ACRES)	MAJOR CONTRIBUTING STREAMS	HISTORICAL AVERAGE ANNUAL FRESH WATER INFLOW (1941-57 AVERAGE)[1]	HISTORICAL AVERAGE ANNUAL RAINFALL ON BAY (1931-60 AVERAGE)	TOTAL HISTORICAL AVERAGE ANNUAL FRESH WATER CONTRIBUTION TO BAY	PROJECTED AVERAGE ANNUAL FRESH WATER CONTRIBUTION TO BAY, INCLUDING PRECIPITATION, UNDER 2020 CONDITIONS[2] (EXCLUSIVE OF RETURN FLOW)	PROPOSED ANNUAL FRESH WATER RELEASES TO BAY FROM TEXAS WATER SYSTEM
Galveston	341,000	Trinity River San Jacinto River	10.2	1.4	11.6	7.4	1.5
East Matagorda	35,000	None	0.2	0.1	0.3	0.3	—
Matagorda	238,000	Lavaca River Navidad River	1.0	0.76	1.8	1.43[3]	0.3
San Antonio	143,000	Guadalupe River San Antonio River	1.5	0.4	1.9	0.8	0.3
Aransas	140,000	Mission River Aransas River	0.22	0.37	0.59	0.5	0.15
Corpus Christi	134,000	Nueces River	0.7	0.33	1.0	0.6	0.2

[1] Includes local runoff from coastal basins and estimated municipal, industrial, and irrigation return flow.

[2] Allowance made for operation of all existing and proposed upstream reservoirs in Texas Water Plan.

[3] Matagorda Bay could receive up to 0.9 million acre-feet of runoff and 0.15 million acre-feet of municipal, industrial, and irrigation return flows on average annual basis with flood channel from Colorado River proposed by Corps of Engineers.

Coast. Rainfall in the area has averaged about 38 inches per year, and the mean annual temperature is about 68°F.

Compared with Galveston Bay, little industry is presently located around Matagorda Bay. Matagorda Bay ranks second to Galveston Bay in economic importance, however, measured in terms of fishery resources. Tourism around Matagorda Bay is less well developed than at either Corpus Christi or Galveston Bays, probably because the latter bays are geographically associated with large metropolitan centers.

Fresh water inflow to Matagorda Bay during the period 1941 through 1957 averaged about one million acre-feet annually. Approximately 0.35 million acre-feet of the total resulted from local runoff. An average of about 0.76 million acre-feet of precipitation is estimated to fall directly on the bay system annually; thus, fresh water available to the bay, historically, has averaged about 1.8 million acre-feet per year.

Projections indicate that by the year 2020 runoff and river inflow to the Matagorda Bay System will average about 0.67 million acre-feet per year. Assuming that an average of about 0.76 million acre-feet of precipitation will continue to fall directly on the bay annually as has occurred in the past, average annual inflows, excluding return flows, will be about 1.43 million acre-feet.

Approximately 0.3 million acre-feet of water from the Texas Water System is allocated for delivery to this bay during years of need.

The Corps of Engineers has recommended a multipurpose project designed to improve navigation in Matagorda Bay. This project, if authorized, would provide for:

(1) a navigation channel to replace the present Colorado River Flood Discharge Channel from the Intracoastal Waterway to the Gulf shoreline; and

(2) a 50 thousand cfs capacity diversion channel from the Colorado River near the community of Matagorda to Matagorda Bay.

Should this project be constructed, these additional flows from the Colorado River would supply additional fresh water to Matagorda Bay in the future.

San Antonio Bay

San Antonio Bay, with about 143 thousand surface acres, is the third largest inland bay system on the Texas Coast. It consists of San Antonio, Espiritu Santo, Hynes, and Mesquite Bays. Rainfall in the area has averaged about 36 inches per year, and the mean annual temperature is about 69°F.

Presently, only two major industries are located in the San Antonio Bay area, and the bay ranks third in fishery resources, far exceeded by Matagorda and Galveston Bays. In terms of tourism, San Antonio Bay is presently less well developed than Corpus Christi and Galveston Bays.

Inflows of fresh water to San Antonio Bay have historically averaged about 1.5 million acre-feet per year. Approximately 0.2 million acre-feet of the total is derived from local runoff. An average of about 0.4 million acre-feet of precipitation is estimated to fall directly on the bay annually. Consequently, fresh water available to the bay has historically averaged about 1.9 million acre-feet per year.

It is projected that by 2020 runoff and inflows from the principal rivers which contribute to the bay will average about 0.37 million acre-feet per year. Thus, by 2020, total fresh water contributions to the bay system, including precipitation on the bay, will average about 0.8 million acre-feet annually. About 0.3 million acre-feet of water from the Texas Water System has been allocated for San Antonio Bay during years of need.

Aransas Bay

Aransas Bay, with about 140 thousand surface acres, is the second smallest inland bay along the Texas Coast. It is comprised of Copano, Aransas, and Redfish Bays. Rainfall has averaged about 32 inches per year, and the mean annual temperature is about 70°F.

Very little industry is presently located in the Aransas Bay area; however, a fairly substantial complex of seafood processing plants is situated in the town of Aransas Pass at the edge of Redfish Bay. Aransas Bay currently ranks fourth in fishery resources, above Corpus Christi Bay but well below the major producers, Galveston and Matagorda Bays. Facilities for tourists are less developed than around Corpus Christi and Galveston Bays.

Historically, Aransas Bay has received an average inflow of about 0.22 million acre-feet of fresh water annually, of which approximately 0.1 million acre-feet resulted from local runoff. Precipitation on the bay surface has averaged about 0.37 million acre-feet annually; thus, the total fresh water contribution to Aransas Bay has averaged about 0.59 million acre-feet per year in the past.

Projections of future land and water resources development within the contributing drainage area of the Aransas Bay System indicate that fresh water inflows may not be significantly reduced in the future; however, under the Texas Water Plan 0.15 million acre-feet of water is tentatively allocated to this bay to meet possible supplemental fresh water needs.

Corpus Christi Bay

Corpus Christi Bay, which covers about 134 thousand surface acres, is the smallest inland bay system, consisting of Nueces, Oso, and Corpus Christi Bays. Rainfall in the area has averaged about 30 inches per year, and the mean annual temperature is about 71°F.

Although industry in the area of Corpus Christi Bay does not approach the diversity and complexity of that in the Galveston Bay area, substantial industry exists around the City of Corpus Christi. Corpus Christi Bay currently ranks last as a commerical fishery resource, far below the other four principal bay systems. However, because of its proximity to the Corpus Christi metropolitan area, the bay area is an important tourist resource.

Inflows of fresh water to the Corpus Christi Bay System have historically averaged about 0.7 million acre-feet per year, which included approximately 0.03 million acre-feet of local runoff (principally from Oso Creek south of Corpus Christi). An average of about 0.33 million acre-feet of precipitation falls directly on the bay annually; consequently, the bay has received approximately 1.0 million acre-feet of fresh water on an average annual basis in the past.

By the year 2020, runoff and river inflow to Corpus Christi Bay are projected to be reduced to an average of about 0.28 million acre-feet per year; thus, the total volume of fresh water which will be available to the bay, excluding return flows, will decline to an average of about 0.6 million acre-feet annually.

Under the Texas Water Plan, approximately 0.2 million acre-feet of fresh water has been allocated annually from the Texas Water System as an aid in preserving and enhancing this bay.

Baffin Bay and Upper Laguna Madre

Owing to the arid climate and the lack of major river systems contributing water to this area, Baffin Bay and Upper Laguna Madre are naturally hypersaline except during periods of intense flooding. These areas represent the only true lagoons of the Texas Coast, being completely cut off from Gulf waters by Padre Island. Preliminary studies suggest that the salinity of bay waters could be significantly reduced and the area enhanced through increased inflow of Gulf waters by construction of properly designed tidal passes through the barrier islands.

Future Studies

The Texas Water Plan tentatively provides for the delivery of up to 1.5 million acre-feet of water to the Galveston Bay System and a total of 0.95 million acre-feet to Matagorda, San Antonio, Aransas, and Corpus Christi Bays from the Texas Water System during years of need. During wet years, such volumes of supplemental water would perhaps not be required; however, during periods of extended drought these supplies tentatively allocated to the individual bay systems may be insufficient.

Comprehensive studies of all of the major bays and estuaries of the Texas Coast, including the development of hydraulic and water quality models, will be necessary to accurately define these areas and establish the optimum fresh water requirements, the seasonal regimen of demands for these inflows, and the precise areas where releases of fresh water should be made. Preservation of the spawning and nursery areas, where salinity and dissolved oxygen content are critical factors, must be given prime consideration in further studies of optimum management programs for these resources.

In order to resolve some of the problems indicated, the following program is recommended:

1. The Board will continue the present reconnaissance-level basic-data collection and economic studies in the bays, other than the Galveston Bay System, and will stress initiation of comprehensive economic and environmental studies, to be conducted in cooperation with other State and Federal agencies. The purpose of such comprehensive studies will be to determine the requirements for continued use, development, and enjoyment of the bays and estuaries within the context of the development and management of the total water resources of the State.

2. The Board will make every effort to assure that present and future comprehensive studies will be oriented toward defining the locations of areas where controlled releases of fresh water should be made so that design of these facilities may be properly considered.

3. The Board will assist and support the Water Quality Board in its efforts to establish requirements for higher levels of waste treatment in order to reduce pollution by return flows and to define other sources of pollution of these areas.

4. The Board will encourage studies of alternative methods of improving circulation patterns in the bays and better distributing points of tidal interchanges, where necessary, which may provide more desirable salinity gradients in some areas and also improve waste-assimilative capacities of some of the bay systems.

ADDITIONAL CONSIDERATIONS AND PROBLEMS ASSOCIATED WITH WATER RESOURCE PLANNING AND DEVELOPMENT

Many aspects of the total water resources picture in Texas must be considered during the planning, implementation, and ultimate operation of water supply and distribution systems. These include water quality management, flood control, upstream flood prevention, floodplain management, soil conservation, maintenance of adequate land drainage, control of phreatophytes (water-wasting vegetation), protection from hurricane-induced tides, preservation of historical and scenic sites and important archeological materials, water-oriented recreation, and fish and wildlife management. Solutions to some of the problems associated with these factors, as proposed under the Texas Water Plan, are discussed below.

Floods, Flood Control, and Floodplain Management

Floods in Texas

Flood stage, which is herein defined as the stage of a stream at which streamflow exceeds the capacity of the channel and begins to cause physical damage within or adjacent to the floodplain of the stream, occurs nearly every year on one or more of the major streams of the State. Damaging floods have occurred throughout Texas, frequently resulting in serious economic losses to agriculture, transportation and utilities industries, and urban areas, as well as loss of human life.

Because of the wide variation in the climate and physiography of Texas, the magnitude and character of floods differ widely, both within and between the major river basins of the State. In the eastern part of Texas, where rainfall is abundant, streams are commonly characterized by broad, flat valleys bordered by timber and dense growths of vegetation. Natural channels commonly have gentle slopes and small capacities, following meandering courses from their headwaters to the Gulf. Runoff is comparatively slow and stream velocities generally low. During periods of intense rainfall, large volumes of water frequently accumulate in the valleys of the basins and are subsequently released slowly to the streams. These conditions generally produce broad, flat-crested floods which move slowly in the lower regions of the basins and cause prolonged periods of inundation of the land.

In the central and western parts of the State, ground and tree cover is sparse. Stream slopes vary from steep to moderately steep, becoming flatter in the coastal plains. During periods of intense rainfall, runoff is more rapid than in the eastern part of the State, with consequent high peak flows, higher stream velocities, and shorter periods of land inundation.

An example of a large local flood is the flood of September 1921. This flood resulted from a severe storm near the community of Thrall, in eastern Williamson County, which established a national record for rainfall intensity. While the general storm extended along the Balcones Escarpment from about Temple to San Antonio, the most severe flooding and the highest rates of stream discharge occurred in the floodplain of the Little River in the Brazos River Basin. During this flood, the peak discharge of the Little River at Cameron was estimated to be 647 thousand cfs which resulted from runoff at a rate of almost 100 cfs per square mile of drainage area. In small areas of the basin, however, runoff of about one thousand cfs per square mile of drainage area was recorded. It is reported that at least 215 lives were lost during the passage of this flood.

The most serious Statewide flooding in recent years occurred in 1957. In a period beginning in April and continuing through June, every major river and principal tributary in the State reached flood stage. Flood conditions existed for as long as 80 days on many of the major rivers during this period.

Prolonged rainfall over a period of about one week in late April 1966 produced large volumes of floodwater and extensive flooding in the Sulphur River, Cypress Creek, upper Sabine, and upper Trinity River Basins, and in the lower Red River Basin. Many municipalities in these areas sustained damages from floods on smaller tributaries and from intense rainfall which produced runoff greatly exceeding capacities of existing drainage facilities. Rainfall totals in some areas reached 24 inches during the period.

Floods resulting from the intense and widespread rainstorms associated with Hurricane Beulah in September and October of 1967 produced record flood peaks on many streams in South Texas. Extensive damage occurred following precipitation in excess of 36 inches in areas of southwest Texas and northeast Mexico. Major damage to agriculture and urban areas occurred in the Rio Grande, Nueces, and San Antonio River Basins and in the San Antonio-Nueces and Nueces-Rio Grande Coastal Basins.

Frequent flooding occurs along the Gulf Coast because of accumulations of streamflow in lower reaches of the basins and as the result of heavy precipitation frequently accompanying tropical disturbances common to the coastal area. Flood damage in this region of the State results largely from inadequate natural drainage.

Table III-6 presents data on loss of life and property damages due to severe floods in Texas.

Flood Control Measures

Flood control measures proposed by the Corps of Engineers and incorporated as part of the Plan include positive control through flood storage capacity in existing and proposed reservoirs, and locally needed flood control projects such as channel modification and levee works. Flood problems and control measures are discussed by basin in Part IV, including channel improvement and levee projects, and Tables IV-52 and IV-53 show flood storage capacities in existing and proposed reservoirs.

Flood Problems and Floodplain Management in Urban Areas

Although floods generally cause serious economic losses in rural areas, the effects of severe flooding in urban areas in terms of human suffering, disruption of normal community life, and long-range economic losses result in public attention being focused largely on the flood problems of the cities. Early in this century, attempts by small groups of residents to provide local flood protection led to construction of many disconnected local levee systems. The State Legislature in 1913 created the office of State Reclamation Engineer to coordinate the development of levee construction and the planning of flood-control facilities. That agency was abolished in 1939, and the functions transferred to the General Land Office. These responsibilities were transferred to a predecessor agency of the Board in 1961 and continue to be a Board responsibility.

Congress has responded to the flood problem by passing the Flood Control Act of 1960, 33 U.S.C. 709a, establishing the Federal Flood Plain Management Program; and the Flood Plain Insurance Act of 1968 (Public Law 90-448). President Johnson provided impetus to the Flood Plain Management Program in 1966 by issuing an Executive order directing all Federal agencies to consider flood hazard in locating new Federal installations and in disposing of Federal land.

As a result, the Corps of Engineers, with the assistance of numerous Federal and State agencies, compiled a list of the flood problems of all cities in the Nation having populations of 2,500 or more in 1960. In Texas, 320 cities were defined as having one or more problems involving stream overflow, local drainage, or coastal flood problems. The list indicates 100 cities are affected principally by stream overflow flood problems, 112 have only drainage problems, 20 have coastal flood problems, and another 88 cities have various combinations of these problems.

It is inaccurate, however, to classify most cities solely as having one type of flooding or another because the problems are not mutually exclusive. In the classification adopted by the Corps of Engineers, stream overflow refers to flooding which occurs over an extended period of time due to one or more watercourses passing through or by a city. Local drainage

Table III-6.--Losses From Severe Floods in Texas Since 1903 1/

(Property Damage in Thousands of Dollars)

DATE	AREA	LIVES LOST	PROPERTY DAMAGE
July 1908	Red River	—	16,200 2/
Dec. 1913	Colorado and Brazos River Basins	177	9,000
Sept. 1921	Brazos, Colorado, Guadalupe, and Rio Grande Basins	215	19,000
Mar.-June 1929	Trinity, Sabine, Guadalupe, Brazos, Neches, and Colorado River Basins	—	8,000
Dec. 1935	Houston Area	—	2,500
July 1936	Central Texas Streams	—	2,000
Sept. 1936	Central and North Texas Streams	—	5,000
Apr.-June 1944	Guadalupe, Nueces, Rio Grande, Trinity, Sabine, and Neches River Basins		(State totals not given)
Feb.-Apr. 1945	Trinity and Sabine Rivers	—	9,000 2/
May-June 1946	Trinity River	—	4,150
Sept. 1946	San Antonio and Nueces Rivers	9	6,050
Apr. 1949	Rio Grande	—	3,300
May 1949	Trinity River Basin	10	14,000
Sept. 1952	Guadalupe, San Antonio, and Pedernales Watersheds	—	(Not given)
Apr.-May 1953	Sabine River Basin	—	38,959
June 1954	Middle Rio Grande and Lower Pecos River	16	19,079
Apr.-June 1957	Statewide	17	(Extensive)
June 1965	Sanderson, Texas (Flash Flood)	26	2,715
Apr.-May 1966	Sabine and Trinity River Basins	14	20,100 2/
Sept.-Oct. 1967	Guadalupe to Rio Grande Basins (Hurricane Beulah)	3	35,000 3/

1/ From Climatological Data, National Summary and Monthly Weather Review, and State Reclamation Department Bulletin 25.
2/ Includes damages in other States.
3/ Preliminary estimate; Corps of Engineers preliminary estimate was $98.4 million.

problems are defined as flooding caused principally by inadequate storm drainage systems, particularly in cities located in regions of relatively flat terrain. Local drainage problems exist throughout the State, however, and are not confined to the flat plains or coastal areas. Coastal flood problems are, of course, inherent to those cities located on or near the Coast which are subject to tidal or wind-driven inundation during severe storms or hurricanes. Several cities in Texas have experienced all three types of flooding, the most noteworthy being Hitchcock, La Marque, and Port Lavaca.

The Federal Flood Plain Management Program of 1960 was designed to assist cities in alleviating some of these problems, particularly stream overflow problems. Under the Program, a detailed study is made to define the limits of flooding from a design storm projected to occur once in every 100 years and for the standard project flood, which is assumed as the maximum probable flood. By means of maps, charts, and tables resulting from these studies, the city planner will have a basis to guide future development by controlling use of the floodplain through zoning ordinances and subdivision regulations. The report resulting from the study does not include plans for the solution of flood problems; rather, it provides a basis for further study and planning by the city.

In order to qualify for a floodplain study requests for Federal assistance must be submitted through the Board. The Board determines the priority of each application and requests the Corps of Engineers to make the study. As of August 31, 1968, 17 studies were underway, and 7 have been completed.

Many cities are making efforts to deal with local flood problems by means of proper land management and in some instances through bond issues for reservoir construction or flood-channel improvement. Cities often request Federal assistance for solution of major local flood problems where these problems are beyond the local capability to correct. Houston, San Antonio, Fort Worth, Dallas, El Paso, Abilene, and many other cities have flood-protection programs completed, in progress, or under study by the Corps of Engineers

In Tables IV-52 and IV-53 which list all existing, authorized, under-construction, and proposed and potential major reservoirs in the State, storage capacities for flood control are indicated for those reservoirs having flood-control provisions. Figure III-9 illustrates the proportion of the total potential storage capacity of major reservoirs in the State which will be allocated to flood control between 1970 and 2020.

Flood Protection and Floodplain Management in Rural Areas

Damages to agriculture by floods are generally most severe in the tributary areas of river basins as the result of comparatively small floods which may occur several times during the year. An additional consequence of flooding in rural, agricultural areas is soil erosion and the accumulation of these eroded soils in stream channels and reservoirs.

Two-thirds of all agricultural lands in the State are subject to soil erosion problems or the threat of erosion. Proper land use and application of soil, water, and plant conservation measures are necessary to protect the State's agricultural production capacity and to reduce sedimentation in reservoirs, stream channels, and coastal waters.

Under Public Law 738 enacted by the 74th Congress, Public Law 534 enacted by the 78th Congress, and the 1953 Appropriation Act of the Department of Agriculture, the Soil Conservation Service assists soil and water conservation districts and other subdivisions of State government in planning and installing measures for soil and water conservation and for the prevention of floodwater and sediment damages within authorized watersheds in the State.

Under the Watershed Protection and Flood Prevention Act (Public Law 566, 83rd Congress, as amended), the Soil Conservation Service also provides technical and financial assistance to State and local organizations for land treatment, flood prevention, and the conservation, development, utilization, and disposal of excess water in watersheds having not more than 250 thousand acres of drainage area. Land treatment measures are an essential part of this program, and must precede or accompany installation of floodwater-retarding structures and drainage and irrigation facilities.

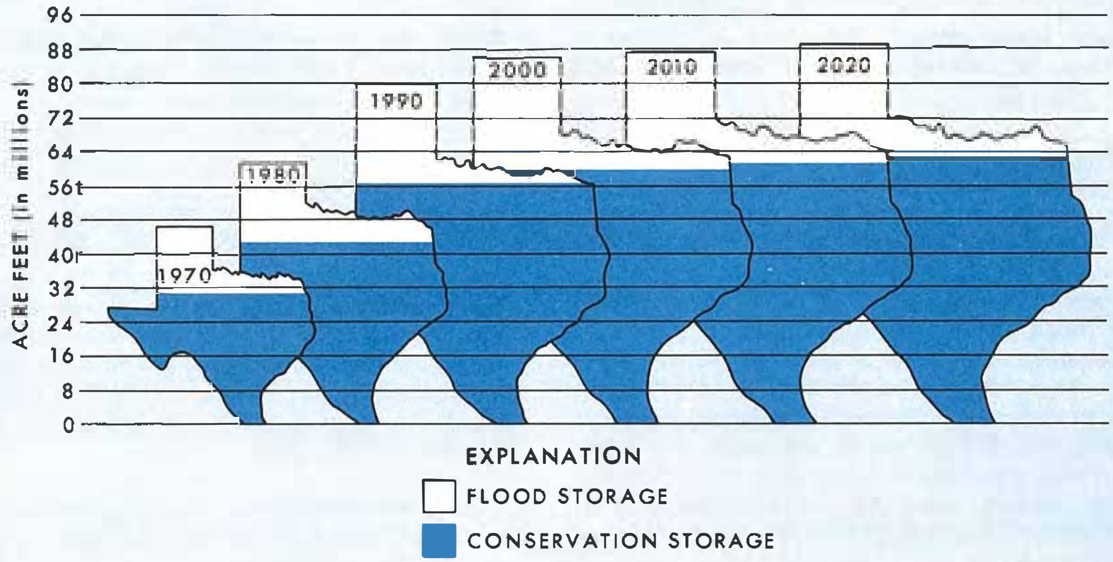
Towns and communities may also benefit from this program by developing additional municipal water supplies in conjunction with floodwater-retarding structures. The system of dams in a watershed may be designed to accommodate water supply needs if such a plan is found to be feasible.

The State agency with responsibility for the land conservation program in Texas is the State Soil and Water Conservation Board. This agency and the Board have closely coordinated their activities and those of the Soil Conservation Service since the passage of the Texas Water Planning Act of 1957.

As of April 1, 1968, plans had been approved and work was completed or in progress for watershed improvement of lands totaling in excess of 13.4 million acres. Plans have been authorized by Congress for additional watershed areas of over 1.2 million acres, and planning is presently underway on about 3.4 million acres. Table III-7 indicates the status of construction of floodwater-retarding structures and channel improvements on authorized watersheds as of April 1, 1968. Studies by the Soil Conservation Service of problem areas throughout the State suggest that watershed

FIGURE III - 9

FLOOD CONTROL AND CONSERVATION STORAGE



management programs will be needed in the future for an additional 17.6 million acres of land in the State. These total projected needs are also summarized in Table III-7.

Land Drainage

Many areas of the State, and particularly areas of the Gulf Coastal Plain, have drainage problems. Investigations conducted by the Soil Conservation Service in 1961 and 1965 indicate a total of about 16.6 million acres of land in the State affected by poor drainage. Much of this total area consists of frequently flooded river valleys, marshlands, and tidewater swamps in areas where elevation is low in relation to the elevation of possible outlets for natural or artificial drainage. Drainage improvements are not proposed for such areas, and they will be maintained as natural habitat for waterfowl and wildlife species, and as spawning and nursery areas for various economically important aquatic life. Other lands are subject to frequent inundations from stream flooding, and will require the construction of extensive protection facilities to prevent such flooding before drainage improvement measures can be effective.

Table III-7.--Existing and Needed Upstream Watershed Development Programs in Texas

	DEVELOPMENT COMPLETED, UNDER CONSTRUCTION, OR AUTHORIZED (APRIL 1968)	ADDITIONAL DEVELOPMENT NEEDED BY 2020
Watershed acreage under development programs (thousands of acres)	14,671.9	17,576.5
Number of floodwater-retarding structures		
Planned	2,099	
Completed or contracted for	1,304	
Needed		2,487
Stream channel improvement (miles)		
Planned	940.3	
Completed or contracted for	149.84	
Needed		1,456

Summary reports prepared by the Soil Conservation Service show, however, that drainage improvement is considered to be feasible for more than 7.8 million acres in Texas. Of this total, about 0.9 million acres, or 11.5%, is considered to have been given adequate drainage improvement so far. The remaining 6.9 million acres for which drainage improvement is considered feasible is distributed widely throughout the State.

One area of the State critically in need of drainage improvement is the Lower Rio Grande Valley (including the lower part of the Nueces-Rio Grande Coastal Basin) in Cameron, Hidalgo, and Willacy Counties, where about 931 thousand acres, principally irrigated lands, will require development of surface or subsurface drainage measures, or both. A recently completed comprehensive study of this area by the Soil Conservation Service has resulted in the development of a drainage plan which is now receiving public review. Recent flooding as a result of intensive rains during and following Hurricane Beulah has emphasized the inadequacy of natural drainage in this entire area and the need for improvement.

The coastal areas of other river basins and intervening coastal basins contain most of the remaining lands requiring major outlet facilities to serve drainage systems for large areas. Hardin, Liberty, Montgomery, Brazoria, Matagorda, Wharton, Colorado, and Jackson Counties contain large areas having poor natural drainage. Major outlets into natural drainage will need to be provided before on-farm and area-wide drainage facilities can be effective on approximately 3.3 million acres of land in this region of the State which requires improved drainage.

Systems of drainage ditches and appurtenant facilities with adequate capacity to connect farm systems with major outlets and natural drainage courses are needed to provide drainage improvement for about 4.5 million acres of land in Texas. All of the nearly 7 million acres of wetlands for which drainage improvement is considered to be feasible will require on-farm drainage system improvements. Over half of this acreage is presently being cultivated, with reduced crop yields resulting from impaired drainage. The remaining acreage, presently in woodland and pasture, would be suitable for production of cultivated crops if properly drained.

The Soil Conservation Service has estimated that about 80% of the needed on-farm and area-wide drainage systems in Texas will probably be installed by the year 2020. The approximate acreages which would be served, by decade, by these systems are shown in Table III-8.

Hurricanes and Hurricane Protection Measures

Occurrence of Hurricanes in Texas

Wind and high water have caused heavy losses of lives and incalculable flood damages in Louisiana and Texas. Flooding from heavy residual rains is often felt for hundreds of miles inland. A total of 33 hurricanes have crossed the Texas Coast in the period between 1900 and 1967 resulting in losses of thousands of lives and severe property damages. The paths followed by major hurricanes of record for which reasonably reliable data are available are illustrated in Figure III-10.

Hurricane Beulah

Hurricane Beulah in September 1967 was probably the most studied and best documented storm of record. Reported first as a hurricane on September 7, 1967, Beulah proceeded westward through the Carribean Sea and the Gulf of Mexico toward Texas (Figure III-11) making landfall at about 6 a.m. on September 20 just east of Brownsville. After making landfall, Beulah continued northwestward to a point about 25 miles west of Alice, thence southwestward, diminishing in intensity to a tropical storm and passing just east of Laredo, ultimately losing identity as an organized storm near Monterrey, Mexico. The rainfall associated with Beulah was of great intensity and duration (an unofficial 36 inches was measured near Falfurrias, Texas).

Table III-8.--Estimated Total Acreage in Texas to be Served by Land Drainage Systems by the Year 2020

(Thousands of Acres)

YEAR	TOTAL ACREAGE SERVED BY ON-FARM SYSTEMS	TOTAL ACREAGE SERVED BY AREA-WIDE (GROUP) SYSTEMS
1970	400	300
1980	1,300	1,000
1990	2,700	1,800
2000	4,100	2,600
2010	5,100	3,300
2020	5,500	3,600

The U.S. Geological Survey dispatched field teams to assess the damage caused by Hurricane Beulah and later prepared a report on Hurricane Beulah in cooperation with the Texas Water Development Board.

In June 1968, the United States Section of the International Boundary and Water Commission published an emergency flood operations manual to outline its responsibilities and prescribe procedures for operating the floodway system in the Lower Rio Grande Valley during floods such as those resulting from Beulah. In cooperation with the U.S. Weather Bureau, the Commission is preparing a report which will revise design storm data for the Lower Rio Grande Valley to include information gained from Beulah.

The Galveston District of the U.S. Army Corps of Engineers in September 1968, about one year following Hurricane Beulah, issued a report which documents the origin and movement of Beulah and describes the flooding due to both rainfall and hurricane tide. The occurrence of some 115 tornados spawned by Beulah is also documented.

Although the Nueces-Rio Grande and the Rio Grande Basins suffered the greatest damage from flooding, the damage was by no means limited to those basins. Damage occurred also in the following:

Nueces	Colorado-Lavaca
San Antonio	Colorado
Guadalupe	All coastal areas as far north as Galveston Bay, which received negligible damage.
Lavaca-Guadalupe	
Lavaca	

Extensive documentation of Beulah is due largely to advances in technology, an increase in the number of rainfall and tide measuring locations, the interest of many Federal, local, and State agencies, and the state of the art of tracking and reporting hurricanes with radar and radio.

Hurricane Protection Projects

Three hurricane protection projects have been authorized for construction by the Corps of Engineers during the past decade. These projects are located in the vicinities of Port Arthur, Freeport, and Texas City. In addition to these projects, the Galveston Harbor and Channel Improvement Project provides for strengthening and extending the existing seawall.

The Port Arthur Hurricane Protection Project, authorized in 1962, provides for enlarging, strengthening, and extending existing levees. The project, when completed, will include about 29 miles of new and enlarged earthen levees 12 to 16 feet high; about 5 miles of concrete seawall and 2 miles of concrete and steel sheet-pile floodwalls having a top elevation of 16 feet above mean sea level; drainage structures; and pumping plants and closure structures at openings left in the levees. Protection is planned against a design project hurricane producing high water 14 feet above mean sea level with an expected frequency of occurrence of once in every 160 years. The estimated cost of the project as of June 1968 is $58.5 million, of which 70% is to be financed from Federal funds and 30% by local interests.

The Freeport Project was authorized by Congress in 1962. This project will include rehabilitation, enlargement, and extension of the existing earthen levees and construction of an additional earthen levee connecting the north end of the system to high ground. The plan includes about 40 miles of earthen levees with crest elevations from 16.5 feet to 22 feet, which would provide protection against a design project hurricane producing high water up to 13 feet above mean sea level with additional wave run-up producing crests to 17 feet above mean sea level. This design storm has an expected frequency of once in every 100 years. The estimated cost of the project is $19 million, of which the Federal share is 70% and the remainder is to be provided by local interests.

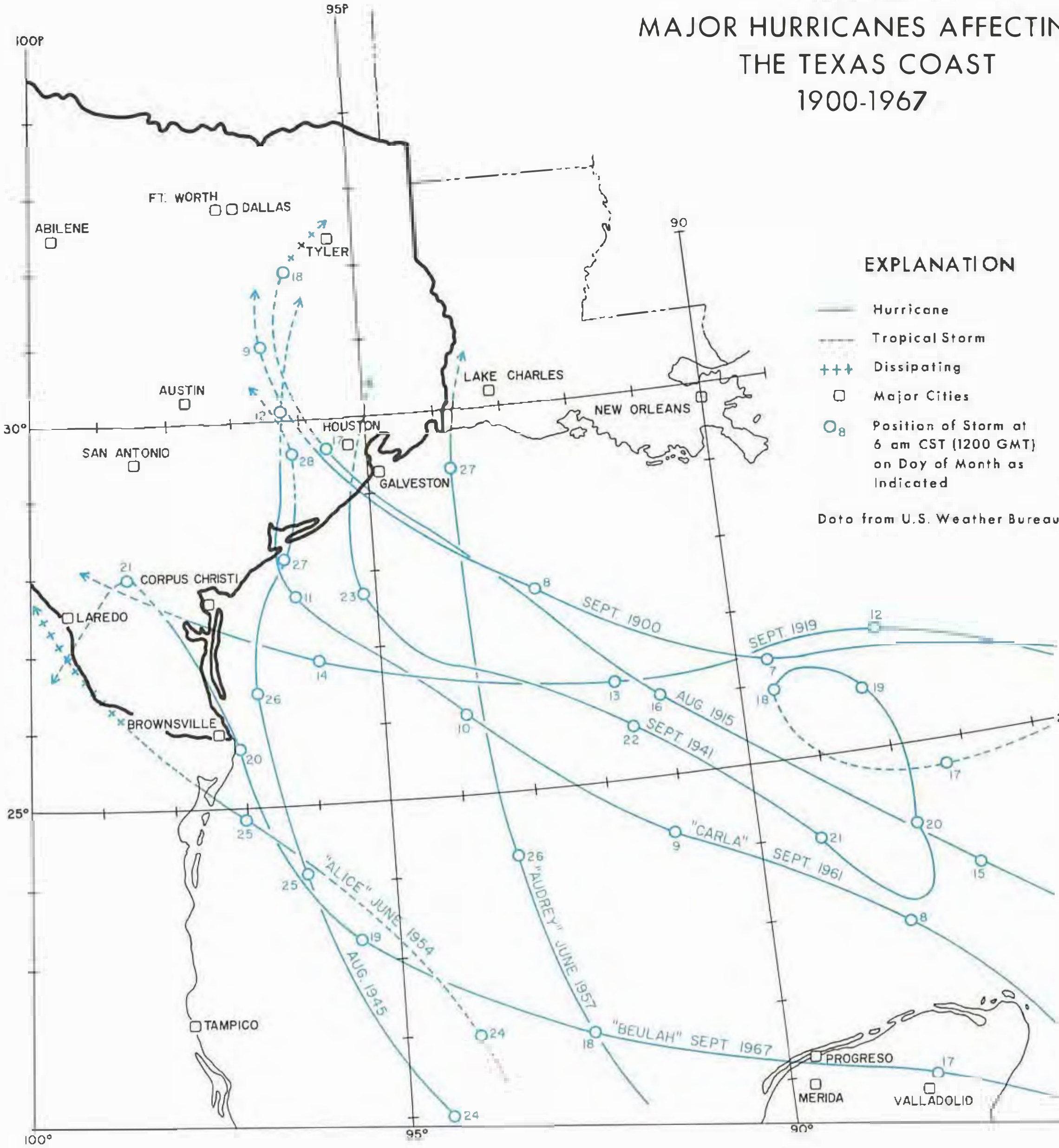
The original Texas City Project, authorized by the Federal Flood Control Act of 1958, was subsequently modified to include a La Marque-Hitchcock extension. The modified plan is presently pending authorization by Congress. The original project provided for about 18 miles of new and enlarged floodwalls, together with related drainage enclosure structures, and a navigation opening and pumping plant, at a cost of $24.8 million. With the modification of the project to include the La Marque-Hitchcock extension, if approved by the Congress, a part of the originally authorized 18-mile section will be omitted and the extension will add 11.4 miles of earthen levees with related drainage enclosure structures and a gated navigation and tidal control structure in Jones Bay. Total cost of the project is estimated at $44.7 million. Elevations of the levees will vary from 15 to 21 feet above mean sea level to provide protection against a design project hurricane producing high water 15 feet above mean sea level and additional wave run-up of 6.26 feet. This design storm has a projected occurrence interval of once in every 100 years.

Land subsidence has occurred in some areas along the Texas Coast due to withdrawals of ground water and petroleum. As much as 5 feet of subsidence has occurred at some points along the Houston Ship Channel. Loss of freeboard will result along any hurricane protection levee constructed in subsiding areas, and levee design must be predicated on a realization of this problem.

Even if withdrawals of underground fluids should be completely halted, land subsidence might continue to occur for an undetermined period as the result of continued compaction of geologic materials comprising aquifers and petroleum reservoirs. For this reason, levees

FIGURE III - 10

MAJOR HURRICANES AFFECTING THE TEXAS COAST 1900-1967



constructed in areas of known or suspected land subsidence should be constructed so as to facilitate additional heightening as necessitated by further land subsidence.

At the request of the State, the Corps of Engineers is presently conducting a study of potential hurricane protection measures along the entire Texas Gulf Coast. The Coast has been divided into five study areas, each area including one or more of the major coastal bays. This study is scheduled for completion in 1973, and will provide information on hurricane protection measures needed for each of the study areas.

The magnitude of industrial and urban growth along the Texas Coast necessitates expanded hurricane flood protection measures. As a result of studies by the Corps of Engineers of the five segments of the Coast, a master plan for hurricane protection projects can be developed. Development of this master plan must also consider maintenance of desirable water quality conditions in the major bay and estuary systems, and must be compatible with the hydraulic systems which control the mixing of waters and tidal exchange essential to the preservation of the ecology of these areas.

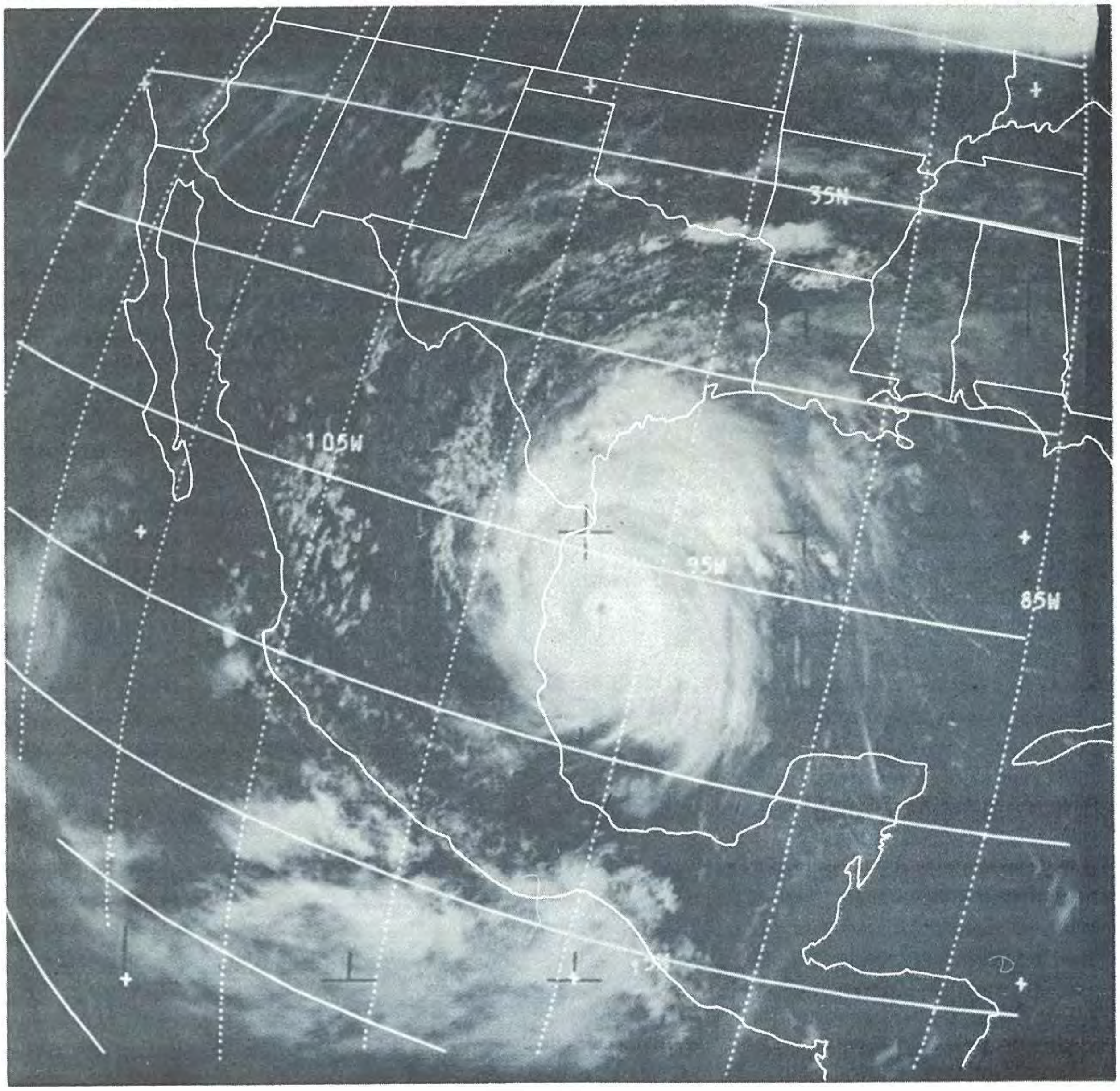


FIGURE III - 11

HURRICANE BEULAH-SATELLITE PHOTOGRAPH

1:19 P.M. CST, SEPTEMBER 19, 1967

Control of Water-Wasting Vegetation

Several species of plants transpire large volumes of water, and many of these have little economic value. Woody plants whose roots penetrate the saturated zones of ground water aquifers and stream channel deposits are termed phreatophytes, and include saltcedar, cottonwood, and willow. Saltcedar, which now grows extensively in 15 of the 17 western States, presents the most severe problem. Texas presently has the unfortunate distinction of having the largest area of saltcedar infestation of the western States.

The Saltcedar Problem

Saltcedar is an aggressive plant which has not only invaded but entirely replaced the native vegetation in many areas. It commonly occurs in floodplains of streams, along the shoreline and in the deltas of lakes and reservoirs, and in and adjacent to unlined ditches and irrigation canals where its roots can reach the water table. Much of the rehabilitation work being done, planned, and required for efficient irrigation systems consists of lining distribution canals and other improvements to reduce seepage which produces ideal conditions for phreatophyte infestation. These rehabilitation measures also can reduce the need for costly phreatophyte eradication.

Saltcedar has also produced serious channel-choking problems in the upper parts of the Red, Brazos, Colorado, and segments of the Rio Grande and Canadian River Basins in Texas. A survey of phreatophyte infestation made by the Soil Conservation Service in 1964, which was updated in 1967, indicates there is now about 600 thousand acres of land infested by saltcedar along these rivers. Of this total acreage, 55.5% or 333 thousand acres is infested by dense stands of this phreatophyte. The distribution of these saltcedar-infested areas throughout the affected river basins is indicated in Table III-9.

Table III-9.--Distribution of Acreage Infested by Saltcedar in Texas as of 1967

RIVER BASIN	INFESTED ACREAGE
Canadian	97,200
Red	170,800
Brazos	36,100
Colorado	10,300
Rio Grande	
(Above Pecos River)	105,200
(Pecos River)	176,400
High Plains (Playa Lake Areas)	3,900
Total	599,900

The most serious effect of this essentially uncontrolled invasion of saltcedar in the State is depletion of streamflow and useless dissipation of water from irrigation conveyance and distribution systems. Based on preliminary studies, it is estimated that in excess of one million acre-feet of water is lost from Texas streams each year as a result of saltcedar alone.

In the Canadian, upper Red, and upper Brazos River Basins, elimination of present and rapidly spreading saltcedar growth, followed by grassland restoration where appropriate, might result in a collective net saving of more than 600 thousand acre-feet of water annually. More than 500 thousand acre-feet of water might be salvaged by saltcedar eradication in the Texas part of the Rio Grande Basin (including the Pecos River watershed), and about 17.1 thousand acre-feet (ground water) might be salvaged in the High Plains. In addition, the Bureau of Reclamation presently has underway a saltcedar control program in the Pecos River watershed in New Mexico, proposed to include that part of the watershed in Texas downstream to the vicinity of Girvin in central Pecos County. Part of this water salvaged within the New Mexico part of the watershed will be available to Texas consistent with the terms of the Pecos River Compact. In the Pecos River watershed in New Mexico, feasibility studies by the Bureau prior to authorization and initiation of this project indicate that an average of as much as 152.6 thousand acre-feet of water could be salvaged annually within the watershed.

Another serious problem associated with the proliferation of these plants in many areas is increased flooding. Rates of sedimentation in streams are commonly increased in the infested areas, thus restricting channel capacities and producing larger flood-plains.

Brush Control

Recent surveys by the Soil Conservation Service indicate that about 88 million acres of land in Texas is now covered with brush and trees having little or no economic value, principally mesquite, huisache, retama, juniper, liveoak, shin oak, cactus, post oak, elm, white-brush, persimmon, sassafras, Macartney rose, blackjack oak, yaupon, and sagebrush, as well as the true phreatophytes saltcedar, willow, cottonwood, baccharis, and others. About 54 million acres of this total infested acreage supports medium to dense stands of brush. Non-economic plants, including brush, weeds, phreatophytes, etc., transpire tremendous quantities of water, tentatively estimated to be on the order of 38% of the average annual water budget of the State.

Many of these brush-infested areas are valuable in their present natural condition for the wildlife habitat they provide, for their contribution to the natural beauty of the countryside, and as recreational areas. However, even with the preservation of all brush-infested areas that are desirable for these purposes, elimination of 70% of the densely infested lands and replacement with grass would be beneficial to the State.

Several programs of the U.S. Department of Agriculture are directed toward eradication and control of brush. The principal objective of these programs is replacement of worthless brush with useful grass or other vegetation, thus conserving the large quantities of water now being consumed by brush to grow useful plants. Where such replacement can be economically accomplished, there is ample incentive for landowners to initiate brush-control measures.

In some areas of the State, eradication of brush and replacement with beneficial vegetation could result in net savings of water in the form of additional natural recharge to ground water aquifers and increased streamflow. Intensive studies are needed to accurately define favorable areas for brush-control programs, as such programs offer a significant potential for salvage of additional water supplies for the State.

The Soil Conservation Service has developed preliminary estimates of the net savings of water which would result from grassland restoration programs throughout much of the brush and phreatophyte infested areas of the State. These preliminary estimates, given in Table III-10, suggest that more than 10 million acre-feet of water might be salvaged annually by a comprehensive, properly planned program involving eradication and control of about 70% of the areas of medium and dense infestation of brush, which would include 90% control of mesquite and 100% control of saltcedar in most affected areas.

Saltcedar is highly tolerant to water salinity, which is one of the principal factors contributing to the proliferation of this plant in many areas where other plant species cannot survive because of excessive salinity of ground water and/or streamflow. Consequently, these preliminary estimates of net water salvage partly include saline waters, some of which probably cannot be beneficially used in many areas. The estimated amounts of net water salvage in Table III-10 do not represent the actual amounts which would be available in streams for beneficial development and use.

Water Quality Management

Planning for the future development of the total water resources of the State must include a program for properly managing water quality to assure that water to supply projected needs will be of suitable quality for the intended uses. The resolution of problems resulting from the maximum use of water resources versus maintenance of desirable water quality conditions presents one of the greatest challenges to water planning efforts. Any planned program of water quality management must include an evaluation of the benefits man is deriving from the revolution taking place in his way of life so that ways can be found to live with the associated liabilities.

Water Quality Considerations in the Plan

Stream quality is influenced by many complex and interrelated factors, which include geology, climate, natural vegetation, land use, population density and industrial development, waste-water treatment and disposal practices, and construction of reservoirs and their methods of operation. Concentration of population and industry in urban areas will continue to augment the waste problem, and increased development will result in an attendant increase in the volume and complexity of the waste by-products.

In Texas' complex environment, consideration must be given to mineral and organic quality; radioactive base levels against which to compare possible increases in radioactive contamination; waste-assimilative capacities of streams, including natural re-aeration capacity, and of ground water basins; maintenance of a favorable salt balance in soils in the various areas of the State; and future municipal and industrial development with due regard to waste treatment and removal needs.

The quality of municipal return flows varies widely throughout the State, depending upon such factors as quality of the water supply, economic base of the municipality, methods of waste-water treatment employed, and efficiency of treatment plant operation. Generally, concentrations of conservative constituents in municipal return flows are lower in the eastern part of Texas than in western areas of the State, which is principally the result of differences in the chemical quality of raw water supplies available to East and West Texas. Concentrations of non-conservative or degradable constituents in municipal return flows depend largely on waste-treatment practices, and therefore exhibit no consistently predictable pattern of geographic variation throughout the State.

Table III-10.--Estimated Annual Net Salvage of Water in Texas by a Comprehensive Phreatophyte and Brush Control and Grassland Restoration Program

RIVER BASIN	ACRE-FEET SALVAGED ANNUALLY[1]	ACRE-FEET SALVAGED BY SALTCEDAR CONTROL ONLY
Canadian	410,400	
Red	1,386,700	
Brazos	2,035,800	625,000
Colorado	1,909,900	
Trinity	704,000	
Sabine and Neches	291,200	
San Jacinto	49,400	
Rio Grande (including Pecos)	799,700	563,200
Nueces	1,121,700	
Guadalupe and San Antonio	646,200	
Other areas:		
High Plains	292,100	17,100
Gulf Coast intervening areas	594,800	
Total	10,244,900	1,310,200

1/ All brush including saltcedar.

Untreated municipal waste water contains both the chemical constituents present in the water supply prior to use and those added during use, as well as many complex organic substances, including nitrogeneous material, and bacteria and viruses, some of which may be pathogenic. An indication of the general range of increase in various conservative or "refractory" constituents through one cycle of municipal use is illustrated in Table III-11.

Table III-11--Increase in Soluble Chemical Constituents in Water Through One Cycle of Municipal Use

(22 U.S. Cities)

CONSTITUENT	GENERAL RANGE OF INCREASE (In mg/l)	AVERAGE INCREASE (In mg/l)
Calcium	1-50	18
Magnesium	0-15	6
Sodium	8-101	66
Bicarbonate	44-265	100
Sulfate	12-57	28
Chloride	6-200	74
Nitrate*	5-24	10
Silica	9-22	15
Phosphate	7-50	24
Total dissolved solids	128-541	320

*Average generally higher in Texas.

Organic material which is added to a supply during use is commonly measured in terms of the amount of oxygen required by aerobic bacteria to decompose or stabilize this material, the unit of measure being the biochemical oxygen demand (BOD), commonly expressed in mg/l or pounds per day. Thus, the higher the percentage of BOD removal during waste treatment the less oxygen will be required to stabilize the remaining degradable organic material in the waste water after it is discharged into a natural watercourse. The per-capita contribution of BOD to a municipal water supply during its use varies widely among municipalities, principally as a result of variations in economic base. Generally, the per-capita contribution ranges between 0.1 and 0.25 pounds per day.

Some organic materials are resistant to biological decomposition. Their presence in water is therefore not detected by the BOD measurement but can be detected and measured by other methods.

Methods of treating municipal waste waters are commonly classified as primary, secondary, and tertiary or "advanced" waste treatment. Primary treatment generally consists of removal of floating and suspended material by mechanical or chemical processes. Essentially none of the refractory constituents are removed by primary treatment, and on the average only about 35% of the BOD is removed.

Secondary treatment generally provides some means of satisfying more of the oxygen demand of the waste water prior to discharge (usually by controlled biological oxidation), and is usually preceded by primary treatment and often followed by chlorination (disinfection) to reduce bacterial populations and possible virus. Conventional secondary treatment removes an average of about 80 to 85% of the BOD, although relative efficiency of plant operation may substantially reduce or increase this percentage. Waste waters provided secondary treatment are presently generally considered to be satisfactorily treated, although as is the case with primary treatment, refractory constituents such as chloride, sulfate, and soluble non-biodegradable organic material are not reduced by most conventional secondary treatment processes. Also, in most conventional secondary treatment systems concentrations of nitrogen and phosphorous are not significantly reduced, although studies involving innovations in routine operation of conventional secondary treatment plants have indicated than in some cases nitrogen and phosphorous removal can be increased. Due to the ultimate oxidation of nitrogenous material to nitrate, the presence of nitrogen compounds may impose an additional oxygen demand on the receiving stream after the waste is discharged. Both nitrogen and phosphorous serve as nutrients for biological growth in streams and reservoirs, which, when excessive, may produce general nuisance conditions, further deplete oxygen from the water, and create taste and odor problems in water supplies.

Tertiary or "advanced" waste treatment may include a wide variety of techniques designed either for a general high degree of pollutant removal or for the removal of a specific pollutant or pollutants. Except where severe conditions of stream pollution might exist below waste-water outfalls from conventional waste treatment facilities, tertiary treatment is not now generally applied to municipal waste waters in Texas. Such techniques are usually restricted to waste-water reclamation projects. The need for tertiary treatment will greatly increase in the future, particularly to provide adequate removal of biostimulants and toxicants.

Industrial waste waters also vary widely in character throughout the State, depending upon such factors as industrial or manufacturing process, type of product, production rates, availability, quality, and costs of water supplies (as these affect the degree of in-plant reuse), methods of disposal, and degree of treatment required for compliance with waste-discharge permit regulations of the Texas Water Quality Board.

A large part of the industrial water used in the State is for cooling and boiler feedwater purposes. Except where coastal industries have designed process systems which will tolerate the use of saline water for cooling, water low in dissolved solids is generally required for these purposes. Consumptive use of water in cooling towers and boilers is comparatively high, and the use of closed recycling systems to further reduce waste-water production is increasing rapidly. Cooling-tower and boiler-blowdown wastes from these processes generally have much higher concentrations of dissolved solids than the original supply.

Wastes from the food and kindred products industry are commonly high in organic material, and are generally treated for BOD removal by conventional biological oxidation methods similar to those employed in municipal waste-treatment plants. Wastes from the dairy and meatpacking industries are also similar to municipal wastes, although the BOD of these wastes is generally much higher. Pulp and paper mill wastes also have relatively high BOD loads and are commonly treated by biological processes. Most paper mill effluents are also highly colored, and some paper production processes result in relatively high chloride concentrations in these effluents as well. These latter problems cannot be significantly improved by conventional treatment techniques generally provided such waste waters.

Methods of industrial waste-water treatment vary as widely as do the waste waters themselves, although practices generally follow the same basic methods used in the treatment of municipal waste waters. In many metropolitan areas, certain industrial return flows are routed through the municipal waste-treatment plants.

In developing the Texas Water Plan, emphasis was placed on study and evaluation of:

(1) those areas of the State where serious water quality problems presently exist that must be corrected or improved, and

(2) the possible beneficial and adverse effects of the Plan on all streams including those where water quality problems do not presently exist. Assumptions were made that where necessary the highest technically feasible levels of waste treatment would be utilized in the future and that pollution resulting from the exploration for—and production of—oil and gas would be eliminated over time.

Conventional waste-treatment techniques may be inadequate in some areas to maintain acceptable stream quality in the future. Centralization of municipal waste-treatment systems in large urban areas and consolidation of the systems of several smaller cities, where feasible, probably offer more promise than other regional approaches to stream quality control. Reliance on the natural assimilative capacities of streams is not a practical long-term solution for the disposal of municipal and industrial waste. This assimilative capacity will be required to accomodate increasing loads of pollutants from land runoff, which is largely beyond practical control.

A report prepared for the Board by consulting engineers provided estimated capital costs for waste-treatment facilities required to serve 21 major metropolitan areas of the State. This study indicates that the costs of such facilities will reach almost one billion dollars by 1990; however, the report emphasized that the regional approach would (1) allow more effective planning for a large area, (2) allow flexibility in serving communities involved, (3) promote economy of construction by providing one or more large plants as compared to a multiplicity of small plants, (4) increase efficiency and economy of plant operation, (5) enhance industrial growth, and (6) relieve individual cities of direct day-to-day responsibility of sewage treatment. Most important, however, is the fact that centralized waste-treatment facilities promise to offer reductions in the pollution loads discharged to streams. With fewer points of treated waste discharge, management of stream quality will also be easier.

The Texas Railroad Commission has worked effectively in controlling pollution resulting from oil and gas exploration and production. In 1967, the Commission adopted a special order, to become effective January 1, 1969, prohibiting the use of unlined earthen pits for the disposal of oil field brines throughout the State. The Commission has also stated its intent to issue other reasonable, realistic, and enforceable rules and regulations designed to control oil field pollution.

Demineralization of saline water resources, which may provide an alternative solution to water supply problems in some areas of Texas, creates a potential future water quality problem which has been given intensive study by the Board. All desalination processes, commonly termed desalting, generate a waste stream which is generally highly saline. Disposition of this effluent so as to prevent pollution of streams and ground water aquifers presents both technical and economic problems, particularly at interior locations. Costs of proper waste disposal may be the margin of economic feasibility for many desalting projects and must be considered in evaluating costs of water supplies produced by desalting. Methods of disposal of brine effluents from potential desalting projects studied by the Board include deep-well injection, lined evaporation ponds, and mixing with municipal return flows. Reuse and recovery of by-products were also considered as potential methods of reducing the waste volumes.

Salinity Alleviation

Reduction in excessive levels of salinity in parts of the Red, Brazos, and Colorado River Basins and the Pecos River watershed in the Rio Grande Basin, by existing, under-construction, authorized, and proposed Federal and local salinity control projects (Plate 4), will provide substantial volumes of water for high priority use which have in the past been largely undeveloped because of these problems. These projected improvements in quality have been considered in the Plan, and the projected supplies of improved chemical quality have been fully allocated to future high priority use in most of the affected basins. Abatement of man-made pollution concomitant with these natural salinity control projects in areas where both problems presently exist has also been considered as an integral part of overall salinity control measures in the affected basins.

Additional water supplies, principally in the form of local diversions from streams for irrigation, mining, and other beneficial uses, might be developed through additional salinity alleviation measures other than those presently proposed for the major salinity contributing areas. Much additional study of the many natural salinity contributing areas in the State of more or less secondary importance are needed in order to estimate the amount of additional water which might be salvaged for beneficial development through possible additional control measures.

Impact of the Texas Water Plan on Stream Quality

Water quality is of critical importance in any plan for the progressive development of water resources and the movement of this water through a system of reservoirs and conveyance facilities. During the development of the Texas Water Plan, the quality of all water supplies proposed for development and conveyance throughout the Texas Water System was evaluated, and preliminary water quality routing studies were performed for selected components of the System to estimate the effects of mixing varying quantities of water from various sources of supply. These studies also included preliminary evaluations of the quality of potential out-of-State sources of water supplies, under both present and future conditions.

These studies will be continued and refined, with emphasis placed on projections of future water quality conditions under various alternative levels of waste treatment and river basin development.

Role of the Texas Water Quality Board

The Texas Water Quality Board actually sets stream quality standards and through its present permitting procedure controls the volume, location, and quality of wastes discharged into streams of the State.

Under the Federal Water Quality Act of 1965, the States were charged with the responsibility for establishing stream quality criteria for all interstate streams. Texas has adopted stream quality criteria for all streams and coastal waters of the State in line with the statement of policy in the Texas Water Quality Act of 1967, which states: "It is declared to be the policy of the State of Texas to maintain the quality of waters of the State consistent with the public health and public enjoyment thereof, the propagation and protection of fish and wildlife, including birds, mammals, and other terrestrial and aquatic life, the operation of existing industries, and the economic development of the State, and to that end to require the use of all reasonable methods to implement this policy."

The Texas Water Quality Board prepared preliminary water quality criteria for each river basin and estuary of the State in 1966. These preliminary criteria were submitted for review at public hearings, held jointly with the Development Board, and comments solicited. After comments were received, the criteria were again reviewed, revised where necessary, and submitted to the Federal Water Pollution Control Administration in June 1967. The criteria were approved by the Secretary of the Interior on January 27, 1968.

Water-Oriented Recreation

Water-oriented recreation facilities in Texas are operated by private developers and public agencies including the Corps of Engineers, the Bureau of Reclamation, the Texas Parks and Wildlife Department, various Texas river authorities, and municipalities and private individuals.

The present level of use of water-oriented recreation facilities indicates that as Texas' population increases, the use of water-oriented recreation facilities can be expected to rise significantly. Information relating to present facilities, present use, and estimated use of possible lakes and reservoirs will aid in planning to meet future water-oriented recreation needs in Texas.

The increase in water recreation is reflected in the rise in purchases of recreation equipment and the increased number of people who fish, boat, camp, swim, and water ski. Texas has more than 150 lakes and reservoirs which have a conservation storage capacity of 5 thousand acre-feet or more. Public and/or private recreation facilities are available at nearly all of these lakes. In addition, there are many smaller lakes which provide recreation possibilities.

Benefits are associated with the use of water development projects for recreation purposes whether or not user fees are charged. People forego the consumption of other goods and incur costs to visit lakes and reservoirs through travel expenses, purchase of recreation equipment, and the purchase of meals and lodging.

The present use of lakes and reservoirs for water-oriented recreation indicates that there is a fairly large demand for this activity and that the recreation consumer receives satisfaction from the water-oriented recreation experience. Project planners are therefore justified in the inclusion of recreation as one of the many purposes of water development projects, and such projects can justifiably be credited with recreation benefits.

Water-oriented recreation in Texas has expanded from its initial beginning along the Gulf Coast, at a few inland lakes, and along flowing streams, to include a wide variety of activities centered around the lakes and reservoirs of Texas.

In 1968, approximately 239 thousand pleasure boats were in use in Texas according to boat registrations and competent data estimates of the Texas Highway Department. Boat ownership is expected to continue to increase. The Texas Parks and Wildlife Department reported the sale of 1,339,969 fishing licenses during the year ended August 31, 1967.

Reports of the Corps of Engineers showed 21.9 million visitors in 1967 at projects which the Corps operates within Texas excluding Lake Texoma, which alone had a reported visitation of over 8 million. The Texas Parks and Wildlife Department reported visitation to its water-oriented parks at 11.2 million in 1968. This figure did not include visitors to the chain of Highland Lakes on the Colorado River. Also, approximately 20.7 million out-of-State tourists visited Texas during 1967, many of whom enjoyed water-oriented recreation facilities.

The distances that visitors travel, when converted into dollars, have been used by the Board to give an indication of the price people are willing to pay for water-oriented recreation. There is a high degree of correlation between cost of travel, time spent in travel, and distance of travel to reservoirs. Studies have shown that visitation rates per unit of population decrease as distances to reservoirs increase. This indicates that as costs increase the number of people seeking a particular recreational area decrease. The cost of travel, therefore, can be used as an indicator of a recreation price-quantity relationship from which recreation benefits can be estimated. This is not to say that recreation benefits equal travel costs, but rather that given the requirement to pay recreation user fees in addition to travel costs, the number of users would probably decline in the same manner that the number of recreators decline as travel costs increase.

Data developed by the Board, Parks and Wildlife Department, and Highway Department were used to develop a visitation forecasting equation. The equation relates the number of visitors from county A to reservoir B, to county A's population, per capita income, distance to reservoir B, size of reservoir B, and the availability of reservoirs which compete with reservoir B. The equation was applied to each county within a circular zone of each proposed reservoir for the purpose of estimating visitation to the reservoir. The estimates of individual county visits, within 100 miles of reservoirs in East Texas and 150 miles in West Texas, were summed to obtain estimates of total annual visits at each proposed reservoir.

Points on a recreation demand curve were obtained by solving the recreation visitation equation for each of several recreation prices. Prices were introduced into the equation by incrementing the cost of travel and finding a new solution to the equation for each price added and for each decade between 1970 and 2020. The prices added ranged from $0.25 per person to $50.00 per person. Population projections used to determine municipal and industrial water requirements were used to calculate visitation at each decade between 1970 and 2020. Per capita county income growth was projected to 2020 at a constant rate of 3% per year. These income projections were used in calculating recreation visitation estimates at decades between 1970 and 2020.

Population and income changes were assumed to be important factors in changing characteristics of recreation demand.

Other important considerations underlying recreation benefits estimates include the reservoirs' locations with respect to large population centers, the level of per capita income in the zones served by reservoirs, size of reservoirs, and the availability of competing reservoirs. As distance between reservoirs and population centers increases, the number of visitors is estimated to decline. Therefore reservoirs nearer large populations are expected to receive more visitors than similar reservoirs located greater distances from equally large populations. The analyses which underlie the estimates indicate that as per capita incomes increase from county to county visitation to reservoirs can also be expected to increase but the changes are smaller and smaller with each successive increase in per capita county income. The recreation benefits estimates were obtained from a systematic calculating procedure and at present are the best estimates available. As the implementation of the Texas Water Plan progresses, additional data will have to be obtained on a continuing basis with which to make more detailed recreation benefits estimates of specific projects.

Fish and Wildlife

A wide range of environmental conditions in coastal bays and estuaries and the warm Gulf waters off the Texas Coast have provided highly productive conditions for a valuable variety of commercial seafood and other aquatic life. The shrimp catch in recent years has ranged in value from $38 million to $48 million yearly. Oyster production is important in many of the coastal bays, with annual values of the oyster harvest ranging from $1.5 million to $1.8 million. Shrimp require the combination of estuary and coastal marshland waters as "nursery" areas, and warm coastal open seawater for adult stages, conditions well supplied along the Texas Coast.

Sport fishing is a popular attraction along the Coast and in the bays and estuaries. The various services such as charter boats, fishing equipment supply, bait supply, and food and lodging facilities for fishing enthusiasts represent a valuable segment of the total economy along the Texas Gulf Coast.

The Texas Gulf Coast area is also a principal wintering ground for migratory ducks and geese, attracting hunters from both Texas and other States.

Fishing the Texas streams is still popular among nearby residents. However, with the construction of dozens of large reservoirs and literally thousands of smaller impoundments, farm ponds, and stock tanks throughout the State, most inland fishing is now done in these, rather than in flowing streams. An exception, of course, is the stream fishing below reservoirs where controlled releases often provide extremely good sport fish environment and fishing conditions. Most reservoirs are stocked for fish production and also provide facilities and services for fishermen. Landowners are, in many instances, engaged in managing their ponds for high fish production. They then either provide for the fishing pleasure of their families, friends, and invited guests, or use the ponds as a source of income by collecting user fees and perhaps furnishing bait, food and beverage, or other services. Fishing opportunities at large public reservoirs attract permanent residents to nearby communities. These structures also add to the time vacationers spend in Texas each year.

In addition to the coastal areas, many of the stream courses and the inland water storage facilities also furnish habitat for ducks and geese. Some hunting is afforded in these areas. Wild turkeys and several species of quail abound in many Texas areas. Doves are numerous. The famed white-winged doves, abundant in the southern tip of Texas, seasonally attract hunters from all parts of the Nation. Many farm ponds and stock tanks provide food, water, shelter, and other required habitat for these game and other species.

Deer and pronghorn antelope are the principal game animals. Texas has one-fifth of the Nation's total deer population. Deer are increasing in numbers because of effective land and game management programs. Screwworm eradication programs have been effective in reducing losses in the deer population. Selling deerhunting leases is a major business in the "Hill Country" and other areas of suitable habitat, particularly the brush-covered areas of the Rio Grande Plain. Antelope in West Texas, likewise, furnish exciting sport for many hunters each year. Many full or part-time residents of the "Hill Country" or other areas abounding in wildlife species chose this environment merely to enjoy a closeness to nature and the outdoors this country provides. Aggressive programs in wildlife management, including 21 established national and State wildlife and migratory waterfowl refuges, game preserves, and wildlife management areas, have helped to maintain favorable conditions for sustaining increased wildlife development in Texas.

The Texas Water Plan includes provisions for sufficient water supplies to maintain these established areas. Supplies will be derived principally from locally available sources. In addition, approximately 60 thousand acre-feet would be made available annually from the Coastal Canal of the Texas Water System for delivery to wildlife refuges along the Texas Coast, principally the Aransas and Anahuac National Wildlife Refuges.

Hydroelectric Power

Electrical energy used in Texas is presently derived from two sources, fossil fuel generating plants and hydroelectric generating facilities. In 1965, steam-electric (thermal) plants furnished 96.5% of the total energy demand, while hydroelectric plants, presently utilized for peaking power purposes, supplied only 3.5%. The percentage of total electrical energy demand supplied from hydroelectric power installations in Texas is estimated to decline to only 0.3% by the year 2020.

Toledo Bend and Sam Rayburn are new major reservoirs with hydroelectric generating facilities, and Amistad is designed to accomodate future installation of generating facilities, but new conventional hydroelectric power developments are unlikely. This results in part from a continuing decrease in the unit cost of energy generated by steam-electric plants due to advances in technology. Also, conditions at potential dam sites in Texas are generally unfavorable for hydroelectric power production because of irregular streamflow, and low powerheads, as well as rising equipment costs. In addition, increasing demands for municipal, industrial, and agricultural water supplies make it less economic to store large volumes of water in the allocated power pool above the minimum level necessary to assure adequate generating head.

Although additional conventional hydroelectric power projects appear improbable, pumped storage projects could be operated with a minimum amount of permanent storage. If the proper balance of available offpeak, dump-rate power service is reasonably close, such installations may be feasible in some areas of Texas where topography is favorable and an adequate water supply is available.

Preservation of Historic Sites and Archeological Material

Texas contains a rich and varied assortment of prehistoric culture. Important historic sites and archeological material include ten-thousand-year-old campsites where ancient man killed and butchered mammoths, giant bisons, and camels during the glacial periods; rock shelters in canyon walls where hundreds of generations of prehistoric peoples left their implements, burials, trash, carvings, and paintings; burned rock middens many feet in thickness containing hearthstones and debris which accumulated over thousands of years; multiroomed pueblos, surrounded by ancient cornfields, with sacred subsurface kivas, mounds of broken pottery of many-colored glazes; Caddoan temple mounds situated in planned villages where an agricultural people supported a complex society; and extensive campsites where the Comanches, Apaches, Tonkawas, Karankawas, and many other historic Indian tribes spent their last years. These and many other sites tell the fascinating story of the prehistory of Texas.

While they chronicle a long span of time and are varied, most of these sites have one thing in common—they are situated near sources of fresh water. Aboriginal communities developed along permanent streams and rivers.

Planning and development of Texas' water resources must proceed so as to preserve this heritage and avoid needless destruction, obliteration, or inundation of important historical sites and artifacts. Certain of these can be assured permanency and made available to the public by featured identification and inclusion with water development.

The Board initiated and is continuing a study to achieve this objective under provisions of an interagency agreement with the State Archeologist. This continuing program will inventory and evaluate the archeological resources in areas of proposed reservoirs prior to actual construction. When the archeological resources of the reservoir area are defined, specific recommendations can then be made for salvaging a representative portion of the sites which will be inundated by the reservoir, and for developing the outstanding archeological sites adjacent to the reservoir in order to enhance the educational and recreational appeal of the area. The field surveys and evaluations by the State Archeologist have been completed in the areas of several existing, under-construction, and proposed reservoirs, and are underway in several others.

From a completed survey of Cibolo Reservoir site, in the San Antonio River Basin, 54 archeological sites were located and described. Although many of these sites are heavily eroded, several are believed to contain numerous additional artifacts. In addition to the prehistoric sites deserving study, in Cibolo Reservoir site is the site of the old Wheeler Mill which was built in the mid-nineteenth century. Very little is known about small, water-powered mills of this type, and it is desirable that this ruin be excavated thoroughly. The materials from this old mill could be salvaged and used to build a replica near the completed reservoir as an historical exhibit.

Archeological surveys have also been completed for the Timber Creek and Bonham (Bois D'Arc) Reservoirs, in the lower Red River Basin. In the Timber Creek Reservoir site survey, two archeological sites were found which reflect intermittent occupation during late Archaic and Neo-American times. Thirteen archeological sites were found in the Bonham Reservoir area, and a variety of lithic and ceramic artifacts was recovered from the surface of these sites, several of which seem to warrant either testing or full excavation. Some of the sites in this reservoir represent small agricultural villages which were occupied in late prehistoric times. Since this reservoir is situated on the extreme western frontier of the Caddoan area, the archeological materials from these sites will be very important in helping to define the nature of the occupations in this frontier area.

At the Titus County and Franklin County Reservoir sites, in the upper Cypress Creek Basin, archeological surveys are near completion. Several important prehistoric village sites have been located in the Titus County Reservoir area, as well as a few Archaic (2 to 6 thousand year old) campsites. One major prehistoric site containing at least seven houses and/or burial mounds is located adjacent to the planned lake, and in one of these mounds has been discovered the fascinating remains of a perpetual fire temple. The State Archeologist has suggested that this site be preserved and developed as a park or historical monument adjacent to the lake. Several interesting sites have also been located in the Franklin County Reservoir area, and it is expected that many others will be found as the heavy timber and underbrush are cleared. The more important of these sites must be salvaged prior to the filling of the reservoir. In addition, the Old Cherokee Trace, used by the Indians as they were being escorted from East Texas to reservations in Oklahoma, crosses the Cypress in the Titus County Reservoir area, and there was supposed to be a fort in the vicinity. Efforts are being made to find and record these historically important features.

Archeological work has continued in Amistad Reservoir in the Rio Grande Basin as this reservoir neared completion. Columns of soil samples have been taken from some of the river terraces which contain occupational debris extending down to depths of as much as 40 feet and representing almost 10 thousand years of prehistory. The soil samples will be used for silt analysis, pollen analysis, and for development of new techniques of site identification. The University of Texas Archeological Laboratory and the Bureau of Reclamation Soil Laboratory are cooperating in this study. Several of the larger archeological sites are being photographically recorded as they are being inundated by the rising waters of the lake.

As heavy vegetation is being cleared in Livingston Reservoir, in the lower Trinity River Basin, some additional reconnaissance is being carried out to supplement the original archeological survey. Three important historic Indian burial grounds which will not be inundated have been found near the reservoir. Two of these sites have yielded large quantities of Venetian glass trade beads and numerous silver ornaments that probably date to the mid-eighteenth century. Tests of these sites are planned to explore their full potential value. Since this reservoir is not far from Texas' only Indian reservation (the Alabama-Coushatta Reservation), an exhibit of historic Indian materials at or near the reservoir should be of particular interest to those who visit the lake, and would contribute to the educational value of this project.

Most of the reservoirs which have been surveyed thus far have been relatively small in size and consequently have produced only modest results. It is expected, however, that some of the larger East Texas reservoir areas will contain major prehistoric sites such as Caddoan villages and temple and burial grounds, and also some important historical sites. The State Archeologist is planning to make the survey of each reservoir area as complete as possible, finding virtually every site that is on or adjacent to the planned lake. Thorough evaluations of the sites are planned, with recommendations for the salvage and development of representative samples of the archeological sites.

Proper salvage and development of archeological resources in a reservoir area will: (1) preserve a wealth of specimens and data which tell the story of 15 thousand years of Texas history and prehistory, (2) furnish material and information for educational institutions and museums throughout the State, and (3) provide additional incentive for Texas' citizens and out-of-State tourists to use water development projects to the maximum extent.

Funds for actually salvaging threatened archeological sites and developing salvaged material should be included in total reservoir project costs and included in the final survey report on each project. Outstanding archeological sites adjacent to the reservoirs could be developed by the Texas Parks and Wildlife Department as part of its long-range recreation program.

Preservation of Scenic Areas and Wild Rivers

Society has demonstrated a need for access to wilderness areas and areas of natural scenic beauty as a balance and retreat from the mounting pressures of present-day living. At the same time, urban and industrial expansion, agricultural development, and vast highway, railroad, utility, and pipeline networks are infringing on many of the scenic and wilderness areas of the State.

While it is important to preserve such areas as Padre Island, the Big Bend, the Big Thicket, and other large areas now protected by Federal or State authorization, the Board recognizes its responsibility for minimizing the effect of reservoir development on smaller scenic areas, many of which are within short distances of major cities and are thus of significant value to many people. Drainage projects associated with land development may also affect some of these areas, and this must also be considered in evaluating the total water resource picture.

Part IV

River Basin Resources, Requirements, And Development

CORRECTIONS

The corrections listed herein are those necessary to bring the Texas Water Plan document (November 1968) up-to-date as of the time of its formal adoption by the Texas Water Development Board, April 25, 1969. All such corrections are in Part IV of the document. Not included herein are certain corrections which are listed in an errata sheet accompanying the first printing of the document, and which are incorporated into the document's second printing in March 1969.

Page IV-31. Table IV-22: Under column head "2020 Supply", the entry for Brazos Basin, "224.3", should read "83.6" and the column total, "3,070.0", should read "2,929.3".
Under column head "Out-of-Basin Requirement", total of "423.5" should read "282.8".

Page IV-33. Left-hand text column: Lines 3 and 4, delete "under existing permits".
Right-hand text column: Line 5, delete "under existing permits".
Table IV-24: Delete the entry "Texas City" and its 2020 requirement, "88.1" (this requirement is added to a succeeding table as indicated below).
For "Other Cities", the requirement of "93.6" should read "41.0".
For "Total Requirements, San Jacinto-Brazos (Houston) System", "363.5" should read "222.8".
For "Total Requirements, Including Proposed Diversions to the Trinity-San Jacinto Coastal Basin", at end of table, "2,577.6" should read "2,436.9".

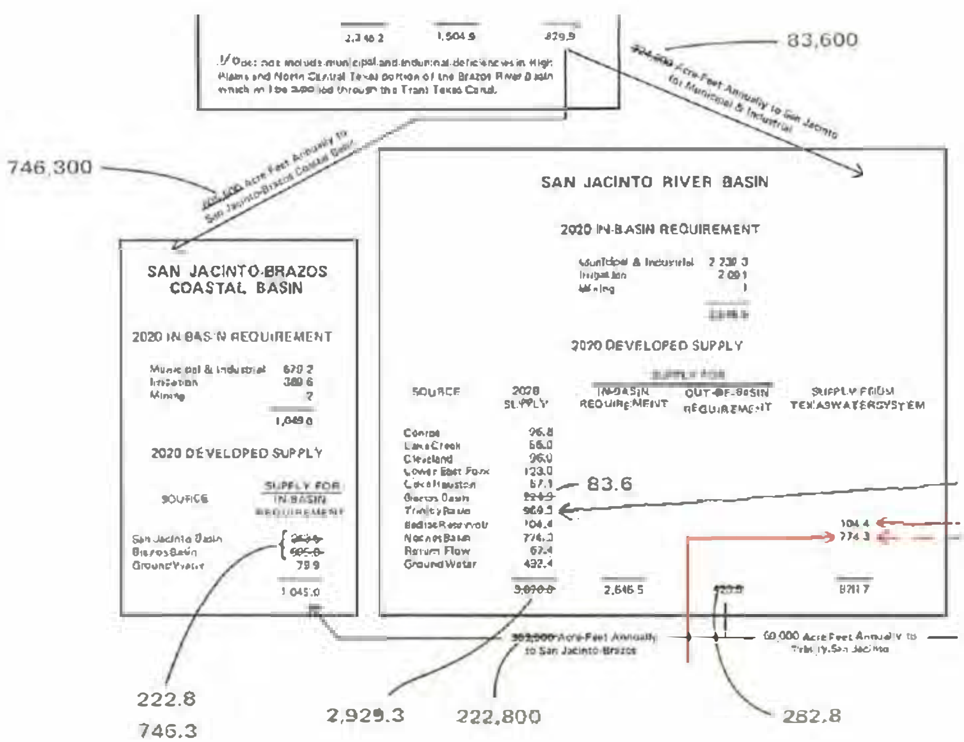
Page IV-36. Right-hand text column: Line 3, "363,500" should read "222,800", and line 5, "605,600" should read "746,300".
Table IV-26: Add two line entries,
"Texas City .... 88,100", and just above the total,
"Other Cities.......... 52,600". This changes the total annual 2020 requirement, from "605,600" to "746,300".
Table IV-27: For "San Jacinto Basin", requirement of "363.5" should read "222.8".
For "Brazos Basin", requirement of "605.6" should read "746.3".

Page IV-78. Table IV-52: In Trinity River Basin, capacities of Lavon Enlargement should read, flood control capacity "275.6", conservation capacity "380.0", dead storage capacity "92.6", and total capacity "748.2".

Page IV-79. Table IV-52: Totals at end of table should read, flood control capacity "17,441.3", conservation capacity "28,903.3", dead storage capacity "6,337.2", and total capacity "52,681.8".

Page IV-82. Table IV-53: Totals at end of table should read, flood control capacity "16,124.2" (no change in this number), conservation capacity "31,602.0", dead storage capacity "2,160.0", and total capacity "49,886.2".

Page IV-85. Figure IV-12: Numbers that have been changed are indicated (in green) in the portion of this chart reproduced below.



RIVER BASIN RESOURCES, REQUIREMENTS, AND DEVELOPMENT

Hydrologic conditions and physical characteristics vary widely in the 23 major river and coastal basins in Texas as illustrated in Figure II-8. Conditions within these basins, present state of development, future water requirements, future sources of supply, and those facilities proposed for construction within each river and coastal basin under the Texas Water Plan are described below. The facilities proposed under the Plan include both those projects related to the Texas Water System and those planned as separate units for local and regional water supply and/or flood control or other purposes but not a part of this System.

Many of the projects proposed as a part of the Plan are also included in river basin comprehensive and river basin master plans already formulated. Some of these projects have been submitted by the Federal agencies for authorization by Congress, others have already been authorized for construction, and several river basin master plans have been approved by the appropriate State agency or agencies. The current status of projects is shown in Tables IV-52 and IV-53. Effects of compacts and treaties are discussed briefly below where applicable. These legal arrangements have been discussed in more detail in Part II.

These descriptions of the water and related land resources of the river and coastal basins of Texas and planned development of these resources are based on the studies of availability and quality of water supplies and on projections of requirements for water throughout the State made by the Board and other State and Federal agencies. Revisions have been made in the water requirements given in the basin reports of the Preliminary State Water Plan published by the Board in 1966, with corresponding changes and refinements in the plans for development to meet these requirements.

The 23 major river and coastal basins of the State have been divided into zones which generally represent drainage areas having similar hydrologic characteristics, and which correspond to drainage areas within which streamflow can or has been regulated. The major river and coastal basins and zones as defined herein are illustrated in Figure IV-11.

Included in the description of the resources, existing projects, and proposed plans for development of each of the river and coastal basins are tables showing: (1) present and projected 1990 and 2020 municipal and industrial water requirements and the in-basin ground and surface water resources to meet these demands within each zone of the basin; and (2) the total projected 2020 water requirements for the basin and the proposed sources of supply to meet these requirements under the Texas Water Plan. Existing, proposed, and alternative projects under the Plan are illustrated by figures in many of the basin discussions.

While the facilities proposed under the Plan provide a systematic, and on the basis of current data, an optimum solution to the problems of water supply in each river and coastal basin and for the State as a whole, their inclusion—or omission of other possible facilities—does not imply that the facilities proposed in the Plan represent the only possible system of development. Continued study could show that other possibilities not presently included in the Plan might prove more desirable to local interests to meet more adequately specific needs in a given area.

Detailed feasibility studies will no doubt result in some changes in site locations, reservoir capacities and storage allocations, yields, and costs from those shown in the Plan. However, at the present stage of planning and on the basis of data presently available, the proposed configuration of project development is considered to provide the greatest benefit to the entire State from its projected future water supplies.

Figure IV-12 summarizes and schematically illustrates the projected 2020 requirements for each basin, the existing and proposed projects for development of supplies (not including all alternative project sites), and the proposed system of interbasin transfers and routings of additional supplies imported from out-of-State through the Texas Water System.

The water supply resources and problems, projected requirements, and existing and proposed facilities to meet future requirements of the High Plains of Texas are discussed at the close of the basin descriptions. This area includes the upper reaches of the Red, Brazos, and Colorado River Basins.

CANADIAN RIVER BASIN

The Canadian River heads in northeastern New Mexico, flows east across the Texas Panhandle, and merges with the Arkansas River in eastern Oklahoma. The Texas part of the basin comprises a total area of about 12,700 square miles.

A compact on the Canadian River between the States of New Mexico, Texas, and Oklahoma was signed on December 6, 1950, and was approved by the Legislatures of the three States in 1951 and by the Congress in 1952. Provisions of the Compact for allocation of the water among the States encompass the Canadian River, North Canadian River, and all tributaries of the Canadian River. Allocations of these resources under the Compact have been respected in the development of the Texas Water Plan.

Average annual runoff to the Canadian River in Texas during the 26-year period 1939 through 1964 ranged from about 25 acre-feet per square mile in the western part of the basin to 45 acre-feet per square mile in the eastern part of the basin. Most of the runoff occurs during wet years, however, and during most years the rate of runoff is substantially less than the long-term average. Large floods occur infrequently in the basin, and are characterized by rapid rise and fall and high stream velocities.

Concentrations of dissolved solids in the Canadian River Basin range widely, both geographically and with the rate of flow. The annual discharge-weighted average concentration of dissolved solids in the river as it enters Texas usually exceeds 500 mg/l. Although inflows from principal tributaries such as Rita Blanca Creek are low in mineral concentrations, the chemical quality of the main stem of the river does not improve as it flows across Texas.

Below Sanford Dam, oil field brines, other industrial wastes, and return flows from the Borger area have seriously degraded the quality of the river in the past. Although waste treatment and disposal practices have significantly improved in recent years, the river remains more saline downstream from Lake Meredith than above the reservoir.

Since closure of Sanford Dam in 1964, the discharge-weighted average concentration of dissolved solids in inflows to Lake Meredith has been about 700 mg/l. Inflow to the reservoir includes return flows from the City of Amarillo, entering the main stem through East Amarillo Creek. Waste treatment in the Amarillo area has been significantly improved, and a part of these return flows are now being reclaimed for industrial water supply in the area. It is also possible that the point of waste discharge for the city's effluent may ultimately be changed. Under a continuation of present conditions, however, additional removal of nutrients from the effluent may be necessary to prevent eutrophication of the reservoir and the associated problems.

Water-quality routing studies of Lake Meredith, performed by the Board, indicate that, assuming a recurrence of conditions in the basin similar to the period 1950 through 1965, concentrations of dissolved solids in water stored in the reservoir would range from about 400 to slightly over 1,000 mg/l, averaging about 750 mg/l. Concentrations of sulfate and chloride, which

Table IV-1.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Canadian River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Perryton	1,200	--	1,200	3,000	--	3,000	5,300	--	5,300
Other cities	5,600	--	5,600	9,900	--	9,900	13,100	--	13,100
Zone 2									
Amarillo 1/	28,900	--	28,900	39,300	37,300	76,600	73,700	38,200	111,900
Borger	26,500	--	26,500	67,500	5,600	73,100	88,400	5,700	94,100
Dalhart	1,000	--	1,000	1,400	--	1,400	1,900	--	1,900
Dumas	17,700	--	17,700	27,200	--	27,200	36,800	--	36,800
Pampa	10,000	--	10,000	24,300	7,200	31,500	33,900	7,400	41,300
Other cities	27,200	--	27,200	47,200	--	47,200	66,800	--	66,800
Total	118,100	--	118,100	219,800	50,100	269,900	319,900	51,300	371,200

1/ Includes the part of Amarillo in the adjacent Red River Basin.

presently average about 150 mg/l each, would continue to remain at about these levels, but may reach 200 to 250 mg/l for short periods of time during a possible drought in the basin.

Most of the present irrigation and over two-thirds of the 2½ million acres of irrigable land in the basin occurs in the North Plains, north of the Canadian River "breaks." Most of the irrigation development has taken place in recent years, but irrigation development has not yet reached its projected peak. In 1964, approximately 678 thousand acres of land was irrigated in the basin, producing mostly wheat and grain sorghum.

Essentially all irrigation is supplied by ground water pumped from the Ogallala Formation. Further expansion of irrigation supplied by ground water is expected to reach a peak of approximately 1.8 million acres by 1990. However, after about 1990, ground water supplies will begin to be progressively exhausted under the projected rate of pumpage, and it is estimated that only 1.4 million irrigated acres can be supplied from this source by the year 2020.

Approximately 200 million acre-feet of ground water is estimated to be in storage in the Ogallala Formation within the Canadian River Basin. Approximately 150 million acre-feet of the total supply stored in the Ogallala Aquifer can be recovered economically; however, a large part of this supply occurs within the "breaks" along the Canadian River—land which is largely not suited for irrigation. Smaller quantities of ground water occur in formations of Cretaceous, Jurassic, and Triassic age underlying the Ogallala Aquifer in the central and western parts of the basin. Most of the ground water being pumped from the Ogallala Aquifer is being withdrawn from storage, as the estimated rate of replenishment is small compared to the potential withdrawal rate. It is projected that the use of ground water will decline to approximately 1.29 million acre-feet annually in the basin by the year 2020. An imported supply from out-of-State source will be required at some time to maintain the irrigated agricultural economy within the basin. Planning is continuing with regard to amount, timing, and source(s) of supply.

Lake Meredith, the only existing major reservoir in the basin, will supply remaining in-basin municipal and industrial requirements to the year 2020. Rita Blanca Lake, a small reservoir with a capacity of 12,100 acre-feet on Rita Blanca Creek, is used only for recreation. From Lake Meredith, with a total capacity of 1,408,000 acre-feet, by the year 2020 approximately 103,100 acre-feet of water will be transported annually through the existing Sanford Project for municipal and industrial use in the basin and other parts of the High Plains, as indicated on Figure IV-12.

Table IV-2.--Water Supply and Demand—Canadian River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	371.2
Irrigation	966.2
Mining	2.0
	1,339.4

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	2020 SUPPLY	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FOR OUT-OF-BASIN REQUIREMENT
Lake Meredith	103.1	51.3	51.8
Ground Water	1,288.1	1,288.1	
	1,391.2	1,339.4	51.8

NOTE: Thousands of Acre-Feet Annually.

RED RIVER BASIN

The Red River Basin is bounded on the north by the Canadian River Basin and on the south, from west to east, by the Brazos, Trinity, and Sulphur River Basins. Beginning in the High Plains of eastern New Mexico at an elevation of about 4,800 feet, the Red River flows east, forming the northern boundary of Texas east of the Panhandle. Where the river leaves the State near Texarkana, elevation of the streambed is about 250 feet above sea level.

The total drainage area of the Red River upstream from the northeast corner of Texas is 48,030 square miles. The total drainage area of the basin within Texas is 24,463 square miles.

Average annual runoff within the basin in Texas ranges from more than 800 acre-feet per square mile at the northeast corner of the State to less than 50 acre-feet per square mile in contributing areas of the basin west of the 100th meridian.

Negotiations for a compact allocating the waters of the Red River Basin were initiated in 1956 between the States of Texas, Oklahoma, Arkansas, and Louisiana. A draft of the compact was submitted to the various States in February 1966. Tentative allocations of these resources to the several States, as proposed under the review draft of the compact, have been met in the development of the Texas Water Plan.

Large floods occur infrequently in the upper part of the Red River. Flood-control storage is provided in existing Texoma and Pat Mayse Reservoirs, and authorized modification of Lake Kemp Dam will provide an additional 200 thousand acre-feet of flood-control capacity on the Wichita River. Flood-control capacity is also planned in proposed Bonham, Pecan Bayou, and Big Pine Reservoirs.

Extreme variations in chemical quality occur in streams of the Red River Basin. In the eastern part of the basin, tributaries carry water generally containing less than 100 mg/l of dissolved solids. Several streams in the western part of the basin, such as Sweetwater Creek, Tule Creek, McClellan Creek, and the upper part of the Salt Fork Red River, also contain good quality water; however, as the result of numerous saline springs and seepage areas, the water in most streams of the upper Red River Basin in Texas is too saline for most uses. For example, the discharge-weighted average concentration of dissolved solids of the Prairie Dog Town Fork Red River near Quanah generally exceeds 6,000 mg/l, with the annual weighted-average chloride concentration ranging between about 2,000 and 4,600 mg/l. The main stem of the Pease River near Childress has a weighted-average dissolved solids concentration exceeding 4,000 mg/l, and near Vernon, the weighted-average presently generally exceeds 2,000 mg/l.

Natural salt springs in the North, Middle, and South Forks of the Wichita River contribute an average of more than 525 tons of chloride daily to the main stem of the Wichita River, and the water in Lake Kemp usually contains more than 2,500 mg/l of dissolved solids, including about 900 mg/l of chloride and 550 mg/l of sulfate.

The Little Wichita River, although degraded by oil field brines in some reaches, generally contains good quality water, and inflow from other tributaries in Texas and Oklahoma progressively reduce the salinity of the main stem in a downstream direction. However, inflows to Lake Texoma generally range between 1,000 and 2,000 mg/l of dissolved solids. Weighted-average monthly concentrations in water released or spilled from the reservoir generally exceed 1,000 mg/l of dissolved solids, and since 1943 chloride concentrations have equaled or exceeded 250 mg/l about 65% of the time. As the river leaves Texas, dissolved solids concentrations generally range between about 600 and 800 mg/l.

As a result of intensive study of the natural salt problems by the U.S. Public Health Service and the Corps of Engineers, 10 principal natural brine-emission areas have been identified in the upper Red River Basin, 9 of which are in Texas. Subsequent studies of the feasibility of controlling these salt-contributing sources and reducing the salinity problem in the basin led to the construction by the Corps of Engineers of one salt-control project in 1964 at Estelline Spring on the Prairie Dog Town Fork Red River. Congress has further authorized construction of three additional salinity alleviation projects in the Wichita River drainage system, and the Corps of Engineers has proposed construction of five additional projects in the upper Red River Basin, four of which would be in Texas and the remaining project in Oklahoma. These projects in Texas are shown on Plate 4.

Early construction of authorized and badly needed salinity alleviation projects in the Wichita River drainage area would result in water in Lake Kemp containing not more than 250 mg/l of chloride, averaging about 165 mg/l. The water would be much more suitable for irrigation, for which it can presently be used only on highly salt tolerant crops.

Authorization and construction of the remaining natural salinity alleviation projects proposed by the Corps of Engineers, together with continuing abatement of oil field pollution which has plagued parts of the basin in the past, would result in substantial improvement in the quality of the basin's water resources. It is projected that following implementation of the authorized and proposed salinity control measures, chloride concentrations of water impounded in Lake Texoma would seldom exceed about 150 mg/l, and would not exceed about 110 mg/l at least 50% of the time. The quality of the lower Red River would thus be significantly improved for beneficial uses by several States.

Organic loading is comparatively low throughout the basin, although dissolved-oxygen deficits occur locally in the Wichita River below Wichita Falls, and in Pine Creek below Paris.

East of the escarpment of the High Plains, about 145 thousand acres of wheat, cotton, and feed crops was irrigated in the basin in 1964, principally in North Central Texas. Ground water supplies most of this irrigated acreage, and Lake Kemp on the Wichita River supplies water for the remainder. Most of the potentially irrigable lands in this part of the basin are widely scattered, and many such areas are not amenable to efficient use of irrigation water delivered by project-type developments. However, water planned for delivery through the Texas Water System to North Central Texas for irrigation could supply some irrigation needs in this part of the Red River Basin, if found to be feasible.

In the Northeast part of the basin, it is projected that up to 75 thousand acres may be irrigated by the year 2020, which would be served by direct diversion of river flows resulting from releases from Lake Texoma.

Approximately 120 thousand acre-feet of ground water is available annually on a safe yield basis from major and minor aquifers (other than the Ogallala Aquifer) in the Red River Basin in Texas. In addition, about 60 million acre-feet is stored in the Ogallala Formation within the basin. Major aquifers present in the basin are the Ogallala, the Alluvium (Seymour Formation), and the Trinity Group. Minor aquifers in the basin include the Woodbine and the Blaine. Less important water-bearing formations supply small quantities of water locally for domestic and livestock uses, and in some areas furnish sufficient supplies for limited municipal, industrial, and irrigation usage. It is estimated that approximately 363,700 acre-feet of ground water will be used annually in the basin by the year 2020.

It is proposed as a part of the Texas Water System to divert water from the Red River below Texoma Reservoir a short distance above its confluence with Pecan Bayou. Approximately 617 thousand acre-feet of water diverted annually from the Red River, together with 30 thousand acre-feet from proposed Pecan Bayou Reservoir, would be conveyed to Naples Reservoir in the Sulphur River Basin.

The Corps of Engineers has developed a Comprehensive Plan for development of the Red River Basin below Denison Dam, including the Sulphur River and Cypress Creek Basins, which is generally compatible with the Texas Water Plan. The Comprehensive Plan includes Bonham, Cooper, Big Pine, Liberty Hill, and Texarkana Reservoirs, Caddo Dam Enalrgement, Cypress Bayou Navigation, and Red River Channel Improvement.

Table IV-3.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Red River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Canyon	1,000	-	1,000	3,200	-	3,200	8,800	-	8,800
Hereford	1,800	-	1,800	7,200	-	7,200	12,600	-	12,600
Other cities	10,000	-	10,000	22,700	-	22,700	26,400	-	26,400
Zone 2									
Burkburnett	1,000	-	1,000	-	2,100	2,100	-	3,700	3,700
Childress	1,100	-	1,100	-	1,700	1,700	-	2,400	2,400
Vernon	2,000	-	2,000	2,000	900	2,900	2,000	2,000	4,000
Other cities	5,400	-	5,400	1,800	5,800	7,600	1,800	8,000	9,800
Zone 3									
Wichita Falls	-	19,500	19,500	-	38,000	38,000	-	61,000	61,000
Other cities	1,300	2,400	3,700	-	8,300	8,300	-	12,900	12,900
Zone 4									
Bonham	1,000	6,100	7,100	1,000	9,200	10,200	-	13,100	13,100
Denison	-	3,800	3,800	-	8,100	8,100	-	16,000	16,000
Paris 1/	-	8,200	8,200	-	46,400	46,400	-	74,700	74,700
Sherman	3,800	-	3,800	5,000	7,600	12,600	-	26,300	26,300
Other cities	1,100	200	1,300	1,500	300	1,800	1,300	45,300	46,600
Total	29,500	40,200	69,700	44,400	128,400	172,800	52,900	265,400	318,300

1/ Includes all requirements for the City of Paris.

Cooper, Big Pine, Cypress Bayou Navigation, and Red River Channel Improvement have been authorized by the Congress for construction.

In the upper Red River Basin, Sweetwater Creek Reservoir is proposed for construction under the Texas Water Plan to develop additional municipal and industrial water supplies which will be needed in this area. Lower McClellan Creek and Lelia Lake Creek Reservoirs are potential reservoirs which could be constructed if sufficient need for these supplies develop.

Continued and accelerated progress toward effective control of salinity problems in the basin will have wide-ranging beneficial effects. Proposed reservoir construction would provide needed flood control to mitigate flood damages, and an enhanced recreational potential in addition to that already developed in the areas of existing reservoirs.

Table IV-4.--Water Supply and Demand— Red River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	318.3
Irrigation	557.9
Mining	7.6
Industrial Cooling	16.4
Fish Hatchery	1.0
	901.2

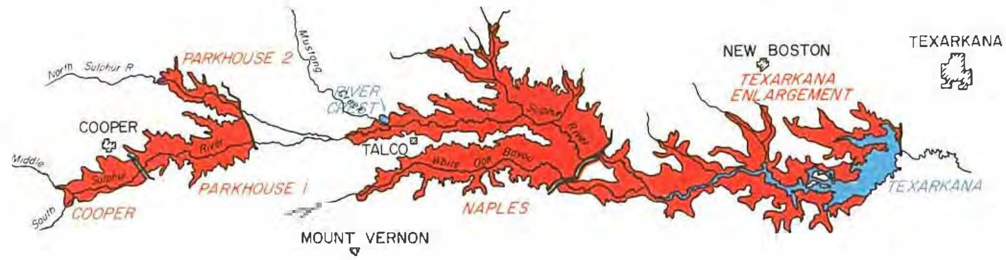
PLANNED
2020 DEVELOPED SUPPLY

SOURCE*	2020 SUPPLY	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FOR OUT-OF-BASIN REQUIREMENT	SUPPLY FOR EXPORT UNDER TEXAS WATER SYSTEM
Greenbelt	9.0	9.0		
Baylor Creek, Wichita Falls System, Sweetwater Creek	11.3	11.3		
Kickapoo	20.7	20.7		
Arrowhead	42.0	40.3		
Moss	6.1		6.1	
Kemp	114.0	114.0		
Farmers Creek	5.8	5.8		
Buffalo Creek	1.1	1.1		
Diversion Lake	1.0	1.0		
Texoma	193.7	193.7		
Timber Creek	6.2	6.2		
Bonham	27.0	6.9		
Pat Mayse	58.5	58.5		
Big Pine	33.0	16.2		
Liberty Hill	33.6			
Diversion, Barkman	45.0	45.0		
Pecan Bayou & Diversion	647.0			647.0
Local Supply	7.8	7.8		
Ground Water	363.7	363.7		
	1,626.5	901.2	6.1	647.0

* Additional reservoirs for possible development include Lower McClellan Creek, Lelia Lake Creek, and Ringgold.
NOTE: Thousands of Acre-Feet Annually.

SULPHUR RIVER BASIN

FIGURE IV - 1
EXISTING AND PROPOSED DEVELOPMENT



EXPLANATION

Existing Reservoirs

Proposed and Alternate Reservoirs

Table IV-5.--Water Supply and Demand—
Sulphur River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	145.9
Irrigation	22.0
Wildlife Refuge	2.3
	170.2

PLANNED
2020 DEVELOPED SUPPLY

SOURCE*	2020 SUPPLY	SUPPLY FOR: IN-BASIN REQUIREMENT	OUT-OF-BASIN REQUIREMENT	EXPORT UNDER TEXAS WATER SYSTEM	SURPLUS
Cooper	128.3	25.3	97.8		
Parkhouse 1	118.7				
Naples	836.3				
Texarkana Enlargement	327.4	144.9			
Return Flow	16.2				
	1,426.9	170.2	97.8	1,105.0	53.9

* Additional reservoir for possible development includes Parkhouse 2.
NOTE: Thousands of Acre-Feet Annually.

The major upstream branches of the Sulphur River—the North Sulphur and South Sulphur Rivers—head in southwestern Fannin County at an elevation about 700 feet above sea level. These streams flow east about 55 miles, merging to form the Sulphur River which continues an easterly flow to the Texas-Arkansas line, thence into the Red River. As the Sulphur River is a part of the Red River drainage system, it is included in the compact draft on the Red River. The total drainage area of the Sulphur River Basin in Texas is about 3,558 square miles.

The average annual rainfall in the basin in Texas is approximately 45 inches, ranging from 42 inches in the western part of the basin to 49 inches in the eastern part. Flood damages along the Sulphur River and its tributaries have been comparatively small, principally because urban and agricultural development in the flood plain has not been extensive. Several tributaries, however, have had frequent damaging floods.

The surface water resources of the Sulphur River Basin are generally of excellent quality. The discharge-weighted average concentration of dissolved solids in the South Sulphur River is about 150 mg/l. Concentrations of dissolved solids in daily flows are less than 100 mg/l about 50% of the time, and have exceeded 500 mg/l less than 2% of the time since 1959. Flows of the North Sulphur River are slightly higher in mineral concentrations, averaging about 250 mg/l.

White Oak Bayou contains good quality water above the Talco oil field, but the quality is impaired by oil field brines in the lower reach of the stream. Flood runoff below this area has been sufficient to dilute these saline flows, however, and the concentration of dissolved solids in existing Texarkana Reservoir on the main stem of the Sulphur River generally ranges between 100 and 150 mg/l.

Table IV-6.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Sulphur River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Commerce	700	--	700	--	3,500	3,500	--	7,000	7,000
Sulphur Springs	--	1,100	1,100	--	3,700	3,700	--	9,000	9,000
Texarkana (Texas)	--	17,600	17,600	--	68,800	68,800	--	92,600	92,600
Texarkana (Arkansas)	--	10,800	10,800	--	17,400	17,400	--	28,000	28,000
Other cities	2,600	1,700	4,300	--	6,900	6,900	--	9,300	9,300
Total	3,300	31,200	34,500	--	100,300	100,300	--	145,900	145,900

Organic loading is comparatively low throughout the basin, although decaying vegetation in heavily wooded areas creates seasonal oxygen depressions and slight coloration of streams locally.

There is presently very little irrigated land in the basin, since rainfall is usually adequate for the crops and pastures grown. Agricultural trends have been toward more commercial forests and pastures rather than cultivated crops. Less than one thousand acres was irrigated in the basin in 1964, but small acreages of pasture, peanuts, and some nursery and specialty crops may be irrigated in the future. About 7 thousand acres is projected to be irrigated by 1990, and about 15 thousand acres by the year 2020.

Approximately 5,700 acre-feet of ground water is available annually on a safe-yield basis from aquifers in the Sulphur River Basin. Of this amount, about 4,000 acre-feet is available from the Carrizo-Wilcox Aquifer, and the remainder from small local aquifers, including the Blossom Sand and the Nacatoch Sand.

The Blossom Sand is an important source of local water supply in parts of Lamar and Red River Counties, and the Nacatoch Sand provides municipal and some industrial and domestic supply in a narrow area extending from east-central Hunt County to southwestern Red River County. The Trinity Group Aquifer and the Woodbine Aquifer extend into the northwestern part of the basin. Ground water available in the basin probably will be limited to supplying domestic and livestock needs in the year 2020.

The two existing major reservoirs in the Sulphur River Basin are Texarkana and River Crest, the latter an off-channel reservoir which provides water for steam powerplant cooling. Cooper Reservoir is a federally authorized project on the South Sulphur River designed to provide municipal and industrial water supply, flood control, and recreation. Export of approximately 97,800 acre-feet of water annually to the Trinity River Basin is committed to the North Texas Municipal Water District and the City of Irving from the water supply to be developed by Cooper Reservoir.

Additional major reservoirs proposed or authorized for construction in the Sulphur River Basin under the Texas Water Plan would serve all projected water demands in the basin to the year 2020 and would develop an additional 1,105,000 acre-feet per year of water supplies surplus to projected in-basin needs that would be available for export through the Texas Water System. These reservoirs include Parkhouse Reservoir Stage 1, Naples Reservoir, and the authorized enlargement of existing Texarkana Reservoir. The conservation storage capacity of Texarkana Reservoir will be increased initially by transfer of present flood-control storage in that reservoir to Cooper Reservoir, and subsequently further increased by additional transfer to proposed Naples Reservoir. It is anticipated that approximately 700 thousand acre-feet of flood-control storage would be exchanged for equivalent storage in Naples Reservoir. An agreement for exchange of 120 thousand acre-feet of flood-control capacity in Texarkana Reservoir for equivalent storage of water in Cooper Reservoir has been negotiated.

Construction of proposed reservoirs would provide a firm water supply to meet all future beneficial water requirements in the basin, including potential industrial growth, flood-control storage capacity to mitigate recurrent flood damages, and a reservoir complex suitable for extensive recreational development. Prospective interstate compact commitments would be met and substantial surpluses would be developed for export through the Texas Water System.

CYPRESS CREEK BASIN

FIGURE IV - 2
EXISTING AND PROPOSED DEVELOPMENT

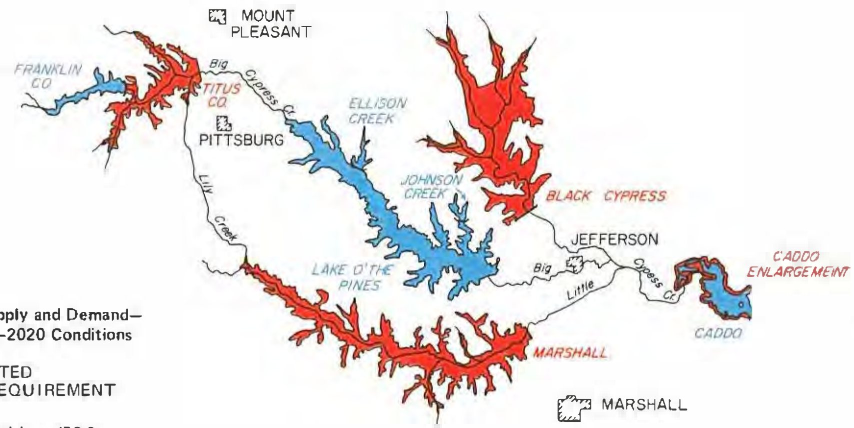


Table IV-7.-Water Supply and Demand—Cypress Creek Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	153.6
Irrigation	11.7
	165.3

PLANNED
2020 DEVELOPED SUPPLY

SOURCE*	2020SUPPLY	SUPPLY FOR IN-BASIN	SUPPLY FOR EXPORT UNDER TEXAS WATER SYSTEM	SURPLUS
Franklin Co. / Titus Co. / Lake O' The Pines	264.0	117.6	96.0	
Marshall	325.0		325.0	
Black Cypress	220.0		220.0	
Caddo	32.8[1/]	32.8		
Return Flow	56.1	8.9		
Ground Water	6.0	6.0		
	903.9	165.3	641.0	97.6

* Additional reservoir for possible development includes Caddo Enlargement.

1/ Texas Share

NOTE: Thousands of Acre-Feet Annually.

Cypress Creek, which enters the Red River in Louisiana, rises in southeastern Hopkins County at an elevation about 550 feet above sea level and flows southeasterly into Caddo Lake on the Texas-Louisiana line. The elevation of the streambed in the backwater area of Caddo Lake is about 168 feet. The basin is bounded on the north by the Sulphur River Basin and on the south by the Sabine River Basin. The Cypress Creek Basin is part of the Red River drainage system and is included in the compact draft on the Red River. Total drainage area of the Cypress Creek Basin in Texas is about 2,812 square miles.

Average annual rainfall in the Cypress Creek Basin ranges from about 48 inches at the Louisiana line to about 42 inches in the western part of the basin. Average annual runoff in the basin ranges from about 700 to 800 acre-feet per square mile in the western part of the basin to about 600 acre-feet in the southern part. These variations in rate of runoff are largely the result of variations in physiography and geology within the basin.

Overall, flood damages have been relatively minor along Cypress Creek and its tributaries in Texas, although locally severe damages have occurred. Since completion of Lake O' the Pines, the flow of Cypress Creek has been regulated and flooding along downstream reaches reduced.

The chemical quality of streamflows throughout most of the Cypress Creek Basin is excellent, with the discharge-weighted average concentrations of dissolved solids in principal streams generally ranging between about 100 and 200 mg/l. Lake O' the Pines on Cypress Creek generally contains about 100 mg/l of dissolved solids. Although oil field drainage and other industrial wastes presently degrade the quality of Sugar, Glade,

Table IV-8.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Cypress Creek Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Marshall 1/	–	5,200	5,200	–	20,700	20,700	–	50,500	50,500
Mount Pleasant	–	1,200	1,200	–	3,800	3,800	–	6,100	6,100
Other cities	4,200	46,800	51,000	–	80,000	80,000	–	97,000	97,000
Total	4,200	53,200	57,400	–	104,500	104,500	–	153,600	153,600

1/ All of Marshall's requirements are included in this basin—its assumed source of all future supply.

and Grays Creeks—tributaries of Little Cypress Creek—these problems are being corrected, and their present effects are comparatively minor when considering the discharge-weighted average quality of the stream.

Organic loading is presently low throughout the basin, although, as in the Sulphur River Basin, decaying vegetation in heavily wooded areas creates minor seasonal dissolved-oxygen depressions and slight coloration in streams locally.

Most of the Cypress Creek Basin is densely forested, and less than one thousand acres was irrigated in the basin in 1964. Cultivated acreage is decreasing, and more land is being provided permanent forest and pasture cover. Scattered, small acreages of specialty crops and pasture lands may be irrigated with locally available surface and ground water supplies, but this acreage is not expected to total more than 5 thousand acres by 1990 and 10 thousand acres by 2020.

Approximately 15 thousand acre-feet of ground water is available annually on a safe yield basis from the Carrizo-Wilcox Aquifer, and a lesser amount from the Queen City Aquifer in the Cypress Creek Basin. It is anticipated that by the year 2020 ground water use will be largely limited to domestic and livestock purposes because of the availability of large quantities of surface water of good quality which would be developed by proposed reservoirs in the basin. Use of ground water for irrigation will increase somewhat, however.

There are three major reservoirs in the Cypress Creek Basin in Texas—Lake O' The Pines, Ellison Creek, and Johnson Creek. In addition, Franklin County Reservoir is presently under construction. Existing Caddo Lake Dam is currently being replaced with a new dam immediately downstream, which is designed so that it can subsequently be raised and the reservoir enlarged. Construction of projects and channel modifications to provide navigation up the Red River in Louisiana into Cypress Creek near Daingerfield, Texas has been authorized by Congress.

Major reservoirs proposed for construction under the Texas Water Plan include Titus County, Marshall, and Black Cypress. These reservoirs, plus existing and under-construction reservoirs in the Cypress Creek Basin, would supply all projected in-basin requirements to the year 2020 and develop an additional 641 thousand acre-feet of water per year—surplus to projected in-basin needs—for export through the Texas Water System.

One or more of these proposed reservoirs could be used to provide regulating storage for the additional water proposed to be brought into the Texas Water System from the lower Mississippi River Basin. Proposed reservoir development would provide water for continued urban and industrial growth in the basin, as well as increased recreational development. The economy of the basin would be further enhanced by navigation of the Red River and Cypress Creek to Daingerfield.

SABINE RIVER BASIN

FIGURE IV - 3

EXISTING AND PROPOSED DEVELOPMENT

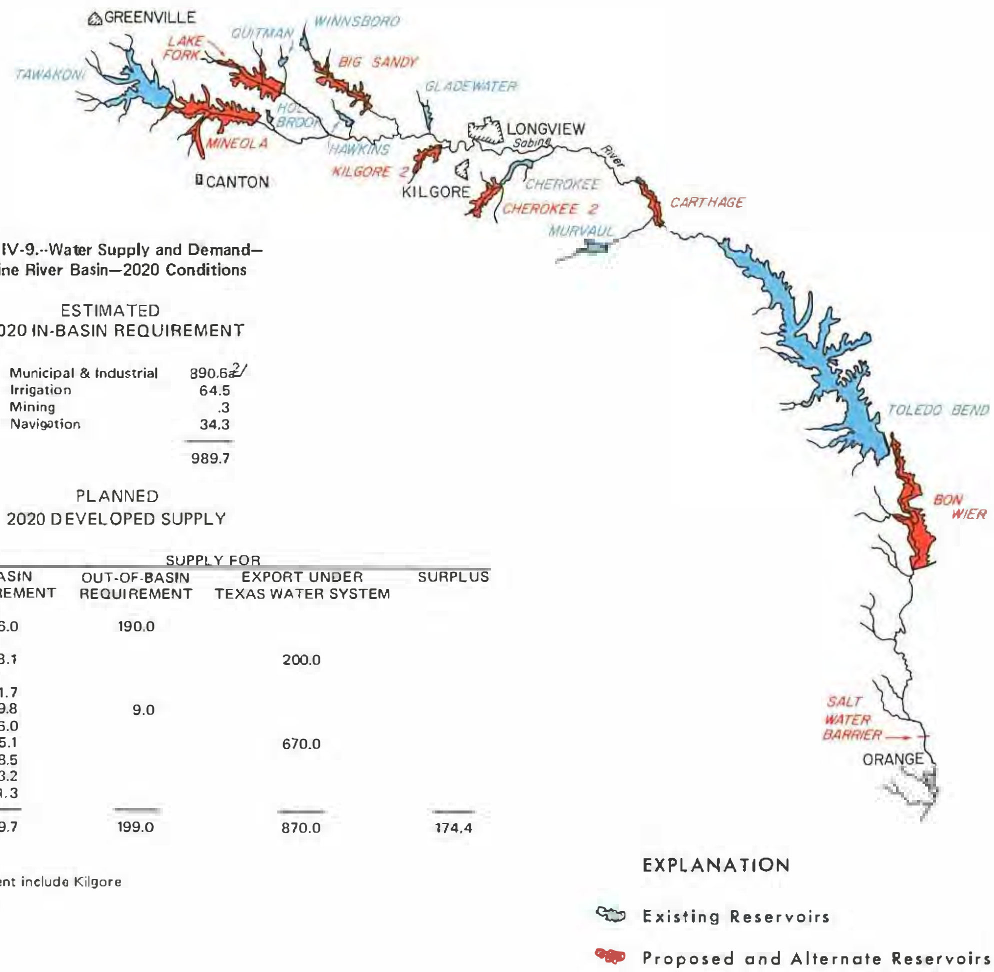


Table IV-9.--Water Supply and Demand—Sabine River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	890.6a 2/
Irrigation	64.5
Mining	.3
Navigation	34.3
	989.7

PLANNED
2020 DEVELOPED SUPPLY

SOURCE*	2020 SUPPLY	SUPPLY FOR: IN-BASIN REQUIREMENT	OUT-OF-BASIN REQUIREMENT	EXPORT UNDER TEXAS WATER SYSTEM	SURPLUS
Tawakoni	216.0	26.0	190.0		
Mineola	93.3 a				
Lake Fork	181.0	148.1		200.0	
Big Sandy	73.8				
Gladewater	5.5	1.7			
Cherokee	58.8	49.8	9.0		
Murvaul	39.4	6.0			
Toledo Bend	1,000.0 1/	285.1		670.0	
Salt Water Barrier	308.5	308.5			
Return Flow	115.5	23.2			
Ground Water	141.3	141.3			
	2,233.1	989.7	199.0	870.0	174.4

* Additional reservoirs for possible development include Kilgore 2, Cherokee 2, Carthage, and Bon Wier.

1/ Texas Share

2/ Includes 3.9 Industrial Cooling.

NOTE: Thousands of Acre-Feet Annually.

The Sabine River Basin is bounded on the north by the Sulphur River and Cypress Creek Basins, on the east by the Red and Calcasieu River Basins, and on the west by the Trinity and Neches River Basins. The river rises in northwestern Hunt County at an elevation of about 650 feet, and flows southeasterly about 160 miles to Logansport, Louisiana, where it becomes the Texas-Louisiana boundary. At this point the elevation of the streambed is about 145 feet and the drainage area is 4,839 square miles, of which 4,775 square miles is in Texas. The river continues as the State boundary southward from Logansport into Sabine Lake. The maximum width of the basin is about 45 miles. The total drainage area of the basin is 9,756 square miles, of which 7,426 square miles is in Texas.

Average annual rainfall in the basin is approximately 48 inches, ranging from about 39 inches in the northwest to about 56 inches in the southeast. The recorded maximum annual rainfall in the basin was 67 inches in 1957, and the recorded minimum was 34 inches in 1917. Average annual runoff in the Sabine River Basin in Texas ranges from a maximum of about 1,100 acre-feet per square mile in southeastern Newton County to a minimum of about 400 acre-feet per square mile in the upper part of the basin in Hunt County. Runoff decreases more or less uniformly from southeast to northwest.

Flooding has occurred along the entire length of the Sabine River on the average of once every 3 years above Logansport, Louisiana, and once every 6 years in the lower reaches of the river. Cities suffering periodic flood damage include Greenville, Gladewater, Deweyville, and Orange.

Surface water resources of the Sabine River Basin are generally of excellent chemical quality. Discharge-

Table IV-10.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Sabine River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Greenville	--	2,600	2,600	--	6,300	6,300	--	13,900	13,900
Other cities	1,300	700	2,000	--	3,600	3,600	--	5,900	5,900
Zone 2									
Longview	--	19,400	19,400	--	51,000	51,000	--	135,100	135,100
Kilgore	1,800	--	1,800	--	5,300	5,300	--	9,500	9,500
Gladewater	--	1,300	1,300	--	3,100	3,100	--	5,900	5,900
Carthage	1,800	--	1,800	--	4,100	4,100	--	6,000	6,000
Other cities	13,300	--	13,300	10,600	17,300	27,900	10,600	25,000	35,600
Zone 3									
Other cities	500	1,300	1,800	500	2,700	3,200	500	5,100	5,600
Zone 4									
Orange	14,900	11,000	25,900	30,800	71,600	102,400	46,700	200,000	246,700
Other cities	5,100	17,400	22,500	38,800	155,600	194,400	72,500	350,000	422,500
Total	38,700	53,700	92,400	80,700	320,600	401,300	130,300	756,400	886,700

weighted average concentrations of dissolved solids are less than 250 mg/l throughout most of the basin. Runoff from the upper part of the basin generally contains dissolved solids concentrations ranging from about 100 to 200 mg/l, and runoff from the lower basin has concentrations less than 100 mg/l. Since 1953, dissolved solids concentrations in daily flows of the Sabine River near Tatum in eastern Rusk County have equaled or exceeded 500 mg/l only about 10% of the time. In the lower basin, daily flows of the river near Ruliff in southern Newton County seldom exceed 250 mg/l of dissolved solids. Water stored in existing major reservoirs in the basin usually contains less than 150 mg/l of dissolved solids.

Salinity problems occur locally in the basin, however, in Dry Creek, Lake Fork Creek, Socagee Creek, Rabbit Creek, and Grand Saline Creek. The salinity problems occurring in Dry, Lake Fork, Rabbit, and Socagee Creeks result principally from drainage from oil fields, but the mineralization in Grand Saline Creek results from natural contributions of salt from the Grand Saline Salt Dome. Above the Orange industrial area, organic loads of most streams in the basin are low.

Irrigation is not extensive in the basin, although the coastal area of the basin includes the eastern edge of the Texas rice-producing area. Parts of this rice-producing area in the basin are being encroached upon by urbanization and industrial development in Orange County. A little over 5 thousand acres was irrigated in 1964, mostly to produce rice. Irrigated acreage has since increased somewhat in the basin. Approximately 7 thousand acres is projected to be irrigated by 1990, and about 8 thousand by the year 2020 in the coastal area.

Irrigation in the remainder of the basin, which is largely forested, is generally minor. Locally available surface water supplied less than 2 thousand acres in 1964. It is estimated that as much as 15 thousand acres of pastures and specialty crops may be irrigated, however, by 1990, and more than 31 thousand acres by 2020, using locally available supplies.

Ground water is an important resource in the basin, with an estimated 320 thousand acre-feet available annually from the Carrizo-Wilcox and the Gulf Coast Aquifers. The Queen City Aquifer, a minor aquifer, is also present in the basin, and other less important water-bearing formations also provide limited quantities of water adequate on a perennial basis for domestic and livestock supplies, and in some instances for municipal, industrial, and irrigation supplies. It is estimated that about 141 thousand acre-feet of ground water will be used annually in the basin by the year 2020.

There are nine major existing or under-construction reservoirs in the basin. These are: Tawakoni, Holbrook, Quitman, Hawkins, Winnsboro, Gladewater, Cherokee, Murvaul, and Toledo Bend. Three reservoirs and a salt water barrier are proposed for construction under the Texas Water Plan, and four additional reservoirs may be constructed. The three proposed reservoirs would have flood control storage capacity.

Use of water from existing reservoirs in the basin and development of new reservoirs will be in accordance with terms of the Sabine River Basin Compact between Texas and Louisiana. This Compact was signed on January 26, 1953, and approved by the Texas Legislature in 1953 and by the Louisiana Legislature and the Congress in 1954. The Compact allocates the waters of the Sabine River Basin and establishes a basis for cooperative planning and action by the States for the construction, operation, and maintenance of projects on that part of the river bordering both States. Under terms of the Compact, Texas and Louisiana share equally in the yield from Toledo Bend Reservoir.

Toledo Bend Dam was constructed as a joint venture of the Sabine River Authorities of Texas and Louisiana. The project was constructed with funds furnished by these two Authorities and the States of Louisiana and Texas, with participation by private power companies, for water supply, power generation, and thermal generation cooling purposes. The Board has invested $15 million in the project, which is operated jointly by the Sabine River Authorities of Texas and Louisiana. Existing contractual requirements for hydroelectric power generation at this dam may impose constraints which could affect the future operation of the reservoir. These constraints would be of particular significance if water from the Mississippi River were brought into the lower Sabine River, to be conveyed in part north through Toledo Bend Reservoir to the Trans-Texas Division of the Texas Water System. In that event, equitable contractual arrangements would have to be reached between the Board and the River Authorities to utilize fully the multipurpose functions of Toledo Bend Reservoir.

Proposed new reservoirs, together with existing development and ground water supplies, would provide water to meet all projected in-basin requirements. Additionally the reservoirs would provide flood control, storage capacity for regulation of import water, and export of surplus water through the Texas Water System. Under the Texas Water Plan, phasing of construction would be planned to provide conservation storage capacity in advance of water needs. Phasing of construction of some facilities may be influenced by flood-control needs.

Mineola, Lake Fork, and Big Sandy Reservoirs in the upper reaches of the Sabine River Basin are planned for future development. These reservoirs would provide essential flood control, supply additional water for future in-basin needs and recreation, and furnish approximately 200 thousand acre-feet of surplus water annually for export through the Texas Water System. Water is presently exported from Tawakoni Reservoir to the upper Trinity River Basin, and the water supplies developed by Mineola and Lake Fork Reservoirs could be conveyed westerly along the same route of this export, or transported northward and thence westward through the Trans-Texas Canal. Final selection of the routing must await the negotiation of water service contracts for the Fort Worth-Dallas metropolitan area under the Texas Water System. Big Sandy Reservoir would be built at the appropriate time to supply intrabasin needs and flood control after the yields of Mineola and Lake Fork Reservoirs are fully utilized.

Based on the proposed plan of development, about 670 thousand acre-feet of developed water supplies would be surplus to in-basin needs in the year 2020 in the lower reaches of the Sabine River Basin and would be diverted into the Coastal Canal of the Texas Water System.

Upstream development will alter the seasonal regimen of fresh water inflow into Sabine Lake, but properly treated return flows, and unregulated streamflows below Toledo Bend Reservoir, together with final releases below the salt water barrier on the Neches River are estimated to be adequate to meet the fresh water requirements projected for Sabine Lake.

Existing facilities provide deep water navigation to Orange in the lower basin. These facilities will need to be progressively deepened to accommodate deeper-draft ocean-going traffic. Extensions of shallow-water navigation facilities up the Sabine River above deep-water navigation would be coordinated with proposed reservoir development when these navigation improvements prove feasible.

However, with deepening of navigation channels and changes in the regimen of streamflow, further salt water intrusions from the Gulf up the Sabine River—possibly to points of diversion for municipal, industrial, and irrigation purposes—would necessitate construction of a salt water barrier. A salt water barrier with provisions for navigation lockage is proposed in the Plan to prevent this upstream movement of salt water. The barrier would serve the dual purpose of limiting the upstream movement of salt water during extended periods of low flow, and creating a forebay for diversion of water to existing or proposed canal systems.

Proposed development of the Sabine River Basin under the Texas Water Plan would provide for all projected future beneficial uses of water in the basin and preservation of Sabine Lake and its associated resources. Shallow-water navigation would be compatible with this development, and the proposed salt water barrier would prevent upstream intrusion of Gulf waters.

NECHES RIVER BASIN

FIGURE IV - 4

EXISTING AND PROPOSED DEVELOPMENT

Table IV-11.--Water Supply and Demand—
Neches River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	915.1
Irrigation	73.0
Mining	.3
Navigation	34.5
	1,022.9

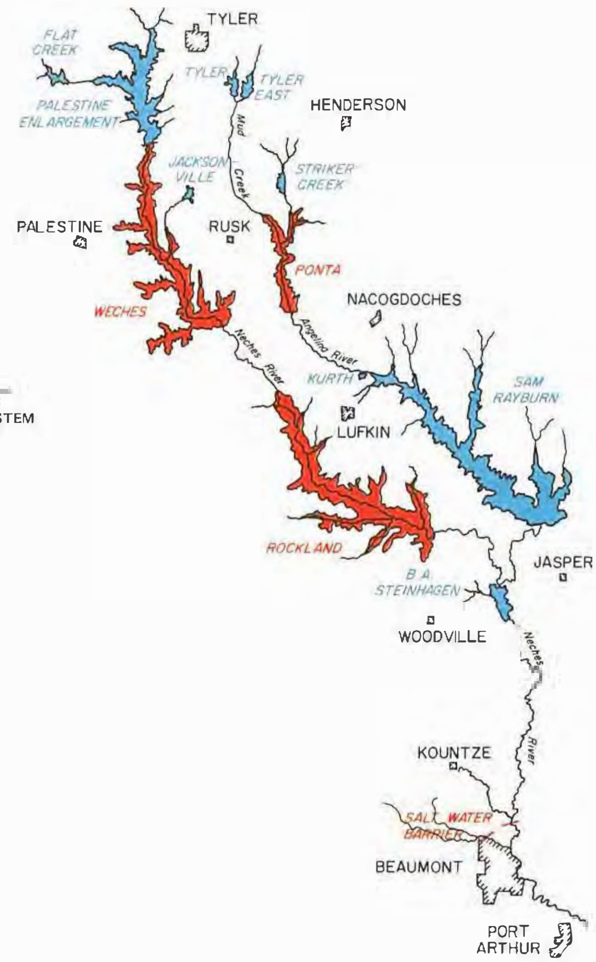
PLANNED
2020 DEVELOPED SUPPLY

SOURCE*	2020 SUPPLY	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FOR OUT-OF-BASIN REQUIREMENT	SUPPLY FOR EXPORT UNDER TEXAS WATER SYSTEM
Sabine Basin	9.0	9.0		
Flat Creek	6.7		6.7	
Jacksonville	9.7	5.0	4.7	
Tyler East	37.4	37.4		
Striker Creek	20.6	20.6		
Palestine Enlargement	234.7	112.7		122.0
Ponta	181.7	92.0		89.7
Rockland	753.3	10.3		743.0
Sam Rayburn	820.0[1/]	381.1	438.7	
B. A. Steinhagen	68.4	58.0	10.4	
to Salt Water Barrier	606.8		722.9	73.2
Return Flow	189.3			
Ground Water	296.8	296.8		
	3,234.4	1,022.9	1,183.4	1,027.9

* Additional reservoir for possible development includes Weches.

1/ With Power

NOTE: Thousands of Acre-Feet Annually. Reservoir supplies include return flows.



EXPLANATION

Existing Reservoirs

Proposed and Alternate Reservoirs

The Neches River Basin is bounded on the north and east by the Sabine River Basin, on the west by the Trinity River Basin, and on the south by the Neches-Trinity Coastal Basin. It rises in southeastern Van Zandt County at an elevation of about 600 feet, and flows southeasterly into Sabine Lake. The total drainage area at the mouth is about 10,011 square miles.

Annual rainfall ranges from an average of about 41 inches in the northern part of the basin to 55 inches in the south, averaging about 48 inches annually. Average annual runoff in the Neches River Basin ranges from a maximum of about 1,000 acre-feet per square mile near its mouth to about 400 acre-feet per square mile in the northwestern part of the basin. Runoff decreases more or less uniformly from east to west, corresponding with the pattern of rainfall.

Streams in the Neches River Basin generally have comparatively narrow channels, flat slopes, and wide floodplains. Floods frequently overflow floodplains for lengthy periods, rise and fall slowly, and generally have low velocities.

Minor flooding has occurred at least once every year, and major flooding about once every 5 years. The Angelina River watershed has experienced minor flooding about every 1½ years, and major flooding once about every 5 years. Damaging floods have occurred in both Beaumont and Nacogdoches.

The quality of water in most streams of the Neches River Basin is excellent. Discharge-weighted average concentrations of dissolved solids are generally less than 250 mg/l, and the water is soft. The Angelina River near Lufkin, several miles upstream from Sam Rayburn Reservoir, contains dissolved solids concentrations less than 150 mg/l about 50% of the time, and dissolved solids have equaled or exceeded 500 mg/l less than 1% of the time during the historical period for which data are available.

Table IV-12.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Neches River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Henderson 1/	2,500	–	2,500	–	5,000	5,000	–	9,000	9,000
Jacksonville	1,800	–	1,800	–	4,800	4,800	–	9,400	9,400
Lufkin	21,400	–	21,400	–	44,400	44,400	–	86,800	86,800
Nacogdoches	2,200	–	2,200	–	6,100	6,100	–	10,500	10,500
Palestine 2/	2,800	–	2,800	–	6,700	6,700	–	14,000	14,000
Tyler	4,000	7,400	11,400	–	35,100	35,100	–	86,700	86,700
Other cities	8,900	–	8,900	19,200	–	19,200	28,200	45,000	73,200
Zone 2									
Port Arthur	–	2,800	2,800	–	10,200	10,200	–	24,000	24,000
Beaumont	6,000	16,200	22,200	6,000	47,900	53,900	6,000	99,700	105,700
Groves	–	300	300	–	1,000	1,000	–	2,200	2,200
Port Neches	–	6,500	6,500	–	24,700	24,700	–	57,800	57,800
Silsbee	41,800	–	41,800	67,800	–	67,800	88,200	–	88,200
Other cities	26,600	–	26,600	88,300	74,100	162,400	150,000	197,600	347,600
Total	118,000	33,200	151,200	181,300	260,000	441,300	272,400	642,700	915,100

1/ Henderson's future water supply from Sabine River Basin.
2/ All of Palestine's requirements are included in this basin.

The Neches River near Evadale, in southern Newton County, contains dissolved solids concentrations less than 150 mg/l about 50% of the time, and dissolved solids have equaled or exceeded 200 mg/l only about 1% of the time.

The quality of streams in the basin is degraded locally, however. Bowles and Striker Creeks, within the drainage area of Striker Creek Reservoir, carry saline flows resulting from operations in the East Texas Oil Field. Paper Mill Creek near Lufkin generally contains more than 500 mg/l of dissolved solids, high BOD concentrations, and high coloration due to paper mill wastes. Theuvenins Creek and Pine Island Bayou frequently carry saline flows resulting from oil field brines.

Urbanization and industrial development will probably reduce the potential of the coastal area for irrigated rice production, although there has been some increase in recent years from the approximately 7 thousand acres irrigated in 1964. Despite this competition for land, over 10 thousand acres of irrigated rice and pasture is projected by 1990, and about 15 thousand acres by 2020 in the coastal area, supplied by locally available surface water and ground water.

About 2 thousand acres was irrigated in the upper part of the basin in 1964. Although rainfall in most years adequately supplies crops and pastures, some pastures and special crops will be periodically irrigated in the future. These acreages have been estimated to total as much as 8 thousand acres by 1990, and about 14 thousand acres by 2020.

Approximately 560 thousand acre-feet of ground water is available annually on a safe-yield basis from the Carrizo-Wilcox and Gulf Coast major aquifers, and the Queen City and Sparta minor aquifers in the basin. Other local water-bearing formations can provide limited quantities of water adequate on a perennial yield basis for domestic and livestock supplies, and in some areas for communities and industrial and irrigation supplies. It is estimated that about 296,800 acre-feet of ground water will be used annually in the basin by the year 2020.

There are nine existing major reservoirs in the Neches River Basin: Flat Creek, Lake Tyler, Lake Tyler East, Palestine Englargement (under construction), Striker Creek, Jacksonville, Kurth, Sam Rayburn, and B. A. Steinhagen. Sam Rayburn Dam has facilities for generation of hydroelectric power, and the reservoir provides flood-control storage. If a minimum pool were not maintained at Sam Rayburn for hydropower generation, the yield of the reservoir could be substantially increased. All of these reservoirs except Flat Creek serve water requirements within the basin or in the Neches-Trinity Coastal Basin under existing permits. Flat Creek Reservoir is used for municipal supply by the City of Athens in the adjoining Trinity River Basin.

Proposed for development are Rockland and Ponta Reservoirs and a permanent salt water barrier. These would provide water supply, and Rockland and Ponta Reservoirs would include needed flood-control storage. Early construction of these projects is needed to provide flood control in the basin, to meet in-basin requirements, and to provide water surplus to in-basin needs for

export. Design of proposed reservoirs could be adapted to accomodate navigation facilities, if found feasible through further studies.

Construction of salt water barriers on the Neches River and Pine Island Bayou near the Coast is proposed to limit upstream movement of salt water during extended low-flow periods, and to increase the yield of the basin's water resources by direct diversions of intervening runoff below the last upstream reservoirs. These barriers would allow diversion of future upstream navigation releases in excess of the last lockage requirements at the proposed salt water barrier to provide part of the fresh water inflow to Sabine Lake.

Recreational development at Sam Rayburn Reservoir is becoming increasingly attractive to vistors from coastal metropolitan cities. Construction of Rockland and Ponta Reservoirs would provide additional recreational opportunities. Additionally, sale of surplus water developed by these reservoirs through the Texas Water System would reduce the share of the reimbursable costs which in-basin users would otherwise have to bear.

The surplus of developed supplies in excess of intrabasin requirements, and of interbasin transfers for beneficial use under existing permits would be transferred through facilities of the Coastal Division of the Texas Water System. The supplemental water requirements of the Houston metropolitan area could be exported directly to Houston from Rockland Reservoir across the basin boundary to Bedias Reservoir in the Trinity River Basin, and from Bedias to the San Jacinto River Basin. Alternatively, these surpluses could be conveyed down the Neches River to the salt water barrier, to be diverted south and west into the existing canals owned by the Lower Neches Valley Authority, which could be extended across the Trinity River to Houston. Other existing canal systems might also be used. A third alternative would involve diversion of these supplies directly into the Coastal Canal, and construction of a turnout and conveyance facility to the Houston area. Final selection of the routing would be determined after cooperative studies conducted by the Board and local agencies.

Proposed development of the resources of the basin under the Texas Water Plan would enhance economic development in the basin, greatly increase recreational opportunities, provide needed flood control in the basin, and develop water supplies surplus to projected in-basin needs and presently existing requirements in coastal basin statutory service areas for use in the Texas Water System.

NECHES-TRINITY COASTAL BASIN

The Neches-Trinity Coastal Basin is bounded on the east by Sabine Lake and Sabine Pass to the Gulf of Mexico, on the north by the Neches and Trinity River Basins, and on the west by Trinity and Galveston Bays. Maximum elevation in the basin is about 50 feet, with elevations in most of the basin less than 25 feet. The basin covers about 769 square miles.

Average annual runoff in the basin ranges from a maximum of about 850 acre-feet per square mile in the eastern part to about 550 acre-feet per square mile in the western part of the basin. The basin is flooded frequently by the usually abundant rainfall, and near the Coast areas are subject to flooding by high tides.

The principal drainage system in the Neches-Trinity Coastal Basin consists of Taylors Bayou and its tributaries in the eastern part of the basin, Oyster Bayou in the southeastern part of the basin, and West Fork and East Fork Bayous which enter Trinity Bay. Although very little water-quality data have been collected in the basin, data presently available indicate that runoff is generally low in concentrations of dissolved solids. Most of the principal drainage systems are affected by tides, and Gulf waters move considerable distances inland during high tide. Much of the major drainage system in the eastern part of the basin has been modified for the regulation and distribution of irrigation supplies imported from the Neches and Trinity River Basins, and upstream intrusion of tidal waters in these canals and channels is inhibited by systems of diversion dams.

The most serious potential water-quality problem in the area is Sabine Lake. Preliminary reconnaissance level studies of the water-quality characteristics of this estuary suggest that extensive efforts will be required to control properly the municipal and industrial return flows from the Port Arthur industrial area, as well as those from the Beaumont area (some of which enter Sabine Lake through the Neches River), in order to prevent serious pollution of the estuary and resulting loss of the resource.

The Neches-Trinity Coastal Basin is an important segment of the Texas rice-producing area. About 104 thousand acres was irrigated in the basin in 1964, principally for growing rice. Irrigated acreage has increased somewhat in the basin since 1964 as a result of increased national demand for rice and greater allotments. The Neches and Trinity Rivers supply most of the irrigation water requirements.

Although urbanization and industrial expansion is encroaching on rice-producing areas, irrigated acreage is projected to increase slightly to about 110 thousand acres by 1990, and to approximately 117 thousand acres by 2020.

Ground water supplies in the basin are developed from the Gulf Coast Aquifer. Although ground water is not used as a major source of supply for municipalities in the basin, it is a source of supply for secondary oil recovery operations by the petroleum industry in the western part of the basin.

There are presently no major water supply reservoirs in the basin. Big Hill Reservoir, a shallow impoundment having a capacity of 32 thousand acre-feet, is owned and operated by the Texas Parks and Wildlife Department for wildlife management purposes.

Table IV-13.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Neches-Trinity Coastal Basin

(Acre-Feet Per Year)

COASTAL BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Port Neches 1/	--	6,500	6,500	--	24,700	24,700	--	57,800	57,800
Port Arthur 1/	--	52,500	52,500	--	193,600	193,600	--	455,500	455,500
Nederland	--	2,100	2,100	--	5,500	5,500	--	11,700	11,700
Groves 1/	--	1,100	1,100	--	3,900	3,900	--	8,700	8,700
Beaumont 1/	--	33,300	33,300	--	80,800	80,800	--	158,500	158,500
Other cities	--	11,700	11,700	--	56,200	56,200	--	66,500	66,500
Zone 2									
Other cities	100	5,600	5,700	--	23,600	23,600	--	53,000	53,000
Total	100	112,800	112,900	--	388,300	388,300	--	811,700	811,700

1/ Includes supplies only for that part of the city in this basin; the remaining requirements are included in the Neches River Basin.

No reservoirs are proposed for construction in the basin under the Texas Water Plan. Projected future requirements will be supplied by water from the Neches and Trinity River Basins under existing permits, and by use of locally available ground water. Projected requirements for municipal and industrial supply are expected to increase almost eight times by 2020, and some increase is projected in rice irrigation.

Table IV-14.--Water Supply and Demand—
Neches-Trinity Coastal Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	811.7
Irrigation	495.0
Mining	.2
	1,306.9

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	SUPPLY FOR IN-BASIN REQUIREMENT
Neches Basin	1,176.7
Trinity Basin	130.0
Ground Water	.2
	1,306.9

NOTE: Thousands of Acre-Feet Annually.

TRINITY RIVER BASIN

FIGURE IV - 5

EXISTING AND PROPOSED DEVELOPMENT

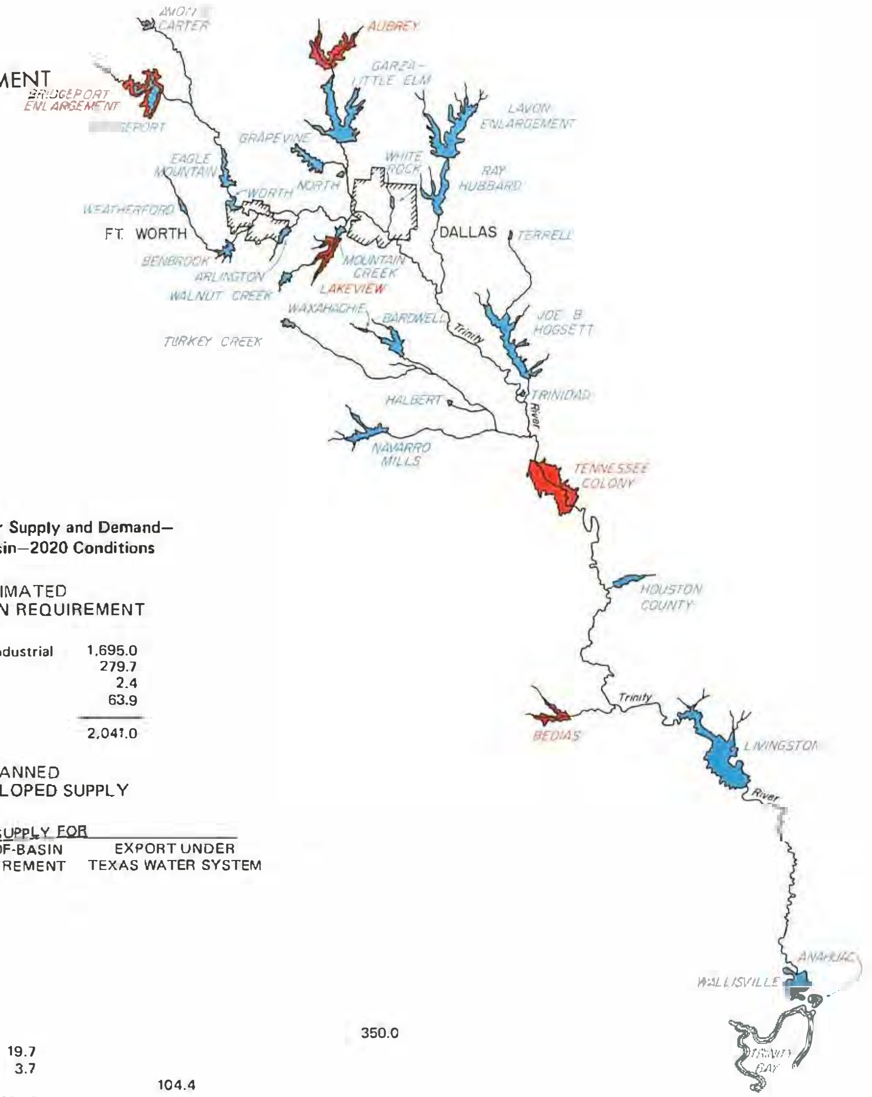


Table IV-15.--Water Supply and Demand—Trinity River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	1,695.0
Irrigation	279.7
Mining	2.4
Navigation	63.9
	2,041.0

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	2020 SUPPLY	SUPPLY FOR: IN-BASIN REQUIREMENT	OUT-OF-BASIN REQUIREMENT	EXPORT UNDER TEXAS WATER SYSTEM	
Ft. Worth System	302.4	302.4			
Dallas System	401.1	401.1			
Other Cities System	43.5	43.5			
Import					
Flat Creek	6.7	6.7			
Moss	6.1	6.1			
Sulphur Basin	97.8	97.8			
Sabine Basin	190.0	190.0			
Trans-Texas Canal	350.0	350.0			350.0
Tennessee Colony	99.7 1/	80.0	19.7		
Little Elkhart	6.9	3.2	3.7		
Bedias	104.4			104.4	
Livingston	1,254.4	183.7	1,070.7		
Wallisville	60.0	60.0			
Return Flow	907.4	132.8	117.4	657.2	
Ground Water	183.7	183.7			
	4,014.1	2,041.0	1,211.5	761.6	350.0

1/ Supply after releases to satisfy permit requirements at Livingston Reservoir

NOTE: Thousands of Acre-Feet Annually.

EXPLANATION

Existing Reservoirs

Proposed and Alternate Reservoirs

The Trinity River Basin is bounded on the north by the Red River Basin, on the east by the Sabine and Neches River Basins and the Neches-Trinity Coastal Basin, and on the west by the Brazos and San Jacinto River Basins and Trinity-San Jacinto Coastal Basins. West Fork Trinity River rises in southeastern Archer County at an elevation of about 1,200 feet, and flows southeasterly to be joined successively by Clear Fork at Fort Worth, Elm Fork at Dallas, and East Fork in Kaufman County. These four streams, together with Denton, Mountain, and Village Creeks, form the upper Trinity River Basin drainage system. The total drainage area of the basin at the mouth of the river is 17,969 square miles.

Average annual runoff ranges from a maximum of about 650 acre-feet per square mile near the mouth of the river to a minimum of about 100 acre-feet per square mile near the headwaters. Runoff decreases more or less uniformly from east to west, and varies widely from year to year.

The Trinity River Basin has widely varying flood characteristics. In the upper basin, floods rise and fall rapidly, and with higher velocities than floods in the lower basin. However, large floods have occurred throughout the basin, causing extensive and costly damage. Major flooding has occurred on the average of once every 4 years in the upper basin, and about once every 5 years in the lower reaches. Floods have occurred on each of the principal streams and many of the minor tributaries in the upper basin, and severe damages have resulted along the main stem in Leon and Houston Counties, and along Chambers and Richland Creeks.

Natural runoff throughout most of the Trinity River Basin is of good quality and is suitable for almost all uses. Throughout most of the upper basin, runoff generally contains between 100 and 250 mg/l of dissolved solids, and water impounded in existing water supply reservoirs generally contains less than 250 mg/l of dissolved solids. The discharge-weighted average concentration of dissolved solids of the Trinity River near Rosser in southeastern Kaufman County is less than 300 mg/l, and the weighted-average concentration of the river near Romayor in northern Liberty County in the lower part of the basin is about 240 mg/l. During the period 1958-1965, dissolved solids in the river near Romayor were less than 300 mg/l about 50% of the time and exceeded 500 mg/l less than 10% of the time. Runoff in the lower part of the basin is generally softer than that from the upper basin.

Table IV-16.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Trinity River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Arlington	2,300	8,900	11,200	—	23,800	23,800	—	44,100	44,100
Athens 1/	300	900	1,200	700	1,400	2,100	1,000	2,500	3,500
Balch Springs	600	—	600	—	2,200	2,200	—	4,600	4,600
Corsicana	—	4,600	4,600	—	8,900	8,900	—	15,400	15,400
Dallas 1/	16,700	146,600	163,300	—	377,300	377,300	—	611,100	611,100
Denton	100	3,700	3,800	800	12,800	13,600	1,500	24,200	25,700
Gainesville 1/	2,300	—	2,300	3,900	1,600	5,500	3,900	6,100	10,000
Garland	300	6,800	7,100	—	24,800	24,800	—	48,400	48,400
Grand Prairie	6,300	700	7,000	—	14,700	14,700	—	23,200	23,200
Ennis	800	200	1,000	900	2,300	3,200	1,000	6,900	7,900
Farmers Branch	—	1,400	1,400	—	12,900	12,900	—	25,300	25,300
Fort Worth	3,000	64,800	67,800	6,500	133,000	139,500	10,000	278,200	288,200
Haltom City	1,900	—	1,900	2,000	2,500	4,500	2,000	4,400	6,400
Highland Park	—	1,400	1,400	—	2,100	2,100	—	2,600	2,600
Hurst	1,200	—	1,200	2,000	5,500	7,500	2,000	12,300	14,300
Irving	2,400	3,200	5,600	—	15,400	15,400	—	23,900	23,900
Lancaster	700	—	700	1,000	2,200	3,200	1,000	6,200	7,200
McKinney	1,600	2,800	4,400	1,000	7,300	8,300	1,000	14,500	15,500
Mesquite	—	2,400	2,400	—	12,400	12,400	—	25,200	25,200
Richardson	1,400	400	1,800	1,000	14,000	15,000	1,000	36,000	37,000
Richland Hills	800	—	800	1,000	400	1,400	1,000	900	1,900
River Oaks	—	1,200	1,200	—	1,700	1,700	—	2,200	2,200
Terrell 1/	—	1,400	1,400	—	4,700	4,700	—	14,200	14,200
University	—	3,200	3,200	—	4,500	4,500	—	5,700	5,700
Waxahachie	—	1,300	1,300	—	4,300	4,300	—	10,600	10,600
Weatherford	—	1,200	1,200	—	3,900	3,900	—	8,300	8,300
White Settlement	900	400	1,300	—	2,200	2,200	—	3,000	3,000
Other cities	43,100	22,200	65,300	18,200	98,100	116,300	18,200	211,200	229,400
Zone 2									
Athens 1/	1,100	2,700	3,800	3,700	2,500	6,200	6,300	4,200	10,500
Crockett	600	—	600	—	1,200	1,200	—	2,000	2,000
Huntsville	1,900	—	1,900	4,800	—	4,800	9,200	—	9,200
Mexia 2/	—	1,600	1,600	1,300	1,600	2,900	4,600	—	4,600
Palestine 3/	—	—	—	—	—	—	—	—	—
Other cities	3,200	600	3,800	6,400	900	7,300	11,300	1,200	12,500
Zone 3									
Liberty	7,100	—	7,100	12,000	—	12,000	12,300	6,900	19,200
Other cities	17,200	—	17,200	36,800	18,600	55,400	36,800	85,400	122,200
Total	110,800	284,600	402,400	104,000	821,700	925,700	124,100	1,570,900	1,695,000

1/ All or part of 2020 requirements to be supplied by water imported from sources out of basin.

2/ Projected 2020 requirements proposed to be supplied from the Trinity River Basin; however, 1960 and 1990 requirements supplied from the Brazos River Basin.

3/ All requirements supplied from the Neches River Basin.

Relatively serious water-quality problems, however, presently affect parts of the Trinity River Basin. Wastes and highly saline flows from oil and gas fields significantly increase the salinity of streamflows in several tributaries, notably the Elm Fork Trinity River above Garza-Little Elm Reservoir, and Chambers, Richland, Tehuacana, and Cottonwood Creeks within the middle part of the basin.

Municipal and industrial return flows and urban runoff from the Dallas-Fort Worth metropolitan area seriously affect the quality of the main stem of the Trinity River for much of its length. Although discharge-weighted average concentrations of dissolved solids in the main stem below Dallas-Fort Worth generally do not exceed about 500 mg/l, during extended periods of low flow the large organic load contributed to the stream creates severe dissolved-oxygen deficits, and anaerobic conditions frequently exist locally. Bacterial populations are generally very high in the main stem in the middle part of the basin. The present heavy nutrient loading on the main stem from municipal and industrial return flows contributes to frequent heavy algae growths. Extensive efforts are underway toward improving waste-water collection and treatment facilities, including nutrient removal, in order to alleviate these problems. Eutrophication of recently completed Livingston Reservoir, and later of Tennessee Colony Reservoir proposed for construction upstream, will be a serious problem unless nutrient loading on the river is substantially reduced and a comprehensive water-quality management program is implemented in the basin.

In order to fully describe future supplemental municipal water requirements in the basin, and to simplify presentation, the existing, authorized, and proposed projects for the cities served in the upper Trinity River Basin have been aggregated into three systems, as shown in Tables IV-17 and IV-18.

Irrigation requirements in the basin will be served by both ground and surface water supplies. The coastal, rice-producing area is the only area of concentrated irrigation development in the basin, with about 23 thousand acres irrigated in 1964. Municipal and industrial expansion is reducing rice and pasture acreage somewhat, but about 26 thousand acres of irrigation is projected by 1990, and more than 28 thousand acres by 2020.

Although only about 4 thousand acres was irrigated in 1964 in the middle part of the basin, additional irrigation development to produce pastures, hay, feed, and fiber crops could be supplied from proposed reservoirs, or from ground water. It is projected that about 47 thousand acres will be irrigated in this area by 1990, and nearly 90 thousand acres by 2020.

Relatively small irrigated acreages growing cotton, grain sorghum, peanuts, some fruits and vegetables, and improved pasture and hay in the upper part of the basin are supplied by locally available surface and ground water supplies. In 1964, about 6 thousand acres of these crops was irrigated, and this is projected to increase to about 29 thousand acres by 1990, and as much as 42 thousand acres by 2020, supplied with locally available water. Most of this projected increase in irrigated acreage is likely to develop south of Dallas County.

Approximately 326 thousand acre-feet of ground water is available as perennial yield from aquifers in the Trinity River Basin, principally from the Trinity Group, Carrizo-Wilcox, and the Gulf Coast major aquifers and the Woodbine, Queen City, and Sparta minor aquifers. Less important water-bearing formations can provide small quantities of water on a perennial basis for domestic and livestock supplies locally, and in some areas for municipal, industrial, and irrigation use. It is projected that about 183,700 acre-feet of ground water will be used annually in the basin by the year 2020.

The Corps of Engineers has completed the *Comprehensive Survey Report on Trinity River and Tributaries, Texas,* **which considered long-range basin requirements, including flood control, and the availability of water resources. This report proposed the following developments: West Fork Floodway, Dallas Floodway Extension, Elm Fork Floodway, Duck Creek Channel, Liberty Levee Project, Lakeview Reservoir, Roanoke Reservoir, Aubrey Reservoir, Tennessee Colony Reservoir, and the Multiple-Purpose Channel (navigation) from Houston to Fort Worth. All of these projects have been authorized for construction by the Congress. The multiple-purpose navigation channel from Houston to Fort Worth was authorized subject to further evaluation. This re-evaluation has been completed, and the Congress has provided funds for advanced Federal participation in construction of one high-level bridge over the Trinity River required to accomodate navigation. Lakeview Reservoir has been funded for design. Additionally, a flood-control study is underway on White Rock Creek in the Dallas area.**

There are 25 major existing or under-construction reservoirs in the Trinity River Basin: Amon G. Carter, Bridgeport, Eagle Mountain, Worth, Weatherford, Benbrook, Arlington, Mountain Creek, Garza-Little Elm, North, Grapevine, White Rock, Lavon Enlargement, Ray Hubbard (Forney), Trinidad, Terrell, Joe B. Hogsett (Cedar Creek), Waxahachie, Bardwell, Halbert, Navarro Mills, Houston County, Livingston, Wallisville, and Anahuac. Authorized for construction are Bridgeport Enlargement, Aubrey, Lakeview, Tennessee Colony, and Roanoke Reservoirs.

Flood-control storage in proposed multipurpose Aubrey Reservoir would permit an exchange of storage in Garza-Little Elm Reservoir, thus increasing the conservation storage in Garza-Little Elm Reservoir. Under the federally authorized comprehensive plan, flood-control storage provided in federally proposed Roanoke Reser-

Table IV-17.--Existing, Under Construction, and Proposed Water Supply Systems to Meet Projected 2020 Municipal and Industrial Water Requirements in the Upper Trinity River Basin

Dallas System Reservoirs and Imports

RESERVOIR	PROJECTED 2020 SUPPLY (1,000 ACRE-FEET ANNUALLY)
Garza-Little Elm	102.4
Grapevine	26.2
North Lake	0.4
White Rock	4.0
Lavon Enlargement	97.1
Ray Hubbard	72.1
Lakeview	34.0
Aubrey	64.9
Total Yield	401.1
Usable Return Flows 1/	55.4
IMPORTS	
Tawakoni (Sabine River Basin)	190.0
Cooper (Sulphur River Basin)	97.8
Total Yield, Return Flow, and Imports	744.3

Fort Worth System Reservoirs

RESERVOIR	PROJECTED 2020 SUPPLY (1,000 ACRE-FEET ANNUALLY)
Benbrook	5.0
Bridgeport Enlargement	73.9
Eagle Mountain	26.9
Lake Worth	1.4
Mountain Creek	0.5
Joe B. Hogsett (Cedar Creek)	194.7
Total Yield	302.4
Usable Return Flows 1/	14.9
Total Yield and Return Flow	317.3

Other Zone 1 City Systems Reservoirs and Imports

RESERVOIR	PROJECTED 2020 SUPPLY (1,000 ACRE-FEET ANNUALLY)
Arlington	6.5
Weatherford	1.8
Terrell	1.6
Navarro Mills	21.1
Waxahachie	2.0
Bardwell	7.3
Amon Carter	0.3
Walnut Creek	1.0
Decatur	0.7
Turkey Creek	0.7
Halbert	0.5
Total Yield	43.5
Usable Return Flows 1/	7.3
IMPORTS	
Moss (Fish Creek) (Red River Basin)	6.1
Flat Creek (Neches River Basin)	2.5
Total Yield, Return Flow, and Imports	59.4

1/ Usable return flows imply those projected 2020 return flows which would be impounded and regulated for beneficial use by the existing and proposed reservoirs indicated.

voir (operated for flood control only) would permit reallocation of flood storage in Grapevine Reservoir to increase its conservation storage.

Existing, under-construction, and authorized reservoirs will all serve in-basin requirements, with Livingston and Wallisville Reservoirs also serving existing and projected industrial (and possibly some municipal) water requirements in adjacent basins.

Supplies available in the upper Trinity River Basin, including existing and authorized interbasin transfers from adajcent basins as shown in Table IV-19, will not be adequate to supply requirements in this area prior to 2020. The Texas Water Plan provides for the importation of additional water through the Texas Water System to meet these projected deficits in the upper basin. Decisions as to routing of these supplies will be made after further cooperative studies with local agencies.

Table IV-18.--Surface Water Storage Projects and Distribution of Supplies to Meet Projected 2020 Municipal and Industrial Requirements in the Upper Trinity River Basin

(Thousands of Acre-Feet Annually)

ZONE	SOURCE	REQUIREMENT	
Zone 1[1/]			
	Fort Worth System	Arlington	37.6
		Waxahachie	8.6
		Weatherford	6.5
		Fort Worth	278.2
		Haltom City	4.4
		Hurst	12.3
		Richland Hills	.9
		River Oaks	2.2
		White Settlement	3.0
	Total Requirement-Fort Worth System		353.7
	Total Supply-Fort Worth System		317.3
	Total Shortage-Fort Worth System		36.4
	Dallas System	Terrell	12.6
		Balch Springs	4.6
		Dallas	611.1
		Denton	24.2
		Garland	48.4
		Grand Prairie	23.2
		Farmers Branch	25.3
		Highland Park	2.6
		Irving	23.9
		Lancaster	6.2
		McKinney	14.5
		Mesquite	25.2
		Richardson	36.0
		University Park	5.7
	Total Requirement-Dallas System		863.5
	Total Supply-Dallas System		744.3
	Total Shortage-Dallas System		119.2
	Other Zone 1 City Systems		
	Arlington	Arlington	6.5
	Flat Creek (Import from Neches River basin)	Athens	2.5
	Halbert	Corsicana	.5
	Navarro Mills	Corsicana	14.9
	Moss (Import from Red River basin)	Gainesville	6.1
	Bardwell	Ennis	6.9
	Waxahachie	Waxahachie	2.0
	Weatherford	Weatherford	1.8
	Terrell	Terrell	1.6
	Navarro Mills	Other cities	6.2
	Bardwell	Other cities	.4
	Amon Carter	Other cities	.3
	Walnut Creek	Other cities	1.0
	Decatur	Other cities	.7
	Turkey Creek	Other cities	.7
	Supply from listed reservoirs		52.1
	Supply from return flows		7.3
	Total supplied from Systems		59.4
	Total requirements—other Zone 1 cities		254.0
	Total Shortage—other Zone 1 cities		194.6

[1/] Total requirements shown for communities proposed to be served by the Fort Worth and Dallas Systems; only those requirements that can be met from the reservoirs listed are shown for the Other Zone 1 City Systems.

Following completion of proposed reservoirs in the basin, there would be surplus water available above in-basin needs for many years in the middle and lower Trinity River Basin, including the needs for navigation and interbasin transfers under existing permits for beneficial use in the Neches-Trinity Coastal Basin, Trinity-San Jacinto Coastal Basin, and San Jacinto River Basin. It is proposed that these surpluses, as available, would be used in the Texas Water System to supply a part of the required fresh water inflow to Trinity and Galveston Bays, or would be diverted to the Coastal Canal for conveyance to points of water need in other basins. Such use of these surpluses through the System would require appropriate equitable agreements between the Board and the owners and operators of the projects involved.

Water from reservoirs in the middle and lower reaches of the basin may require extensive treatment prior to municipal use, however, because of the large volume of present and projected municipal and industrial return flows from the upper basin.

Under the Texas Water Plan, Bedias Reservoir is an element of the Texas Water System to supply water for transfer to the San Jacinto River Basin and the only additional reservoir proposed for the basin beyond those already existing, permitted, or authorized. These projects would essentially fully develop the projected available water resources of the basin. Channel improvements would provide needed flood control, and the reservoir complex would provide greatly expanded recreational opportunities. Barge navigation from Houston to Fort Worth will also be possible. Coordinated operation of reservoirs could assist in providing needed fresh water inflows to Trinity and Galveston Bays.

The total future water requirements of the Dallas-Fort Worth metropolitan area in excess of those which can be met by local supplies and presently available and authorized imports can be provided from the Texas Water System. Remaining future requirements in the basin can be met by supplies developed by existing and authorized projects and from ground water. Interbasin transfers for beneficial use under existing permits will provide substantial contributions to future needs in the Neches-Trinity and Trinity-San Jacinto Coastal Basins, and the San Jacinto River Basin.

Table IV-19.--Existing and Proposed Water Imports to Supply Projected 2020 Municipal and Industrial Water Requirements in the Upper Trinity River Basin

Imports

EXISTING SOURCES OF IMPORT AND PROPOSED 2020 IMPORT SUPPLY	THOUSANDS OF ACRE-FEET ANNUALLY
Sabine River Basin (Tawakoni Reservoir)	190.0
Sulphur River Basin (Cooper Reservoir)	97.8
Red River Basin (Moss Reservoir)	6.1
Neches River Basin (Flat Creek Reservoir)	2.5
Subtotal—Existing	296.4
PROJECTED DEFICIENCES OF SUPPLIES BY 2020	
Fort Worth System shortage	36.4
Dallas System shortage	119.2
Other Zone 1 City Systems shortage	194.6
Subtotal	350.2
Proposed import through Texas Water System to meet total projected 2020 requirements.	350.2

TRINITY-SAN JACINTO COASTAL BASIN

The Trinity-San Jacinto Coastal Basin is bounded on the east by the Trinity River Basin and the Neches-Trinity Coastal Basin, on the west and north by the San Jacinto River Basin and the San Jacinto-Brazos Coastal Basin, and on the south by Trinity and Galveston Bays. Maximum elevation is about 100 feet, with most of the area being less than 50 feet in elevation. Total area of the basin is 247 square miles.

Average annual runoff per square mile is about 600 acre-feet. No measurements of flood flows are available, but because of the usually abundant rainfall and the characteristics of the terrain, a substantial part of the basin has been frequently inundated. Some areas of the basin near Trinity and Galveston Bays are subject to inundation by high tides.

Ground water, an important basin resource, is obtained from the Gulf Coast Aquifer which extends over the entire basin. Approximately 50 thousand acre-feet of ground water is estimated to be available annually in 2020 from the aquifer in the basin.

Highlands Reservoir is the only surface water development in this coastal basin. This 5,580 acre-foot capacity off-channel reservoir is supplied with water from the San Jacinto River. No additional reservoirs are proposed in the basin.

Future requirements in the basin will be met by supplies from the Trinity and San Jacinto River Basins, and by locally available surface and ground water supplies.

Table IV-20.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Trinity-San Jacinto Coastal Basin

(Acre-Feet Per Year)

COASTAL BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Baytown	16,300	26,200	42,500	10,500	70,000	80,500	10,500	127,200	137,700
Other cities	5,500	–	5,500	7,200	–	7,200	14,500	–	14,500
Total	21,800	26,200	48,000	17,700	70,000	87,700	25,000	127,200	152,200

Very little water-quality data have been collected in the Trinity-San Jacinto Coastal Basin. Runoff is generally of good quality, although the lower reaches of streams entering the coastal bays are affected by tides. Periodic sampling of Cedar Bayou, the principal drainage system in the basin, indicates that streamflows in the upper part of the basin probably usually contain less than 1,000 mg/l of dissolved solids; however, below the Mt. Belvieu area the stream becomes highly saline as a result of oil field brines.

Municipal and industrial return flows from the Baytown area, which presently total about 30 thousand acre-feet annually, are discharged into the Galveston Bay System and thus contribute to the organic loading on the bay system.

Irrigation in the basin is not extensive, but is important locally. Urban and industrial expansion in the Houston metropolitan area is rapidly encroaching on acreage suitable for irrigated rice and pasture—a trend likely to continue. Only a slight increase can be expected from the 1964 acreage of nearly 13 thousand, to around 15 thousand acres by 1990 and 16 thousand by 2020. Local supplies of both ground water and surface water will continue to be adequate to supply this amount of irrigation.

Table IV-21.--Water Supply and Demand—Trinity-San Jacinto Coastal Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	152.2
Irrigation	70.0
	222.2

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	SUPPLY FOR IN-BASIN REQUIREMENT
Trinity Basin	112.2
San Jacinto Basin	60.0
Ground Water	50.0
	222.2

NOTE: Thousands of Acre-Feet Annually.

FIGURE IV - 6
EXISTING AND PROPOSED DEVELOPMENT

Table IV-22.-Water Supply and Demand--San Jacinto River Basin--2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	2,437.3
Irrigation	209.1
Mining	.1
	2,646.5

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	2020 SUPPLY	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FOR OUT-OF-BASIN REQUIREMENT	SUPPLY FROM TEXAS WATER SYSTEM
Conroe	96.8			
Lake Creek	55.0			
Cleveland	96.0			
Lower East Fork	123.0			
Lake Houston	67.1			
Brazos Basin	224.3			
Trinity Basin	969.3			
Bedias Reservoir	104.4			104.4
Neches Basin	774.3			774.3
Return Flow	67.4			
Ground Water	492.4			
	3,070.0	2,646.5	423.5	878.7

NOTE: Thousands of Acre-Feet Annually.

EXPLANATION

Existing Reservoirs

Proposed and Alternate Reservoirs

Reservoirs for Flood Control Only

The San Jacinto River Basin is bounded on the north and east by the Trinity River Basin and Trinity-San Jacinto Coastal Basin, on the west by the Brazos River Basin, and on the south by the San Jacinto-Brazos Coastal Basin. Maximum width of the basin is about 65 miles. There are two principal drainage systems in the basin, the San Jacinto River system and Buffalo Bayou. The drainage area of the San Jacinto River above the confluence of the East and West Forks is 2,800 square miles, of which about 1,750 square miles is in the West Fork drainage area and 1,050 is in the East Fork drainage area. The drainage area of Buffalo Bayou, which enters the river from the west, is 1,034 square miles.

Average annual runoff in the basin ranges from a maximum of about 600 acre-feet per square mile in the eastern part of the basin to a minimum of about 350 acre-feet in the western part, decreasing uniformly from east to west.

Streams in the basin are characterized by small main channels, wide timbered flood plains, and flat slopes. These characteristics, plus the usually abundant rainfall, produce frequent floods with low velocities and low peak rates of discharge. In the San Jacinto River system drainage area, minor flooding has occurred on the average of twice a year, and major flooding has occurred at least once every 4 years. In the Buffalo Bayou system, minor flooding has occurred on the average of nearly three times a year, and major flooding about once every 4 years. Flood damages along the San Jacinto River and its tributaries are relatively minor, with the exception of the Cleveland area. By contrast, the flood problem is very serious in the Houston metropolitan area along Buffalo Bayou and its tributaries.

The Corps of Engineers has made several studies of flood-control measures for the San Jacinto River Basin and has initiated construction of projects on several streams. Studies are underway on Cypress Creek and Buffalo Bayou, and channel improvement projects are presently under construction on Vince, Little Vince, Brays, Buffalo, and White Oak Bayous.

Surface water resources of the San Jacinto River Basin are for the most part of excellent chemical quality. Discharge-weighted average concentrations of dissolved solids in streamflows outside of the Houston metropolitan area generally do not exceed 250 mg/l, and throughout much of the basin (exclusive of the Houston area) do not exceed about 100 mg/l. Lake Houston usually contains less than 150 mg/l of dissolved solids, although Cypress Creek and Buffalo Bayou, above the Houston area, have been periodically affected by pollution from oil fields.

Decay of natural vegetation in the densely forested northeastern part of the basin imposes an oxygen demand on several streams in this area, however, and creates dissolved-oxygen depressions locally during summer months. Lake Houston, which furnishes municipal water supplies for the City of Houston, is usually rather highly colored during spring and early summer as a result of decaying vegetation in upstream areas.

Municipal and industrial return flows and urban runoff contribute relatively large organic loads to most of the streams and bayous within the Houston metropolitan area. These streams and bayous also carry high bacterial populations, high nutrient concentrations, and locally, comparatively high mineral concentrations. The Houston Ship Channel, an extension of Buffalo Bayou, is severely polluted and essentially devoid of dissolved oxygen throughout much of its length most of the time. Intensive study of the optimum solution of this problem is underway by the Texas Water Quality Board. Quality criteria for various segments of the Channel have been formulated and existing waste discharge permits amended to conform to a management program promulgated by the Water Quality Board. A comprehensive study of the overall effects of present and future municipal, industrial, and agricultural return flows and urban runoff from the Houston metropolitan and industrial area on the Galveston Bay System is presently underway by the Texas Water Quality Board in cooperation with Federal and other State and local agencies.

About 48 thousand acres in the basin was irrigated in 1964, served principally by ground water. Irrigable lands are rapidly being converted to subdivisions, homesites, and industrial installations in the Houston metropolitan area. Nevertheless, continued use of ground water for irrigation is anticipated for rice, improved pastures, truck crops, and nurseries. Irrigated acreage is estimated to be about 51 thousand by 1990 and about 54 thousand by 2020, with most of the acreage used for rice growing and pastures.

The Gulf Coast Aquifer underlies the entire San Jacinto River Basin. Approximately 500 thousand acre-feet of ground water annually is estimated to be available as a perennial yield from the aquifer in the basin, and it is estimated that most of this annually available ground water will be in use by the year 2020.

Land subsidence has occurred in the Houston area, partly as the result of extensive withdrawals of ground water and the resultant compaction of geologic material comprising the Gulf Coast Aquifer. By altering the pattern of pumping from the interconnected formations of the aquifer to avoid concentrating ground water withdrawals in the southern part of the basin, it may be possible to reduce land subsidence and associated damages. The problems of land surface subsidence and saline water intrusion resulting partly from concentrated pumping for municipal and industrial uses are discussed in more detail in Part II.

Lake Houston is the only major existing water supply reservoir in the basin. Sheldon Reservoir, with a capacity of 5,400 acre-feet, is owned by the Texas Parks and Wildlife Department and is used for recreation, game preservation, and fish hatchery. Addicks and Barker Reservoirs are single-purpose, flood-control reservoirs without permanent water storage pools. Conroe Reservoir is under construction. Humble Reservoir, formerly proposed for construction under the Preliminary Texas Water Plan, has been eliminated from the Plan because of the high costs of land acquisition. Construction of Cleveland, Lower East Fork, and Lake Creek Reservoirs is proposed.

Table IV-23.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, San Jacinto River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Cleveland	8,100	-	8,100	10,400	-	10,400	13,200	-	13,200
Conroe	3,600	-	3,600	9,300	-	9,300	15,200	-	15,200
Other cities	24,200	-	24,200	43,100	-	43,100	92,900	-	92,900
Zone 2									
Belaire	4,400	-	4,400	2,200	3,800	6,000	-	6,900	6,900
Galena Park	3,500	-	3,500	1,700	5,000	6,700	-	9,200	9,200
Houston (95%)	215,900	33,600	249,500	108,000	879,200	987,200	37,000	2,022,500	2,059,500
Jacinto City	1,400	-	1,400	700	2,500	3,200	-	4,900	4,900
Pasadena	70,400	-	70,400	35,200	50,100	85,300	-	103,000	103,000
South Houston	1,100	-	1,100	600	1,700	2,300	-	3,800	3,800
West University Place	2,200	-	2,200	1,100	1,900	3,000	-	3,800	3,800
Other cities	57,200	-	57,200	81,500	-	81,500	124,900	-	124,900
Total	392,000	33,600	425,600	293,800	944,200	1,238,000	283,200	2,154,100	2,437,300

Water to meet future requirements will be supplied by in-basin ground and surface water supplies, interbasin transfers from the Trinity and Brazos River Basins under existing permits, and through the Texas Water System.

Sources of interbasin supplies into the basin, in addition to water delivered through the Texas Water System from Bedias Reservoir and either directly from the Neches River Basin or via the Coastal Canal, will include Livingston and Wallisville Reservoirs in the Trinity River Basin, and proposed additional diversions from the lower Brazos River Basin.

The same combination of water supplies will probably also serve in-basin requirements of that part of the Houston metropolitan area in the San Jacinto-Brazos Coastal Basin and requirements in the Trinity-San Jacinto Coastal Basin under existing permits. The two systems shown in Table IV-24 divide the projected 2020 municipal and industrial water requirements—to be served by the combined surface water supplies of the San Jacinto River Basin and proposed importations—into the San Jacinto (Houston) System and the San Jacinto-Brazos (Houston) System. Also included are the projected 2020 diversions to the Trinity-San Jacinto Coastal Basin.

Table IV-24.--Projected Municipal and Industrial Surface Water Requirements and Distribution of Surface Water Supplies to the San Jacinto and San Jacinto-Brazos Systems of the Houston Metropolitan Area

(Including Proposed Diversions to Trinity-San Jacinto Coastal Basin)

(Thousands of Acre-Feet Annually)

San Jacinto (Houston) System

CITY	2020 REQUIREMENTS
Bellaire	6.9
Galena Park	9.2
Houston (95%)	2,022.5 1/
Jacinto City	4.9
Pasadena	103.0
South Houston	3.8
West University Place	3.8
Total requirements, San Jacinto (Houston) System	2,154.1

San Jacinto-Brazos (Houston) System (out-of-basin requirements)

CITY	2020 REQUIREMENTS
Alvin	31.1
Galveston	27.4
Hitchcock	6.4
Houston (5%)	103.4 1/
LaMarque	13.5
Texas City	88.1
Other Cities	93.6
Total Requirements, San Jacinto-Brazos (Houston) System	363.5
Diversion to Trinity-San Jacinto Coastal Basin	60.0
Total Requirements, Including Proposed Diversions to the Trinity-San Jacinto Coastal Basin	2,577.6

1/ The projected 2020 water requirements for the City of Houston are 95% in the San Jacinto Basin and 5% in the San Jacinto-Brazos Coastal Basin.

SAN JACINTO-BRAZOS COASTAL BASIN

The San Jacinto-Brazos Coastal Basin, with a drainage area of 1,440 square miles, is bounded on the north by the San Jacinto River Basin, on the east by Galveston Bay and the Trinity-San Jacinto Coastal Basin, and on the west by the Brazos River Basin. Maximum elevation in the basin is about 100 feet, with most of the area at an elevation less than 50 feet. Small streams draining from the basin into Galveston Bay and the Gulf of Mexico include Clear Creek, Oyster Creek, and Dickinson, Mustang, Chocolate, and Bastrop Bayous.

Average annual runoff ranges from about 500 acre-feet per square mile in the eastern part of the basin to about 400 acre-feet per square mile in the west. Part of the basin is subject to flooding by overflows from the Brazos River. Low areas near the Coast adjoining Galveston Bay are inundated by high tides. Principal flood problems result from poor drainage of storm waters.

Stream quality varies widely throughout the basin, principally as the result of urban expansion, suburban development, irrigation, industrial complexes, and oil and gas development. The principal drainage systems are tide affected in their lower reaches, and most are affected by municipal, industrial, and irrigation return flows.

Clear Lake, essentially an estuary of Clear Creek and Galveston Bay, varies widely in salinity from more than 12,000 to less than 400 mg/l. Clear Lake has in the past experienced a serious pollution problem—in terms of dissolved-oxygen deficits and high bacterial populations—from inadequately treated wastes, but much of this problem is being abated. Data collected periodically from Clear Creek indicate that dissolved solids concentrations above the tide affected reach average less than 500 mg/l. Frequent serious dissolved-oxygen deficits exist locally, however, particularly upstream from the Friendswood area. Cowart Bayou, a tributary of Clear Creek, frequently is highly saline.

Dickinson Bayou is tide affected for much of its length, but runoff within the upper part of its drainage area is comparatively low in dissolved solids. However, frequent dissolved-oxygen deficits and high bacterial populations occur in the Bayou.

Mustang Bayou and Halls Bayou drain extensive oil fields and rice irrigation areas, and the quality of streamflow varies widely. Mustang Bayou carries a large organic load and a high bacterial population.

Chocolate Bayou is tide affected for much of its length, but runoff is comparatively low in dissolved solids, the weighted average probably being less than 500 mg/l.

Irrigation of rice acreage and pasture in the basin is projected to increase slightly above present levels by the year 2020. About 70 thousand acres of land was irrigated in the basin in 1964, using surface water diverted from the Brazos River in addition to locally available surface and ground water supplies. Irrigated acreage is estimated to increase to about 76 thousand acres by 1990, and 82 thousand acres by 2020, mostly for rice and pasture production.

The Gulf Coast Aquifer underlies the entire San Jacinto-Brazos Coastal Basin. Approximately 80 thousand acre-feet of ground water is available on a perennial basis from the aquifer in the basin, and it is projected that about 80 thousand acre-feet of ground

Table IV-25.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, San Jacinto-Brazos Coastal Basin

(Acre-Feet Per Year)

COASTAL BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Alvin	1,800	–	1,800	5,000	10,900	15,900	5,000	31,100	36,100
Angleton	700	–	700	2,000	900	2,900	2,000	6,400	8,400
Freeport (75%)	9,000	38,200	47,200	–	126,900	126,900	–	216,200	216,200
Galveston	12,200	–	12,200	–	19,000	19,000	–	27,400	27,400
Hitchcock	400	–	400	–	2,700	2,700	–	6,400	6,400
Houston (5%)	11,000	2,100	13,100	5,000	47,000	52,000	5,000	103,400	108,400
Lake Jackson	1,100	–	1,100	–	2,400	2,400	–	4,500	4,500
La Marque	1,500	–	1,500	–	5,700	5,700	–	13,500	13,500
Texas City	16,500	19,700	36,200	–	58,400	58,400	–	88,100	88,100
Other cities	26,700	–	26,700	30,800	31,100	61,900	30,800	139,400	170,200
Total Municipal and Industrial	80,900	60,000	140,900	42,800	305,000	347,800	42,800	636,400	679,200

water will be used annually by the year 2020. However, ground water pumped from the aquifer in the southern part of the basin has become more saline as a result of saline water encroachment.

There are no major reservoirs with conservation storage on streams in the basin. The basin has numerous natural watercourses and canals, however, which serve as sources of water supply and for conveying water from the Brazos River to irrigated areas and to the fast growing industrial areas. In the eastern part of the basin, an existing 12,500 acre-foot capacity off-channel reservoir receives water diverted from the Brazos River through the Briscoe Canal. These supplies serve municipal, industrial, and irrigation uses.

No on-channel surface reservoirs are proposed in the basin under the Texas Water Plan. Off-channel reservoirs can be developed if needed for re-regulation and distribution purposes.

Table IV-26.--2020 Surface Water Requirements, Brazos System of the San Jacinto-Brazos Coastal Basin

USE	ANNUAL 2020 REQUIREMENT (ACRE-FEET)
Angleton	6,400
Freeport (75%)	216,200
Lake Jackson	4,500
Irrigation (all in-basin)	332,700
Industrial	45,800
Total	605,600

The projected annual surface water requirement of the San Jacinto-Brazos Coastal Basin by the year 2020 (*not* including the 363,500 acre-feet required by that part of the Houston metropolitan complex in this basin supplied by the San Jacinto River Basin) is 605,600 acre-feet. Supply for this requirement is to be met by diversion from the lower Brazos River as shown on Table IV-26. (Some diversion is presently being made under existing permits.)

Table IV-27.--Water Supply and Demand—San Jacinto-Brazos Coastal Basin—2020 Conditions

ESTIMATED 2020 IN-BASIN REQUIREMENT

Municipal & Industrial	679.2
Irrigation	369.6
Mining	.2
	1,049.0

PLANNED 2020 DEVELOPED SUPPLY

SOURCE	SUPPLY FOR IN-BASIN REQUIREMENT
San Jacinto Basin	363.5
Brazos Basin	605.6
Ground Water	79.9
	1,049.0

NOTE: Thousands of Acre-Feet Annually.

BRAZOS RIVER BASIN

FIGURE IV - 7

EXISTING AND PROPOSED DEVELOPMENT

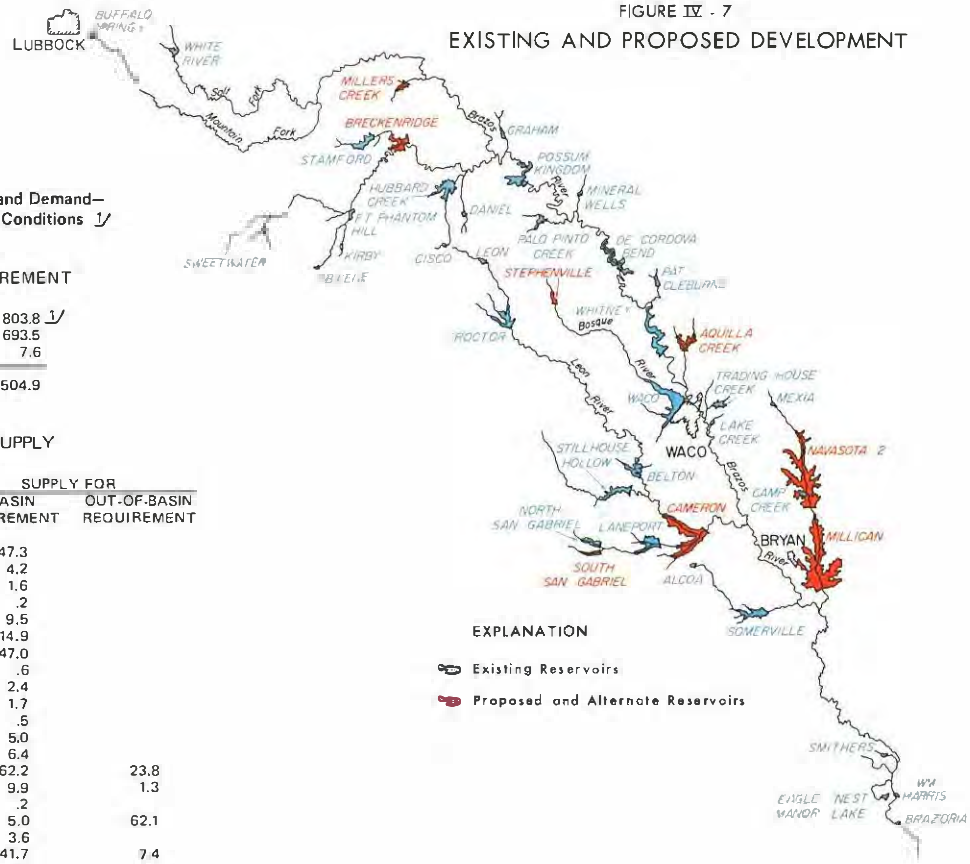


Table IV-28.--Water Supply and Demand—Brazos River Basin—2020 Conditions 1/

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	803.8 1/
Irrigation	693.5
Mining	7.6
	1,504.9

PLANNED
2020 DEVELOPED SUPPLY

SOURCE*	2020 SUPPLY	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FOR OUT-OF-BASIN REQUIREMENT
Canadian Basin.	47.3	47.3	
White River	4.2	4.2	
Abilene	1.6	1.6	
Kirby	.2	.2	
Ft. Phantom Hill	9.5	9.5	
Hubbard Creek	14.9	14.9	
Breckenridge	54.9	47.0	
Stamford	.6	.6	
Oak Creek	2.4	2.4	
Sweetwater	1.7	1.7	
Cisco	.5	.5	
Millers Creek	5.0	5.0	
Graham	6.4	6.4	
Possum Kingdom	86.0	62.2	23.8
Palo Pinto	11.2	9.9	1.3
Mineral Wells	.2	.2	
De Cordova Bend	67.1	5.0	62.1
Pat Cleburne	3.6	3.6	
Whitney	49.1	41.7	7.4
Aquilla Creek	15.2	5.8	9.4
Stephenville	6.0	5.3	.7
Waco	57.3	57.3	
Leon	3.1	3.1	
Procter	14.6	10.0	4.6
Belton	103.7	70.6	33.1
Stillhouse Hollow	62.0	1.7	60.3
North San Gabriel	11.5	10.0	1.5
Laneport	10.8	4.4	6.4
Cameron	95.4	6.8	88.6
Camp Creek	2.6	2.6	
Somerville	35.6	7.9	27.7
Millican	128.6	17.3	111.3
Navasota 2	231.6	0.0	231.6
Diversion Structure	85.0	85.0	
Ground Water	749.9	749.9	
Return Flow	365.9	203.3	160.1
	2,345.2	1,504.9	829.9

* Additional reservoir for possible development inludes South San Gabriel.

1/ Does not include municipal and industrial deficiencies in High Plains and North Central Texas portion of the Brazos River Basin which will be supplied through the Trans-Texas Canal.

NOTE: Thousands of Acre-Feet Annually.

The Brazos River Basin is bounded on the north by the Red River Basin, on the east by the Trinity and San Jacinto River Basins and the San Jacinto-Brazos Coastal Basin, and on the south and west by the Colorado River Basin and the Brazos-Colorado Coastal Basin. A small part of the basin lies within New Mexico. Elevation ranges from about 4,700 feet in Running Water Draw near Plainview on the High Plains to sea level at the mouth of the Brazos River. The basin has a total drainage area of 44,640 square miles, of which 42,840 square miles is in Texas.

The Brazos River Basin varies in width from about 70 miles in the High Plains to 110 miles in the vicinity of Waco, decreasing gradually in width to approximately 10 miles near Richmond.

Average annual runoff ranges from about 400 acre-feet per square mile near the mouth of the river to a minimum of less than 50 acre-feet per square mile near the escarpment of the High Plains. Most of the area of the basin in the High Plains is non-contributing. Runoff decreases more or less uniformly from east to west. Wide physiographic variations in the basin affect floodflow characteristics, although many large floods in the basin have occurred all the way from Running Water Draw to the mouth of the river near Freeport.

Construction is under way on a major flood-control system for the basin, but serious flood problems will continue to occur in the lower part of the basin until this system is completed.

Sources of saline water, principally of natural origin, in the upper Brazos River Basin seriously degrade the chemical quality of the main stem of the river throughout its entire length. Flows of the Salt Fork, parts of the Double Mountain Fork, and the main stem of the river above Possum Kingdom Reservoir are too

saline for most beneficial uses. Concentrations of dissolved solids in the Salt Fork Brazos River near Aspermont have equaled or exceeded about 34 thousand mg/l 50% of the time, and have exceeded 50 thousand mg/l about 10% of the time during the period of available record. The Double Mountain Fork, near its confluence with the Salt Fork to form the main stem of the Brazos River, has contained about 3,700 mg/l of dissolved solids 50% of the time, and dissolved solids frequently exceed 6,000 mg/l. Downstream, since closure of Possum Kingdom Reservoir in 1941 the weighted-average monthly concentrations of dissolved solids in water released and spilled from the reservoir have exceeded 1,000 mg/l more than 90% of the time, have exceeded 1,300 mg/l 50% of the time, and have reached more than 3,500 mg/l during drought periods. Similarly, chloride concentrations generally range from more than 300 to over 800 mg/l, and have equaled or exceeded 500 mg/l about 50% of the time during this period.

Table IV-29.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Brazos River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Levelland	3,300	–	3,300	3,000	2,800	5,800	5,100	2,900	8,000
Littlefield	5,700	–	5,700	9,200	–	9,200	11,900	–	11,900
Lubbock	23,000	–	23,000	15,000	37,300	52,300	57,700	118,200	175,900
Plainview	3,400	–	3,400	7,900	3,700	11,600	13,800	3,800	17,600
Slaton	800	–	800	1,000	1,600	2,600	3,000	1,600	4,600
Other cities	17,200	–	17,200	21,700	4,300	26,000	29,900	4,400	34,300
Zone 2									
Abilene	–	17,600	17,600	–	34,000	34,000	–	75,100	75,100
Breckenridge	–	1,000	1,000	–	2,100	2,100	–	3,000	3,000
Stamford	–	1,200	1,200	–	1,700	1,700	–	2,500	2,500
Sweetwater	–	2,600	2,600	–	7,900	7,900	–	30,300	30,300
Other cities	5,900	5,900	11,800	8,500	8,500	17,000	12,300	12,500	24,800
Zone 3									
Bellmead	400	–	400	–	3,500	3,500	–	11,800	11,800
Cleburne	2,400	–	2,400	–	5,900	5,900	–	12,800	12,800
Graham	–	2,900	2,900	–	5,300	5,300	–	8,500	8,500
Hillsboro	1,200	–	1,200	–	2,400	2,400	–	5,300	5,300
Mineral Wells	–	2,100	2,100	–	5,100	5,100	–	10,100	10,100
Stephenville	1,200	–	1,200	2,000	1,400	3,400	2,000	4,800	6,800
Waco	600	21,400	22,000	–	61,700	61,700	–	130,600	130,600
Other cities	11,100	3,800	14,900	6,000	17,200	23,200	6,000	29,000	35,000
Zone 4									
Belton	1,700	–	1,700	–	3,500	3,500	–	5,900	5,900
Cameron	–	700	700	–	1,400	1,400	–	2,200	2,200
Georgetown	2,500	–	2,500	–	2,600	2,600	–	5,000	5,000
Killeen	–	3,500	3,500	–	7,400	7,400	–	12,300	12,300
Lampasas	–	1,000	1,000	–	2,000	2,000	–	3,400	3,400
Taylor	1,200	–	1,200	–	2,400	2,400	–	4,400	4,400
Temple	–	4,800	4,800	–	12,300	12,300	–	22,400	22,400
Other cities	5,000	7,400	12,400	6,500	14,800	21,300	8,000	19,400	27,400
Zone 5									
Brenham	1,000	–	1,000	2,000	–	2,000	3,600	–	3,600
Bryan	5,200	–	5,200	13,500	–	13,500	20,000	11,900	31,900
College Station	2,200	–	2,200	5,000	1,300	6,300	5,000	7,500	12,500
Hearne	900	–	900	2,000	–	2,000	3,000	–	3,000
Marlin	–	1,000	1,000	–	2,100	2,100	–	3,500	3,500
Mexia 1/	–	–	–	–	–	–	–	–	–
Other cities	5,000	1,400	6,400	8,200	2,200	10,400	11,400	3,300	14,700
Zone 6									
Freeport (25%)	3,400	12,300	15,700	–	42,300	42,300	–	72,100	72,100
Rosenberg	9,800	–	9,800	16,700	–	16,700	25,000	–	25,000
Other cities	19,200	–	19,200	30,400	–	30,400	52,100	13,500	65,600
Total	133,300	90,600	223,900	158,600	300,700	459,300	269,800	654,000	923,800

1/ All of Mexia's requirements are included in the Trinity River Basin; however, present and proposed 1990 surface water supply is from the Brazos River Basin, and 1990 and 2020 ground water supplies would be from the Trinity River Basin.

Regulation of streamflow by Possum Kingdom and Whitney Reservoirs on the main stem, and contributions of good quality water from most downstream tributaries such as the Paluxy River, Little River, Navasota River, and San Gabriel River decrease extreme variations in mineral concentrations and thus provide water of a more uniform quality in the lower Brazos River Basin. However, during periods of extended drought, dissolved solids concentrations in the river near Richmond have ranged upward to 1,400 mg/l, and have equaled or exceeded 500 mg/l about 45% of the time. Chloride and sulfate concentrations and the excessive hardness of flows of the main stem have severely limited full potential development of the surface water resources of the basin.

The principal sources of natural salt (NaCl) contributed to the basin originate in natural springs and seepage areas in the drainage area of the Salt Fork Brazos River, although surface runoff also contributes large quantities of calcium and sulfate by the solution of gypsum-bearing formations and soils which are widespread in the upper Brazos River Basin. Salt Croton Creek, a small tributary of the Salt Fork Brazos River in Stonewall County, contributes more than 25% of the dissolved solids load and 40% of the total chloride load which enters Possum Kingdom Reservoir. Additional principal natural salt-contributing tributaries include nearby Croton and North Croton Creeks, Salt Creek in southern Kent County, and McDonald Creek in northern Garza County.

Oil field wastes have seriously degraded the chemical quality of many streams in the basin, principally within the drainage areas of the Clear Fork Brazos River and the Navasota River. Serious pollution problems occur within the drainage area of Hubbard Creek Reservoir. Extensive efforts are underway to abate man-made pollution in the basin.

Abatement of man-made pollution and measures to alleviate natural salinity in the basin are essential elements of the Texas Water Plan. Planning studies have indicated that the Brazos River Basin has potential natural resources and economic incentives for significant economic growth provided water supplies of suitable quality for a wide variety of uses are available. In addition to allocating supplies in the basin to meet this future projected growth, additional diversion to service areas in adjacent coastal basins is proposed by the Plan. In the future, during periods when flow of the river in the lower basin may consist largely of releases from upstream reservoirs on the main stem, it will be essential that the chemical quality of releases from these reservoirs be significantly improved over present quality.

The Board is presently actively participating with the Corps of Engineers, Federal Water Pollution Control Administration, Brazos River Authority, and other State and Federal agencies in comprehensive studies of the sources and magnitude of natural and man-made salt loads in the Brazos River Basin and of the feasibility of salt-control projects. Design criteria for salt-control structures on Croton and Salt Croton Creeks and economic studies of associated benefits from stream-quality improvements are in advanced stages. The feasibility of controlling other natural salt-emission areas in the upper basin is also being evaluated. Preliminary studies indicate that removal of the natural salt loads presently contributed by Croton and Salt Croton Creeks, together with abatement of man-made pollution, would reduce chloride and dissolved solids concentrations in Possum Kingdom Reservoir to levels that would allow the water in the reservoir and downstream releases to be used for a wider variety of beneficial uses. Main stem flows in the lower basin would be of suitable quality for municipal, irrigation, and most industrial uses virtually all of the time.

Currently, no serious organic pollution problems exist in any of the principal streams of the Brazos River Basin. Periodic dissolved-oxygen deficits exist locally in streams below municipal and industrial waste-water outfalls, and the main stem frequently contains relatively high phosphate concentrations, presumably contributed largely by runoff from agricultural lands. Present levels of nutrients in municipal return flows from the Bryan-College Station area entering the lower Navasota River may create eutrophic conditions in authorized Millican Reservoir if continued.

Irrigation development has been extensive in the Brazos River Basin in the High Plains, in North Central Texas, along the Brazos River below Waco, and in areas near the Coast. Under the Plan, irrigation developments in the basin will be supplied by a combination of ground water, in-basin surface water supplies, and water transported through the Texas Water System to irrigation projects in the North Central Texas and the High Plains areas of the basin. Ground water in the Ogallala Formation constitutes essentially the total locally available irrigation water supply for the intensively developed High Plains irrigation area in the basin. As these supplies are depleted, an imported water supply through the Texas Water System will be needed to maintain the existing irrigation economy.

About 136 thousand acres was irrigated in 1964 in North Central Texas (east of the High Plains escarpment) in the basin, supplied largely by shallow ground water. Ground water in the area is being depleted, however, and imported water through the Texas Water System will be needed. Part of the water planned for importation to the North Central Texas area for irrigating about 95 thousand acres would be used in this basin in areas suitable for project-type development.

Below Waco, about 95 thousand acres of land was irrigated in 1964, principally for cotton production. The Brazos River supplied about one-fourth of this acreage, with ground water supplying the remainder. It is projected that ground water and locally available surface water can supply increased irrigation acreage in this area in the future, projected to be about 113 thousand acres by 1990. An expected slight decrease in available ground water supplies by 2020, however, decreases the total estimate for 2020 to about 108 thousand acres.

This basin has a narrow coastal area, which in 1964 contained about 25 thousand acres of irrigation. More than half of this acreage was supplied by ground water. Although municipal and industrial growth in this area will expand, irrigated acreage—adapted to a large variety of crops including rice, cotton, corn, and other feed crops—is also expected to expand to about 52 thousand acres by 1990 and 80 thousand acres by 2020. The more friable, sandy, delta soils will be used for most crops, while rice will be grown on the heavier coastal prairie soils.

Ground water is an extremely significant resource in the basin, both locally to meet municipal and industrial needs and regionally as a supply for irrigation. Approximately 425 thousand acre-feet of ground water is available as a perennial yield from aquifers in the Brazos River Basin. Major aquifers in the basin are the Ogallala, Alluvium (Seymour Formation), Trinity Group, Edwards (Balcones Fault Zone), Brazos River Alluvium, Carrizo-Wilcox, and Gulf Coast Aquifers. Minor aquifers in the basin for which estimates of available water have been made are the Santa Rosa and Sparta Aquifers. Less important water-bearing formations can provide limited quantities of water adequate on a perennial yield basis for domestic and livestock supplies, and in some areas for municipal, industrial, and irrigation supplies.

There are 34 major existing and under-construction reservoirs in the Brazos River Basin, and eight additional reservoirs are authorized or proposed for development under the Texas Water Plan. These eight reservoirs include: Millers Creek, Breckenridge, Stephenville, Aquilla Creek, Cameron, Navasota 2, Millican, and South San Gabriel Reservoirs. Flood control will be provided by Aquilla Creek, Navasota 2, Millican, and South San Gabriel Reservoirs which, together with planned channel improvements and other works and existing facilities, would mitigate the flood problems in the basin.

There are alternative sites available for development of some of the reservoirs proposed for construction as illustrated on Plate 3. Selection between these alternatives will be determined by further studies and plans of local interests.

The Corps of Engineers was authorized in 1954 to undertake a comprehensive study of the Brazos River Basin. This comprehensive study will incorporate previously authorized Federal studies in the basin. Primary objectives of the comprehensive study are to: (1) develop a basinwide solution to the problems of flood control; (2) evaluate basin water requirements and resources for the purpose of meeting needs through a basinwide plan; (3) determine the feasibility of navigation in the lower basin, and if found feasible incorporate into basin plans for development; and (4) evaluate hydroelectric power potential in the basin. Proposed reservoir development under the Texas Water Plan is compatible with these objectives.

Additional water supplies to serve potential municipal and industrial needs in the Abilene and Sweetwater areas could be conveyed through the Trans-Texas Canal of the Texas Water System to "Megargel Junction" southwest of Wichita Falls, thence by pipeline to these cities. Additional municipal and industrial supply for the City of Lubbock could be transported through the Trans-Texas Canal and delivered from the main canal between Caprock and Bull Lake Reservoirs.

The San Jacinto River Basin and the San Jacinto-Brazos Coastal Basin will continue to be supplied in part from the Brazos River Basin under existing permits.

Proposed surface water development in the Brazos River Basin, together with ground water, existing and permitted imports into the basin from the Canadian and Colorado River Basins, and proposed supplies from the Texas Water System will meet all future municipal and industrial water requirements in the basin to the year 2020, and will maintain a viable irrigated agriculture. Flood-control measures developed by the Corps of Engineers comprehensive system will mitigate flood damages, and continuing studies of mineral pollution in the upper basin will be directed toward alleviating this problem.

BRAZOS-COLORADO COASTAL BASIN

The Brazos-Colorado Coastal Basin, with a total drainage area of 1,850 square miles, is bounded on the east by the Brazos River Basin, on the west by the Colorado River Basin, and on the south by the Gulf of Mexico. Average annual runoff is about 400 acre-feet per square mile. The eastern part of the lower basin is subject to overflows from the Brazos River and the western part to overflows from the Colorado River. Near the Coast the basin is occasionally inundated by high tides.

acreage will not exceed about 53 thousand acres in the basin and irrigated acreage will be about 55 thousand acres by the year 2020—small increases over the present acreage.

No major reservoirs are proposed in the basin. Future water requirements not met from ground water and by direct diversion of flood flows from tributaries would be served from the Colorado River. Ground water obtained from the Gulf Coast Aquifer is projected to supply about 125 thousand acre-feet of water annually by 2020, about half for municipal and industrial use and half for irrigation. Diversion of about 254,400 acre-feet of water annually from the Colorado River Basin will be required to meet 2020 in-basin requirements not supplied with ground water or by in-basin surface water supplies.

Table IV-30.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Brazos-Colorado Coastal Basin

(Acre-Feet Per Year)

COASTAL BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Bay City 1/	3,900	-	3,900	3,900	13,100	17,000	-	35,600	35,600
Wharton 1/	6,600	-	6,600	6,600	3,000	9,600	-	13,500	13,500
Other cities	16,900	-	16,900	39,700	-	39,700	65,200	23,900	89,100
Total Municipal and Industrial	27,400	-	27,400	50,200	16,100	66,300	65,200	73,000	138,200

1/ Includes 65% of requirements; the remaining 35% is included in the Colorado River Basin.

Available water-quality data indicate that runoff throughout the basin is generally low in concentrations of dissolved solids. Moderate to high flows of the San Bernard River commonly contain less than 100 mg/l; however, low flows of the river are frequently saline in some reaches as a result of discharges of industrial wastes, principally oil field brines, into the stream. The lower reach of the San Bernard River and the principal coastal tributaries such as Caney Creek and Cedar Lake Creek are affected by tide-induced saline water intrusion for several miles upstream. The organic load of the San Bernard river is comparatively low.

There are no major reservoirs in this coastal basin, although some off-channel storage has been developed. Surface water used in the basin is obtained largely by diversion through a canal system from the Colorado River Basin under existing permits.

Irrigation is expected to continue at about the present level as a major water use in this coastal area, where heavy prairie soils are well suited for rice and pasture production. Sandy soils in parts of the basin are generally suitable for most field crops. One-fifth of the 51 thousand acres irrigated in 1964 was supplied with ground water, the remainder was supplied with surface water from local streams or from the Colorado River.

Future municipal and industrial development in the basin will compete for available land resources. Consequently, it is anticipated that by 1990 irrigated

Table IV-31.--Water Supply and Demand—Brazos-Colorado Coastal Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	138.2
Irrigation	241.1
	379.3

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	SUPPLY FOR IN-BASIN REQUIREMENT
Colorado Basin	254.4
Ground Water	124.9
	379.3

NOTE: Thousands of Acre-Feet Annually.

FIGURE IV - 8
EXISTING AND PROPOSED DEVELOPMENT

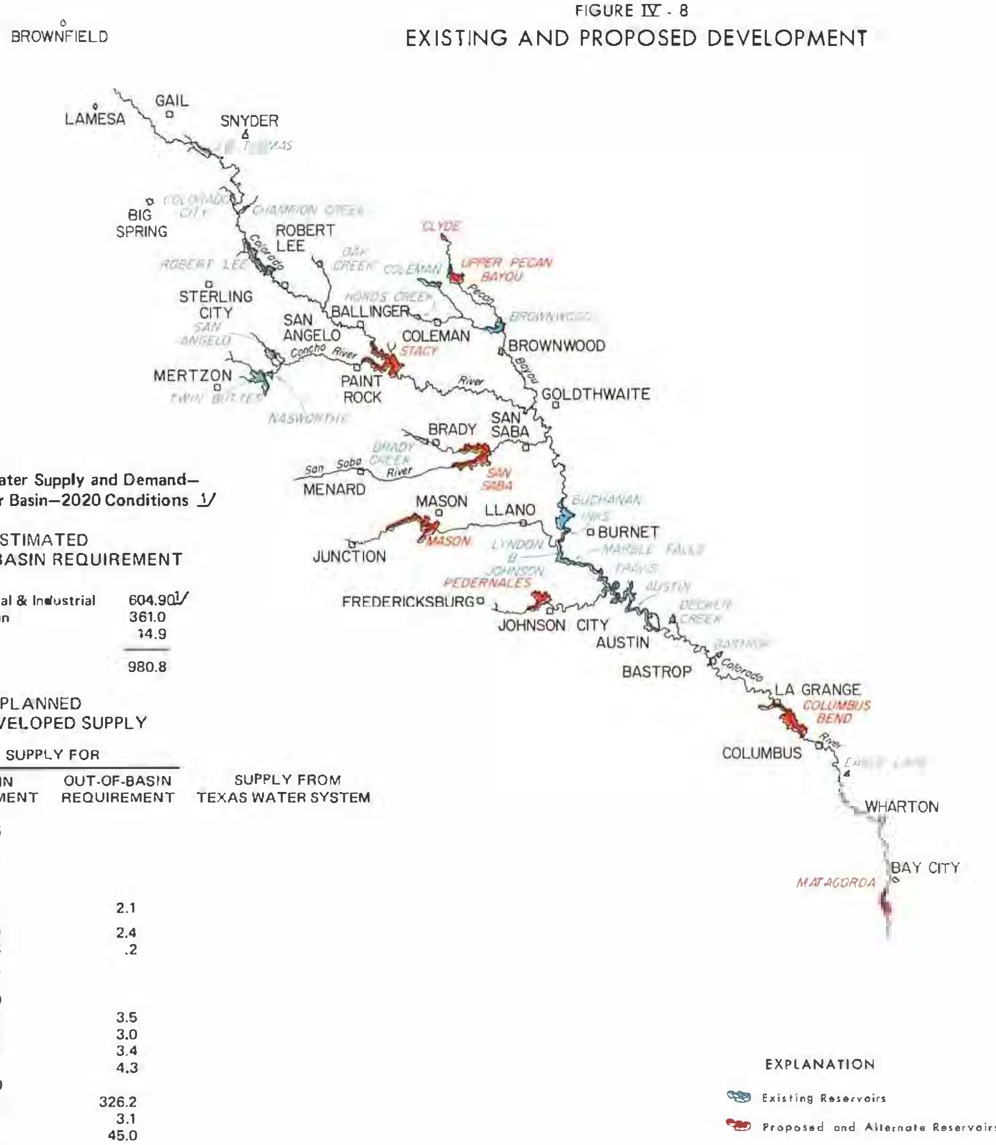


Table IV-32.--Water Supply and Demand—Colorado River Basin—2020 Conditions 1/

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	604.9 1/
Irrigation	361.0
Mining	14.9
	980.8

PLANNED
2020 DEVELOPED SUPPLY

SOURCE*	2020 SUPPLY	SUPPLY FOR: IN-BASIN REQUIREMENT	SUPPLY FOR: OUT-OF-BASIN REQUIREMENT	SUPPLY FROM TEXAS WATER SYSTEM
Canadian Basin	4.5	4.5		
J. B. Thomas, Robert Lee, Return Flow	81.5	81.5		
Colorado City, Champion Creek	8.2	6.1	2.1	
Oak Creek	3.4	1.0	2.4	
Stacy	93.0	92.8	.2	
Twin Buttes, San Angelo	38.7	38.7		
Hords Creek	1.0	1.0		
Jim Ned Creek	7.2	3.7	3.5	
Brady	8.8	5.8	3.0	
Brownwood	27.5	24.1	3.4	
Pecan Bayou	4.3		4.3	
Buchanan	242.0	242.0		
Travis	335.3	9.1	326.2	
Columbus Bend	123.2	120.1	3.1	
Matagorda	45.0		45.0	
Return Flow	212.9	31.0	181.9	
Ground Water	319.4	319.4		
Coastal Canal	85.0		51.1	85.0
	1,640.9	980.8	626.2	85.0

* Additional reservoirs for possible development include San Saba, Mason, and Pedernales.

1/ Does not include municipal and industrial deficiencies in High Plains and North Central Texas portion of the Colorado River Basin which will be supplied through the Trans-Texas Canal.

NOTE: Thousands of Acre-Feet Annually.

The Colorado River Basin is bounded on the north and east by the Brazos River Basin and Brazos-Colorado Coastal Basin and on the west and south by the Rio Grande, Nueces, Guadalupe, and Lavaca River Basins and the Colorado-Lavaca Coastal Basin. The Colorado River originates in north-central Dawson County at an elevation of about 3,000 feet. From its headwaters, the river flows southeasterly along its entire length. At the mouth on the Gulf of Mexico, the basin has a total drainage area of 41,763 square miles, of which 39,893 square miles is in Texas and the remainder in New Mexico.

Average annual runoff in the basin ranges from a maximum of about 350 acre-feet per square mile near the mouth of the Colorado River to less than 50 acre-feet per square mile in the contributing area of the basin west of Coke County.

There have been many large floods throughout the Colorado River Basin from the headwaters to the Gulf, with major floods occurring on an average of every 4½ years. Extensive overflows are restricted mostly to the coastal plains downstream from Austin. Flood damages have occurred along the main stem below Austin, above Lake Buchanan on the main stem, and on some of the major tributaries, particularly Pecan Bayou and the San Saba and Llano Rivers. Significant damages have occurred at Big Spring, Ballinger, Brownwood, San Saba, Austin, LaGrange, Columbus, Wharton, Bay City, and Matagorda.

Runoff from the drainage area above J.iB. Thomas Reservoir is generally low in dissolved solids, and water impounded in the reservoir since its completion in 1952 has generally contained not more than 250 mg/l of dissolved solids, about 25 mg/l of chloride, and about 60 mg/l of sulfate. Below J. B. Thomas Reservoir, however, the main stem of the Colorado River becomes highly mineralized as a result of inflows of oil field brine and naturally saline ground water. At Colorado City, approximately 35 river miles below J. B. Thomas Reservoir, dissolved solids concentrations have ranged upward to more than 48 thousand mg/l since 1957, and have equaled or exceeded 9 thousand mg/l 50% of the time. Although the quality of the river improves downstream, dissolved solids concentrations in flows past the Robert Lee Reservoir site (presently under construction) have reached 15 thousand mg/l, and have equaled or exceeded about 3 thousand mg/l 50% of the time since 1957. Chloride concentrations ranged between about 1,300 to more than 4,000 mg/l 50% of the time during this period.

Beals Creek, a comparatively large tributary which has its headwaters in Natural Dam Salt Lake, a large, natural saline lake in eastern Howard County, also contributes to the salt load of the river where it enters the main stem a short distance above Robert Lee Reservoir. Although the quality of water in Natural Dam Salt Lake varies widely in response to precipitation, concentrations of dissolved solids have frequently exceeded 250 thousand mg/l, and potential major flooding in this area could have a serious short-term effect on the quality of water in Robert Lee Reservoir.

Former waste-disposal practices in oil and gas fields which have contributed to this salinity problem have been largely rectified. However, the residual effects of past practices continue to plague development of water resources in this part of the basin, and the chemical quality of low flows of the river which carry much of the salt load have, as yet, not significantly improved.

Table IV-33.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Colorado River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Andrews	4,100	–	4,100	6,200	–	6,200	7,900	–	7,900
Big Spring	200	7,200	7,400	–	19,800	19,800	–	75,600	75,600
Brownfield	2,200	–	2,200	2,400	2,200	4,600	4,500	2,300	6,800
Colorado City	–	3,100	3,100	–	4,400	4,400	–	16,100	16,100
Lamesa	1,800	–	1,800	1,200	2,200	3,400	2,600	2,200	4,800
Midland	10,600	–	10,600	10,500	11,700	22,200	10,500	83,400	93,900
Odessa	4,500	10,700	15,200	3,000	38,300	41,300	3,000	150,400	153,400
Seminole	1,600	–	1,600	2,700	–	2,700	3,600	–	3,600
Snyder	500	2,300	2,800	–	4,500	4,500	–	31,500	31,500
Other cities	14,700	400	15,100	22,400	1,000	23,400	28,800	1,000	29,800
Zone 2									
Ballinger	–	800	800	–	1,500	1,500	–	2,300	2,300
Brady	1,800	–	1,800	–	3,400	3,400	–	5,800	5,800
Brownwood	–	4,500	4,500	–	8,700	8,700	–	12,900	12,900
Coleman	–	1,900	1,900	–	3,200	3,200	–	4,700	4,700
San Angelo	–	9,600	9,600	–	22,000	22,000	–	62,000	62,000
Other cities	3,500	2,500	6,000	6,700	3,700	10,400	10,000	5,900	15,900
Zone 3									
Austin	–	38,000	38,000	–	110,100	110,100	–	244,100	244,100
Other cities	2,300	2,400	4,700	4,600	4,700	9,300	7,000	7,000	14,000
Zone 4									
Wharton 1/	3,500	–	3,500	5,100	–	5,100	7,300	–	7,300
Other cities	9,200	–	9,200	31,200	–	31,200	48,000	4,500	52,500
Total	60,500	83,400	143,900	96,000	241,400	337,400	133,200	711,700	844,900

1/ Includes 35% of requirements; remaining 65% is included in the Brazos-Colorado Coastal Basin.

Assuming continuation of water-quality conditions which have existed in the problem area during the past decade, studies by the Board indicate that without remedial salinity control measures the water impounded in Robert Lee Reservoir may contain chloride concentrations of more than 500 mg/l part of the time, and may equal or exceed 250 mg/l about 75% of the time. Part of the water supply storage in the reservoir is scheduled for municipal and industrial use throughout the upper Colorado River Basin, and this supply is planned to be blended with other supplies of superior chemical quality (which will be increasingly in short supply in the future) prior to use.

Partial control of this salinity problem in the upper basin will be accomplished by construction of a low-flow dam on the main stem of the river several miles upstream from Colorado City (Plate 4) and diversion of saline low flows having a chloride concentration in excess of about 500 mg/l to a small off-channel reservoir. From this regulating facility, the saline water will be distributed to oil fields in the area for use in secondary oil recovery projects. This project, presently under construction by the Colorado River Municipal Water District, will, if successful, remove a significant part of the salt load carried by the stream and reduce the salinity of water impounded in Robert Lee Reservoir to more desirable levels.

The saline inflows in the upper basin have historically degraded the quality of main stem flows for a considerable distance downstream, even though most major tributaries such as the Concho River, Pecan Bayou, and the San Saba River contribute good quality water which has diluted these saline flows from the upper basin. Oil field wastes have periodically degraded the quality of flows in the upper reaches of Pecan Bayou, however, as well as in the lower part of Elm Creek in Runnels County. The Colorado River near San Saba has contained dissolved solids concentrations ranging from about 200 to more than 1,000 mg/l, equaling or exceeding 500 mg/l about 30% of the time. Since Robert Lee Reservoir will impound the presently highly saline flows below J. B. Thomas Reservoir, the quality of the Colorado River below Robert Lee Reservoir should improve as a result of this project, as is shown in Plate 4.

Runoff throughout most of the remainder of the Colorado River Basin is of good chemical quality and suitable for most municipal, industrial, and agricultural purposes, although generally hard. As a result of impoundment and releases of water from the series of reservoirs in the middle Colorado River Basin (the Highland Lakes), the chemical quality of water in the main stem below Austin is comparatively uniform. Dissolved solids concentrations in the river at Wharton in the lower basin generally range between 100 and 400 mg/l, and have equaled or exceeded 300 mg/l only about 50% of the time.

Organic loading throughout the Colorado River Basin is generally low, and presently no serious dissolved-oxygen deficits exist for extended periods of time. However, as a result of municipal and/or industrial return flows in Beals Creek below Big Spring, the Concho River below San Angelo, and in the main stem of the river below Austin, dissolved-oxygen depressions have occurred seasonally. Continuation of present levels of nutrient concentrations in the Colorado River below Austin could create eutrophic conditions in proposed Columbus Bend Reservoir at an early stage.

Irrigation is an important factor in the basin's economy. In the High Plains, however, ground water supplies are being depleted. Since 1964, there has been a small increase in irrigated acreage within the basin in the South High Plains, particularly in the sandy areas, with the substantial increase in use of sprinkler irrigation systems. Extensive irrigable areas, where local water supplies are being depleted, would be served by water imported through the Trans-Texas Division of the Texas Water System to maintain the irrigated agriculture upon which the economy of the area is partly based.

Some expansion in irrigated acreage in the middle part of the basin is projected from the 82 thousand acres irrigated in this area in 1964. By 1990, irrigated lands in this region are expected to reach about 105 thousand acres, and remain at about this level through the year 2020. Ground water supplies most of the water for irrigation below the High Plains escarpment. Further downstream, surface water is used to Irrigate pastures, hay, feed crops, and peanuts.

The Colorado River delta soils and prairie soils of the coastal area of the basin are highly productive under irrigation and adaptable to producing a wide variety of crops. In 1964, lower basin irrigation totaled 25 thousand acres, supplied by both ground water and surface water. It is estimated that by 1990 irrigated acreage may reach about 38 thousand acres in the lower basin, and 50 thousand acres by 2020.

Ground water is an important source of water to meet basin needs. Approximately 538,700 acre-feet per year of ground water is available as a perennial yield from major and minor aquifers in the basin. Major aquifers in the basin are the Ogallala, Edwards-Trinity (Plateau), Edwards (Balcones Fault Zone), Carrizo-Wilcox, and Gulf Coast Aquifers. Minor aquifers include the Santa Rosa, Ellenburger-San Saba, and Hickory Aquifers. Less important water-bearing formations can continue to provide small quantities of water adequate for local domestic and livestock supply, and in some areas for municipal, industrial, and irrigation supplies. It is estimated that about 320 thousand acre-feet of ground water will be used in the basin by the year 2020.

The Colorado River Basin has 21 existing and under-construction major reservoirs. Five new reservoirs are proposed under the Texas Water Plan: Stacy, Upper Pecan Bayou, Clyde, Columbus Bend, and Matagorda. Hydroelectric generating facilities are presently in operation at Buchanan, Inks, Lyndon B. Johnson, Marble Falls, Travis, and Austin Reservoirs, with a combined installed generating capacity of 202,250 kilowatts.

Storage and use of water from proposed Stacy Reservoir would reduce the presently permitted yield of the Highland Lakes. It will be necessary to replace this reduction in yield, projected to be approximately 85 thousand acre-feet annually, by deliveries through the Coastal Canal of the Texas Water System in order that demands for supplies from the Colorado River can be met. Cost of providing this replacement water must be included in the costs of water supplied from proposed Stacy Reservoir.

A possible diversion of water from the Colorado River Basin to supply the City of San Antonio, with replacement to the lower reaches of the basin through the Texas Water System, has been studied in some detail by the Board. Results of these studies indicate that if such a diversion is made, an equivalent amount of water would have to be imported into the basin, above the Lower Colorado River Authority's system of reservoirs, by deliveries through the Trans-Texas Canal in an expanded Texas Water System. This would be necessary to maintain adequate flows for quality control in the river below Austin, to replace water for needs in the lower Colorado River Basin and adjoining statutory service areas, and to keep the Lower Colorado River Authority reservoir system operating as efficiently as possible under future conditions of basin development. Costs of such replacement water brought into the upper Colorado River Basin would be a part of the cost of water delivered to San Antonio. This alternative has therefore not been included in the Texas Water Plan to meet requirements to the year 2020, due to the high costs involved.

Water would be imported into the upper basin for municipal uses through the existing Sanford Project, and for potential municipal, industrial, and irrigation uses in the Midland, Odessa, Big Spring, San Angelo, and Colorado City areas through the Trans-Texas Division of the Texas Water System. San Saba, Mason, and Pedernales Reservoirs are alternative projects for development of conservation storage and flood control.

Proposed reservoir development under the Plan would provide seriously needed flood-control storage in Stacy, Upper Pecan Bayou, and Columbus Bend Reservoirs. Existing extensive recreational development in the basin would be enhanced by the proposed pattern of new reservoirs. These reservoirs would develop a firm water supply in the basin, and together with existing reservoirs and ground water supplies, water imported into the basin from the Canadian River Basin, and water conveyed through the Texas Water System into the North Central Texas part of the basin for municipal, industrial, and irrigation-uses and into the lower basin to compensate for the effects of storage in Stacy Reservoir, would meet all projected requirements in the basin and adjacent statutory service areas, including anticipated industrial expansion.

The Colorado-Lavaca Coastal Basin is bounded on the east by the Colorado River Basin and on the west by the Lavaca River Basin and the Lavaca-Guadalupe Coastal Basin. Maximum elevation in the basin is about 100 feet, with most of the basin being less than 50 feet. Average annual runoff from the basin is about 300 acre-feet per square mile.

Table IV-34.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Colorado-Lavaca Coastal Basin

(Acre-Feet Per Year)

COASTAL BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
El Campo	1,000	–	1,000	2,600	–	2,600	4,500	–	4,500
Other Cities	5,000	–	5,000	500	36,800	37,300	500	83,600	84,100
Total Municipal and Industrial	6,000	–	6,000	3,100	36,800	39,900	5,000	83,600	88,600

Tres Palacios and Carancahua Creeks form the principal natural drainage system in the basin. Very little water-quality data have been collected, but runoff in the basin is comparatively low in dissolved solids. Both Tres Palacios and Carancahua Creeks are tide affected for considerable distances upstream from Tres Palacios and Carancahua Bays, respectively. Tres Palacios Creek receives municipal and industrial return flows from the El Campo area, and both streams drain extensive oil field and irrigation areas. Significant concentrations of pesticides found by the Texas Parks and Wildlife Department in tissues of various marine life in Tres Palacios Bay suggest these pesticides may be contributed by streams within the basin.

Irrigation of rice and pasture is expected to increase slightly from the 47 thousand acres irrigated in 1964 to about 52 thousand acres in 2020. Over half of the acreage irrigated in 1964 was supplied by ground water, and the remainder by water from coastal streams and supplies from the Colorado River Basin.

Ground water in the Colorado-Lavaca Coastal Basin is obtained from the Gulf Coast Aquifer which underlies the entire basin. It is estimated that about 75 thousand acre-feet of water available from the aquifer as perennial yield will be used annually in the basin by 2020.

Surface water used in the basin is obtained largely from the Colorado River Basin under existing water permits. Additional requirements not supplied with ground water or local supplies of surface water are planned to be served by approximately 181,700 acre-feet of water annually from the Colorado River Basin, and about 69,300 acre-feet annually from Palmetto Bend Reservoir in the Lavaca River Basin by the year 2020. Fresh water inflows to Matagorda Bay would be supplied in part through the Coastal Canal of the Texas Water System.

Table IV-35.--Water Supply and Demand—Colorado-Lavaca Coastal Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	88.6
Irrigation	237.4
	326.0

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	SUPPLY FOR IN-BASIN REQUIREMENT
Lavaca Basin	69.3
Colorado Basin	181.7
Ground Water	75.0
	326.0

NOTE: Thousands of Acre-Feet Annually.

LAVACA RIVER BASIN

The Lavaca River Basin is bounded on the east by the Colorado River Basin and Colorado-Lavaca Coastal Basin, and on the west by the Guadalupe River Basin and Lavaca-Guadalupe Coastal Basin. The Lavaca River heads in Fayette County at an elevation of about 400 feet and drains south into Lavaca Bay. The total drainage area at the mouth of the river is 2,409 square miles.

Average annual runoff in the basin ranges from a maximum of about 325 acre-feet per square mile in the eastern part of the basin to a minimum of about 175 acre-feet per square mile in the western part. Floods in the upper part of the basin generally rise and fall quickly and have higher velocities and higher maximum unit discharges than streams in the lower basin.

About 73 thousand acres was irrigated in the basin in 1964. It is expected to increase slightly to about 79 thousand acres by 1990 and 85 thousand acres by 2020, mostly for rice and pasture production. Although there is additional irrigable land in the basin, encroachment by municipal and industrial expansion will probably prevent additional increase in irrigation.

Ground water in the Lavaca River Basin is produced from the Gulf Coast Aquifer which underlies the entire basin. About 200 thousand acre-feet is estimated to be available as a perennial yield from the aquifer in the basin, and it is projected that this amount will be used annually by the year 2020 to supply in-basin needs.

Table IV-36.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Lavaca River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Edna	900	--	900	1,600	--	1,600	2,900	--	2,900
Yoakum	700	--	700	2,000	--	2,000	3,400	--	3,400
Other cities	3,800	--	3,800	11,200	--	11,200	20,500	--	20,500
Total Municipal and Industrial	5,400	--	5,400	14,800	--	14,800	26,800	--	26,800

Runoff throughout most of the Lavaca River Basin is of good quality, and most streams carry water containing less than 200 mg/l of dissolved solids and 25 mg/l of chloride. The water is moderately hard. The discharge-weighted average concentration of dissolved solids in the Navidad River near Ganado for the period 1960-1966 was 135 mg/l. About 50% of the time, dissolved solids concentrations equaled or exceeded about 370 mg/l, and concentrations of 500 mg/l were exceeded only about 5% of the time. During this same period, the Lavaca River near Edna had a discharge-weighted average of about 170 mg/l of dissolved solids. The organic loads of both the Lavaca and Navidad Rivers are comparatively low.

Streamflow in several tributaries and in the Navidad River near Ganado have frequently carried saline low flows in the past; however, as a result of oil field pollution, and during periods of low flow the main stem of the Lavaca River below Edna is frequently saline, both as a result of oil field pollution and tide effects.

There are presently no major reservoirs in the basin, but construction of Palmetto Bend Reservoir Stage 1 on the Navidad River and land acquisition for Stage 2 on the Lavaca River have been authorized by Congress. The Bureau of Reclamation will construct the project. This reservoir would supply parts of the requirements in the adjoining Colorado-Lavaca and Lavaca-Guadalupe Coastal Basins. Projections indicate that the yield of the reservoir would be fully utilized before 2020; however, water may be supplied to the Coastal Canal of the Texas Water System from Palmetto Bend Reservoir for a short period of time after completion when there may be some surplus supply available. The reservoir may also be used for regulation of flow in the Coastal Canal, with both uses under appropriate operating agreements and contracts.

Water to meet future requirements in the Lavaca River Basin, in addition to supplies available from ground water, would be supplied from the Colorado River Basin.

Table IV-37.--Water Supply and Demand—Lavaca River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	26.8
Irrigation	363.2
	390.0

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	2020 SUPPLY	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FOR OUT-OF-BASIN REQUIREMENT
Colorado Basin	190.1	190.1	
Palmetto Bend	105.0		105.0
Return Flow	65.3		65.3
Ground Water	199.9	199.9	
	560.3	390.0	170.3

NOTE: Thousands of Acre-Feet Annually.

LAVACA-GUADALUPE COASTAL BASIN

The Lavaca-Guadalupe Coastal Basin is bounded on the east by the Lavaca River Basin and the Colorado-Lavaca Coastal Basin and on the west by the Guadalupe River Basin and the San Antonio-Nueces Coastal Basin. The basin heads in southeastern DeWitt County at an elevation of about 200 feet and is about 20 miles wide and 60 miles long. Runoff from the basin flows into Lavaca, Matagorda, Espirito Santo, and San Antonio Bays. The basin has a total drainage area of approximately 998 square miles.

Average annual runoff from the basin is about 200 acre-feet per square mile. Considerable flooding has occurred following heavy rainfall, and lowlands near the Gulf are inundated by high tides.

would supplement supplies to meet future water requirements of the region and possibly furnish some re-regulation for the Coastal Canal of the Texas Water System.

Future municipal, industrial, and irrigation demands in the basin would be served by supplies developed in proposed Garcitas Reservoir, water diverted from the Guadalupe, San Antonio, and Lavaca River Basins, and by ground water from the Gulf Coast Aquifer. This aquifer is estimated to have a perennial yield of about 75 thousand acre-feet per year within the basin, of which about 50 thousand acre-feet will be used annually by the year 2020. Supplemental fresh water inflows for San Antonio Bay would be supplied through the Coastal Canal.

Table IV-38.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Lavaca-Guadalupe Coastal Basin

(Acre-Feet Per Year)

COASTAL BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Port Lavaca	1,200	31,300	32,500	—	44,000	44,000	—	66,900	66,900
Victoria (5%) 1/	1,300	—	1,300	2,500	—	2,500	3,400	—	3,400
Other cities	8,100	—	8,100	5,200	78,600	83,800	2,300	185,600	187,900
Total Municipal and Industrial	10,600	31,300	41,900	7,700	122,600	130,300	5,700	252,500	258,200

1/ The remaining 95% of the total requirement is included in the Guadalupe River Basin.

Arenosa, Garcitas, and Placedo Creeks form the principal drainage system in the basin. Water-quality data collected periodically from Garcitas and Arenosa Creeks near Inez indicate that runoff from above this area is of very good quality, and the weighted-average dissolved solids concentration of flows passing the site of proposed Garcitas Reservoir is less than 250 mg/l. The streams are tide affected in their lower reaches.

The basin includes the lower edge of the coastal rice-producing area of Texas, and soils are locally suitable for rice and pasture production. In 1964, more than 18 thousand acres was irrigated, about two-thirds of which was supplied with ground water. Most of the surface water used for irrigation is supplied from the Guadalupe River, with small amounts from Garcitas Creek and the Lavaca River used in western Jackson County. Urbanization and industrial development is encroaching to a marked degree on irrigable lands, particularly in the Victoria area, thus limiting future increases in irrigation. Total irrigated acreage in the basin is estimated to be about 22 thousand acres by 1990 and 25 thousand acres by the year 2020.

There are no major surface water reservoirs in the basin, but the proposed reservoir on Garcitas Creek

Table IV-39.--Water Supply and Demand—Lavaca-Guadalupe Coastal Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	258.2
Irrigation	97.0
	355.2

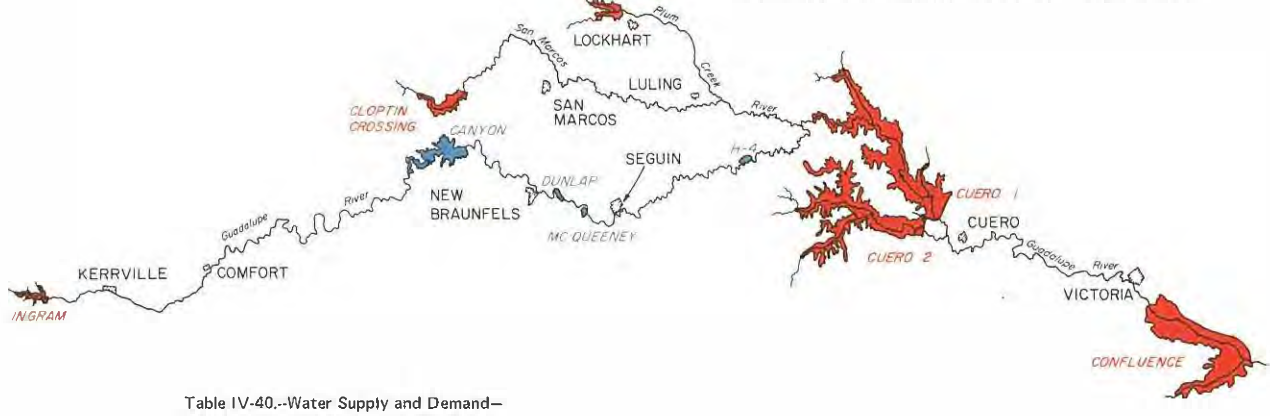
PLANNED
2020 DEVELOPED SUPPLY

SOURCE	SUPPLY FOR IN-BASIN REQUIREMENT
Guadalupe & San Antonio Basin	182.8
Garcitas	20.7
Lavaca Basin	101.0
Ground Water	50.7
	355.2

NOTE: Thousands of Acre-Feet Annually.

GUADALUPE RIVER BASIN

FIGURE IV - 9
EXISTING AND PROPOSED DEVELOPMENT



EXPLANATION

Existing Reservoirs

Proposed and Alternate Reservoirs

Table IV-40.--Water Supply and Demand—
Guadalupe River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	191.1
Irrigation	52.1
Mining	.3
Navigation	7.0
	250.5

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	2020 SUPPLY	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FOR OUT-OF-BASIN REQUIREMENT	SUPPLY FOR EXPORT UNDER TEXAS WATER SYSTEM
Ingram	7.6			
Canyon	83.7			
Lockhart	5.0			
Cloptin Crossing	29.9			
Cuero 1 & 2	242.9			205.0
Return Flow	89.3			51.1
Ground Water	104.3			
	562.7	250.5	56.1	256.1

NOTE: Thousands of Acre-Feet Annually.

The Guadalupe River Basin is bounded on the north by the Colorado River Basin, on the east by the Lavaca River Basin and Lavaca-Guadalupe Coastal Basin, and on the west and south by the Nueces and San Antonio River Basins. The Guadalupe River heads in southwest Kerr County at an elevation of about 2,200 feet, flowing easterly and then southeasterly to Guadalupe Bay, a part of the San Antonio Bay System. The total drainage area of the basin is 6,070 square miles.

Average annual runoff in the Guadalupe River Basin ranges from a maximum of about 200 acre-feet per square mile in the eastern part of the basin to a minimum of about 100 acre-feet per square mile in the western part of the basin in Kerr County. Large floodflows have occurred in the Guadalupe River and many of its tributaries. High unit discharge rates have frequently occurred upstream from New Braunfels where channel slopes are steep and the valley is narrow. Floodflows generally rise and fall rapidly and have high velocities. In the coastal plain, downstream from New Braunfels, stream discharge rates are lower and floodplains are wider.

The surface water resources throughout most of the Guadalupe River Basin are of good quality. Concentrations of dissolved solids in streams of the upper part of the basin are generally less than 250 mg/l, and water impounded in Canyon Reservoir on the main stem of the Guadalupe River has contained dissolved solids ranging from less than 200 to about 280 mg/l. The water is very hard, however. Below Canyon Reservoir and above the confluence of the San Marcos River, runoff is low in dissolved solids, and numerous springs—the largest of which is Comal Springs at New Braunfels—contribute ground water usually containing less than 300 mg/l.

The Blanco River, which merges with the San Marcos River near San Marcos, also usually contains less than 250 mg/l of dissolved solids. The flow of San Marcos Springs, which sustains the flow of the upper part of the San Marcos River, contains an average of about 330 mg/l, and the San Marcos River generally contains more than 250 mg/l but less than 500 mg/l of dissolved solids. Plum Creek, a major tributary of the San Marcos River, is degraded by oil field drainage in its lower reaches and carries water containing an average of more than 500 mg/l of dissolved solids.

Low flows of several tributary streams in the lower part of the basin, such as Peach Creek and Sandies Creek, are relatively highly mineralized, but floodflows are of good quality and the discharge-weighted average dissolved solids concentration of the Guadalupe River at Victoria is about 290 mg/l. Since 1955, dissolved solids in the river at Victoria equaled or exceeded 250 mg/l about 70% of the time, but exceeded 500 mg/l less than 1% of the time.

Organic loading throughout the basin is comparatively low, and since most streams receiving treated municipal wastewaters have substantial base flows and their natural waste-assimilative capacity is relatively high, dissolved-oxygen deficits are infrequent and no serious water quality problems presently exist. During extended dry periods, dissolved-oxygen depressions have occurred in streams locally, however.

The basin has potential for irrigation development. Although only about 11 thousand acres was irrigated in the basin in 1964, there are approximately 140 thousand acres of potentially irrigable land in the basin below the Balcones Escarpment. A large part of this land, however, is in areas where ground water is not available on a dependable basis, and some irrigable land along tributary streams cannot be supplied adequately from streamflow throughout the growing season. Planned reservoirs will also reduce somewhat the amount of land that will be available for irrigation along the principal streams and lower reaches of tributaries. It is projected that approximately 37 thousand acres will be irrigated in the basin by the year 2020.

Under any selected system of surface water development, ground water will continue to be a significant part of the resources of the basin. Approximately 160 thousand acre-feet of ground water is available as an annual safe yield from aquifers in the basin, principally from the Edwards-Trinity (Plateau), Edwards (Balcones Fault Zone), Carrizo-Wilcox, and Gulf Coast Aquifers. Although it is projected that as much as 50 thousand acre-feet of ground water could be pumped annually from the Edwards-Trinity (Plateau) Aquifer in the upper part of the Guadalupe River Basin on a safe-yield basis, pumpage at this rate from the aquifer would cause a significant reduction in the base flow of streams draining the Plateau; thus, little of this potential yield is proposed for use in the basin, and the resource is not included in evaluation of total ground water supplies available in the basin. It is estimated that as much as 104,300 acre-feet of ground water may be pumped annually in the basin by the year 2020, principally from the Edwards (Balcones Fault Zone), Carrizo-Wilcox, and Gulf Coast Aquifers.

Approximately 50 thousand acre-feet of ground water is available as a perennial yield from the Edwards (Balcones Fault Zone) Aquifer, which hydraulically connects the Guadalupe, San Antonio, and Nueces River Basins. Numerous springs in each of the basins discharge

Table IV-41.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Guadalupe River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Kerrville	1,900	—	1,900	3,300	700	4,000	3,300	3,400	6,700
Other cities	400	—	400	600	—	600	800	—	800
Zone 2									
Lockhart	600	—	600	—	1,600	1,600	—	3,300	3,300
San Marcos	2,600	—	2,600	6,500	—	6,500	14,300	—	14,300
Other cities	1,400	—	1,400	2,300	—	2,300	3,000	—	3,000
Zone 3									
Gonzales	—	1,000	1,000	—	1,900	1,900	—	3,200	3,200
New Braunfels	6,800	—	6,800	6,800	5,600	12,400	6,800	18,400	25,200
Seguin	—	2,200	2,200	—	6,600	6,600	—	16,700	16,700
Other cities	900	—	900	1,400	—	1,400	1,700	—	1,700
Zone 4									
Cuero	1,000	—	1,000	1,800	—	1,800	3,000	—	3,000
Victoria (95%) 1/	24,200	—	24,200	20,000	27,400	47,400	20,000	56,800	76,800
Other cities	700	—	700	3,600	—	3,600	27,600	8,800	36,400
Total municipal and industrial	40,500	3,200	43,700	46,300	43,800	90,100	80,500	110,600	191,100

1/ The remaining 5% of the total requirement is included in the Lavaca-Guadalupe Coastal Basin.

ground water from this aquifer when water levels are sufficiently high. Two of the largest springs in Texas discharge water from the Edwards (Balcones Fault Zone) Aquifer—Comal Springs at New Braunfels and San Marcos Springs at San Marcos—and these springflows provide most of the base flow of the Guadalupe and San Marcos Rivers below the springs. Pumpage from the Edwards Aquifers in the three river basins affects the rate of spring discharge, thus affecting streamflow and the total supply of surface water in the Guadalupe River Basin. Maintenance of adequate springflows is an important feature of the Texas Water Plan.

Because of the hydraulic interconnection of the upper and middle parts of the Guadalupe, San Antonio, and Nueces River Basins resulting from the limestone aquifers which underlie the basins—previously described in Part I—it is essential to consider the interrelationships in water requirements and development. San Antonio is the largest municipality in the three basins, and this metropolitan area strongly influences cultural and economic conditions throughout the region. Therefore, the Board has directed its studies and evaluation of the water resources of these basins toward seeking the most economic solution to the water supply problem of the San Antonio metropolitan area concurrently with—and in the context of formulation of—the best overall solution to the construction and operation of a water supply system to develop the long-range economic potential of the three river basins. Several alternatives for meeting these interrelated water supply problems have been considered. These include the various alternative supply systems described in Part I and in this discussion of the Guadalupe River Basin, plus other supply systems which have been proposed by various groups.

Final decisions as to specific plans for meeting all of the water needs of these river basins, including maintenance of springflows which is particularly important to the optimum development and utilization of the Guadalupe River Basin's water resources and the associated recreational and scientific value, will require detailed studies in cooperation with local entities and negotiations to arrive at mutually satisfactory arrangements among the many interests involved.

There are two alternative operational systems of the proposed physical facilities to supply the City of San Antonio from the Guadalupe and San Antonio River Basins under the Texas Water System. One alternative would involve diversion of part of the yield of proposed Cuero Reservoir directly to Cibolo Reservoir in the San Antonio River Basin, and thence to San Antonio. Another alternative would supply water to San Antonio through a pipeline from the Guadalupe River with diversion facilities constructed in the river upstream from Cuero Reservoir at a location somewhere in the New Braunfels-Seguin area. This arrangement would permit an effective system operation of the Guadalupe River, allowing upstream flows to be diverted to San Antonio without the necessity for pumpback from proposed Cuero Reservoir, except when upstream flows were not sufficient to meet requirements. Water from proposed Cibolo Reservoir would be pumped directly to San Antonio.

Under either of these alternatives, part of the yield of proposed Goliad Reservoir in the San Antonio River Basin, plus adequately treated municipal and industrial return flows from the San Antonio area, would be used to supply projected requirements in the lower Guadalupe and San Antonio River Basins and in adjacent coastal service areas. Cuero Reservoir would be constructed before it would be needed to serve in-basin requirements—or for San Antonio's supplemental supply—in order to make the temporary surplus yield of the reservoir available on an interim basis to the Texas Water System by diversion into the Coastal Canal. Interim use of these supplies would be appropriately reduced as in-basin requirements increase. **Such interim use of these supplies would have three major advantages to the basin, to San Antonio, and to the State:**

(1) Interim use of the yield of proposed Cuero Reservoir as a supply to the Coastal Canal would partially amortize the cost of the dam and reservoir, thus reducing the unit cost of water developed by the reservoir when it is required by in-basin users and San Antonio.

(2) The reservoir could be constructed at an early date, with consequent lower costs for land and right-of-way.

(3) Optimum staging of construction of the Coastal Canal would be possible. This staged development would allow earlier repayment for project costs and would result in significant savings in total project financing.

The buildup in demands for water from the Coastal Canal is projected to exceed the yield of Cuero Reservoir within a few years after construction of the initial segment, making it essential that construction of the Canal toward the Sabine River begin immediately following completion of the segment from the Lower Rio Grande Valley to the Guadalupe River Basin.

Canyon Reservoir is the only existing major water supply storage reservoir in the basin, and it also provides flood control storage. Supplies from the lower basin are presently diverted to the adjacent Lavaca-Guadalupe Coastal Basin under existing permits. There are six small hydroelectric dams on the Guadalupe River downstream from New Braunfels. Although not a major reservoir, the existing salt water barrier below the confluence of the San Antonio and Guadalupe Rivers is important to basin development and operation. This collapsible fabric dam prevents salt water intrusion upstream.

Ingram, Cloptin Crossing, Lockhart, Cuero 1 and 2, and Confluence Reservoirs are proposed for construction under the Texas Water Plan, and together with Canyon Reservoir would provide flood control, water supply storage for both in-basin supply and interbasin transfers, and a potential recreational complex to supplement the present recreational development at Canyon Reservoir.

Proposed Confluence Reservoir would be a facility of the Coastal Canal of the Texas Water System, to be used primarily for re-regulation; however, future feasibility studies will define more precisely the locations where re-regulation is needed and the regulation storage capacity required for the Canal.

SAN ANTONIO RIVER BASIN

FIGURE IV - 10
EXISTING AND PROPOSED DEVELOPMENT

EXPLANATION

Existing Reservoirs
Proposed and Alternate Reservoirs
Reservoirs for Flood Control Only

Table IV-42.--Water Supply and Demand—San Antonio River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	446.5
Irrigation	69.4
Mining	.1
	516.0

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	2020 SUPPLY	SUPPLY FOR: IN-BASIN REQUIREMENT	SUPPLY FOR: OUT-OF-BASIN REQUIREMENT	SUPPLY FOR: EXPORT UNDER TEXAS WATER SYSTEM	SUPPLY FROM TEXAS WATER SYSTEM
Cibolo	23.9				
Goliad	114.4				
Guadalupe Basin	205.0				205.0
Ground Water	276.5				
Return Flow	239.4		126.7		
	859.2	516.0	126.7	216.5	205.0

NOTE: Thousands of Acre-Feet Annually.

The San Antonio River Basin is bounded on the north and east by the Guadalupe River Basin and on the south and west by the Nueces River Basin and San Antonio-Nueces Coastal Basin. The Medina River, which is the headwater stream of the San Antonio River Basin, rises in the northwest corner of Bandera County at an elevation of about 2,000 feet. The total drainage area of the basin is 4,180 square miles.

Average annual runoff ranges from a maximum of about 150 acre-feet per square mile near the mouth of the San Antonio River to a minimum of about 100 acre-feet per square mile at the headwaters.

Large floods with high unit discharge rates have occurred in the San Antonio River and its tributaries. Major flooding has occurred about once every 12 years in the upper basin and once every five years in the lower basin. Floods in the tributaries originating in the Edwards Plateau upstream from San Antonio rise and fall more rapidly and have higher velocities than floods originating at San Antonio and downstream in the coastal plain area of the basin. Damaging floods have occurred in the San Antonio urban area.

The discharge-weighted average concentration of dissolved solids in streams within the upper part of the San Antonio River Basin is on the order of 300-350 mg/l. Medina Lake, on the main stem of the Medina River northwest of San Antonio, stores water usually containing concentrations from about 250 to 300 mg/l of dissolved solids, and the quality of the river remains good downstream to the western edge of the San Antonio metropolitan area.

Cibolo Creek, originating in the upper part of the basin in the Edwards Plateau, usually contains about 300 mg/l of dissolved solids, although the quality of flows ranges widely under extreme flow conditions. Much of the flow of the stream enters ground water aquifers as it crosses the Balcones Fault Zone, and low flows of the stream within the lower half of its drainage area generally contain between 500 and 750 mg/l as the result of municipal, industrial, and irrigation return flows entering the stream. However, natural runoff to Cibolo Creek from the lower part of its drainage area is low in dissolved solids, and the discharge-weighted average concentration of dissolved solids in Cibolo Creek near Falls City in northern Karnes County is about 280 mg/l.

Calaveras Creek and other tributaries within the upper reaches of the San Antonio River drainage area carry water low in dissolved solids. Flow of the upper part of the main stem of the San Antonio River and the lower reach of the Medina River is sustained partly by municipal and industrial return flows from the San Antonio area, and dissolved solids concentrations in low flows of the main stem of the river just below San Antonio generally exceed 600 mg/l. However, principal tributaries such as Escondido and Ecleto Creeks contribute good quality water, and runoff throughout most of the lower basin is low in dissolved solids. During the period 1959-1966, the discharge-weighted average dissolved solids concentration of the river at Goliad was about 400 mg/l. This weighted-average value was exceeded about 80% of the time, however, and about 50% of the time dissolved solids concentrations of daily flows of the river at Goliad ranged between approximately 580 and 800 mg/l. Below Goliad, the chemical quality of the river does not change significantly. Flows throughout the main stem of the river are very hard.

The lower part of the Medina River and the main stem of the San Antonio River below the San Antonio area have carried a heavy organic load in the past, and although municipal and industrial waste-water treatment and efficiency of plant operation have steadily improved, BOD concentrations throughout the main stem of the San Antonio River usually exceed 5 mg/l. One of the most severe problems affecting the river results from the heavy nutrient load carried by the stream. Phosphate concentrations have consistently ranged between about 2 and 7 mg/l. Heavy algal growths resulting from the heavy nutrient loading have further contributed to frequently severe dissolved-oxygen deficits in the stream. However, recent innovations in the operation of conventional municipal waste-treatment plants at San Antonio have resulted in some reduction in phosphate loading on the stream, and intensive studies of methods of further improving water quality conditions in the San Antonio River are underway and will be continued.

Irrigable land in the basin occurs mostly below the Balcones Escarpment. About 50 thousand acres was irrigated in 1964. Most irrigable lands are in areas where existing ground water supplies are not economically recoverable for irrigation and where no surface water supplies are available for irrigation use.

With projected increases in use of available water supplies for non-agricultural purposes and encroachment of the San Antonio metropolitan area on irrigable lands, irrigated acreage in the basin is expected to remain essentially at the present level, with about 49 thousand acres projected to be irrigated by 1990 and about 47 thousand acres by the year 2020.

Ground water is pumped from the Edwards-Trinity (Plateau), Edwards (Balcones Fault Zone), Carrizo-Wilcox, and Gulf Coast Aquifers in the basin. Although as much as 25 thousand acre-feet might be pumped annually from the Edwards-Trinity (Plateau) Aquifer in northern Bandera County, this would result in reduction of springflows which sustain the base flows of the Medina River and Cibolo Creek, also decreasing the amount of available recharge to the Edwards (Balcones Fault Zone) Aquifer downstream. For this reason, these supplies have not been included in the projected total available ground water supply in the basin.

Approximately 344 thousand acre-feet of ground water is available as a perennial yield from the major

Table IV-43.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, San Antonio River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960 GROUND WATER	1960 SURFACE WATER	1960 TOTAL	PROJECTED 1990 GROUND WATER	PROJECTED 1990 SURFACE WATER	PROJECTED 1990 TOTAL	PROJECTED 2020 GROUND WATER	PROJECTED 2020 SURFACE WATER	PROJECTED 2020 TOTAL
Zone 1									
Alamo Heights	1,700	—	1,700	2,000	—	2,000	2,400	—	2,400
San Antonio	108,100	—	108,100	201,900	60,800	262,700	201,900	220,000	421,900
Terrell Hills	800	—	800	1,300	—	1,300	1,800	—	1,800
Other cities	4,900	—	4,900	6,100	—	6,100	8,900	—	8,900
Zone 2									
Other cities	5,100	—	5,100	7,900	—	7,900	11,500	—	11,500
Total	120,600	—	120,600	219,200	60,800	280,000	226,500	220,000	446,500

aquifers in the basin—excluding the Edwards-Trinity (Plateau) Aquifer. Of this total, about 260 thousand acre-feet is available annually under present conditions of development from the Edwards (Balcones Fault Zone) Aquifer, about 33,500 acre-feet annually from the Carrizo-Wilcox Aquifer, and approximately 50 thousand acre-feet annually from the Gulf Coast Aquifer. By the year 2020, it is projected that about 276 thousand acre-feet of ground water will be used annually in the basin.

Locally, water-bearing formations, including the Queen City Aquifer, can supply small amounts adequate for domestic and livestock use, and in some areas for municipal, industrial, and irrigation needs. As previously discussed in Part I, it is proposed that pumpage from the Edwards (Balcones Fault Zone) Aquifer for municipal and industrial use in the San Antonio metropolitan area be maintained at an average of not more than about 215 thousand acre-feet annually, to be supplemented by surface water supplies from the Texas Water System. The additional ground water supplies projected to be used in the basin would be used primarily for irrigation, supplied largely from the Edwards (Balcones Fault Zone) and Carrizo-Wilcox Aquifers.

Major reservoirs in the San Antonio River Basin include Medina Lake on the Medina River, which provides water supply for irrigation in the San Antonio and adjoining Nueces River Basins under existing permits, and Olmos Reservoir, which provides flood control storage north of San Antonio. Supplies from Victor Braunig Lake and Calaveras Creek Reservoir are used for cooling water for steam generation plants.

Cibolo and Goliad Reservoirs are proposed for additional development of the surface water resources of the basin under the Texas Water Plan. They would provide in-basin water supply; water supply for a progressive exchange with water developed in the Guadalupe River Basin and delivered to the City of San Antonio; needed flood control storage to mitigate flood hazards in the lower basin; and would provide surpluses in excess of projected in-basin requirements for export through the Texas Water System.

Longer-range requirements of the San Antonio metropolitan area beyond the year 2020 might possibly be served by additional supplies delivered through the Trans-Texas Division of the Texas Water System to the Colorado River Basin, thence to the San Antonio area as previously described in Part I.

As previously described in the discussion of the Guadalupe River Basin, planning for solution of water supply problems in the San Antonio River Basin is interrelated with solution of the regional water supply and development problems in the Guadalupe, San Antonio, and Nueces River Basins. There are significant opportunities in this area for optimum solution through a conjunctive management program for the ground and surface water supplies projected to be available to the area. Proposals in the Texas Water Plan, described in Part I, are directed toward such a solution in order to meet Federal, State, and local interests in this area. This would involve development of techniques and institutional arrangements for developing the regional water supply at optimum cost through coordinated operation of surface reservoirs in the Guadalupe and San Antonio River Basins conjunctively with the utilization of the water from—and the storage capacity of—the Edwards Aquifers.

SAN ANTONIO-NUECES COASTAL BASIN

The San Antonio-Nueces Coastal Basin is bounded on the north and east by the San Antonio River Basin and the Lavaca-Guadalupe Coastal Basin and on the south and west by the Nueces River Basin and the Nueces-Rio Grande Coastal Basin. Tributaries of Blanco Creek, which form the headwaters of the basin, begin in southwestern Karnes County at an elevation of about 400 feet, and runoff from the basins enters Copano and Aransas Bays. The total drainage area of the basin is 2,652 square miles.

Average annual runoff in the basin ranges from a maximum of about 150 acre-feet per square mile near the eastern boundary to a minimum of less than 50 acre-feet per square mile near the western boundary. Infrequent but occasionally heavy rains in the basin flood considerable areas near the Coast, and parts of the basin are subject to inundation by high tides. Natural drainage in the basin is poor, and the effects of the heavy rains resulting from Hurricane Beulah in 1967 caused major damage in the basin.

The principal drainage system in the San Antonio-Nueces Coastal Basin consists of the Mission River and its principal tributaries Blanco and Medio Creeks; the Aransas River; and Chiltipin Creek. These principal streams, together with other smaller coastal tributaries, drain into Copano Bay.

Runoff from the upper part of the basin is of good quality, and the discharge-weighted average concentration of dissolved solids in flows of Medio and Blanco Creeks above the Refugio area is less than 250 mg/l. The lower reaches of these streams in the Refugio area frequently carry saline flows, however, and the main stem of the Mission River is presently highly saline for its entire length as a result of discharges of oil field brines and other industrial wastes to the river in the Refugio area. Dissolved solids in low flows of the river at Refugio frequently exceed 50 thousand mg/l, and during dry years the concentration of dissolved solids in the river has averaged between 30 thousand and 45 thousand mg/l. The discharge-weighted average dissolved solids concentration of the river below Refugio presently exceeds 3 thousand mg/l.

Runoff to the Aransas River is of good quality, but the quality of the stream is also degraded locally by drainage from oil fields, and low flows frequently contain between 1,000 and 2,000 mg/l of dissolved solids. The discharge-weighted average quality of the river under present conditions is estimated to be greater than 250 mg/l but less than 500 mg/l of dissolved solids.

Chiltipin Creek is presently used for the conveyance of oil field brines, produced in numerous oil fields in the southern part of the basin, to Copano Bay. Near its mouth, dissolved solids concentrations of the stream generally range between 50 thousand and 75 thousand mg/l.

The organic loads carried by the Mission River below Refugio, Chiltipin Creek, and Poesta Creek below Beeville are high as the result of municipal and industrial return flows to these streams.

Although the basin has large areas of irrigable lands, in 1964 only about 16 thousand acres were irrigated, all supplied by ground water. Irrigated acreage supplied by ground water is projected to remain at about present levels in the basin through the year 2020.

Part of the proposed Coastal Bend irrigation development which would be served by the Texas Water System lies within the San Antonio-Nueces Coastal Basin north of Corpus Christi. Fertile soils and long growing seasons make the area particularly adaptable for irrigated agriculture, provided water can be made available at economically supportable costs. Under the Texas Water Plan, it is proposed to deliver approximately 246,600

Table IV-44.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, San Antonio-Nueces Coastal Basin

(Acre-Feet Per Year)

COASTAL BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Aransas Pass	--	1,300	1,300	--	2,700	2,700	--	5,500	5,500
Beeville	2,500	--	2,500	3,000	1,900	4,900	3,000	6,200	9,200
Sinton	1,200	--	1,200	--	3,200	3,200	--	8,800	8,800
Other cities	4,600	4,300	8,900	--	17,400	17,400	--	25,100	25,100
Total municipal and industrial	8,300	5,600	13,900	3,000	25,200	28,200	3,000	45,600	48,600

acre-feet of water annually through the Coastal Canal to supply about 180 thousand acres that can be efficiently irrigated by project water delivery systems in the San Antonio-Nueces Coastal Basin.

The Gulf Coast Aquifer underlies the entire San Antonio-Nueces Coastal Basin, with the exception of the southern parts of San Patricio and Aransas Counties where no fresh ground water is available. Approximately 30 thousand acre-feet of ground water of a quality suitable for most beneficial uses is available as a perennial yield from the aquifer in the basin. It is projected that as much as 25 thousand acre-feet will be used annually in the basin by the year 2020, principally to supply sufficient water to maintain present ground water irrigated areas in the basin.

There are presently no existing major surface water reservoirs in the basin. Small supplies, totaling less than 6 thousand acre-feet annually, are diverted from the adjoining Nueces River Basin under existing permits.

No major reservoirs are proposed for construction in the basin, and the total projected 2020 requirements in the basin are proposed to be met by increased diversions from the Nueces River Basin, existing ground water supplies, possible desalting of saline supplies in local areas, and deliveries of irrigation supplies through the Texas Water System.

Table IV-45.--Water Supply and Demand— San Antonio-Nueces Coastal Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	48.6
Irrigation	268.6
Mining	.1
	317.3

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FROM TEXAS WATER SYSTEM
Nueces Basin	45.6	
Ground Water	25.1	
Coastal Canal	246.6	246.6
	317.3	246.6

NOTE: Thousands of Acre-Feet Annually.

The Nueces River Basin is bounded on the north and east by the Colorado, Guadalupe, and San Antonio River Basins, and the San Antonio-Nueces Coastal Basin and on the west and south by the Rio Grande Basin and Nueces-Rio Grande Coastal Basin. The Nueces River and several of its principal tributaries head in north central Edwards and northern Real County at an elevation of about 2,300 feet, and the river discharges into Nueces Bay, an arm of Corpus Christi Bay. The total drainage area of the basin is 16,950 square miles.

Average annual runoff ranges from a maximum of approximately 100 acre-feet per square mile near the eastern edge of the basin and about 150 acre-feet per square mile in the northern part of the basin (upstream from the Balcones Fault Zone) to a minimum of less than 50 acre-feet per square mile in the southwestern part of the basin. The Balcones Fault Zone crosses the basin along an approximate east-west line from San Antonio to Del Rio, passing just north of Uvalde. A substantial part of the flows of the Nueces River and its principal tributaries which originate in the Edwards Plateau enter the fractured and cavernous limestone beds of the Edwards and stratigraphically associated limestone formations as these streams cross the fault zone, thus providing recharge to the ground water aquifers, but reducing potential surface water supplies in the lower basin.

Although the basin receives comparatively little rainfall on an average annual basis, heavy rains and major floods have occurred, particularly in the upper part of the basin which drains the Edwards Plateau. Below the Plateau, stream channel gradients become flatter and the floodplains wider. Floods consequently move more slowly and have lower unit discharge rates than in the Edwards Plateau area.

Principal streams in the Nueces River Basin include the Atascosa River; the Frio River and its principal tributaries San Miguel Creek, Hondo Creek, and the Sabinal, Dry Frio, and Leona Rivers; and the Nueces River. The Atascosa and Frio Rivers drain into the Nueces River above Lake Corpus Christi.

Streamflows throughout most of the Nueces River Basin are relatively low in dissolved solids. Low flows of the Atascosa River rarely exceed 1,000 mg/l, and on the basis of available water quality data the discharge-weighted average dissolved solids concentration of the river is estimated to be less than 250 mg/l.

In the Frio River drainage basin, available data from San Miguel and Hondo Creeks indicate that the discharge-weighted average concentration of these streams is probably less than 250 mg/l. Flows of the Sabinal River are somewhat more highly mineralized, and the discharge-weighted average concentration of dissolved solids is estimated to be between 250 and 300 mg/l. The discharge-weighted average dissolved solids concentration of Hondo Creek is estimated to be about 200 mg/l on the basis of available data.

The Frio River generally carries water containing less than 250 mg/l of dissolved solids, but in the lower reaches it is more highly mineralized. The discharge-weighted average dissolved solids concentration of the Frio River near its confluence with the Atascosa River is

Table IV-46.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Nueces River Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Carrizo Springs	900	--	900	1,700	--	1,700	2,500	--	2,500
Crystal City	1,500	--	1,500	3,100	--	3,100	5,100	--	5,100
Uvalde	3,900	--	3,900	7,500	--	7,500	12,200	--	12,200
Other cities	8,500	--	8,500	13,400	--	13,400	18,500	--	18,500
Zone 2									
Corpus Christi (5%) [1]	--	2,900	2,900	--	8,700	8,700	--	18,300	18,300
Mathis	800	--	800	--	2,500	2,500	--	7,000	7,000
Other cities	800	600	1,400	1,500	1,300	2,800	2,200	1,400	3,600
Total	16,400	3,500	19,900	27,200	12,500	39,700	40,500	26,700	67,200

[1] The remaining 95% of the total requirement is included in the Nueces-Rio Grande Coastal Basin.

about 250 mg/l, except during possible extended dry periods.

The main stem of the Nueces River contains water of very good quality throughout most of the length, and flows in most areas contain less than 300 mg/l of dissolved solids. Low flows of the stream are relatively highly mineralized locally, however, principally as a result of irrigation return flows and the discharge of municipal wastewaters. The discharge-weighted average dissolved solids concentration of the river as it enters Lake Corpus Christi is less than 250 mg/l, but as a result of evaporation the annual discharge-weighted average concentration of dissolved solids in water released from the reservoir generally ranges between 250 and 400 mg/l. The flow of the river below Lake Corpus Christi also frequently becomes more saline as a result of inflows of saline ground water and drainage from oil field areas.

Organic loads in most streams of the basin are low. However, relatively high nutrient concentrations occur periodically in streams in some areas, principally in the Nueces River below Uvalde. This apparently results from irrigation return flows entering the stream from the Winter Garden.

About 308 thousand acres was irrigated in the basin in 1964, of which about 290 thousand acres was in the Winter Garden and adjacent lands below the Balcones Escarpment, in the upper part of the basin. About 265 thousand acres of this total irrigated acreage was supplied by ground water, the remainder by locally available surface water supplies and diversions from Medina Lake in the San Antonio River Basin under an existing permit.

As an element of the Texas Water System, it is proposed to divert at least 200 thousand acre-feet of water annually into the Winter Garden irrigation area from releases and spills from Amistad Reservoir in the Rio Grande Basin. This proposed diversion, together with projected locally available supplies, would provide supplies sufficient to irrigate approximately 170 thousand acres in the upper Nueces River Basin by the year 2020. This proposed diversion project may offer the possibility for conjunctive operation with the ground water supplies through a managed system of ground water recharge, surface water storage, and irrigation use from either ground water, surface water, or both. This could result in a substantial increase in the total water supply available and lower unit costs of supply than the unit cost of surface water alone.

Existing Upper Nueces Reservoir could possibly be used for regulation of supplies diverted from the Rio Grande.

Water supplied to the Winter Garden by diversion of releases from Amistad Reservoir would be replaced by water delivered through the Coastal Canal of the Texas Water System to the area served from Amistad and International Falcon Reservoirs in the Lower Rio Grande Valley. The allocated reimbursable costs of providing this replacement water through the Canal would have to be assumed as a repayment obligation by the beneficiaries in the Winter Garden area in addition to the costs of the diversion and distribution facilities required in the Winter Garden area.

In the coastal area of the basin, approximately 20 thousand acres would also be irrigated as a part of the Coastal Bend irrigation adjoining the planned 180 thousand acres in this project within the San Antonio-Nueces Coastal Basin. Approximately 27,400 acre-feet of water would be delivered annually from the Coastal Canal to supply these 20 thousand irrigated acres in the basin. Together with the locally available water supplies projected to be available in the lower basin, this project would provide for irrigation of a total of about 30 thousand acres by 1990 and 37 thousand acres by the year 2020 in this coastal area of the basin.

Ground water occurs in the Edwards-Trinity (Plateau), Edwards (Balcones Fault Zone), Carrizo-Wilcox, and Gulf Coast Aquifers which underlie the basin. Approximately 200 thousand acre-feet of water is estimated to be available as an annual yield from the Edwards-Trinity (Plateau) Aquifer; however, large-scale development of these supplies would reduce springflows from the aquifer, which provide part of the downstream surface water supplies and also recharge to intensely developed aquifers to the south. This water is therefore not included in the basin's total available ground water supplies. In addition, the geologic and hydraulic characteristics of this aquifer are not conducive to large-scale development.

Approximately 168 thousand acre-feet of ground water is available as a perennial yield from the remaining major aquifers in the basin, of which approximately 90 thousand acre-feet is available annually from the Edwards (Balcones Fault Zone) Aquifer, 63 thousand acre-feet from the Carrizo-Wilcox Aquifer and about 15 thousand acre-feet, or less, from the Gulf Coast Aquifer. It is projected that about 168 thousand acre-feet of ground water will be used in the basin annually by the year 2020.

Lake Corpus Christi is the largest existing surface water reservoir in the basin. This reservoir provides municipal and industrial supplies for the Corpus Christi area, the City of Alice in the adjacent Nueces-Rio Grande Coastal Basin, and areas of the San Antonio-Nueces Coastal Basin under existing permits. Upper Nueces Reservoir on the Nueces River north of Crystal City is an important source of irrigation water for the Winter Garden.

The Texas Water Plan includes possible construction of Choke Canyon or R&M, Montell, Concan, and

Sabinal Reservoirs in the basin. Choke Canyon and R&M Reservoirs are included as alternative projects, the choice of which reservoir would be built will depend on plans of local interests.

Montell, Concan, and Sabinal Reservoirs would provide essential flood control on the upper Nueces, Frio, and Sabinal Rivers; supplemental recharge to the Edwards Aquifers during periods of high streamflow; and recreational potential in the basin that will supply a large tourism demand. Required fresh water inflows to Corpus Christi Bay not available from tributary sources would be provided from the Coastal Canal of the Texas Water System.

Table IV-47.--Water Supply and Demand—Nueces River Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	67.2
Irrigation	379.2
Mining	1.2
	447.6

PLANNED
2020 DEVELOPED SUPPLY

SOURCE*	2020 SUPPLY	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FOR OUT-OF-BASIN REQUIREMENT	SUPPLY FROM TEXAS WATER SYSTEM
Choke Canyon & Corpus Christi	222.5	52.6	169.9	
Coastal Canal	27.4	27.4		27.4
Rio Grande Basin	200.0	200.0		200.0
Ground Water	167.6	167.6		
	617.5	447.6	169.9	227.4

* Additional reservoirs for possible development include R&M, Montell, Concan, and Sabinal.

NOTE: Thousands of Acre-Feet Annually.

NUECES-RIO GRANDE COASTAL BASIN

The Nueces-Rio Grande Coastal Basin is bounded on the north by the Nueces River Basin and Corpus Christi Bay, on the west by the Rio Grande Basin, and on the south by the Rio Grande. Maximum elevation in the basin is about 900 feet in southeastern Webb County. The total drainage area of the basin is 10,442 square miles.

Average annual runoff in this generally flat coastal area is estimated to be less than 50 acre-feet per square mile. Many of the natural stream channels are not deeply incised, and drainage is generally rather poorly defined. The major drainage system includes Petronila, San Fernando, Santa Gertrudis, and Los Olmos Creeks in the upper part of the basin, which drain into Baffin Bay, and Arroyo Colorado in the lower basin.

Runoff within the upper reaches of Petronila Creek is of comparatively good quality; however, the lower part of the stream presently consists largely of oil field brines and industrial wastes, and dissolved solids concentrations in streamflows generally range between 30 thousand and 50 thousand mg/l.

San Fernando Creek and its principal upstream tributaries Chiltipin and San Diego Creeks contain good quality flows; however, the quality of water in lower reaches of the stream is degraded by oil field wastes, and flows usually contain between 1,000 and 2,000 mg/l of dissolved solids.

The Arroyo Colorado, including the Main Floodway and North Floodway, presently serves principally for the drainage of periodic floodwaters in the lower basin. The base flow of Arroyo Colorado is partly sustained by natural ground water discharge, but largely by municipal effluents, process waters from canneries and vegetable packing plants, some industrial cooling water, and irrigation return flows. The waters of the Arroyo Colorado are presently used principally for recreation in the Mercedes and Arroyo City areas, and for irrigation. The main channel has been made navigable to the vicinity of Harlingen, and is thus tide affected for a considerable distance upstream.

Except during floods, the quality of water in the Arroyo Colorado is very poor, and the concentration of

Table IV-48.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Nueces-Rio Grande Coastal Basin

(Acre-Feet Per Year)

COASTAL BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
Alice	2,700	-	2,700	2,700	2,600	5,300	2,700	6,600	9,300
Corpus Christi (95%) 1/	-	54,900	54,900	-	165,500	165,500	-	347,300	347,300
Falfurrias	2,600	-	2,600	3,200	-	3,200	3,900	-	3,900
Kingsville	5,900	-	5,900	3,000	12,400	15,400	-	31,800	31,800
Robstown-San Pedro	-	2,900	2,900	-	6,900	6,900	-	15,800	15,800
Other cities	14,400	-	14,400	27,800	-	27,800	33,800	6,400	40,200
Zone 2									
Other cities	3,900	-	3,900	3,400	-	3,400	3,400	-	3,400
Zone 3									
Brownsville	-	10,100	10,100	-	20,300	20,300	-	33,200	33,200
Donna	-	1,900	1,900	-	4,400	4,400	-	7,700	7,700
Edinburg	-	6,900	6,900	-	11,900	11,900	-	18,200	18,200
Harlingen	-	9,600	9,600	-	19,400	19,400	-	31,900	31,900
McAllen	-	6,600	6,600	-	15,300	15,300	-	28,000	28,000
Mercedes	-	1,600	1,600	-	4,000	4,000	-	6,900	6,900
Mission	-	1,800	1,800	-	5,600	5,600	-	9,200	9,200
Pharr	-	1,800	1,800	-	4,300	4,300	-	7,500	7,500
Raymondville	-	1,400	1,400	-	3,100	3,100	-	6,700	6,700
San Benito	-	6,500	6,500	-	10,700	10,700	-	17,000	17,000
Weslaco	-	2,500	2,500	-	5,300	5,300	-	10,400	10,400
Other cities	-	25,700	25,700	-	28,600	28,600	-	32,800	32,800
Total Municipal and Industrial	29,500	134,200	163,700	40,100	320,300	360,400	43,800	616,900	660,700

1/ Includes 95% of the use and requirements of Corpus Christi; the remaining 5% is included in the Nueces River Basin.

dissolved solids averages about 4 thousand mg/l, with chloride concentrations generally ranging between 1,200 and 1,300 mg/l. The water is extremely hard, poorly suited for irrigation due to excessive salinity and sodium content, and throughout much of the upper reaches generally carries a heavy organic load, high nutrient concentrations, and large bacterial populations.

Ground water is supplied from the Gulf Coast Aquifer, which underlies all of the basin with the exception of the eastern parts of Nueces, Willacy, and Cameron Counties, where no fresh ground water is available. Approximately 54 thousand acre-feet of ground water is available, mostly from the northern part of the basin, as a safe annual yield from the Gulf Coast Aquifer in the basin. It is projected that about 52 thousand acre-feet of these ground water supplies may be used annually in the basin by the year 2020, principally for municipal and industrial use in the northern part of the basin west of the Corpus Christi area.

The southern part of the basin includes much of the Lower Rio Grande Valley irrigation area, and more than 742 thousand acres was irrigated in this part of the basin in 1964, principally by water diverted from the Rio Grande. Future supplies are projected to be insufficient to sustain the present level of irrigation, and additional supplies are proposed to be made available to this area through the Texas Water System. This proposed project is described in the summary of the Rio Grande Basin.

A large segment of the proposed Coastal Bend irrigation lies within the upper part of the Nueces-Rio Grande Coastal Basin south of Corpus Christi. Approximately 453 thousand acre-feet of water would be delivered through the Coastal Canal to this area to supply water sufficient to irrigate approximately 300 thousand acres annually within this proposed project area.

The Coastal Canal would also deliver 283,100 acre-feet annually to the Corpus Christi and Kingsville areas to meet the total projected industrial water requirements of these areas. Thus, with the development of a large irrigation project in the upper basin, sufficient water supplies to meet projected industrial expansion, and a firm supply of water for the Lower Rio Grande Valley, the economy of the basin will be greatly enhanced under the Texas Water Plan.

Surface storage reservoirs in this coastal basin include Alice Terminal, Tranquitas, Valley Acres, Monte Alto, and Loma Alta Reservoirs. The latter three are off-channel reservoirs used for temporary storage of irrigation water pumped from the Rio Grande. Alice Terminal Reservoir provides storage for municipal water supplies pumped from Lake Corpus Christi in the adjacent Nueces River Basin, and Tranquitas Reservoir on Tranquitas Creek provides water supplies for the King Ranch. No additional on-channel surface water storage reservoirs are proposed for construction in the basin under the Texas Water Plan. Future requirements, which will be in excess of locally available supplies, are proposed to be met by water imported through the Texas Water System.

Table IV-49.--Water Supply and Demand—Nueces-Rio Grande Coastal Basin—2020 Conditions

ESTIMATED
2020 IN-BASIN REQUIREMENT

Municipal & Industrial	660.7
Irrigation	2,337.8
Mining	2.0
	3,000.5

PLANNED
2020 DEVELOPED SUPPLY

SOURCE	SUPPLY FOR IN-BASIN REQUIREMENT	SUPPLY FROM TEXAS WATER SYSTEM
Rio Grande Basin	848.8	
Nueces Basin	124.3	
Ground Water	51.8	
Coastal Canal	1,975.6	1,975.6
	3,000.5	1,975.6

NOTE: Thousands of Acre-Feet Annually.

RIO GRANDE BASIN

The Rio Grande rises in southern Colorado, flows southerly across New Mexico, and enters Texas 20 miles northwest of El Paso. It forms the boundary between the United States and Mexico from El Paso to the Gulf of Mexico. Elevation of the streambed at the New Mexico-Texas line is about 3,000 feet. The total drainage area of the Rio Grande at its mouth is 182,215 square miles, of which 88,968 square miles are within the United States. The Pecos River and Devils River are the principal tributaries of the Rio Grande in Texas. The total drainage area of the basin within Texas is 48,259 square miles.

Amounts and rates of runoff vary widely throughout the Rio Grande Basin. Reservoirs, numerous diversions, and substantial return flows also modify the flows of the main stem throughout its length, and the effects of upstream development have progressively reduced the flow of the river as it enters Texas.

The average annual flow of the Rio Grande at El Paso for the period 1890-1963 was 623,500 acre-feet. During the period 1938-1966, the flow at El Paso averaged 398,594 acre-feet annually, and during the period 1951 through 1966, which generally reflects current conditions, the flow at El Paso averaged 239,436 acre-feet annually.

Runoff throughout the Texas part of the basin varies widely. The flow of the main stem of the Rio Grande is substantially modified locally by diversions and return flows, and the river is regulated by existing International Falcon Reservoir. Amistad Reservoir, which is presently under construction, will provide additional regulation of the Rio Grande. The flow of the Pecos River in Texas is controlled by releases from Red Bluff Reservoir and further modified by diversions and return flows downstream. Flows of the Devils River are essentially uncontrolled above its mouth.

Table IV-50.--Municipal and Industrial Water Requirements Supplied by Ground and Surface Water, Rio Grande Basin

(Acre-Feet Per Year)

RIVER BASIN ZONE AND AREA OF USE	1960			PROJECTED 1990			PROJECTED 2020		
	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL	GROUND WATER	SURFACE WATER	TOTAL
Zone 1									
El Paso	52,200	12,200	64,400	120,100	12,200	132,300	50,000	201,900	251,900
Other cities	3,300	—	3,300	7,200	—	7,200	—	11,200	11,200
Zone 2									
Other cities	1,200	—	1,200	2,200	—	2,200	3,600	—	3,600
Zone 3									
Other cities	800	—	800	1,600	—	1,600	2,600	—	2,600
Zone 4									
Monahans	5,300	—	5,300	9,300	—	9,300	13,900	—	13,900
Kermit	4,200	—	4,200	6,000	—	6,000	8,500	—	8,500
Other cities	3,800	—	3,800	6,900	—	6,900	10,900	—	10,900
Zone 5									
Alpine	900	—	900	2,000	—	2,000	3,600	—	3,600
Fort Stockton	1,500	—	1,500	2,800	—	2,800	4,800	—	4,800
Pecos	3,400	—	3,400	6,600	—	6,600	10,400	40,000	50,400
Other cities	4,900	600	5,500	8,200	1,000	9,200	12,200	1,300	13,500
Zone 6									
Other cities	1,900	—	1,900	2,200	—	2,200	2,500	—	2,500
Zone 7									
Del Rio	4,000	—	4,000	—	8,200	8,200	—	14,900	14,900
Eagle Pass	—	2,200	2,200	—	4,600	4,600	—	7,900	7,900
Laredo	—	10,000	10,000	—	19,100	19,100	—	32,600	32,600
Other cities	400	—	400	700	—	700	800	—	800
Zone 8									
Rio Grande City	—	1,400	1,400	—	2,600	2,600	—	5,200	5,200
Other cities	—	2,300	2,300	100	2,900	3,000	100	3,400	3,500
Total	87,800	28,700	116,500	175,900	50,600	226,500	123,900	278,400	442,300

The United States has entered into two international treaties with Mexico pertaining to allocation of the waters of the Rio Grande. In 1906, the United States and Mexico signed a Treaty providing for the delivery of 60 thousand acre-feet of water annually by the United States to Mexico from the Rio Grande in the El Paso-Juarez Valley upstream from Fort Quitman, Texas. If shortages of water occur in the United States in the Rio Grande Compact area, deliveries to Mexico may be reduced in proportion to the reduction of deliveries to the basin within the Compact area.

A Treaty between the United States and Mexico encompassing the Rio Grande and the Colorado and Tijuana Rivers was ratified by both countries in 1945. The provisions of this Treaty pertaining to the Rio Grande include that part of the river between Fort Quitman, Texas, and the Gulf of Mexico. The Treaty provides for allocation of water between the two countries and for the joint construction of as many as three major storage reservoirs on the main stream for water supply and flood control. The development of hydroelectric power generation at the major storage reservoirs is also permitted. Control of flood waters in the Rio Grande is a joint function. The International Boundary and Water Commission is designated to administer the responsibilities and obligations prescribed by the treaty. Falcon Dam was completed in 1953 as the first major storage project on the Rio Grande. Amistad Dam, the second major project, is presently under construction.

The Rio Grande Compact between the States of Colorado, New Mexico, and Texas was approved by the Legislatures of these three States and by the Congress in 1939. This Compact includes that part of the Rio Grande Basin in Texas above Fort Quitman, Hudspeth County. The Compact provides for water delivery schedules from Colorado to New Mexico to Elephant Butte Reservoir upstream from El Paso. The Rio Grande Irrigation Project of the U.S. Bureau of Reclamation in the El Paso area includes lands in both New Mexico and Texas downstream from Elephant Butte Dam.

The Rio Grande Compact provides for release of water from project storage (Elephant Butte and Cavallo Reservoirs), when available, of 790 thousand acre-feet annually to the project. These project releases are used in the Mesilla Valley in New Mexico and the Rio Grande Project in Texas. This normal project release includes the allocation of water to the Republic of Mexico.

The Pecos River Compact between New Mexico and Texas was approved by the two States and the Congress in 1949. It includes the entire drainage area of the Pecos River. This Compact provides for an allocation of water to Texas which varies with streamflow and other conditions in New Mexico. The Compact also provides for cooperative programs for the salvage of water wasted by phreatophytes and for alleviation of the excessive salinity of the Pecos River.

These Compacts are discussed in more detail in Part II.

The surface water resources of the Rio Grande Basin also vary widely in quality owing to the size of the basin, wide variations in geology and climate, and the wide geographic distribution of concentrations of population, industry, and irrigated agriculture.

The flow of the Pecos River is highly saline for most of its length in Texas. Discharge of natural brine from aquifers a short distance above the Texas-New Mexico State line is largely responsible for inflows of highly saline water to Red Bluff Reservoir. Except during floods, the flow of the Pecos River in Texas for a considerable distance downstream from Red Bluff Reservoir consists principally of releases and some seepage from the reservoir, and since 1955, concentrations of dissolved solids in the river immediately below the reservoir have ranged between about 2,700 and 15,000 mg/l, exceeding about 7,500 mg/l during 50% of the days of flow. Chloride concentrations in these flows exceeded 1,000 mg/l about 95% of the time during this period.

Inflow of saline ground water, drainage from oil fields, and irrigation return flows to the river within the upper half of the Pecos River drainage system in Texas further contribute to the salinity problem. Flows of the river in the vicinity of Girvin in northern Pecos County are usually significantly more saline than upstream near Red Bluff Dam.

Runoff and ground water discharge from limestone aquifers in Crockett, Terrell, and Val Verde Counties in the lower half of the basin are comparatively low in dissolved solids, and the quality of the river continually improves downstream. However, because of the salinity problem within the upper part of the basin and the usually saline water released from Red Bluff Reservoir, the river in southern Val Verde County usually contains between 1,500 and 3,000 mg/l of dissolved solids.

Studies by the U.S. Geological Survey of the salinity problem in the Pecos River above Red Bluff Reservoir have resulted in the definition of several areas of natural brine inflow to the river, the most significant of which occurs near Malaga, New Mexico, where an average of about 430 tons of dissolved solids is contributed daily to the stream. In 1963, the U.S. Bureau of Reclamation completed construction of an experimental salinity alleviation project in this area, whereby the artesian head of the brine-contributing aquifer is reduced by pumping, and the brine pumped from the aquifer by a well is stored and evaporated in a nearby natural depression. Data provided by the U.S. Geological Survey indicate that as of December 1967, approximately 3,132 acre-feet of brine had been pumped from the aquifer by the project, representing a potential removal from the river of about 1.4 million tons of dissolved solids, of which about 1.3 million tons was sodium chloride.

The effects of this experimental project on the quality of water in the Pecos River are continually being evaluated, and hydrologic studies of the natural brine—contributing areas are continuing in an effort to find ways of further reducing the salinity of the river. The U.S. Bureau of Reclamation's phreatophyte eradication and control program presently under way in the basin (briefly described in Part III) will result in the salvage of substantial quantities of water which should also improve the quality of water in the river.

Concentrations of dissolved solids in the Rio Grande as it enters Texas generally range between 500 and 2,000 mg/l, the higher concentrations usually corresponding with the period of low flow during winter months. The long term discharge-weighted average dissolved solids concentration of the river at El Paso is approximately 800 mg/l.

Part of the flow of the river entering Texas is diverted for irrigation above El Paso, and most of the remainder for municipal use at El Paso and for irrigation in the El Paso Valley below the city. Between El Paso and the southern extent of the El Paso Valley, the main channel usually has very little flow except for local irrigation drainage and remaining municipal return flows from El Paso not used for irrigation upstream. These flows generally contain more than 1,000 mg/l of dissolved solids progressively increasing in salinity downstream. The organic load, including nutrient concentration, is high, as are bacterial populations.

Below the El Paso Valley irrigation projects, intermittent flows of the river consist largely of return flows. The flow of the river at Fort Quitman, 81 river miles below El Paso, averaged 21,256 acre-feet annually during the period 1951-1966 as compared to the annual average flow of 239,436 acre-feet at El Paso for the same period. Concentrations of dissolved solids in the river within this reach generally exceed 3,000 mg/l, although the long-term discharge-weighted average dissolved solids concentration of the river at Fort Quitman is about 1,700 mg/l.

Near Presidio, the Rio Conchos contributes good quality water (averaging less than 500 mg/l) to the river from Mexico, and Alimeto Creek in southern Brewster County contributes water having a weighted-average dissolved solids concentration of about 250 mg/l. The long-term discharge-weighted average dissolved solids concentration of the river entering Amistad Reservoir is about 550 mg/l.

The Devils River, which now drains into Amistad Reservoir, contains good quality water—the discharge-weighted average being slightly less than 250 mg/l of dissolved solids.

Before initiation of construction of Amistad Dam, the long-term weighted-average dissolved solids concentration of the Rio Grande between the reservoir site and downstream International Falcon Reservoir had been about 600 mg/l, although in recent years flows have averaged about 450 mg/l. Since closure of Falcon Dam in 1953, water released from the reservoir has generally contained between 450 and 550 mg/l of dissolved solids.

Below International Falcon Reservoir, saline irrigation return flows enter the river principally by way of the Morillo Drain in Mexico, which during recent years has contained a weighted-average dissolved concentration of more than 10 thousand mg/l. At Anzalduas Dam on the main stem of the Rio Grande near McAllen, just downstream from the entrance of Morillo Drain, concentrations of dissolved solids usually range between about 500 and 1,100 mg/l, the weighted average in recent years being about 750 mg/l.

A salinity alleviation project designed to divert the flows of Morillo Drain from the Rio Grande and convey these saline return flows through a 75 mile long channel to the Gulf of Mexico is presently nearing completion. This project, jointly funded by the United States and Mexico, will reduce the salinity of the lower reach of the Rio Grande and provide water more suitable for the municipal, industrial, and irrigation purposes for which it is presently being used in the Lower Rio Grande Valley.

Below the El Paso area, organic loading, dissolved-oxygen concentration, and the density of bacterial populations in flows of the Rio Grande vary widely. Severe dissolved-oxygen deficits and high bacterial populations occur in the main stem below Laredo. Organic loads are also comparatively high in the river below Del Rio, in the Lower Valley in Hidalgo County, and below Brownsville.

Irrigation is an extremely important segment of the economy of the basin and the Lower Rio Grande Valley part of the adjacent Nueces-Rio Grande Coastal Basin. The El Paso Valley is one of the oldest irrigation areas in Texas, growing produce for the local market; American and Egyptian (long staple) cotton, hay, and feed; and other crops in an area of sparse rainfall. About 64 thousand acres was irrigated in the El Paso Valley in 1964, supplied by releases from Elephant Butte Reservoir, return flows from upstream irrigators and the City of El Paso, and ground water. This acreage can possibly be maintained at near the present level of irrigation through the year 2020 provided return flows remain available; however, serious buildup of salt in soils has occurred in some areas as a result of the use of saline ground water during periods when streamflows are insufficient to meet irrigation demands. Solutions to this problem must be found in order to maintain this irrigation area.

The Texas Water Plan does not presently provide for delivery through the System of a supplemental supply for irrigation in the El Paso Valley and the irrigated areas downstream in Hudspeth County. However, if local interests are able to provide assurances of the repayment of the reimbursable costs of such deliveries, as these costs are defined in further planning studies, it would be possible to include added capacity in the System to provide water for this purpose. The physiography and geology of the region between Pecos and El Paso and the distance of travel make it inevitable that the cost of water delivered to irrigated lands in this area would be high.

Irrigated lands in the Pecos River Valley which produce cotton, alfalfa, grain sorghum, and other crops are presently supplied mostly by ground water which is being depleted and also increasing in salinity in some areas. Some of the irrigated acreage is also supplied by water from the Red Bluff Project, some from diversions of water from the Pecos River, and some is served from spring flows in the Balmorhea area. About 245 thousand acres was irrigated in the Pecos Valley in 1964. By 1990 it is estimated that ground water and the locally available surface water can supply about 150 thousand acres of irrigated land, and by 2020 these sources will be able to supply only about 37 thousand acres. To maintain the agricultural economy of this area, it is proposed to deliver water through the Trans-Texas Division of the Texas Water System to the Pecos Valley, 933 thousand acre-feet annually in 2020, to maintain irrigation at about the present level.

About 55 thousand acres was irrigated in 1964 along the Rio Grande below Amistad Reservoir and upstream from International Falcon Reservoir. There are additional irrigable lands in this reach, mostly in Maverick and Webb Counties. The Texas Water System would provide for 190 thousand acre-feet per year of net streamflow depletion from the Rio Grande to supply water sufficient to irrigate about 73 thousand acres annually in Maverick and Webb Counties. The depletion would be replaced by deliveries from the Coastal Canal to lands in the Lower Rio Grande Valley which would otherwise be served from Rio Grande storage.

Diversion of at least 200 thousand acre-feet of water annually from releases from Amistad Reservoir to the Winter Garden irrigation area is proposed as a project element of the Texas Water System. These diversions for irrigation use in the Winter Garden would be replaced by deliveries of water from the Coastal Canal to the existing irrigation areas presently served by the Rio Grande below International Falcon Reservoir. Replacement of these proposed upstream diversions in the irrigation service area below the reservoir would minimize the effect of such diversions on the combined system storage operation of Amistad and International Falcon Reservoirs. The unit cost of irrigation water delivered to the Winter Garden would include the cost of supplies delivered to the Lower Rio Grande Valley by the Coastal Canal to replace the gross amount of water diverted to the Winter Garden project.

Detailed studies of the extent of existing irrigation and of the water supply presently available in the Lower Rio Grande Valley (principally in the Nueces-Rio Grande Coastal Basin), conducted in connection with litigation involving water rights in the area, indicate that there is a shortage of a firm water supply from storage in reservoirs on the Rio Grande for the present irrigated areas. Under the Texas Water System, it is proposed to deliver a total of 385 thousand acre-feet of water annually through the Coastal Canal to this area to supplement the available irrigation supply for the existing irrigated lands. Through the same facilities, an additional 315 thousand acre-feet of water will be provided annually for development of proposed new irrigation development in the Nueces-Rio Grande Coastal Basin north of the existing irrigated lands. A total of about 316 thousand acres could be irrigated with these supplemental supplies, bringing the total 2020 irrigated acreage in this area to about 966 thousand acres annually.

Ground water aquifers present in the basin include the Alluvium and Edwards-Trinity (Plateau) major aquifers and the Bone Spring-Victorio Peak and Santa Rosa minor aquifers. More than 1.3 million acre-feet of ground water is presently used annually in the basin. However, only about 600 thousand acre-feet of ground water is available as a perennial yield from these aquifers and several small local aquifers in the basin. A substantial volume of water also occurs in the alluvial deposits bordering the Rio Grande; however, these supplies are hydraulically connected with the streamflows and are therefore not included in the total available ground water supply in the basin.

In addition, about 65 million acre-feet of ground water could possibly be economically pumped from storage in these aquifers, although the quality of these supplies would vary widely and a part of the water in storage is too saline for a wide range of beneficial uses.

Of the total ground water supplies available as an annual yield in the basin, about 50 thousand acre-feet is available from the alluvium and bolson deposits in the El Paso area, about 50 thousand acre-feet from Bone Spring-Victorio Peak Aquifer in the Dell City irrigation area of northeastern Hudspeth County, about 70 thousand acre-feet from the alluvium of the Pecos River Valley, and approximately 390 thousand acre-feet from the Edwards-Trinity (Plateau) Aquifer. Large-scale pumpage from the Edwards-Trinity (Plateau) Aquifer would reduce the base flow of streams such as the lower Pecos and Devils Rivers which drain the Edwards Plateau, thus reducing downstream surface water supplies.

It is estimated that approximately 275 thousand acre-feet of ground water will be used annually in the basin by the year 2020. About 124 thousand acre-feet of this total will be used for municipal and industrial

purposes (including the total annual safe yield of the aquifer in the El Paso area) and the remainder largely for irrigation, principally in the Dell City irrigation area and in the Pecos River Valley.

The most critical municipal water supply problem in the Rio Grande Basin is that of the City of El Paso, which is presently supplied principally by ground water and diversions from the Rio Grande. The Trans-Texas Division of the Texas Water System would provide 200 thousand acre-feet of water annually to El Paso to supplement supplies projected to be locally available and to meet the total projected 2020 municipal and industrial requirements of the area. However, even with optimum staging of construction of the Texas Water System, these supplemental supplies could not be delivered to the El Paso area before about the year 2000. Alternative possibilities for the city to meet projected municipal and industrial water requirements during the interim period include:

(1) Reallocation of surface water supplies presently used for irrigation in projects north and south of the city through renegotiations of the Bureau of Reclamation project contracts;

(2) reclamation, renovation through advanced wastewater treatment techniques, and reuse of return flows from the city and upstream irrigation;

(3) substantial increase in ground water pumpage above the safe yield of the aquifer, with a consequent probable significant increase in salinity of the ground water supplies pumped from storage;

(4) staged development of desalting facilities utilizing saline ground water pumped from storage in the lower part of the aquifer in the area; or

(5) a combination of two or more of the above alternatives which may provide the optimum solution to the water supply problem during the interim period.

Should desalting facilities be installed, these could possibly be utilized after the year 2000 to provide peaking capacity as a supplement to the imported water delivered to the city through the Texas Water System.

Table IV-51.--Water Supply and Demand—Rio Grande Basin—2020 Conditions

ESTIMATED 2020 IN-BASIN REQUIREMENT 3/

Municipal & Industrial	202.3
Irrigation	1,026.2
Mining	21.2
	1,249.7

PLANNED 2020 DEVELOPED SUPPLY

SOURCE	2020 SUPPLY	SUPPLY FOR: IN-BASIN REQUIREMENT	OUT-OF-BASIN REQUIREMENT	EXPORT UNDER TEXAS WATER SYSTEM
Rio Grande Basin	209.4	209.4		
Red Bluff & Balmorhea		70.2		
Amistad & Falcon	1,624.0 1/	659.3	764.7	200.0
Ground Water	290.1 2/	290.1		
Return Flow	104.8	20.7	84.1	
	2,298.5	1,249.7	848.8	200.0

1/United States (Texas) Share

2/Includes 14,000 acre-feet annually interconnected surface water Zone 2

3/Does not include municipal, industrial, and irrigation deficiencies of Trans-Pecos and El Paso areas of the Rio Grande Basin which will be supplied through the Trans-Texas Canal, as explained in text.

NOTE: Thousands of Acre-Feet Annually.

The Trans-Texas Division would also deliver 40 thousand acre-feet of municipal and industrial supplies to the Pecos area to meet total projected requirements in the area, including industrial expansion.

Supplemental water supplies will also be needed to meet projected municipal and industrial requirements of the City of Brownsville and other towns and communities in the Lower Rio Grande Valley in the Nueces-Rio Grande Coastal Basin, which are presently supplied from the Rio Grande and by ground water. The Coastal Canal of the Texas Water System would deliver 150 thousand acre-feet annually to the Lower Rio Grande Valley to meet these total projected 2020 requirements. However, as in the El Paso area, supplemental water supplies will be needed before it will be feasible to deliver water into the areas through the Texas Water System. Results of studies conducted by the Board, in cooperation with the Office of Saline Water of the United States Department of the Interior, indicate that one or more large-scale desalting plants offer an immediate interim solution to this problem. Such plants would obtain source water either from the Gulf of Mexico or from saline ground water supplies in the Gulf Coast Aquifer, or both.

Major existing reservoirs in the Texas part of the Rio Grande Basin include San Esteban Reservoir in Presidio County, Red Bluff and Balmorhea Reservoirs in Reeves County, Devils Lake and Lake Walk on the Devils River, Casa Blanca Reservoir near Laredo, and International Falcon Reservoir on the Rio Grande. Amistad Reservoir on the Rio Grande near Del Rio is nearing completion. International Falcon and Amistad Reservoirs are multiple-purpose projects of the International Boundary and Water Commission. Devils Lake and Lake Walk will be inundated by Amistad Reservoir. In addition to the flood control storage in International Falcon and Amistad Reservoirs, the International Boundary and Water Commission maintains a levee and floodway system in the Lower Rio Grande Valley to convey Rio Grande floodwaters to the Gulf. Storm waters resulting from Hurricane Beulah in 1967 emphasized the need for additional flood control improvements in this area.

THE HIGH PLAINS

The High Plains of Texas is the southernmost extension of the Great Plains Physiographic Province of North America which extends from the northern edge of the Pecos Valley across western Texas, Oklahoma, Kansas, and Nebraska into southern South Dakota. The High Plains within Texas covers an area of about 35 thousand square miles, and includes the Canadian River Basin and the upper parts of the Red, Brazos, and Colorado River Basins within the State. This broad area, which averages about 300 miles from north to south and about 120 miles from east to west, includes parts or all of 42 counties within the State.

As the result of the incision of the channel of the Canadian River, the High Plains of Texas has been separated into two distinct provinces. The North Plains includes all of the Texas Panhandle north of the Canadian River, an area of about 9,300 square miles, and the South Plains includes the remaining 25,700 square miles.

The High Plains surface is essentially flat, sloping eastward to a boundary which, in most places, is sharply defined by a prominent escarpment ranging upward to several hundred feet high. The surface is characterized by thousands of small shallow depressions termed "playas," several large playa lakes, and locally sand dunes and small stream valleys.

Soils range from principally sandy types in the South Plains to heavier, clayey types in much of the North Plains.

Average annual precipitation ranges from about 12 inches in the southwestern part of the High Plains to about 22 inches in the northeastern Panhandle. Much of the annual precipitation is local rather than regional in nature, and a large percentage of the annual total occurs within short periods of time, particularly during the growing season (April through September) when on the average about 70% of the annual precipitation falls. Most of the precipitation on the High Plains is evaporated, absorbed by the soil (part of which is later evaporated or transpired), or collected in the numerous shallow playas of the region. Most of the water collected in these depressions evaporates, although a small part percolates downward.

An intensive study is continuing of the possible health hazards from mosquito infestations from water accumulating in the playas. Encephalitis has been a problem in some areas, and a continuing program of modification of the thousands of playas for water conservation and mosquito control is needed.

Virtually all of the water supply for irrigation, producing cotton, grain sorghum, wheat, vegetables, and other crops, is pumped from underlying Ogallala Aquifer. In 1964, about 5.1 million acres was irrigated in the High Plains. Although the volume of ground water pumped annually for irrigation varies somewhat from year to year according to the amount or frequency of precipitation received during the growing season, irrigation is still expanding, principally in the North Plains. However, on the basis of studies of the irrigable areas remaining and the rate of depletion of the existing ground water supply, it is projected that irrigated acreage will reach a peak of about 6 million acres by about 1980. Up to that time, expansion of irrigated acreage in the North Plains will proceed at a higher rate than reduction in total irrigated acreage in areas to the south.

After about 1980, irrigated acreage will steadily decline to a total of about 2.2 million acres, assuming certain levels of ground water remaining as recoverable from storage by the year 2020, unless a supplemental irrigation supply is made available to the area.

The Ogallala Formation of Pliocene age, and locally overlying soil profiles and alluvial and windblown deposits of more recent geologic age, covers virtually all of the North Plains with the exception of the Canadian River Valley where erosion has exposed older geologic formations. The formation covers about 22 thousand square miles of the South Plains.

In this area of limited water supplies, the saturated part of the Ogallala Formation constitutes the principal source of ground water and virtually all of the municipal, industrial, and irrigation water supply. The thickness of the saturated part of the formation and the rate and magnitude of ground water movement through the formation varies widely. These are key factors in the performance of wells and the extent of ground water development. Although the quality of water in the Ogallala aquifer ranges over wide limits within relatively short distances, the water, as well as most of the water in overlying deposits, is satisfactory for almost all present uses.

About 379 million acre-feet of ground water is stored in the Ogallala Formation in the High Plains. Of this total, about 200 million acre-feet occurs in that part of the formation in the Canadian River Basin, 60 million acre-feet in the Red River Basin, 89 million acre-feet in the Brazos River Basin, and about 30 million acre-feet in the Colorado River Basin. Of this total, at least 280 million acre-feet of water is estimated to be economically recoverable from storage, and some estimates are somewhat higher. By the year 2020, about 1.28 million acre-feet of the remainder of this estimated economically recoverable supply will be pumped annually from the aquifer within the Canadian River Basin, approximately 427 thousand acre-feet from the aquifer in the Brazos River Basin, and the remainder from that part of the aquifer lying within the Red and Colorado River Basins.

Annual water level measurements, made in hundreds of selected water wells throughout the High Plains show that the ground water supply in the Ogallala Aquifer is being depleted. This depletion is most pronounced in the major irrigation areas in the northern part of the South Plains and in areas to the south where municipal and industrial supplies are pumped, such as in Martin County.

Extensive efforts are underway to slow the rate of depletion by attaining a highly efficient use of the available ground water supplies through water conservation practices, including measures to utilize the natural rainfall more effectively, playa lake modifications, underground plastic pipe, sprinkler systems, changes in cropping patterns, lining of irrigation ditches to reduce losses, recirculating systems, plant hormone study, and others which may be developed.

The principal geologic structure of the area is the Permian Basin, an elongated geologic basin extending north and south and centered almost directly under the South Plains. There are two notable geologic features in formations underlying the Ogallala Formation—the Bravo Dome, centered in Oldham County, and the Matador Arch, centered along the Hockley-Lamb County line. These geologic structures are particularly significant in the area because they influence the accumulation and the direction and rate of movement of ground water in the Ogallala Aquifer and other local water-bearing formations. Deeply incised stream channels in the rocks underlying the Ogallala Aquifer and other physiographic features of the pre-Ogallala surface strongly affect the geographic distribution of saturated thickness and have also affected the geologic characteristics of the Ogallala Formation and the related hydraulic characteristics of the aquifer.

From the studies which have been conducted, it is apparent that supplemental water supplies for irrigation in the High Plains must be obtained from out-of-State sources. There is not sufficient surface water available from the eastern river basins of Texas for export for irrigation purposes to sustain existing irrigation development in the High Plains area.

Under the Texas Water Plan, up to 6,605,000 acre-feet of water would be delivered through the Trans-Texas Division of the Texas Water System to supplement the remaining ground water supply in the High Plains area. This water would be delivered to the High Plains area through the Trans-Texas Canal and would be partly supplied by surpluses imported from the Mississippi River.

Additional importation will probably be necessary at a later point in time.

Before construction of a water delivery system to the High Plains can be initiated, however, a master district, or master districts, must be created which will have the authority and the revenue capacity—through water sales and tax sources—to commit the credit of the area to repayment of the reimbursable costs which will be allocated to irrigation supply.

The major surface water supply reservoir of the High Plains is Lake Meredith on the Canadian River. The 322 mile long aqueduct system from this reservoir, constructed and operated by the U.S. Bureau of Reclamation, provides water supplies to 11 cities in the High Plains. White River Reservoir, located east of the escarpment in Crosby County, provides municipal water supplies to 4 cities of the area. Several small reservoirs are proposed for construction in the western part of the North Central Texas region, which may also provide municipal and industrial supplies for a few communities in the High Plains region of Texas.

Table IV-52.--Incremental Capacities of Major Reservoirs, Existing or Under Construction

Storage Capacity in Thousands of Acre-Feet

BASIN & RESERVOIR	FLOOD CONTROL	CONSERVATION	DEAD	TOTAL
CANADIAN—				
Rita Blanca	0.0	12.1	0.0	12.1
Meredith	544.0	821.0	0.0	1,365.0
RED—				
Bivins	0.0	5.1	0.0	5.1
Buffalo	0.0	18.1	0.0	18.1
Greenbelt	0.0	50.3	9.5	59.8
Baylor Creek	0.0	9.2	0.0	9.2
Kemp 5/	200.0	245.8	80.2	526.0
Diversion	0.0	40.0	0.0	40.0
Santa Rosa	0.0	11.6	0.0	11.6
Buffalo Creek	0.0	13.8	1.1	14.9
Kickapoo	0.0	98.0	8.0	106.0
Wichita	0.0	11.1	3.0	14.1
Arrowhead	0.0	211.5	16.5	228.0
Farmers Creek	0.0	20.3	5.1	25.4
Moss	0.0	2106	1.6	23.2
Texoma	2,615.0	1,730.0	1,047.0 1/	5,392.0
Randall 2/	0.0	5.4	—	5.4
Brushy Creek 2/	0.0	6.2	10.6	16.8
Timber Creek (Bonham Lake)	0.0	12.0	1.0	13.0
Coffee Mill Creek	0.0	10.0	0.0	10.0
Pat Mayse	64.6	124.5	4.6	193.7
Crook	0.0	7.2	0.0	7.2
SULPHUR—				
River Crest 2/	0.0	7.2	0.0	7.2
Texarkana	2,509.0	145.3	0.0	2,654.3
CYPRESS—				
Franklin County (Big Cypress Creek)	0.0	71.8	1.2	73.0
Ellison Creek	0.0	23.9	0.8	24.7
Johnson Creek	0.0	10.1	0.0	10.1
Lake O' the Pines	587.2	243.2	11.7	842.1
Caddo	0.0	136.5	38.5	175.0
SABINE—				
Tawakoni	0.0	907.2	29.0	936.2
Holbrook	0.0	7.8	0.2	8.0
Quitman	0.0	7.4	0.0	7.4
Hawkins	0.0	10.0	0.3	10.3
Winnsboro	0.0	6.6	0.0	6.6
Gladewater	0.0	6.2	0.7	6.9
Cherokee	0.0	43.6	3.1	46.7
Murvaul	0.0	43.7	2.1	45.8
Toledo Bend	0.0	3,790.8	686.2 4/	4,477.0
NECHES—				
Flat Creek	0.0	27.0	5.8	32.8
Palestine Enlargement (Blackburn Crossing) 6/	0.0	401.4	8.6	410.0
Tyler (Including Tyler East)	0.0	85.5	1.9	87.4
Jacksonville	0.0	29.8	0.7	30.5
Striker Creek	0.0	23.9	2.8	26.7
Kurth 2/	0.0	16.2	0.0	16.2
Sam Rayburn	1,148.9	1,400.6	1,452.0 1/	4,001.5
B. A. Steinhagen	0.0	40.3	28.4	68.7
TRINITY—				
Among G. Carter	0.0	16.0	4.0	20.0
Bridgeport 8/	0.0	233.9	37.0	270.9
Eagle Mountain	0.0	135.5	47.2	182.7
Worth	0.0	30.6	3.0	33.6
Weatherford	0.0	15.2	4.4	19.6
Benbrook	76.5	77.5	10.8	164.8
Arlington	0.0	43.0	2.7	45.7
Walnut Creek	0.0	2.9	1.1	4.0
Mountain Creek	0.0	11.2	15.9	27.1
Garza-Little Elm	520.9	481.8	0.2	1,002.9
North	0.0	17.0	0.0	17.0

Table IV-52.--Incremental Capacities of Major Reservoirs, Existing or Under Construction--Continued

BASIN & RESERVOIR	FLOOD CONTROL	CONSERVATION	DEAD	TOTAL
TRINITY (Cont'd.)—				
Grapevine	238.3	165.1	23.4	426.8
White Rock	0.0	8.2	4.1	12.3
Lavon Enlargement	412.5	95.8	47.8	556.1
Ray Hubbard (Forney)	0.0	483.7	6.3	490.0
Trinidad 2/	0.0	7.8	0.0	7.8
Terrell	0.0	7.3	1.0	8.3
Joe B. Hogsett (Cedar Creek)	0.0	661.1	17.9	679.0
Turkey Creek	0.0	3.6	1.1	4.7
Waxahachie	0.0	12.6	1.0	13.6
Bardwell	79.6	49.5	5.4	134.5
Halbert	0.0	6.6	0.9	7.5
Navarro Mills	143.2	53.2	7.7	204.1
Houston County	0.0	18.8	0.8	19.6
Livingston	0.0	1,675.0	75.0	1,750.0
Wallisville	0.0	46.7	12.4	59.1
Anahuac 2/	0.0	35.3	0.0	35.3
SAN JACINTO—				
Conroe	0.0	420.5	9.8	430.3
Houston	0.0	116.7	41.6	158.3
Sheldon	0.0	5.4	0.0	5.4
Addicks	204.5	0.0	0.0	204.5
Barker	207.0	0.0	0.0	207.0
BRAZOS—				
Buffalo Springs	0.0	5.4	0.0	5.4
White River	0.0	36.4	1.8	38.2
Sweetwater	0.0	8.2	3.7	11.9
Abilene	0.0	8.0	1.8	9.8
Kirby	0.0	4.8	2.8	7.6
Fort Phantom Hill	0.0	67.0	7.3	74.3
Stamford	0.0	47.6	12.4	60.0
Hubbard Creek	0.0	277.8	40.0	317.8
Daniel	0.0	3.0	7.0	10.0
Cisco	0.0	6.5	2.4	8.9
Leon	0.0	17.5	9.8	27.3
Graham	0.0	47.0	5.6	52.6
Possum Kingdom	0.0	188.1	536.3	724.4
Palo Pinto Creek	0.0	39.5	4.6	44.1
Mineral Wells	0.0	5.0	3.4	8.4
DeCordova Bend	0.0	105.4	44.6	150.0
Proctor	314.8	37.5	21.9	374.2
Pat Cleburne	0.0	18.3	7.3	25.6
Whitney	1,372.4	381.9	245.2 1/	1,999.5
Waco	553.3	104.1	69.0	726.4
Belton	640.0	398.5	59.1	1,097.6
North San Gabriel 5/	87.6	29.2	14.0	130.8
Laneport 5/	162.2	37.9	44.1	244.2
Stillhouse Hollow	394.7	218.2	17.5	630.4
Lake Creek	—	—	—	—
Mexia	0.0	0.0 3/	10.0	10.0
Trading House Creek 2/	0.0	37.8	0.0	37.8
Camp Creek	0.0	7.7	0.9	8.6
Alcoa	0.0	10.5	0.0	10.5
Somerville 8/	337.7	143.9	25.9	507.5
Smithers	0.0	18.0	0.0	18.0
William Harris 2/	0.0	11.1	0.9	12.0
Eagle Nest—Manor Lake	0.0	18.0	0.0	18.0
Brazoria 2/	0.0	21.3	0.7	22.0
COLORADO—				
J.B. Thomas	0.0	172.1	31.6	203.7
Colorado City	0.0	21.6	9.4	31.0
Champion Creek	0.0	36.8	5.8	42.6
Robert Lee	0.0	454.8	34.0	488.8
Oak Creek	0.0	34.5	4.8	39.3
San Angelo	277.2	107.0	12.2	396.4
Twin Buttes	454.4	171.9	14.3	640.6
Nasworthy	0.0	12.4	0.0	12.4
Coleman	0.0	36.9	3.1	40.0
Hords Creek	0.0	8.5	0.2	8.7
Brady Creek	0.0	28.6	0.5	29.1
Brownwood	0.0	133.2	10.2	143.4
Buchanan	0.0	756.9	235.2	992.1
Inks	0.0	17.0	—	17.0

Table IV-52.--Incremental Capacities of Major Reservoirs, Existing or Under Construction--Continued

BASIN & RESERVOIR	FLOOD CONTROL	CONSERVATION	DEAD	TOTAL
COLORADO (Cont'd.)—				
Lyndon B. Johnson	0.0	117.3	21.2	138.5
Marble Falls	0.0	8.8	—	8.8
Travis	778.0	1,172.0	—	1,950.0
Austin	0.0	20.0	1.0	21.0
Decker Creek	0.0	33.9	0.0	33.9
Bastrop 2/	0.0	16.6	0.0	16.6
Eagle Lake 2/	0.0	9.6	0.0	9.6
GUADALUPE—				
Canyon	354.7	383.3	2.9	740.9
Dunlap	0.0	3.6	2.4	6.0
McQueeney	0.0	5.0	0.0	5.0
H-4	0.0	5.4	1.3	6.7
SAN ANTONIO—				
Medina	0.0	251.7	2.3	254.0
Victor Braunig 2/	0.0	26.5	0.0	26.5
Calaveras Creek	0.0	63.2	0.0	63.2
Olmos	15.5	0.0	0.0	15.5
NUECES—				
Upper Nueces	0.0	7.6	0.0	7.6
Corpus Christi	0.0	259.1	42.9	302.0
RIO GRANDE—				
San Estaban	0.0	18.8	0.0	18.8
Red Bluff	0.0	307.0	3.0	310.0
Balmorhea	0.0	5.9	0.5	6.4
Amistad	1,775.0	3,000.0	550.0	5,325.0
Texas Share	997.6	1,686.0	—	2,683.6
Casa Blanca	0.0	20.0	0.0	20.0
International Falcon				
Summer Storage	909.5	2,112.3	258.9 1/	3,280.7
Texas Summer Share	533.0	1,237.8	—	1,770.8
Winter Storage	509.5	2,512.3	258.9 1/	3,280.7
Texas Winter Share	298.6	1,472.2	—	1,770.8
COASTAL—				
Big Hill	0.0	32.0	0.0	32.0
Highlands	0.0	5.6	0.0	5.6
Austin	—	—	—	—
Alice Terminal	0.0	7.0	0.0	7.0
Tranquitas	0.0	6.0	0.0	6.0
Monte Alto	0.0	25.0	0.0	25.0
Valley Acres	0.0	7.8	0.0	7.8
Loma Alta	0.0	26.5	0.0	26.5
TOTAL 7/	17,578.2	28,619.1	6,292.4	52,489.7

1/ Minimum pool for hydroelectric power generation.

2/ Off-channel reservoir.

3/ Reservoir will be sedimented by 2020.

4/ Minimum pool for thermal power generation.

5/ Land acquisition initiated.

6/ Land clearing initiated.

7/ For reservoirs on boundary streams, the total storage (not the Texas share) has been included. For International Falcon the winter storage figures have been included.

8/ Figures shown in "Texas Water Plan Summary" are in error, and are corrected as shown in this document.

Table IV-53.--Incremental Capacities of Major Reservoirs, Proposed and Potential

Storage Capacity in Thousands of Acre-Feet

BASIN & RESERVOIR	FLOOD CONTROL	CONSERVATION	DEAD	TOTAL
RED—				
Lower McClellan Creek	0.0	22.0	106.0	128.0
Lelia Lake Creek	0.0	17.2	3.0	20.2
Sweetwater Creek	0.0	49.2	16.5	65.7
Ringgold	0.0	413.1	19.9	433.0
Bonham (Bois D'Arc)	48.5	75.1	7.0	130.6
Big Pine	54.7	77.9	6.0	138.6
Pecan Bayou	52.4	564.3	8.3	625.0
Liberty Hill	0.0	89.8	7.9	97.7
Barkman Creek	0.0	10.8	5.1	15.9
SULPHUR—				
Cooper	127.5	273.0	9.3	409.8
Parkhouse 1	0.0	548.2	87.2	635.4
Parkhouse 2	0.0	750.1	96.9	847.0
Naples (Initial) 7/	0.0 7/	1,466.5 7/	135.8 7/	1,602.3 7/
(Ultimate)	701.7	2,220.0	190.0	3,111.7
Texarkana Enlargement	1,687.7	802.9	125.8	2,616.4
CYPRESS—				
Titus County	0.0	311.3	2.9	314.2
Marshall	0.0	775.0	7.3	782.3
Black Cypress	0.0	820.0	4.4	824.4
Caddo Enlargement	0.0	213.5	38.5	252.0
SABINE—				
Mineola	674.5	370.1	20.4	1,065.0
Lake Fork	413.2	621.5	18.9	1,053.6
Big Sandy	163.7	215.3	6.9	385.9
Kilgore 2 1/	0.0	14.0	1.0	15.0
Cherokee 2 1/	0.0	110.6	1.7	112.3
Carthage	636.6	456.5	41.0	1,134.1
Bon Wier	124.5	215.3	23.0	362.8
Salt Water Barrier 6/	—	—	—	—
NECHES—				
Weches	839.7	1,401.7	26.2	2,267.6
Ponta	517.8	805.8	25.5	1,349.1
Rockland	1,502.5	1,789.9	58.9	3,351.3
Salt Water Barrier 6/	—	—	—	—
TRINITY—				
Bridgeport Enlargement	0.0	396.1	37.0	433.1
Aubrey	258.3	603.8	37.8	899.9
Garza-Little Elm 2/	331.6	630.6	40.7	1,002.9
Lakeview	136.7	306.4	45.6	488.7
Tennessee Colony	2,187.8	2,044.6	328.6	4,561.0
Bedias	0.0	488.0	16.7	504.7
SAN JACINTO—				
Cleveland	0.0	479.8	4.2	484.0
Lower East Fork	0.0	330.7	7.3	338.0
Lake Creek	0.0	200.0	6.0	206.0
BRAZOS—				
Millers Creek	0.0	7.4	18.1	25.5
Breckenridge	0.0	550.0	67.0	617.0
Stephenville 3/	0.0	40.6	10.9	51.5
Aquilla Creek	111.5	59.7	28.1	199.3
Cameron	0.0	1,200.0	18.0	1,218.0
Navasota 2	550.7	1,315.4	69.5	1,935.6
Millican	359.0	1,125.8	72.0	1,556.8
South San Gabriel	46.5	30.2	8.0	84.7
COLORADO—				
Stacy	659.3	650.0	50.0	1,359.3
Upper Pecan Bayou	102.7	93.5	10.1	206.3
Clyde	0.0	4.7	1.0	5.7
San Saba 4/	331.6	195.6	5.0	532.2
Mason 4/	433.8	319.9	15.2	768.9
Pedernales 4/	212.0	233.4	5.0	450.4
Columbus Bend	481.7	483.9	88.1	1,053.7
Matagorda	0.0	61.4	28.6	90.0

Table IV-53.--Incremental Capacities of Major Reservoirs, Proposed and Potential--Continued

BASIN & RESERVOIR	FLOOD CONTROL	CONSERVATION	DEAD	TOTAL
LAVACA—				
Palmetto Bend	0.0	230.0	55.0	285.0
GUADALUPE—				
Ingram	36.4	53.5	0.5	90.4
Cloptin Crossing	107.0	146.8	3.2	257.0
Lockhart	0.0	59.9	9.5	69.4
Cuero 1 and 2	843.0	2,816.0	50.0	3,709.0
Confluence	0.0	406.0	33.0	439.0
SAN ANTONIO—				
Cibolo	218.0	172.0	28.0	418.0
Goliad	702.0	958.0	42.0	1,702.0
NUECES—				
Choke Canyon 5/	0.0	686.0	14.0	700.0
R & M 5/	0.0	672.4	—	672.4
Montell	239.3	1.0	12.0	252.3
Concan	141.2	0.0	7.8	149.0
Sabinal	89.1	0.0	4.2	93.3
COASTAL—				
Garcitas	0.0	63.0	4.0	67.0
TOTAL 8/—	16,124.2	32,150.2	2,247.2	50,521.6

1/ Potential, alternate to obtaining water from Sabine River.

2/ Capacities after storage exchange with Aubrey Reservoir.

3/ Potential, alternate to obtaining water from Proctor Reservoir.

4/ Alternate for Colorado River development.

5/ Alternate for Nueces River development.

6/ Location and capacity not determined as yet.

7/ Initial capacities not included in total.

8/ The totals do not necessarily indicate the projected net increase in storage because the individual allocations reflect the ultimate storage for enlargements and exchanges rather than the incremental increases.

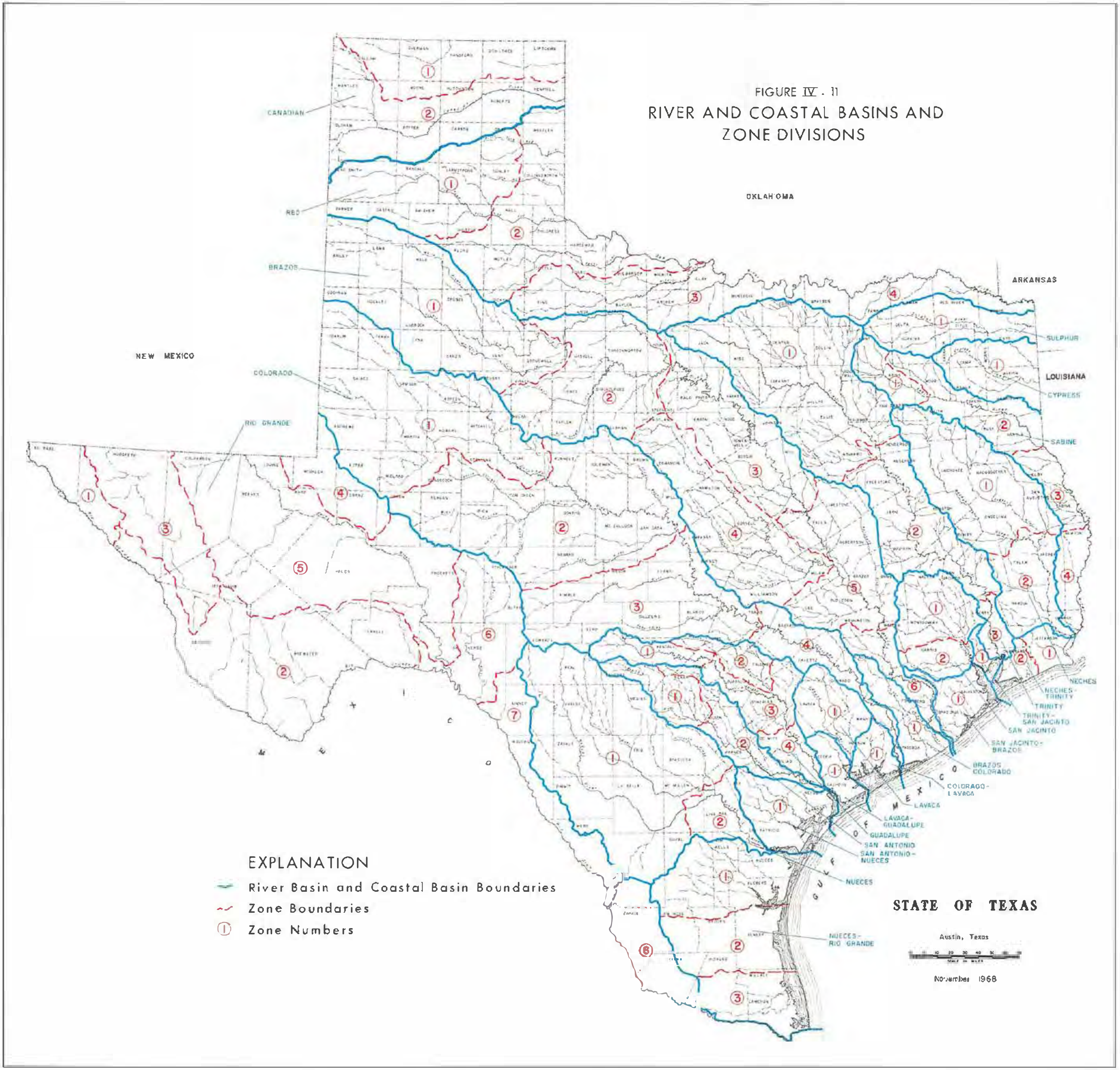


FIGURE IV-11
RIVER AND COASTAL BASINS AND ZONE DIVISIONS

Figure IV-12 at right summarizes the Texas Water Plan as outlined in the foregoing description of the water resources of each river and coastal basin. This illustration shows the projected requirements and the planned means of meeting those requirements including the interbasin transfer of surface water. Some of the proposed and potential reservoirs listed in Table IV-53 are not included in the configuration of demand and supply shown in Figure IV-12. These are: Lower McClellan Creek, Lelia Lake Creek, Ringgold, Parkhouse 2, Caddo Enlargement, Kilgore 2, Cherokee 2, Carthage, Bon Wier, Weches, South San Gabriel, San Saba, Mason, Pedernales, Montell, Concan, Sabinal, and R&M.

The following explanatory notes will be of value in using Figure IV-12. For further detail the text and Plate 2 should be consulted.

(1) This illustration, for simplicity, does not show the detailed routing of the interbasin transfers. For example, the 647,000 acre-feet shown as a planned export under the Texas Water System from the Red River Basin would be routed through Naples Reservoir and thence to the Trans-Texas Canal. Two alternative routings proposed for the 641,000 acre-feet planned for annual export from the Cypress Creek Basin are described in the text and shown on Plate 2.

(2) Fresh water flows into Sabine Lake would be supplied by uncontrolled flows at the proposed salt water barrier, treated return flows, and last lockage navigation releases of 34,300 and 34,500 acre-feet annually in the Sabine and Neches River Basins, respectively.

(3) The projected surplus waters from the Trinity River Basin and the last lockage navigation requirement on the Trinity would be utilized as fresh water inflows to Galveston Bay. If projected Trinity River Basin surpluses are routed to the Coastal Canal, described as an alternative in the text, the last lockage navigation release would still enter Galveston Bay.

(4) Some minor surpluses are projected in the Red, Neches, Brazos, and Colorado River Basins in addition to those shown as having surpluses in Figure IV-12.

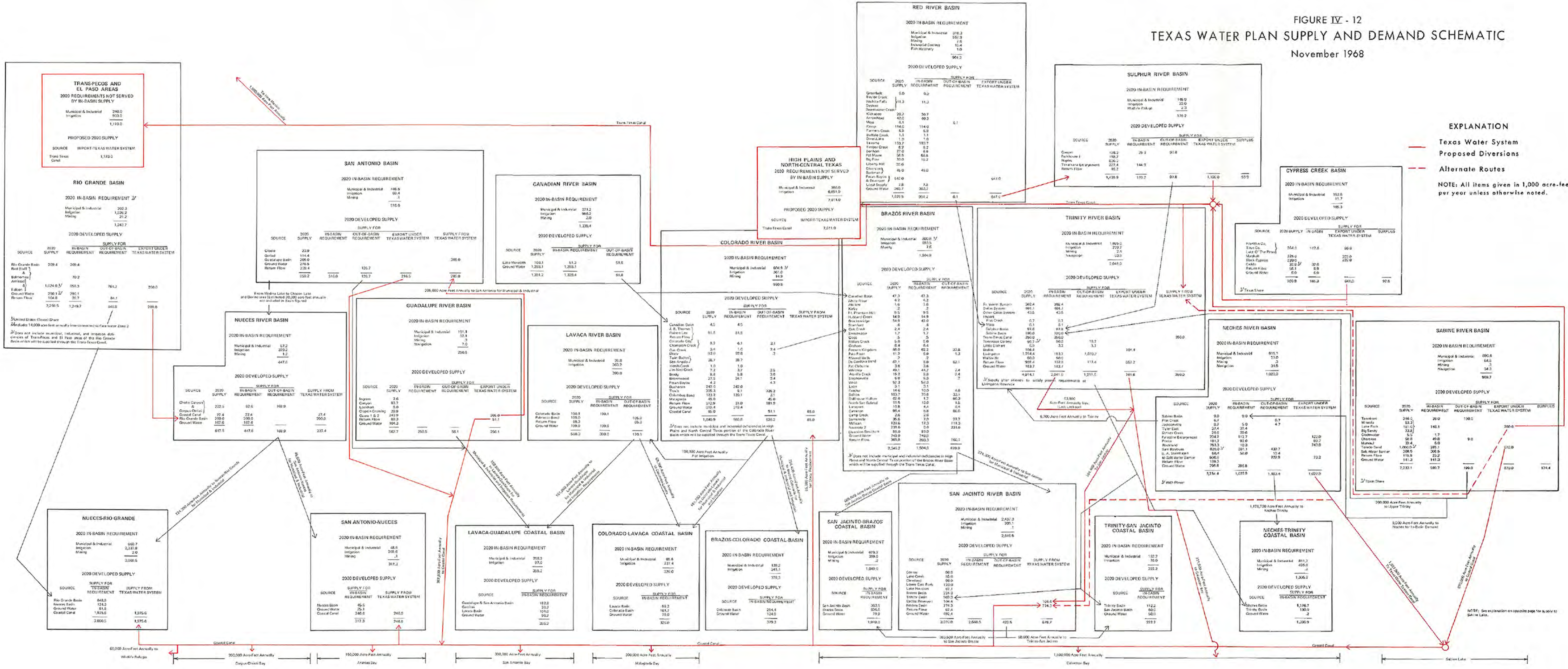
(5) In the San Jacinto and Guadalupe River Basins the supply for out-of-basin requirements was not itemized by individual projects because in both cases a systems approach to the operation of the indicated surface water supply projects is proposed. For the same reason, exports under the Texas Water System were not itemized by individual projects for the Sulphur and San Antonio River Basins.

(6) In this configuration, Choke Canyon Reservoir is shown in the Nueces River Basin. The R&M site, if selected for construction in lieu of Choke Canyon, would serve the same requirements. This decision is yet to be made by local interests.

FIGURE IV - 12

TEXAS WATER PLAN SUPPLY AND DEMAND SCHEMATIC

November 1968



EXPLANATION

Texas Water System

Proposed Diversions

Alternate Routes

NOTE: All items given in 1,000 acre-feet per year unless otherwise noted.

Part V

Implementing The Texas Water Plan

IMPLEMENTING THE TEXAS WATER PLAN

The development of Texas' water resources on the scale proposed presents many engineering and similar technical problems, but these are soluble for the most part in terms of presently available technology. The concepts and modes of governmental and institutional arrangements, legal practices, financing, and economic and social adjustments, however, must be developed or adapted to meet the complexities of water development on such a scale.

The Board has viewed the implementation of the Texas Water Plan as requiring a realistic cooperative approach to intergovernmental activity to achieve the maximum benefit from the water resources involved with maximum participation by all affected levels of government. Necessary legal, financial, and contractual arrangements must be evolved through a continuing process of discussion and negotiation between the Federal agencies and the Board, between the Board and other State agencies, between the Board and local agencies, and jointly among Federal, State, and local agencies. Contractual arrangements will be necessary with many private interests, including investor-owned utilities.

If it could be assumed that unlimited capital and construction capability were available, implementation of the Texas Water Plan would be relatively simple. However, in a period of intense competition for investment of Federal and State funds, and recognizing that there are limits both as to labor supply and construction capability, the criteria by which the priority and scale of projects will be determined must be carefully examined. In establishing theoretical criteria to reach an optimum solution to the questions involved, there must also be recognition that political and operational considerations will have an impact on the pattern of optimum development.

This part of the document summarizes the Board's proposed approach to plan implementation. Many of the proposals will require Congressional and Legislative approval or confirmation. All will require acceptance by the general public if the Texas Water Plan is to be effective.

INTERGOVERNMENTAL RELATIONSHIPS AND RESPONSIBILITIES

The State's participation in water planning and development is essential if Texas is to have a voice in the management of its water resources. The facilities needed to supply water to Texas requiring concerted action by the United States and the State of Texas are:

(1) The Interstate System—those works required to divert from the Mississippi River and convey water to the Texas-Louisiana State line. Other States will be involved, too.

(2) The Texas Water System—those facilities within the State of Texas required to protect, conserve, transport, and distribute Texas' intrastate water resources and Texas' share of interstate waters for various purposes throughout the State, and to regulate and transport water from out-of-State sources brought to the State line through the Interstate System to users in Texas. The conveyance works of the Texas Water System would also transport water from the Mississippi River to the State of New Mexico.

(3) Water development projects not a part of the Texas Water System.

Federal-State-Local Action

1) The Board would complete the planning for the Texas Water System and participate in the preparation of feasibility reports with the Federal agencies.

2) The Interstate System would be designed and constructed by such agency or agencies as Congress may direct.

3) The most economical pumping energy for the Texas Water System should be provided, possibly by nuclear-fueled generating plants and transmission systems financed jointly by the United States, the State of Texas, and the investor-owned utilities.

4) Most of the units of the Texas Water System would be designed and built by the Corps of Engineers and the Bureau of Reclamation; some might be designed and constructed by the Board and/or by local agencies. The Board's involvement in design and construction would be minimal, but the Board must

maintain liaison with the Federal and local agencies in design, and must monitor work on design and construction to insure that Texas' interests are properly taken into consideration and protected.

5) For those units of the Texas Water System designed and constructed by the Federal agencies, the State of Texas would provide a substantial portion of the funds required for engineering and construction on a partnership basis with the United States. This partnership arrangement would be on the basis of investments in the total System by the United States and by the State of Texas, rather than on the basis of ownership of a specific facility or of a particular portion of a facility.

6) For those units to be designed and built by local agencies (or by the Federal agencies for local interests) but from which some water is to be derived for interbasin transfers through the Texas Water System either on an interim or long-term basis, the Board would participate financially either by purchase of storage facilities or by purchase of water. This would necessitate the negotiation and execution of purchase and operating agreements with such local agencies.

7) The Board would hold the appropriative rights to water conveyed through the Texas Water System.

8) The Board would execute the base contract with the United States for repayment of that portion of the reimbursable Federal investment in the intrastate facilities of the Texas Water System allocated to water supply in Texas. The Board would in turn execute contracts with local agencies for their purchase of water, thus obtaining revenues to meet its obligations to the United States, to repay the State's investment, and to cover operation, maintenance, and management expenses. These water contracts would provide the financial security for the base repayment contract with the United States. Generally, Federal laws and policies regarding reimbursability and repayment will apply except as to the interest rate to be charged on the investment from the Texas Water Development Fund.

9) The Board would assist local interests in the formation of master districts with adequate powers to enter into water service contracts with the State of Texas in those areas where such political subdivisions do not now exist.

10) The Board would purchase water from the Interstate System at the State line from the United States, or from some agency thereof, for conveyance and sale through the Texas Water System.

11) Under agreement with the United States and the State of New Mexico, the Board would convey the water to be imported into New Mexico from the Mississippi River through the Texas Water System.

12) The Board would operate and maintain, and be responsible for administration and fiscal management of the Texas Water System as elements thereof are completed by the Federal agencies, except for those units which are to be operated, maintained, and managed by local agencies. Fulfillment of this responsibility would entail the negotiation and execution of a master agreement with holders of existing and authorized projects on streams on which Texas Water System conservation units are to be built.

13) Responsibility for operation, maintenance, and management of the Interstate System should be vested in such agency as Congress may direct.

The key element in carrying out the above actions is the assurance of an effective responsible relationship between the United States and the State of Texas within which each level of government can assume its proper authority and discharge its appropriate obligations. Similarly, responsible relationships between the Board and other State agencies, between the Board and local political subdivisions, and between the Board and water agencies in other States must be established and actively maintained.

These relationships should be formally organized in such a way that effective working partnerships are possible. This organization might be formulated along these lines:

(a) Memoranda of understanding with the Bureau of Reclamation and the Corps of Engineers, the major Federal construction agencies, establishing institutional arrangements required to achieve coordination of planning, and the policies and criteria under which the Texas Water System is to be presented to the Congress and the State of Texas as a joint Federal-State-Local project.

(b) Permanent committees with representatives of the Board, the Bureau of Reclamation, the Corps of Engineers, and of other States or agencies as appropriate. A Policy Committee is needed for review and decision making; a Planning Committee to formulate objectives, policies, and criteria under which the Texas Water System will be developed for consideration of the Policy Committee; and staff committees responsible to the Planning Committee for analysis of hydrology, water requirements, economics, and design.

(c) The Congress to set forth in the authorization for Federal participation in the Texas Water System and in the Interstate System the basic policies under which cooperative Federal-State implementation will proceed. These policies would establish the terms under which the Board would assume responsibility for operation, maintenance, and management of the Texas Water System and guarantee repayment of the reimbursable Federal costs allocated to Texas. Since out-of-State elements will be involved, a special commission or agency with specifically defined powers and duties should be created by parallel or complementary actions of the Congress and the States to oversee the construction, operation and maintenance, and management of the Interstate System, and to insure that the interests of both the United States and the States are protected.

(d) For projects not a part of the Texas Water System, the Board will maintain active liaison with the Federal construction agencies (Corps of Engineers, Bureau of Reclamation, and Soil Conservation Service), and with concerned local entities, and will take appropriate actions on pre-project planning, investigations, authorizations, final planning, and construction.

State Coordination

The Board will coordinate the interests and participation of other State agencies in planning for construction and operation of the Texas Water System and related projects, by direct liaison of the executive head of the Board with other State agencies, or between designated staff principals of the Board and other State agencies.

The Board will work closely with river authorities, major cities, and other entities. Continuing communication and coordination is essential with these regional and local interests regarding immediate and long-range planning, operational criteria of local projects consistent with objectives of the Texas Water Plan, contractual agreements on various features, and joint participation as needed in project financing.

This continuing communication and coordination is especially important on projects not directly related to the Texas Water System such as conservation storage, channeling for flood control, hurricane and tidal flood protection, coastal navigation, upstream watershed protection programs, and drainage facilities.

Interstate Coordination

The Board will continue to participate in programs of interstate cooperation including:

(1) Necessary activities relating to interstate and international streams bordering or crossing Texas.

(2) National or regional water associations or councils such as National Rivers and Harbors Congress, the National Reclamation Association, Interstate Conference on Water Problems, the Council of State Governments, the Southern States Water Conference.

(3) Interstate groups such as the Western States Water Council, and cooperation with the States adjacent to Texas with regard to importation of water from out-of-State, including continuing interest and cooperation in regional systems which have been proposed such as the North American Water and Power Alliance.

Master Districts

Many political subdivisions dealing with water resource development have been created in the State with greatly differing statutory authority. Implementing the Texas Water Plan will involve these agencies directly through water purchase and project financing, through contractual arrangements for operation and management of the Texas Water System, and through long-range continuing planning activities.

The Board has developed the Texas Water Plan on the premise that no construction will begin, and no water can move to any area to be served by the Texas Water System, until there is a firm commitment on the part of the locally responsible political entity to contract for the repayment of the reimbursable System costs allocated to the area. Where irrigation is to be served by the Texas Water System, master districts must be available to make contract commitments. Although these master districts may take varying forms—creation of a new district, combination of a group of districts, or the enlargement of areas and functions of existing districts—a number of broad powers will be needed. These powers, not necessarily all applicable to any given area, include but are not limited to the following:

(1) Power to contract for a water supply and to assure repayment of the costs for such a supply.

(2) Power to contract with local entities or subdistricts for "retail" distribution of water.

(3) Power to borrow money and incur indebtedness, issue bonds, levy taxes, and take all other required responsible financial actions necessary to repay obligations for the delivery of water.

(4) Power to charge direct water tolls and charge indirect beneficiaries who obtain water from underground sources recharged as a consequence of delivery and use of water through the Texas Water System.

(5) Power to construct works.

The Board, appropriate to its statutory duties, will assist local areas in any way in establishing viable political entities with authority and financial competence to assume contractual obligations required under the Texas Water System.

MODES AND PROCEDURES FOR THE ADJUSTMENT OF WATER RIGHTS

Article 8280-9 states in part:

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 public hearing and upon notification by the Texas Water Commission or its successors 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. A majority vote shall be necessary for adoption.

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 this State. The Texas Water Commission or its successors shall take the Texas Water Plan into consideration in matters coming before the Commission but need not be bound thereby. Nothing in the State Water Plan or any modifications and amendments thereto shall be construed so as to increase or diminish any water right existing at the effective date of this Act.

It is not the intent nor can it be the effect of the Texas Water Plan to quantify, alter, increase, or diminish in any way the existing water rights of any individual or entity within the State.

The implementation of water development in Texas—by whatever course or speed—will adhere to the established procedure of full consideration by the Texas Water Rights Commission in reviewing and granting applications and the subsequent issuance of permits. The implementation of elements contained in this report, whether constructed by local entities, the Texas Water Development Board, a Federal agency, or a combination of two or more of these groups, will require that applications for water permits be made to the Texas Water Rights Commission prior to the initiation of construction of such elements. The parties making the application will be required to follow the procedures prescribed by statute, and by the Rules and Regulations of the Texas Water Rights Commission.

Those units proposed for construction as Federal projects must follow the course of review prescribed by Article 7472e, involving formal public review and hearing before the Texas Water Rights Commission. Under existing procedures, Federally proposed projects affecting public waters of the State are submitted to the Governor for his approval. In accordance with Article 7472e (V.A.C.S.) the Governor must transmit the Federal project report to the Texas Water Rights Commission for study and subsequent recommendation. A public hearing by the Commission on all proposed Federal projects is required by law. The inclusion of projects within this document, which projects may be subsequently proposed by a Federal agency and submitted to the Governor for approval in accordance with Article 7472e, does not necessarily imply approval of such projects.

Contemporaneously with the filing of each application for the construction of each project proposed by this document and the resulting diversion and use of public waters, detailed hydrologic and economic studies relating to existing and proposed water use and the rights affected thereby must be prepared and submitted to the Commission, whose primary responsibility is to assure the protection of permit rights, certified filings, and other rights to the use of water which may then exist.

Although the Texas Water Rights Commission and the Texas Water Development Board are directed to recognize and protect water rights in planning and permitting the use of public waters, the task is not easily performed. Implementation of the present statutory procedure to facilitate determination of what claims of right to use water constitute a vested water right in terms of amount and priority will be helpful.

In those instances where operation of proposed elements of the Texas Water System, as now constituted or subsequently amended, present a possibility of interference with beneficial use under existing rights, it is expected that appropriate restrictive terms and conditions will be imposed by the Texas Water Rights Commission in those permits subsequently issued, and/or agreements developed between present and prospective permittees defining operational conditions with respect to existing rights. If, in the operation of the Texas Water System, it becomes necessary to acquire water on a term basis, compensation must be paid or a replacement supply in kind must be furnished.

Where appropriate, it will be necessary to negotiate agreements with numerous local entities defining the operational criteria for and the interrelationships of elements of the Texas Water System and the projects and diversions operated by others, to achieve mutually satisfactory and harmonious operation of all projects concerned, to protect the rights of others, and to insure the operational integrity of the System.

The form of future applications for permits for the System, and that of the permit instruments, will merit detailed attention, particularly with reference to rights to be associated with the movement of large volumes of water from one region to another through an integrated reservoir operation system containing numerous reservoir facilities. It would be impractical to define that particular reservoir from which each user would obtain water pursuant to permit as is customary at present. It would appear that the more appropriate course of action would be an application for a permit to store water in the reservoir system and either a concurrent or subsequent application to beneficially use waters. The form of future permitted rights may assume the nature of a contractual right in a reservoir system rather than in specific reservoirs.

Construction of reservoir units proposed by the Plan is scheduled throughout the next 50 years. New patterns of industry, advances in agriculture, shifts in population, development of science and technology, and the impact of new legal and financial concepts will require frequent reanalyses of objectives in meeting the needs of Texas. Continuing review and revision of present proposals to protect vested water rights will be necessary.

FINANCIAL CONSIDERATIONS

Texas Water Development Fund

Authorization

In 1957, an amendment to the Constitution of the State of Texas created the Texas Water Development Board, and further empowered the Board, through the Texas Water Development Fund, to make loans to local governmental agencies sponsoring the construction of projects for the conservation and development of water resources of the State.

The Constitution was further amended in 1962 and 1966 to broaden the Board's powers by authorizing it to acquire conservation storage in reservoirs to be constructed on Texas streams and for any system or works necessary for the filtration, treatment, and/or transportation of water by Federal or local governmental agencies to the end that the remaining reservoir sites in Texas may be developed to their optimum potential. The program administrered by the Board is currently limited by Constitutional provision to $400,000,000, provided that the last $200,000,000 be approved by a two-thirds majority of each house of the Texas Legislature. By statutory provision, the Board is limited to a maximum investment of $25,000,000 in any one project, and is further restricted to an aggregate investment of $100,000,000 in all reservoir conservation storage facilities.

The Texas Water Development Board may participate in projects by financing construction either wholly or in part, or by guaranteeing payment of reimbursable costs to the United States. The State's participation in local projects may take one or more of the following forms:

1. Purchase of storage facilities in reservoirs constructed by Federal agencies for subsequent use by local agencies. In the purchase of such facilities the State will take advantage of the delayed repayment provisions of the Water Supply Act of 1958.

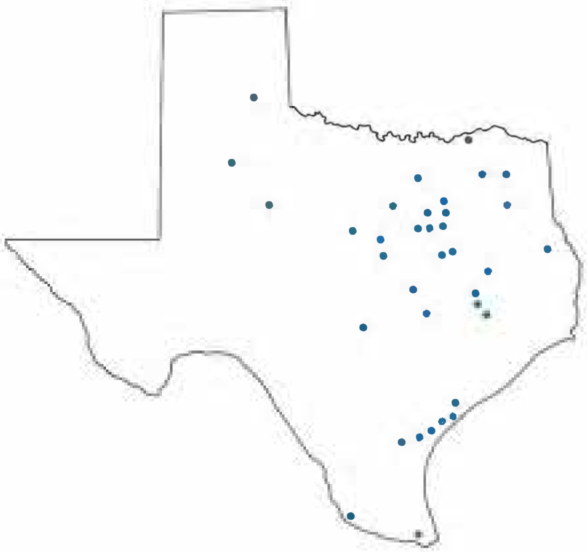
2. Purchase of storage facilities in reservoirs constructed by local agencies for local supply purposes.

3. Loans to local agencies to assist with construction of projects to meet local needs.

4. Participation in the construction of conveyance or other water facilities by loan or by acquisition of a portion of such facilities.

As of August 31, 1968, the Board has participated in 36 water projects, completed or in advanced stages of construction or planning, which involve an aggregate commitment on the part of the Board of $77,318,101.04. Figure V-1 shows the various geographic locations in which local governmental agencies have availed themselves of Board financial assistance for development of water supply projects through loans and/or acquisition capacity in storage and other facilities.

FIGURE V-1
GEOGRAPHIC LOCATIONS OF COMMITTED INVESTMENTS UNDER THE ASSISTANCE PROGRAM OF THE BOARD
AUGUST 31, 1968



Utilization

The initial series of Water Development Bonds was issued in August 1959, and the aggregate of all bonds issued to date by the Board is $100,000,000. Full recovery of the principal of the Board's outlay, together with interest at the rate of ½ of 1% in excess of the Board's own borrowing costs, is the basic principle of the Texas Water Development Act. With the recent sale and delivery of the Board's Series 1968 Bonds, the weighted average interest rate on all bonds sold by the Board is 3.22322%, which, in turn, fixes its present lending rate at 3.72322%.

It is the stated policy of the Board, pending investment in eligible projects, that uncommitted sums in the Fund be invested on a temporary basis in obligations of or guaranteed by the United States of America.

The historical pattern in growth of and investments within the Fund are illustrated in Figure V-2. This chart has been prepared on the basis of an assigned value of par to all securities, both local and governmental, and no consideration has been given for any amortized premium or discount.

Criteria for Financial Assistance From the Texas Water Development Fund

The Act creating the Texas Water Development Board sets forth certain rules governing its Program of Financial Assistance. The term "financial assistance" as used in the Act means a loan evidenced and fully secured by the bonds issued by a legally eligible political subdivision of the State of Texas. Under certain conditions, pursuant to the Board's Water Facilities Acquisition Program, the Board may purchase and acquire an undivided interest in storage reservoirs when it is evidenced that there is no local sponsor or sponsors capable of financing and developing such facilities.

Before any financial assistance may be granted by the Board, it must determine the eligibility of the proposed project. "Project" is defined under the Act as: "any engineering undertaking or work for the purpose of the conservation and development of the surface or subsurface water resources in the State of Texas, including the control, storing, and preservation of its storm and floodwaters and the waters of its rivers and streams for all useful and lawful purposes by the acquisition, improvement, extension, or construction of dams, reservoirs, and other water storage projects (including underground storage projects), filtration and water treatment plants including any system necessary for the transportation of water from storage to points of distribution, or from storage to filtration plants, including facilities for transporting water therefrom to wholesale purchasers, by the acquisition, by purchase of rights in underground water, by the drilling of wells, or for any one or more of such purposes or methods."

Requirements for eligibility under all financial assistance applications are detailed in the Board's published Rules and Regulations.

Investments from the Texas Water Development Fund in local projects through the acquisition of storage facilities in reservoirs or capacity in other facilities will be recouped through later sale of the storage facilities or capacity, or by sale of water made available thereby, pursuant to the provisions of the Texas Water Development Board Act.

Augmentation of the Texas Water Development Fund

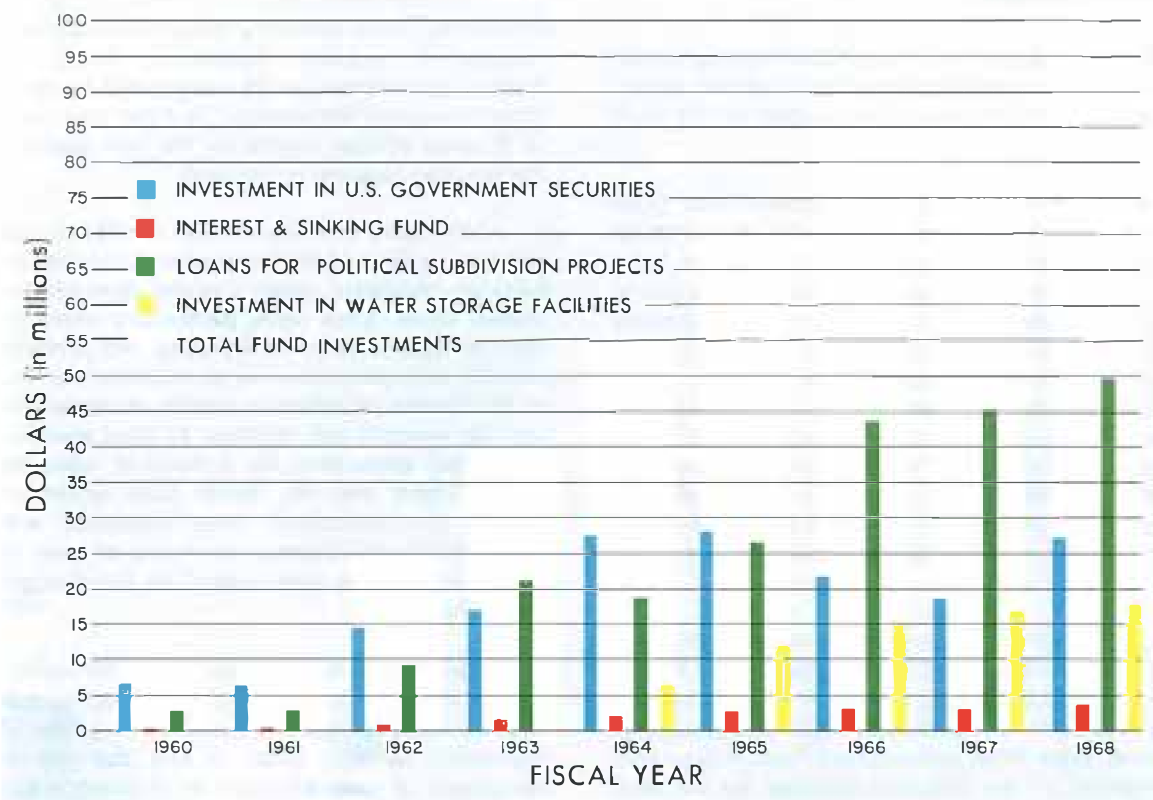
The magnitude of the investment from the Texas Water Development Fund in the Texas Water System must be related to the costs allocated to those functions which are to be repaid by the water users with interest, in particular the provision of municipal and industrial water supplies, in accordance with provisions of the Texas Water Development Board Act.

The Texas Water Development Fund will need to be augmented to cover the State's share of the cost of the Texas Water System, presently estimated at between 20 and 35% of the total cost. In addition, more funds will be required for State participation in local projects.

The provision of funds for future construction must take into account the anticipated escalation in construction costs.

FIGURE V - 2

HISTORICAL PATTERN OF INVESTMENT OF THE TEXAS WATER DEVELOPMENT FUND



Financing and Repayment

Specific arrangements for financing and for repayment of the reimbursable costs of the Texas Water System and other units of the Texas Water Plan will depend upon the purposes of the facility to be constructed, the purposes and objectives of sponsoring agency(s) and the construction agency, and the policies of the Federal and State governments with respect to reimbursability in effect at the time of execution of repayment contracts.

The term "financing" as used herein means the provision of funds for construction by the Federal or State governments, by direct appropriations or by sale of bonds or both, or from other sources. "Repayment" means the recouping of those portions of the investments made and the other costs incurred by the Federal and State governments which by law or policy must be reimbursed by the direct beneficiaries of the project or by others.

Financing for the complex elements of the Texas Water Plan could take several forms. The following discussion of financing and repayment, and of the form of water service contracts, provides a means of financing **compatible with the proposed form of intergovernmental relationships. The proposals herein may be modified in response to changes in Federal or State policies or laws, or as is appropriate to provide the most effective financing structure possible.**

It may be argued that the Federal Government should and would finance the entire Texas Water System. However, the record of appropriations by Congress for water development in the United States as a whole and in Texas, under the Reclamation Program and the Rivers and Harbors Program, coupled with the large backlog of authorized but unfunded Federal projects, and the probable future demands on the Federal Treasury for other purposes, demonstrate that it would be unrealistic to assume that the United States would fully finance the entire Texas Water System. Other States, too, have large water development needs in which the United States will participate. The State of Texas must be prepared to invest substantial sums in the Texas Water System if it is to be completed in time to meet the anticipated buildup in water needs and thus avoid economic detriment. The State's share must be assured before Congress can be expected to authorize elements of the System and to appropriate the Federal funds required.

The Texas Water System will be planned, designed, financed, and constructed as a joint Federal-State-Local enterprise. It will be planned, designed, staged, constructed, operated, and managed as a single, integrated water system in its entirety.

Water imported from out-of-State sources for use in Texas will be purchased from the Interstate System with delivery to the Texas Water System at the State line.

It is contemplated that most units of the Texas Water System will be constructed by the United States Bureau of Reclamation and the United States Army Corps of Engineers, although the Board may need to construct some elements in order to meet the necessary construction schedule. Financing and construction of the major reservoirs and conveyance facilities of the Texas Water System by local agencies is not anticipated. However, some of the smaller reservoirs and some conveyance facilities from the main canals or reservoirs primarily to serve local municipal and industrial demands could be financed in whole or in part and/or constructed by local political subdivisions if they so elect.

It is proposed that financing to be provided by the Federal Government be equal in amount to the sum of certain allocated construction costs, or portions thereof, as discussed below in this section. The State, through an augmented Texas Water Development Fund, will provide the remainder of the financing required for the total Texas Water System.

This financial partnership arrangement is proposed to be on the basis of investments in the total System by the United States and by the State of Texas, rather than on the basis of ownership of a specific facility or of a particular portion of a facility. One means of implementing this complex financial arrangement would be the establishment of a "Texas Water System Construction Fund" by the Congress, into which Federal appropriations and State monies from the Texas Water Development Fund for construction would flow and from which payments for engineering work and construction by the Federal agencies would be made. This Fund would be administered by the United States. Monies from the Texas Water Development Fund for construction facilities to be built by the Board or local agencies would not need to flow through the Texas Water System Construction Fund but the State would receive proper credit toward the total cost of the System.

Local agencies may elect to participate in financing certain elements of the Texas Water System where the ultimate benefits are primarily local but where some of the water made available by such units is planned for use elsewhere on either an interim or a permanent basis. In such cases, the Board will purchase the requisite storage facilities in the reservoirs and capacity in conveyance facilities required to provide such water, or will enter into contracts with the local agencies for purchase of water.

Irrigation distribution and main drainage systems in the areas to be served by the System could be locally constructed, probably financed by loans from the Federal Government, or be constructed by the United States Bureau of Reclamation. In either case, repayment in 40 years without interest by the local agencies under Reclamation Law will be required.

The Board will assume responsibility for operation and management of the principal units of the System as units are completed, under a master agreement with the United States. Some units, particularly where the local agencies participate in the financing, with primarily local benefits but with some water available for the remainder of the System on either an interim or permanent basis, may be operated and managed by local agencies under contractual agreements for delivery of water with the United States and the Board. Such agreements will specify the operational interrelationship with the remainder of the System, the sharing of costs, and the operational criteria with respect to flood control and similar functions.

The Board will provide funds for costs of the System allocated to municipal and industrial supply, as well as contract for the repayment of any Federal investment in such costs. It will also contract for repayment of costs allocated to irrigation water. Contractual arrangements for repayment of all necessary water supply costs will be under master agreement(s) with the United States, which agreements will also define the terms for purchase of water from the Interstate System. Such contract or contracts with the United States will be secured by water service contracts executed by the Board with local agencies for the sale of water for municipal and industrial purposes and for irrigation. The State's investment will be recovered with interest and the costs of operation, maintenance, replacement, administration, and management incurred by the Board, as well as the financial obligations to the United States, will be met by the revenues received under these water service contracts.

Other agreements with the United States involving the Board, other State agencies, and local political subdivisions will be necessary to cover other reimbursable Federal costs such as recreation, the enhancement of fish and wildlife resources, and water quality control.

Costs reasonably incurred in mitigation of fish and wildlife resource losses caused by construction of System facilities will be allocated among the functions served by the facilities as required by Federal policies, and will be reimbursable to the extent that the costs allocated to those functions are reimbursable.

Insofar as possible, cost allocation methodology will conform to that used by the Federal agencies. However, the discount rate to be used for cost allocation purposes must be negotiated and agreed upon in advance between the Board and the Federal agencies. The discount rate used for wholly Federally financed projects and that used for projects financed in whole or in part by the State should be different.

Federal Financing and Reimbursement

Based on present Federal statutes and policies, it is proposed that Federal financing cover the capital costs allocated to the following purposes for the Texas Water System and for local projects in which the Federal agencies participate. It is assumed that these costs will be reimbursable to the extent required by those laws and policies:

1. *Navigation.*—These costs will be fully nonreimbursable.

2. *Flood Control and Hurricane Flood Protection.*—These costs will be nonreimbursable except that the costs of the lands, easements and rights-of-way, and relocation of utilities necessary for channel improvements must generally be borne by non-Federal interests.

3. *Water Quality Control.*—As this document is being prepared, there is no definitive Federal policy defining the extent of reimbursability of the costs of dams, reservoirs, and conveyance facilities allocated to water quality control. No Federal policy has been established for reimbursement of costs for releases of stored water to stream channels where such releases may be necessary to prevent deterioration below established water quality standards as a result of the final disposal of treated municipal, industrial, and other waste effluents. The question is under study by Federal agencies. The costs for construction of facilities designed to control natural sources of quality degradation, such as saline springs, are assumed to be nonreimbursable in accordance with the authorization by Congress of the Estelline Spring Salinity Alleviation Project by the Flood Control Act of 1962, 87th Congress, and the Wichita River Chloride Control Project by the Flood Control Act of 1966 (P.L. 89-789).

4. *Recreation and Fish and Wildlife Enhancement.*—The Federal Water Project Recreation Act requires that non-Federal interests reimburse the Federal Government, under a repayment contract, for one-half of the separable costs allocated to recreation, including the initial recreation facilities, and to the enhancement of fish and wildlife resources. Non-Federal interests must bear the annual operation and maintenance costs for those functions and must fully finance subsequent installation of additional recreation facilities.

5. *Irrigation.*—Costs will be fully reimbursable by the areas benefited except that no interest will be charged on the capital costs allocated to irrigation pursuant to Federal Reclamation Law. Reimbursement will be accomplished by master districts with adequate revenue raising powers. As noted above, financing of the associated irrigation distribution and drainage systems will be a local responsibility, probably through loans from the Federal Government, or by direct Federal financing and construction of the distribution system and main drains by the United States Bureau of Reclamation. Repayment within 40 years after completion without interest will be required.

The Interstate System

It is assumed that construction of the Interstate System will be financed entirely by the Federal Government. The State of Texas will buy the water from that System at the State line for use in Texas at charges established to repay the State's proportionate share of the reimbursable Federal investment in accordance with Federal laws and policies in effect at the time of construction.

Other Functions and Facilities

The costs of other project functions, not listed above, will be financed partly by the Federal Government, partly from an augmented Texas Water Development Fund, and in some cases partly by local agencies, under the following general repayment policies:

1. *Municipal and Industrial Water Supply.*—In negotiating a master agreement(s) with the United States, advantage will be taken of the provisions of the Water Supply Act of 1958 relating to delayed repayment of reservoir costs allocated to future water supply for municipal and industrial purposes considering the State's participation in initial financing of these projects. State costs allocated to this purpose will be fully reimbursable by water users with interest in accordance with the Texas Water Development Board Act.

2. *Bays and Estuaries.*—There are at present no Federal or State statutes or policies relating to the financing or the reimbursability of costs incurred to preserve or enhance the quality of the aquatic environment of the bays and estuaries by the controlled addition of fresh water. There is a high degree of both national

and State interest in these resources. The formation of local political subdivisions to reimburse all or part of the costs allocated to non-Federal interests would be difficult. Federal and State policies need to be established by statute as soon as possible.

3. *Local Projects (Not a part of the integrated Texas Water System).*—These may be financed and constructed solely by local agencies, solely by Federal agencies, solely by the State, jointly by Federal and local agencies, jointly by the Federal Government and the State, jointly by the Board and local agencies, or jointly by the Federal Government, the Board, and local agencies.

Texas Water Projects Recreation Fund

It is proposed that operation, maintenance, and expansion of the recreation facilities at units of the Texas Water System, management of the fish and wildlife resource enhancement program of the System, and repayment of the reimbursable Federal costs involved be made the responsibility of the Parks and Wildlife Department. That Department might contract with local agencies for operation of the recreational facilities at some units. The costs incurred by the Department in excess of the revenues obtained from user fees and concession leases would be covered by other funds or resources or by annual appropriations from the General Revenue Fund.

Clean Water Fund

If the water requirements of Texas are to be met, it is essential that the quality of the available water resources be maintained at levels sufficiently high that there will be no significant adverse effect on beneficial uses. This will require a high degree of treatment for all municipal sewage and industrial wastes. Large regional systems for the collection, treatment, and disposal of waste waters provide an excellent vehicle for the major urban and industrial complexes of the State to accomplish this high degree of treatment. Reclamation of such waste waters for reuse should be accomplished wherever possible.

It is proposed that a Clean Water Fund be established to provide a program of State grants for sewerage systems as envisioned in the Federal Water Pollution Control Act as amended. This will not only stimulate action to abate and prevent pollution but also maximize the amount of Federal grant funds that may be obtained by Texas.

The Clean Water Fund should be administered by the Texas Water Quality Board. In analyzing the merits of any application for a grant from the Fund, the Texas Water Development Board should be consulted to insure that the quality and reclamation objectives of the Texas Water Plan will be met by the plan proposed.

Water Service Contracts

It is proposed that (1) the State of Texas, through the Texas Water Development Board, participate financially with the United States, and, in some instances, with local agencies in constructing the Texas Water System; (2) the Board assume responsibility for operation, maintenance, and administrative and fiscal management of the major units of the Texas Water System as each is completed and ready for service; and (3) the Board contract for payment of the reimbursable portion of the Federal investment allocated to water supply. Such contract will be secured by water service contracts between the Board and local agencies for municipal, industrial, and irrigation and other supplies. This section discusses the proposed provisions of water service contracts for water supplied by the Texas Water System.

These contracts will be written on the premise that not only the reimbursable Federal costs must be repaid in accordance with Federal laws and policies but also that investments from the Texas Water Development Fund for construction must be repaid in accordance with provisions of the Texas Water Development Board Act.

Water service contracts under the Texas Water System will be executed only with public agencies having adequate revenue-raising powers to meet the financial obligation imposed by the contracts. For the areas proposed for irrigation under the System, where there are no legal entities with appropriate authority, the creation of master districts, with adequate revenue raising powers, will be required. Master districts in the metropolitan and industrial complexes may also be desirable to minimize the costs of treatment and distribution.

The water service contracts will convey a contract right to a water supply of suitable quality without specifying the source or sources from which the water will be obtained. The contracts will contain provisions relating to the amounts, timing, and places of delivery; the amounts and manner of payment; and such other terms and conditions as necessary to protect the interests of the United States, the State, and contracting agencies.

The Texas Water System will deliver water to one or more terminal points or at main conveyance facility turnouts in the service area of each contracting agency. Allocation and distribution of the water beyond the terminal points or turnouts will be the responsibility of the local contracting entity.

Water service contract commitments will be executed in advance of construction to assure payment. When capacity is to be included in a storage or conveyance facility for an agency which has a future but not immediate need for water, that agency will be required to execute a water service contract in advance of construction. Payments in accordance with these contracts will be such as to repay the Board for the proper apportioned investment made in the System with interest on such investment. Payments may begin some years before water is taken.

Each water service contract will provide for payments broken down into components: (1) capital repayment, including applicable interest charges; (2) fixed operation, maintenance, and administrative costs, i.e., those costs which are generally independent of the amount of water delivered; and (3) variable operation, maintenance, replacement, administrative, and management costs, i.e., those which vary directly with the amount of the water delivered. This procedure will be more equitable than contracts written on fixed schedules of water delivery, since in some years, such as those of heavy rainfall, lesser amounts of water may be required. Final capital cost repayment obligations will be on the basis of actual costs incurred in construction, not on the costs estimated in advance of construction.

Irrigation Water Supply

It is proposed that water for irrigation be supplied under the provisions of Federal Reclamation Law, i.e., no interest to be charged by the United States on capital costs allocated to irrigation of non-excess lands, for both the Texas Water System and the Interstate System. This will, however, make the lands served subject to whatever acreage limitation provisions may be in effect at the time.

Each of the water service contracts providing for irrigation will contain a schedule of payments based on anticipated buildup in demand estimated to be sufficient in magnitude to provide (a) adequate funds to meet the repayment requirements of the United States for the construction costs allocated to irrigation of the particular area under the Texas Water System, (b) plus purchase of irrigation water from the Interstate System or any mandatory payments to that System in the interest of irrigation, and (c) plus that portion of the anticipated fixed operation, maintenance, administrative, and management costs properly allocable to irrigation in the area concerned. The variable costs will be estimated and paid in advance with subsequent adjustment for actual costs incurred.

To the extent that the contracting entity or master district cannot obtain sufficient revenues from water charges because of the limited payment capacity of agriculture, it will be necessary to provide other sources of income to make up the difference.

Municipal and Industrial Supply

The Board will execute contracts with local political subdivisions such as municipalities, river authorities, and districts, which will take delivery of raw water and treat it as necessary for distribution to other political subdivisions or directly to retail customers.

A repayment schedule in each water service contract will be established for municipal and industrial water supplied which in the aggregate will provide, insofar as possible, sufficient revenues each year to meet:

1. **Interest on, and repayment of, principal from the Texas Water Development Fund used to finance the State's investment in the Texas Water System allocated to municipal and industrial water supply.**
2. **Operation, maintenance, and replacement costs of the Texas Water System allocated to municipal and industrial water supply.**
3. **Board administrative and management costs properly allocable to municipal and industrial water supply.**

Zones will be established, within any one of which the charges for raw water will be computed on the same basis for all municipal and industrial water service contractors taking delivery within that zone. The charges for water in each zone will be made of two basic elements, (a) a water supply charge and (b) a conveyance charge.

Each of these charges will include fixed and variable components. The fixed component of the total water charge for each contractor includes those costs which are independent of the actual amount of water delivered and will be paid under a fixed schedule established in contract. The variable component will include those costs, such as energy for pumping, which are directly related to the amount of water delivered under a contract in a particular year. Separate water supply charges will be established for the Trans-Texas Division and for the Coastal Division. The conveyance charge will be determined by the conveyance facilities necessary to transport the water from the supply complexes to the individual contractor, such as the Trans-Texas and Coastal Canals.

Either or both the water supply charge and the conveyance charge may be changed as new conservation units or additional conveyance capacity are added to the Texas Water System.

The water service contracts will provide for periodic review and revision as needed of the water charges and demand schedules to adjust for variations in past costs from those previously projected, for the cost of units added, and for new projections of future requirements and costs.

Charges for water that might be delivered on a temporary or as available basis, say for ground water recharge, would be on a unit volume charge basis equal to the incremental cost involved in collecting and transporting the water to the point of delivery.

Basins of Origin

The charges for water from the Texas Water System to users in the basins of origin will not be greater in any event than would have been the case had there been no export by the System. Such users will, on the other hand, share fully in any financial advantages accruing because of staged development and systematized operation of the System.

BOARD PROGRAMS

Plate 1 outlines the steps that must be taken by the State and Federal governments if the Texas Water Plan is to become a reality. The controlling time schedule is keyed to times at which essential actions must be taken to assure that first deliveries of water to the High Plains and other areas through the Texas Water System will meet critical times of water demand. The Board has scheduled each of its major programs to meet the target dates shown on Plate 1.

The Board's major programs are shown diagrammatically on Figure V-3. The following summary of major programs is descriptive only, rather than inclusive of every task. Detailed schedules and budgets will guide each program.

Water Requirements and Water Problems

This program involves the continuing evaluation of water requirements and water problems throughout the State of Texas.

Required are projections of future population and economic development, both for local areas and the State as a whole; future State and national demands for irrigated crops; soil classification studies, particularly as these relate to application of water for irrigation; land use plans; projections of future irrigated acreages and locations; unit use values for municipal and industrial demands; consumptive use of water by irrigated crops; studies of irrigation efficiency; future recreation demands; fish and wildlife demand studies; and hydraulic, hydrologic, biologic, and economic studies of the bays and estuaries.

Basic Data Management

This program relates to compiling, collecting, storing, retrieving, presenting, and publishing basic data obtained under other Board programs, from other State agencies, from Federal and local agencies, and from private interests. The Board is actively working with other State agencies in inventorying and evaluating all available water-oriented data and in determining future requirements for basic data of all kinds to effectively implement the Texas Water Plan.

All of these data are essential to sound water planning and for the effective and economic development and utilization of the limited water resources which are now or may become available to Texas. To proceed without adequate basic data and a proper data management program would cost the water users of Texas hundreds of millions of dollars.

Because water resource systems are dynamic and continually changing, due both to natural phenomena and to the effects of man's activities, the longer, more continuous and complete the historical records, and the greater the frequency of observations, the more valuable and useful the data will be.

Water Resource Availability

The collection, analysis, and use of data relating to the occurrence and quality of all sources of water is essential to determining the location and quantitative and qualitative characteristics of the available resource.

Hydrologic studies have been made for all present and proposed reservoirs in the Texas Water System. Their physical characteristics, operational effects upon one another and on the System as a whole, quality of water now and under future conditions, and their yields under present and future conditions have been examined. These refined studies must be conducted for all of the river basins of the State.

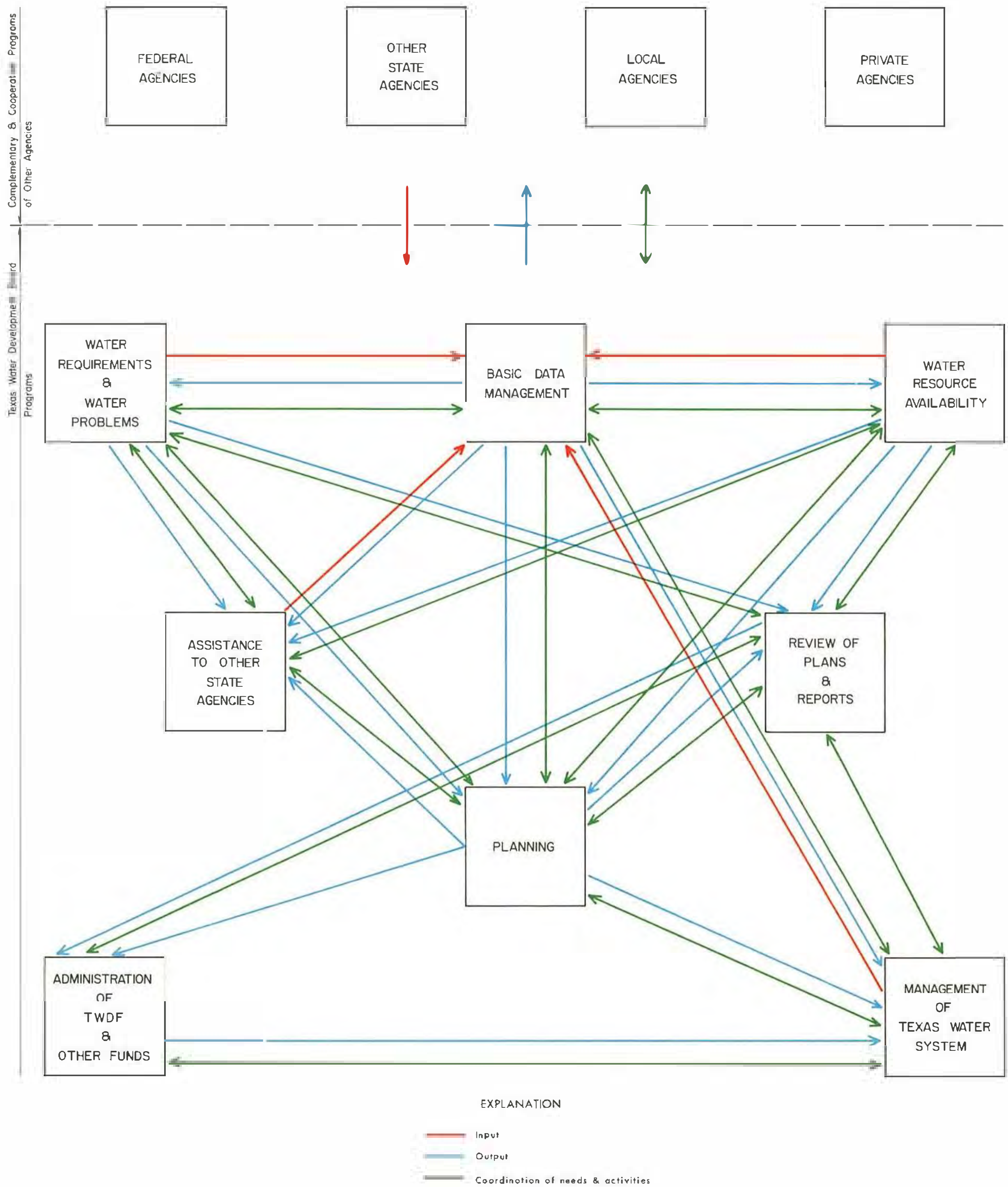
Studies providing information on the geology, hydrology, and hydraulic characteristics of ground water basins at a level suitable for general planning have been completed for approximately 40% of the State. These studies, however, must now be refined, and new techniques of analysis applied for each of the ground water basins upon which the State must rely.

Assistance to Other State Agencies

The Board is necessarily involved in this Plan with all State agencies and colleges and universities whenever related functions touch on water resource matters.

FIGURE V - 3

MAJOR PROGRAMS OF TEXAS WATER DEVELOPMENT BOARD



Individual Board programs provide necessary assistance to PACT (Planning Agency Council for Texas), Texas Water Rights Commission, Texas Water Quality Board, Parks and Wildlife Department, Railroad Commission, and Water Well Drillers Board.

This structured relationship between State agencies engaged in corollary activities is essential to an effective State management system designed to avoid duplication of effort while meeting fully the State's governmental needs. Conceptually, these relationships must be flexible and responsive to the increasing need for a multidisciplinary approach to common problems which does not penalize the State by duplicating either services or professional competence.

Review of Plans and Reports

The Board will review reports prepared by Federal, State, and local entities on water projects and analyze their import to the State's total water development picture in the context of the Texas Water Plan.

Planning

Sound continued planning is especially important in Texas where internally available water resources are inadequate to meet rapidly expanding Statewide demands, and where the cost of water development and conveyance will be high.

Texas water planning studies described in this document have been, of necessity, conducted at a reconnaissance level. These plans must now be refined and detailed so as to serve adequately for feasibility level reports, as a basis to proceed with design at the proper time, and to provide the basis for decisions which will insure the most efficient use of intrastate waters.

Economic and financial analyses must be refined prior to the presentation of feasibility reports to the Congress for authorization of Texas Water Plan facilities, and to form the basis for execution of water service contracts. These analyses, which the State must assume the responsibility of preparing and supporting to the Congress, must be adequately detailed to provide assurance to the Congress that the benefits to the State and to the Nation justify the costs of the Plan; and that the repayment capability of those areas to which water will be taken is adequate to reimburse the Federal investment to the extent required by Federal laws and policies.

Administration of Texas Water Development Fund and Other Funds

The Texas Water Development Fund was created by Constitutional amendment in 1957. The purpose of the Fund's establishment was to make loans to local governmental entities sponsoring construction of projects for the conservation and development of the State's water resources. Further Constitutional amendments in 1962 and 1966 broadened the authority of the Board in administering the Fund to include powers to acquire conservation storage facilities in reservoirs to be constructed on Texas streams and for any system or works necessary for the filtration, treatment, and/or transportation of water by Federal or local governmental agencies to the end that the remaining reservoir sites in Texas may be developed to their optimum potential. The program administered by the Board is currently limited by Constitutional provision to $400,000,000 provided that the last $200,000,000 be approved by a two-thirds majority of each House of the Texas Legislature. By statutory provision, the Board is limited to a maximum investment in any one local project, and further restricted to an aggregate investment of $100,000,000 in all reservoir conservation storage facilities.

The State of Texas must continue to share in the costs of Texas water development throughout the period of implementing the Texas Water Plan if it is to provide the assistance that will be needed in water development.

The authorization by the Legislature and the citizens of Texas of an augmented Texas Water Development Fund will be necessary before feasibility reports for the Texas Water System go to Congress for authorization in order that Texas can be in a strong position to say that the State is ready to accept its share of the responsibility for meeting its water needs.

Management of Texas Water System

While actual operation, maintenance, and administrative and fiscal management of specific elements of the System will not start until 1979, certain necessary preliminary actions must be initiated now as indicated on Plate 1.

Operation of any system as complex as the Texas Water System must be fully automated to achieve maximum efficiency and economy. Only one similar system, the California State Water Project, which is much less complex, has been designed for automated operation. The Board must provide the design concepts and the research needed for automated operation.

Hundreds of millions of dollars in revenue will be generated annually by sales of water from the Texas Water System. Millions of acre-feet of water will be moved through the System to a wide variety of water users. There is no precedent for the management of a complex water resource system on this scale, and experienced management capability must, therefore, be developed over time to assume control as the elements of the System become operational.

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