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Identification of Water Resources Planning Problems in the Metropolitan Area of Greater San Antonio and Its Associated Counties

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Texas A&M University

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IDENTIFICATION OF WATER RESOURCES PLANNING PROBLEMS IN THE METROPOLITAN AREA OF GREATER SAN ANTONIO AND ITS ASSOCIATED COUNTIES

Principal Investigators

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PREFACE

This report describes the research performed to date on Project A-17-TEX sponsored by the U.S. Department of Interior, Office of Water Resources Research, Texas Water Resources Institute, and the Texas A&M University.

The research reported herein describes the region incompassed by the San Antonio River Basin. Included in the description is a brief summary of the regional economy, demography, and geographical characteristics. Additionally, the quantitative information including the inventory and planning control for both surface and groundwater resource management of the San Antonio area is presented. Emphasis has been placed upon the indentification of the probabilistic nature of regional water quality management. The methods and techniques developed for handling massive data and the reliability analysis for regional water quality control are also presented.

Appreciation is expressed to the Alamo Area Council of Governments, San Antonio River Authority, City of San Antonio and the Texas Water Development Board for their assistance in this research. Numerous graduate students contributed to this research. Chief amoung these is Miss Sharon Tu for her efforts in developing the San Antonio Data Retrieval Program. Special acknowledgement is given to Messrs. Dhira Phantumvanit and Chennupati Rao for their assistance in preparing the manuscript for publication. The cooperation of Dr. J. R. Runkles and the entire staff of the Texas Water Resources Institute is appreciated. Also, a special thanks to Mrs. Sharon Biehle for her diligent effort in typing the manuscript.

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CHAPTER I

INTRODUCTION

Growth in population and economic activity has been accepted as the essential elements of American life for almost two centuries. Since the beginning of the seventies, we have begun to concern ourselves with the quality of this growth. Meanwhile, modern civilization has created the high concentration in urban areas, the enormous inflation of resources consumption and the consequent increase of production requirements. Unfortunately, all these phenomena also became the driving force for the acceleration of waste generation and resources depletion.

The development of the San Antonio metropolitan area has followed the same pattern as that of other urban areas in the United States. It has become the largest metropolitan area primarily depending upon groundwater for its water supply. The availability of water has also played a most important role in shaping the history and development of the San Antonio area and its vicinity. Along with age of this metropolitan area, multiplicity of governments, planning agencies, river authorities and interest groups in water resources management have evolved into a complicated system in this area. Thus, it was realized that an overview embedded with the systems approach for the current water resources problems is needed. However, the total spectrum of problems would be enormous and the analysis phase must then be concentrated on one of the most urgent problems.

The primary objective of this study as reported herein is to give overview of the current status of different aspects of urban water.

resources management in the San Antonio area. Special emphasis has been placed upon handling of water quantity and quality data and analysis of regional water quality of the San Antonio Riber. Specific investigations which have been conducted are as follows:

(1) Identification of basic managerial problems for the urban water resources management in the San Antonio area.

(2) Development of information storage and retrieval programs for quality and quantity.

(3) Development of a mathematical model describing the variability of regional water quality of San Antonio River Basin.

There are three distinct parts in this report. The first part describes urban water resources management components in San Antonio (Chapters II and III). The second part describes the information retrieval programs developed in this project (Chapter IV), and the third part concentrates on the development of a regional water quality reliability analysis model and its implications (Chapter V).

PART I

Identification of Problems in General Water Resources Management in the San Antonio Area

CHAPTER II

DESCRIPTION OF THE SAN ANTONIO AREA

San Antonio, the fifteenth largest city in population in the United States, is located in South Central Texas. This ares is not endowed with an abundance of surface water and is largely dependent upon groundwater resources for its water supply. Although San Antonio is not facing an immediate shortage of water, its major problem is insuring itself an adequate supply in the future.

San Antonio is an old city that lies in the center of a populated area of almost one million people. It is the largest city in the world primarily dependent upon groundwater as its water supply. San Antonio is presently 182.73 square miles in size, and is composed of five separately incorporated cities, which are enclaved within the city and seven military installations within or adjacent to the city. San Antonio is an active business community, and the region of the San Antonio River Basin is well developed with both agricultural and commercial enterprises. There is comparatively little basic industry in the region. Therefore, the economy depends heavily on tourism and the military complexes.

Physical Characteristics

Geology. The San Antonio River Basin comprises an area of 4,100 square miles in south central Texas. The river basin includes two physiographic sections, the West Gulf Coastal Plain of the Coastal Plain province and the Edwards Plateau of the Great Plains province. These physiographic sections within the basin are separated by the Balcones

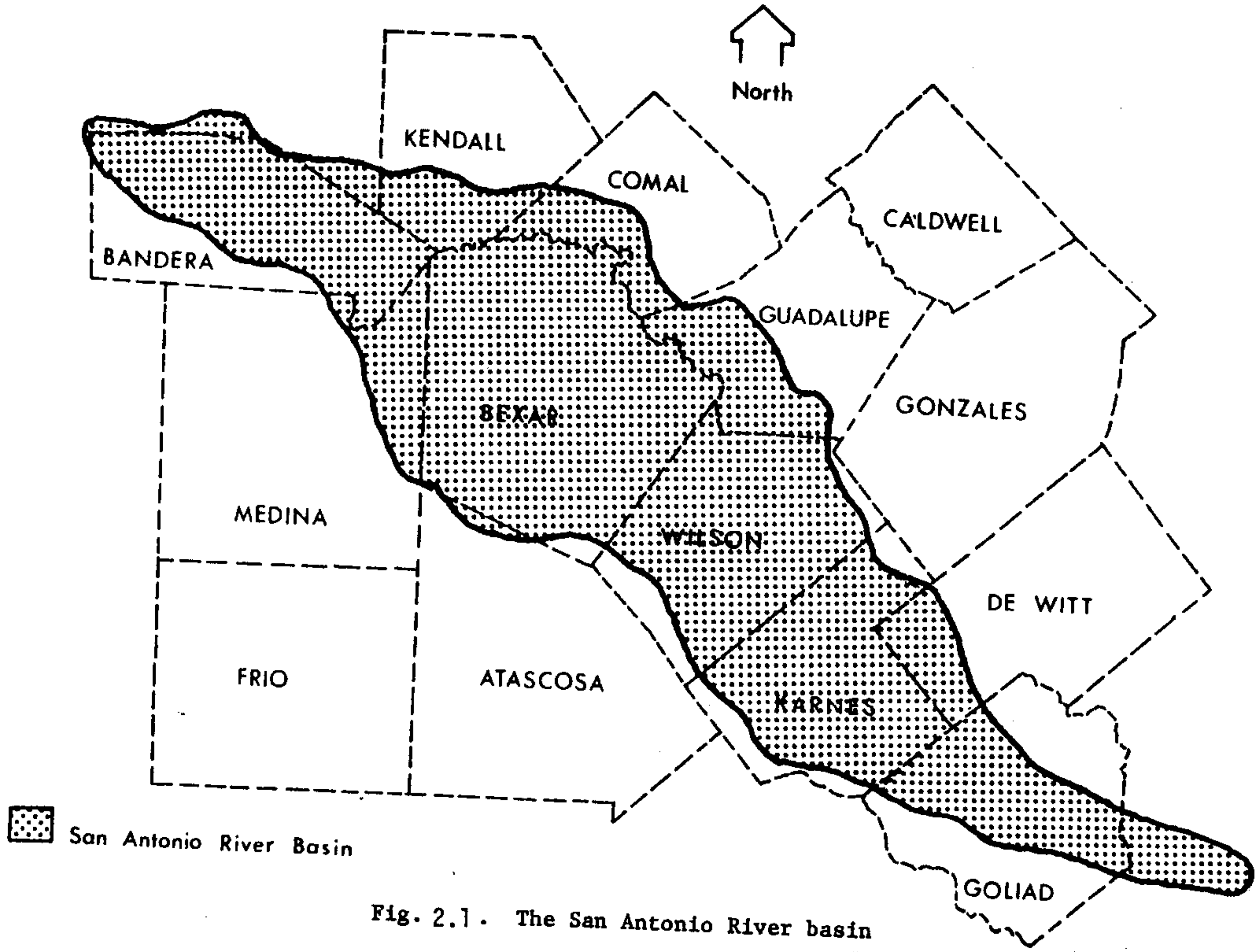


Fig. 2.1. The San Antonio River basin

Escarpment. Although both the Edwards Plateau and the top of the Balcones Escarpment are partly protected from erosion by a cap of resistant limestone, streams that originate in the plateau have cut broad valleys below the upland surface. Between these valleys, remnants of the resistant limestone form steep cliffs. The resulting terrain is rough and rugged, and the soil mantle is very thin except along the major stream valleys (58).

The West Gulf Coastal Plain extends from the Balcones Escarpment to the Gulf of Mexico. In this section, the rolling to moderately hilly country merges with the level Gulf Coastal Prairie.

The principal stream that drains the Edwards Plateau section of the basin is the Medina River, which rises in the northwestern section of Bandera County, flows eastward across the Edwards Plateau, and joins the San Antonio River about 15 miles south of the city of San Antonio.

Surface Water. The main stream of the San Antonio River rises in the city of San Antonio near the center of Bexar County, flows southeastward across the West Gulf Coastal Plain, and joins the Guadalupe River about 11 miles upstream from San Antonio Bay. Figure 2.1 shows the geographic location of the San Antonio River Basin.

Cibolo Creek, the principal tributary to the San Antonio River, rises in Kendall County in the Edwards Plateau section, flows southeastward across the Balcones Escarpment and the West Gulf Coastal Plains section, and joins the San Antonio River in Karnes County (58).

Springflow from the Edwards Plateau and associated limestones within the Edwards Plateau contribute to the base flow of the Medina

River and Cibolo Creek. In turn, most of the base flow and part of the flood flow infiltrates into the Balcones Fault Zone on the outcrop of the Edwards and associated limestones. Consequently, south of the Balcones Fault Zone, these streams are often dry (87).

Although the area depends solely upon groundwater to meet the water needs of the population, there is a limited amount of surface water in the region. Canyon, Medina, Dunlap, Brauning, Calaveras, and Mitchell are major lakes and reservoirs in the area. All are man-made and are used primarily for flood control, waste treatment, power generation, or as recreational facilities. Mitchell Lake is part of the San Antonio waste treatment process and, as such has limited recreational usage. It does, however, supply water for irrigation (34).

Soils. Soils in the area of the Edwards Plateau generally overlay cretaceous limestones and are characterized by steep slopes, shallow depth and limestone fragments in the surface soil. These types of soils are generally least suited for agricultural and urban development due to the high cost of pre-use preparation. Soils in the lower regions of the valley are of the Rio Grande Plains Association. These soils have a medium to coarse texture with great depth. The permeability and stability of these soils render them ideal for intensive urban development. Soils will characterize the type of vegetation and in turn the wildlife within the area. Juniper, oak, and mesquite, which are surrounded by dense undergrowth, dominate the area. In the river bottoms, cypress is not unusual. Turkey, deer, quail, javalina, and squirrel are the most abundant wildlife in the area. These species are non-migratory and will continue to inhabit and populate the area if sufficient water and feed are available. Freshwater fish exist in abundance in the reservoirs and streams in the basin. All game fish common to the southwestern area of the United States are found in the region, and additionally, rainbow trout can be found in the cold waters near Canyon Dam. Birdlife is likewise varied in the area including quail, duck, turkey, goose, hawk, and eagle. The most famous North American bird which traverses the region is the almost extinct whooping crane, which makes its annual migration between Texas and Canada (34).

Natural Resources. The availability of natural resources plays an important part in the economy of the river basin. Paramount amoung these is groundwater, which may be acquired from several aquifers. There are four major aquifers in the region. They are the Edwards-Trinity (Plateau), Gulf Coast, Carrizo-Wilcox, and the Edwards (Balcones Fault Zone). Figure 2.2 shows the location of these aquifers. However, the Edwards and its associated limestones is the most important aquifer in the region. The Edwards provides the water supply to the major populations of the region including the city of San Antonio.

Crude oil, natural gas liquids, and natural gas are also mined from the region. To the north of the Balcones Escarpment the cretaceous limestones and dolomites furnish building stone, lime and cement. To the south of the Balcones Escarpement the tertiary formations contain large deposits of gravel, sand, and clay (34).

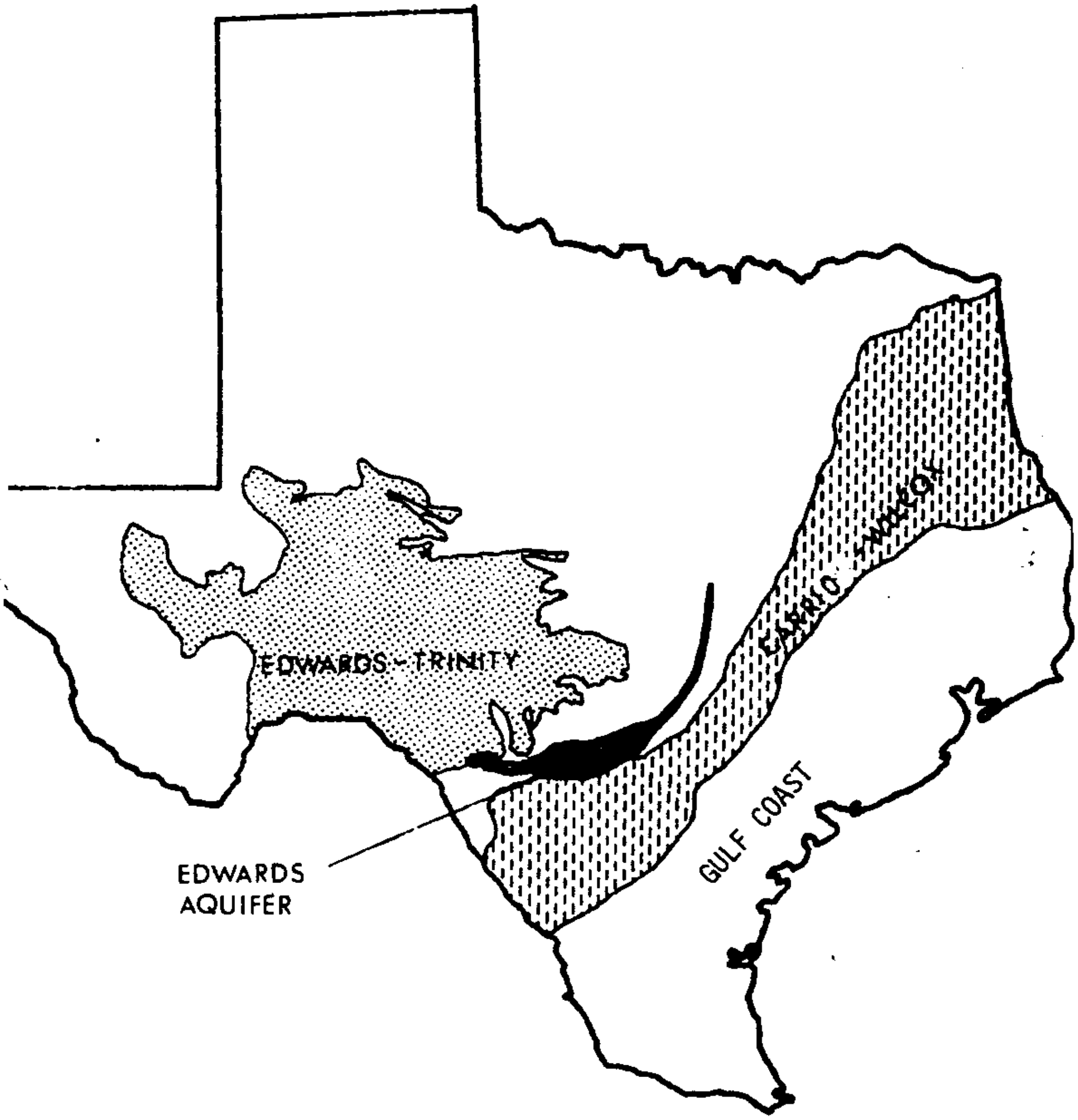


Fig.2.2 Geographic location of the four major aquifers which influence the San Antonio area

Climate

The San Antonio River Valley is classified as a modified subtropical climate, predominantly continental during the winter months and marine during the summer months. The river divides a semi-arid area to the west and a coastal area of heavy precipitation to the southeast. The drainage to the east of the San Antonio River Valley is toward the Mississippi Basin, while the drainage to the west is toward the Rio Grande Basin. Nearly all of the streams east of the San Antonio River are right-branched, while the streams to the west are left-branched. This is primarily due to the influence of the San Marcos Arch which strikes from the Llano Uplift to the Gulf Coast of Texas.

Rainfall. Average annual rainfall varies across the river valley from 25 to 36 inches per year. The rainfall is relatively well distributed throughout the year with heaviest amounts during the months of May and September. Precipitation from April through September usually occurs with thunderstorms, whereas most of the winter rain occurs as drizzle. Hail of damage intensity seldom falls but light hail is frequent in connection with the springtime thunderstorms. Measurable snow occurs only once in three or more years. The greatest amount, 7.4 inches, fell in 1926 at San Antonio.

Figure 2.3 shows the average annual rainfall over the area. Several anomalies occur on this map around the San Antonio area. One high area occurs at the common junction of Comal, Mays, and Blanco Counties. A notable low area occurs over the city of San Antonio. It was recognized that the attibutes for the low rainfall

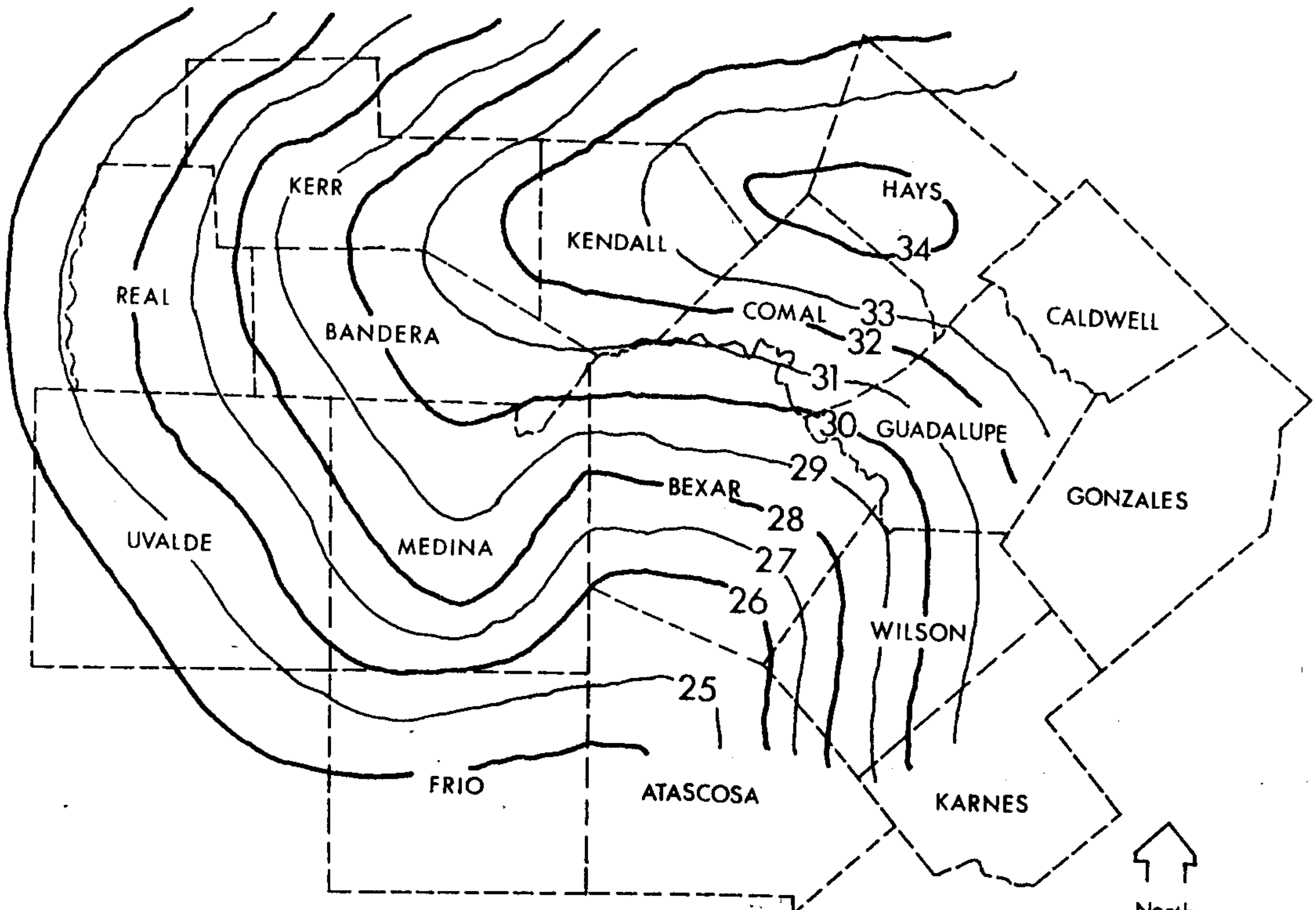


Fig. 2.3 Average annual rainfall

Table 2.1 Annual rainfall, San Antonio, Texas, 1871-1970

Year	Inches	Year	Inches	Year	Inches
1871	22.79	1910	16.22	1950	19.86
1872	29.09	1911	18.68	1951	24.44
1873	34.02	1912	23.73	1952	26.24
1874	41.55	1913	37.68	1953	17.56
1875	21.95	1914	33.67	1954	13.70
1876	-	1915	27.28	1955	18.18
1877	30.20	1916	27.66	1956	14.31
1878	39.60	1917	10.11	1957	48.83
1879	22.80	1918	29.91	1958	39.69
		1919	50.30	1959	24.50
1880	41.91	1920	19.56	1960	29.76
1881	26.78	1921	28.53	1961	26.47
1882	36.39	1922	24.59	1962	23.90
1883	-	1923	32.71	1963	18.65
1884	-	1924	23.65	1964	31.88
1885	32.92	1925	14.99	1965	36.72
1886	26.22	1926	30.39	1966	21.42
1887	20.13	1927	22.75	1967	29.09
1888	40.55	1928	30.20	1968	30.39
1889	38.95	1929	29.24	1969	31.41
				1970	-
1890	29.79	1930	22.79		
1891	30.04	1931	25.00		
1892	25.81	1932	35.57		
1893	18.24	1933	17.64		
1894	21.75	1934	27.65		
1895	26.07	1935	42.93		
1896	34.09	1936	34.11		
1897	15.92	1937	26.07		
1898	22.49	1938	23.26		
1899	19.71	1939	18.83		
1900	37.19	1940	30.79		
1901	16.44	1941	26.34		
1902	24.79	1942	38.46		
1903	33.11	1943	20.51		
1904	29.38	1944	33.19		
1905	32.59	1945	30.46		
1906	20.42	1946	45.17		
1907	27.77	1947	17.32		
1908	38.52	1948	23.64		
1909	14.92	1949	40.81		

may be due to the upward air movement over the valley area of the San Antonio River. The Weather Bureau has stated that air fronts approaching the city often break open over the valley. The broad valley creates a slight amount of uplift from the prevailing winds which forces precipitation to higher elevations. Annual readings from the San Antonio weather station are listed in Table 2.1 (86).

Tropical storms occasionally bring strong winds and heavy rains to the area. Rains that accompany these storms often measure 12 to 15 inches of rain in 24 hours. The record rainfall for the area occured in September of 1952 when 23 to 26 inches fell in 24 hours in the vicinity of Boerne and Blanco. The storm was triggered by an advancing cool front (86).

Economy

The economy of the San Antonio area is centered in the city of San Antonio in Bexar County. The population of Bexar County was set at 830,460 by the 1970 census, up 20.9 percent from the 1960 census of 687,151 (15). The population figures for 1970 and 1960 along with the rate of change for the various subdivisons of Bexar County are shown in Tabel 2.2.

From Table 2.2 it can be seen that the trend of urbanization has been a steady movement to the suburbs, however, the city itself has experienced tremendous growth. Of the 830,460 people residing within Bexar County, 764,621 are white, 56,630 are black and 9,209 are of other races. There are 408,334 males compared to 422,126 females. There are 23,567 households which house 794,033 individuals. The

TABLE 2.2

POPULATION BY POLITICAL SUBDIVISION
1960 AND 1970

Political Subdivision	1970	1960	Percent Change
China Grove	329		
Randolph	5,329		
Kirby	2,558	680	267.2
St. Hedwig	690	589	17.1
Converse	1,383		
Hill County Village	636	418	52.2
Hollywood Park	2,299	783	193.6
Live Oak	2,779		
Selma	207		
Universal City	7,613		
Windcrest	3,371	441	664.4
Grey Forist	385		
Leon Valley	1,960	536	265.7
Shavano Park	881	343	156.9
Alamo Heights	6,933	7,552	8.2
Balcones Heights	2,504	950	163.6
Castle Hills	5,311	2,622	102.6
Fort Sam Houston	10,535		
Olmos Park	2,250	2,457	8.4
San Antonio City	654,153	587,718	11.3
Terrell Hills	5,225	5,572	6.2
Elmendorf	400		
Lackland	19,141		

TABLE 2.3

RETAIL TRADE BY TYPE SMSA

Type	Number Establishments	Sales	Payroll
Building Materials, Hardware, and Farm Equipment Dealers	205	$39,217,000	$4,877,000
Department Stores	28	171,954,000	26,861,000
Variety Stores	72	19,957,000	
Miscellaneous General Merchandise Stores	90	17,001,000	
Food Stores	1,200	227,105,000	16,200,000
Automobile	468	215,629,000	21,966,000
Gasoline Service Stations	986	91,229,000	8,573,000
Women's Clothing, Specialty Stores, Furriers	108	25,005,000	3,646,000
Other Apparel and Accessory Stores	191	37,612,000	6,012,000
Family Clothing Stores	25	7,730,000	1,155,000
Shoe Stores	66	11,600,000	1,610,000
Apparel and Accessory Stores	15	923,000	197,000
Furniture Stores	97	25,633,000	3,837,000
Home Furnishings Stores	50	4,460,000	813,000
Household Appliance, Radio, Television and Music Stores	127	18,343,000	2,879,000
Eating Places	925	68,899,000	16,311,000
Drinking Places (Alcoholic Beverages)	573	13,318,000	1,643,000
Drug Stores and Proprietary Stores	167	30,451,000	5,117,000
Liquor Stores	153	21,424,000	2,074,000
Sporting Goods Stores And Bicycle Shops	33	2,801,000	330,000
Jewelry Stores	72	10,994,000	1,606,000
Florists	84	2,779,000	471,000

TABLE 2.4

RETAIL TRADE BY TYPE CBD

Type	Number Establishments	Sales	Payroll
Building Materials, Hardware, and Farm Equipment Dealers	4	$1,305,000	$174,000
Department Stores	5	57,685,000	13,994,000
Variety Stores	9	6,490,000	1,258,000
Miscellaneous General Merchandise Stores	12	2,361,000	297,000
Food Stores	39	3,083,000	320,000
Automobile Dealers	30	56,646,000	5,358,000
Gasoline Service Stations	16	1,249,000	98,000
Women's Clothing, Specialty Stores, Furriers	27	12,310,000	1,890,000
Other Apparel and Accessory Stores	63	17,651,000	3,294,000
Family Clothing Stores	11	3,217,000	651,000
Shoe Stores	22	3,313,000	459,000
Apparel and Accessory Stores, N.E.C.	5	287,000	100,000
Furniture Stores	17	9,570,000	1,828,000
Eating Places	96	8,777,000	2,307,000
Drinking Places (Alcoholic Beverages)	46	1,779,000	340,000
Drug Stores and Proprietary Stores	27	5,202,000	937,000
Liquor Stores	6	712,000	35,000
Sporting Goods Stores and Bicycle Shops	8	1,465,000	186,000
Jewelry Stores	22	6,552,000	1,094,000
Florists	4	120,000	25,000

population is approximately evenly distributed between those over and under 25 years of age (15).

Portions of the region are considered to form a Standard Metropolitan Statistical Area (SMSA) as designated by the Bureau of the Census. This is a designation applied to an area whose city boundaries and subdivisions are interconnected, and the compilation of data for one particular sector is meaningless. For this reason it is better to speak of the economy of the area in terms of the SMSA rather than the various governmental units.

Total population within the San Antonio SMSA in 1970 was 864,014. Of this, 794,737 were white, 59,887 were black and 9,390 were of some other race. The 1967 Census of Business reports there were 6,301 retail establishments within the SMSA with total sales of $1,075,774,000 and a payroll of $132,524,000 annually. The Central Business District of San Antonio accounted for 18.6 percent of sales within the SMSA. Central District (CBD) sales were $200,480,000 and its payroll was $34,760,000. Table 2.3 shows the retail business by type for the SMSA and Table 2.4 shows the same information for the CBD (14).

In 1967, there were over 1,300 financial institutions in the region including banking, insurance, and real estate. Of these, 51 were commercial banks. In addition, there is a local Federal Reserve Branch Bank located in San Antonio. In 1967, total deposits of the region's banks were $1,374,105,000 and total leans outstanding were $650,643,000. Using the ratio of loans to deposits as a measure of responsiveness of area banks to the financial needs of the community, a ratio of .47 to 1 indicates that current banking policies should help sustain the continued growth demands of the area (31).

Educational institutions in the area account for more than eight percent of the non-agricultural employment. There are 41 independent school districts, two junior colleges and five senior colleges. In addition, numerous private organizations provide specialized training which is not provided in other educational institutions.

Agriculture in the area consists of private farms whose production is common to the southwest region. Cattle and beef production account for a portion while the rest are farm products. In the past several years, farm production has remained constant while the number of farms has decreased (31).

CHAPTER III

Overview of Management and Planning Problems of Urban Water Resources

As the history and growth of the San Antonio area has been dominated by water resources development, so will continued urban growth depend on availability of high-quality water. The early development of the San Antonio area was prompted by the springflow in this area. A new era of urban development was ushered when the first "flowing well" above the Edwards Aquifer was drilled in 1888. It not only ended the dependence upon unreliable springflow, but also triggered the surge of population growth. Since then the expansion of agricultural, industrial and urban demands of water have been accelerated with time. Now the entire area of San Antonio and its associated counties, through the linkage of groundwater resources, has become a metropolitan center of one million people. In the future, the population growth and its linked industrial, agricultural and urban development will highly depend upon the ability to furnish ample water supply for the diverse demands.

The current status of the urban water resources management and planning problems will be reviewed herein. Special attention will be addressed to the institutional and groundwater management problems.

Recreation

The San Antonio area is endowed with a wide range of recreational opportunities besides water-based activities. Partly because of its geographical location and historical significance, and partly because of municipal encouragement to recreational development, it is one of the major tourist areas of Texas.

Millions of people have traveled to the San Antonio area to see those historical sites which have played such an important role in the development of Texas and the Nation. The area Missions, and Spanish Governor's Palace, and of course, the Alamo, are only a few of the tourist attractions of the area. In addition, San Antonio itself has encouraged tourists with such attractions as the Hemisfair, the San Antonio Zoo, and various other activities along the San Antonio River such as the San Antonio Festival and River Theater.

Water Based Recreation. Water based recreation in the San Antonio area is scarce or non-existant at the present time. The most popular boating facilities are on Canyon Reservoir, a 50,000 acre reservoir in the Guadalupe River Basin. Calavaras Lake supports a limited amount of pleasure boating, but overcrowding is a problem. Boating is allowed on Brauning Lake but is limited to 10 m.p.h. Brauning Lake is the primary fishing facility of the area.

The Parks Department operates 16 public swimming pools in San Antonio, and there are numerous private swimming pools available. There are no natural swimming facilities in the area. None of the lakes around San Antonio are suitable for swimming or other activities which require direct human contact with the water. This, of course, precludes water skiing and other associated water sports.

The city of San Antonio has 2,932 acres of park area. This represents less than 4.6 acres per thousand population. Brackenridge park is the largest park in San Antonio. Several thousand feet of winding river channels are in the park, and are fed by pumped water from the Edwards. Limited fishing and paddle boating are permitted in the channel when flow is sufficient. Water is used mainly for its scenic attributes, and the main activities of the park are not related to water.

The Paseo Del Rio is considered to be as important a tourist attraction as it is a recreation area. The mile long horseshoe bend, or river bend, or the San Antonio River is as successful and imaginative a use of the river for environmental purposes as can be found in the United States. Although originally built as a flood prevention program, active political efforts have turned the area into an aesthetically pleasing area. The river in the horseshoe bend area is kept at a constant four foot depth by augmenting the river flow from deep wells. Restaurants and other private enterprises line portions of the river walk and sightseeing boats are permitted along this well-lighted segment of the river. Part of the area south of the river bend known as "La Villita" dates back to Colonial times. This area has been restored to its original character and thus the section has been designated a cultural center.

The demand for water-oriented recreation within the San Antonio area has experienced a phenomenal rate of growth in the past several years. This increased emphasis and the demand for water-based recreation have caused future planning and water management policy-making to include this aspect of water use. Recreation is essentially a non-consumptive use of water yet it competes for the available water along with other water (possibly conflicting) objectives. Meanwhile, most usages of water require the release of water from reservoirs to fulfill the required objective, yet recreation generally requires a containment of water along with the maintenance of a fairly high water level in a reservoir or river. Thus, while considering recreation in total water resources planning, the planner must compare the benefits of each objective and derive an equitable trade-off relationship.

In the pursuit of recreation there is a large economic turnover of money and goods. As leisure time increases, so will the economic impact of recreation. As a result, the total regional development of the San Antonio water resources systems should include the economic development of recreational opportunities. There are, however, some difficulties engendered due to the intangible characteristics of recreation in a total water resources plan. Some of the most significant difficulties arise from the attempt to apply economic quantification for recreation. Specifically, these difficulties may be catagorized as the following three factors: (a) estimation of the demand for recreation, (b) measurement of recreational values and benefits, and (c) evaluation of the quality of the recreational experience. Furthermore, they often are compounded by the fact that the public attitude may vary through time and that each factor is not independent of the other.

There is an unusual interaction among these three factors. That is, as the demand for recreational facilities increase, the quality of recreational experience decreases, for people usually do not enjoy "crowded" areas. Then, as the quality of recreational experience decreases, the value of the facilities decrease. However, it is also true that as the demand for a facility increases, its value increases.

Therefore, there is a direct relationship between demand and value of a recreational facility; yet an inverse relationship exists between demand and recreational growth of the facility. Hence, the interactions between these variables are unstable and extremely difficult, if not impossible, to predict.

Several attempts have been made to develop a model which successfully overcomes these difficulties. The most notable models are by Clawson and Knetsch (20), Merewitz (75), and Grubb and Goodwin (48). The Grubb and Goodwin model was published by the Texas Water Development Board and is based in part on previous work done by Clawson (19). The final selection of adaptable planning techniques for the San Antonio area cannot be made due to the constraints associated with the requirements of time and money as well as the staff and data available.

Recreation and Primary Water Use Conflicts. In general, water-based recreation is a by-product of water resources. Seldom are water resources developed whose primary purposes are recreation. Water resource projects are undertaken for certain social considerations such as flood control, irrigation, water supply, etc. Recreation on these water projects is developed after the project has been proposed and completed. It is inevitable that conflicts found in the San Antonio River Basin are described below.

The chief conflict between water used for recreation and irrigation is the scarcity of good quality water for both purposes. Irrigation reservoirs can (and are) used for recreation; however, in dry years it can be expected that they will be drained to well below the minimum recreational level.

A serious conflict may also arise between water used for industrial and recreational purposes. Water required for industrial production processes may also provide a body of water for recreational purposes. It must be remembered, however, that water must meet the demands of its primary user. Again in dry periods the water level may fall below the minimum necessary for recreational purposes. Industries often use public water sources as a disposal medium for wastewater. Often the wastewater is treated to some degree, but in most cases it is unsatisfactorily treated. Thus, pollution of streams and lakes isthe result, and recreational value is affected. To combat this problem stronger laws must be enacted and enforced concerning industrial pollution.

Conflicts between recreation and municipal water supply are similar to the conflicts experienced by flood control and power generators. Should a municipality allow recreation on their water resources they must treat the water to a higher degree. This involves a higher cost of construction of water treatment plants (129).

These problems all exist in the San Antonio River Basin; however, some are more acute than others. The most serious problem to be faced at the present is the deterioration of water quality and hence the discouragement of recreation in the area, especially the lower reach of the San Antonio River.

Flood Control

Historically flood control and drainage have been serious problems for the city of San Antonio. During the years of 1921 and 1946, considerable damage of property and loss of lives resulted from major flooding of the area. Residential and commerical buildings, railroads, roads and bridges in the watershed area have been damaged yearly by uncontrolled flooding.

Following the flood of 1921 the city of San Antonio adopted a flood control plan formulated by the engineering firm of Metcalf and Eddy. This plan included construction of the present Olmos Creek Dam and Reservoir, in addition to enlarging, straightening, deepening, and paving certain reaches of the San Antonio River and its tributaries. This work, however, did not prove sufficient against a major flood as was indicated by the serious damage which resulted from the flood of 1946.

Flood Damage. Floods in the tributaries of the San Antonio River originating in the Edwards Plateau upstream from San Antonio rise and fall more rapidly and have higher velocities than those originating at San Antonio and downstream in the Coastal Plain province. However, the slower moving floods occurring in the Coastal Plain overflood wider flood plains than those of the Edwards Plateau.

Average annual flood damages along the San Antonio River are $4,300 per mile above its confluence at Cibolo Creek and $8,000 per mile from Cibolo Creek to its mouth. For the principal tributaries, the average annual flood damages are less than $100 per mile along the Medina River and $300 to $2,800 along Cibolo Creek. San Antonio and Kenedy are among the cities in the basin which have experienced severe flood damage.

The frequency of major floods along the San Antonio River is about once every 12 years in the upper reaches and once every five years in the lower reaches. Minor flooding occurs about once every year and a half (82).

Urbanization of the San Antonio area has altered the characteristics of the flood runoff. Previous studies have found that an increase in storm runoff coincided with urban development of the area (50). It is recognized that runoff and flooding within the area will continue to increase as urbanization moves farther into the basin. As urbanization changes the natural watersheds, the characteristics of runoff will also change. Therefore, future plans for flood control should consider the expected future areas of population.

Flood Control Projects. The San Antonio River Authority along with U.S. Army Corps of Engineers are the major agencies responsible for flood control in the area. Several projects have been initiated to help relieve the flood problem in urban areas. Two planned reservoirs, Goliad and Cibolo, will have flood control storage capacities of 702,000 and 218,000 acre-feel respectively. In addition, a channel improvement project on the San Antonio River and its tributaries will help relieve the existing problem (3). The Salado Watershed Project is also under construction. It will consist of sixteen floodwater retarding structures with a total drainage area of 117.7 square miles. This will represent 47,982 acre-feet of storage capacity with a flood water detention pool surface area of 2,887 acres.

The San Antonio Channel Improvement Project is a joint effort of the San Antonio River Authority (SARA) and the U.S. Army Corps of Engineers. SARA provides the required land and easements and relocates utilities and bridges. The U.S. Army Corps of Engineers performs the actual construction of the structures. Presently five structures have been completed and two are under construction. The total length of the completed project is 64.79 miles.

As the magnitude and frequency of floods are reduced, the water carrying capacity of stream channels gradually decreses due to the natural encroachment of vegetation. Thus, overbank flooding will occur with less volume of flow than was required to cause flooding before the flood structures were built.

Flood protection for a large portion of the city of San Antonio is provided by Olmos Dam. This structure is located on Olmos Creek and is operated for flood control only. Olmos Creek is generally dry during periods of normal rainfall (82). Prior to the Corps of Engineers, in cooperation with the San Antonio River Authority, undertaking the San Antonio Channel Improvement Project, urban flooding was a major problem of the region. Although the possibility of another occurance of urban flooding is not eliminated, this threat has been sharply reduced. Close cooperation of local, state and federal governmental agencies is imperative if this problem is to be completely resolved.

The Soil Conservation Service is actively administering the U.S. Department of Agriculture's programs of watershed protection and flood prevention on a number of watersheds in the San Antonio River Basin. Plans have been developed for five watersheds totaling about 361,500 acres. Of these five planned watersheds, 31 floodwater retarding structures and over two miles of channel improvements have been constructed. At the end of 1971, 60 percent of the planned river miles have been finished, and the remaining construction to be completed is in the urban area of the city. In addition, the regional wastewater collection system proposed by Alamo Area Council of Governments also considers flooding and storm runoff (88).

If should be emphasized that once storm and urban runoff are intercepted and directed to the wastewater treatment system, the change of wastewater characteristics must be considered. This effect manifests itself not only in the quality of wastewater but also in the quantity of the wastewater during peak periods of runoff. At present, only 20 percent of the storm water runoff is drained by separate storm sewers. This limited drainage has resulted in partial flooding of the city during heavy periods of storm runoff. In addition, there was only a preliminary attempt to treat storm runoff in order to meet minimum water quality standards. Essentially the water quality in this area is greatly affected by the ability to handle the pollution associated with storm drainage in the future. Currently, about 25 percent of the flow of the lower San Antonio River is composed of storm runoff.

The Cibolo Reservoir located in Wilson County near the center of the River Basin is currently being considered for use as a multi-purpose project. This reservoir will be designed to serve the pruposes of flood control, water supply and recreation. The reservoir will store 179,000 acre-feet for a water supply and 278,000 acre-feet of water as a flood control measure. The project will require 19,000 acres of land, 7,000 of which are designated as flood control.

Flood Warning. The Environmental Science Services Administration (ESSA), U.S. Weather Bureau, provides a flash flood warning service to the San Antonio area (38). Flash flooding results from heavy rainfalls, generally three to four inches or more. A limited amount of cooperative observations at military installations and fire stations report rainfall.

The ability to accurately forecast flow quantity and flood data requires the timely rainfall and river gauging information. Moreover, timely receipt of such information is particularly important to areas subject to flash flooding. Unfortunately, present economic constraints do not permit Weather Bureau funding for the relatively dense networks required for optimum benefits. Meanwhile, a community flash flood reporting network or stream and rainfall stations, operated in cooperation with the Weather Bureau, may be an approach that can be effective in reducing danger to lives and property.

ESSA - U.S. Weather Bureau has facilitated an information dissemination facility called the ESSA Weather Wire Service. This wire service links the weather bureau with the news media and other private or governmental agencies in the area by teletype. A community may, at their expense, arrange for a teletype drop on this circuit which could provide invaluable information regarding a hazardous weather situation (37).

Executive Order No. 11296 signed by the President on August 11, 1966, prohibits any federal installation to be constructed on a flood plain and also prohibits the granting of federal loan or mortgage insurance against any construction in a designated flood plain. This includes any federal loan insured under the Veterans Administration or Federal Housing Authority. This executive Order only applies to those areas which have been officially designated as a flood plain.

Local governmental authorities should request, from appropriate agencies, that areas susceptible to flooding be designated as flood plains. Once this is done, private enterprise development will be sharply restricted, thus reducing future damage. Perhaps a better solution would be State legislation requiring that proposed urban development areas be evaluated for possible flooding before construction is permitted. This type of legislation would facilitate the reinforcement of Executive Order 11296 and in addition would significantly reduce future flooding damage to common citizens.

Other alternative methods of controlling development of flood plain areas are the implementation of zoning ordinances or the refusal to issue building permits in potential flooding areas. Close cooperation of city officials and local and state water resource management agencies would be necessary for positive enforcement of this alternative.

Governmental Organization

The San Antonio area, as is the rest of the United States, is a pluralistic society with a mixed economy. The process of opinion formation, planning, development and utilization of water resources along with its decision-making and administration policies are part public and private. At present numerous private organizations, both commercial and non-profit, exist in the San Antonio area. These private institutions act in their own interest and do not consider planning for future water resources as part of their present activities. The major planning tool that can be used to encourage private institutions to act in the interest of the public are the rules and regulations placed upon these private concerns or tax and/or other incentives made available to these private organizations.

The philosophy of the political system instigated in the United States has consciously attempted to maintain a nation in which the patterns of decision-making and administration often appear amorphous. This is certainly true for the San Antonio area. However, this area is fortunate in that the myriad of public organizations at all levels are cooperating amoung themselves toward the common goal of water resource planning. This is unique in itself.

Within the region there exists an intricate network of governmental units which have the responsibility for water resource planning. These include competing agencies at local and state levels. In addition to the problems which arise from the interaction of these various agencies, the Texas Water Law gives little support to public development of integrated ground and surface systems. A short description and summary of activities of each of the agencies which have jurisdiction over the water resources of the San Antonio Basin are given below (126).

The San Antonio Water Board. The San Antonio Water Board was established in 1925 and is governed by a Board of Trustees that is appointed by the City Council. In turn, the Board of Trustees appoints the general manager who acts as chief administrator of the San Antonio Water Board. Even though the San Antonio Water Board is owned by the city and must act in accordance with the terms of the bond ordinance under which the system's bonds are issued, it is still somewhat autonomous in conducting its business.

Since the City Water Board is the largest supplier and distributor of water in Bexar County, it is greatly concerned with the development of additional water resources and conservation of the existing supply. The Board has participated in various programs aimed at developing means of recharging the Edwards aquifer and developed supplemental surface water supplies from the surrounding areas.

Water Control and Improvement Districts. The Texas Legislature authorized water control and improvement districts to regulate irrigation, flood control, drainage, reclamation, forest preservation, conservation, creation of hydro-electric power, navigation, sewage, garbage collection and waste disposal within the district's boundaries. The Legislature has also empowered these districts to issue bonds and levy taxes.

There are eleven water control and improvement districts in the San Antonio area. Seven of their districts actually furnish water to the area. Five of the districts deal in sewage disposal, and two of them also engage in garbage collection and disposal. Three are not active at this time.

All of the active districts have issued bonds for the construction of water systems. These bonds are paid off through water charges and taxes. Three of the districts have raised funds by levying taxes on property. In order to avoid heavily indebted, or inadequate systems for the districts that are situated in newly annexed territory, the City Water Board requires these water districts to maintain adequate systems in accordance with a set of criteria.

Bexar-Medina-Atascosa Water Improvement District One. This district has approximately 34,000 acres under its jurisdiction; about 60%

of the district lies within Medina County, about 10% in Atacosa County and 30% in Bexar County. This district is empowered to obtain and distribute water for irrigation, domestic, power, and commercial purposes. Persons using water for domestic purposes must install their own purification facilities. The district also levies a 20% ad valorem tax and a "maintenance charge" on all persons residing within the boundaries of the district, and a "crop water charge" is paid by all persons who actually use water from Medina Lake.

Bexar Metropolitan Water District. The Bexar Metropolitan Water District is a multi-purpose conservation district with jurisdiction over "metropolitan" San Antonio (Alamo Heights, Olmos Park and Terrell Hills are excluded from this jurisdiction). The district has the power to "control, conserve, protect, preserve, distribute, and utilize storm and flood waters of rivers and streams and underground water situated in the district and to control and regulate the accumulation and disposal of sewage, wastes, refuse, and residuum." It also has the power to protect and preserve the purity of surface and underground waters, and to make rules and regulations pertaining to operations and providing penalties for violations thereof. In addition, the district is also authorized to regulate waters of the San Antonio River watershed, and to cooperate with the state and federal governments in such undertakings.

The functions and jurisdictional area of this district overlap those of the City Water Board and San Antonio River Authority; however, the district has limited itself to water supply, and confined its operation to Southwest San Antonio and Castle Hills.

San Antonio River Authority. The San Antonio River Authority is a conservation and reclamation district. It includes all of that part of of all of Uvalde County, most of Medina and Bexar Counties, and a small part of Comal and Hays Counties (see Figure 3.1).

Three directors from each county area make up the fifteen member Board of Directors of the district. An Engineer-Manager and Assistant Secretary, with a central office in the Tower Life Building, San Antonio, Texas, constitutes the business set-up of the district. A two cent tax per $100 property evaluation provides the funds for operation. (32).

The U.S. Geological Survey maintains an inventory of the quantity of water in the reservoir, water movement through the reservoir, and the quality of the water.

The district operates a data gathering and evaluation program with the U.S. Geological Survey and expands the scope as needed to insure prevention of pollution from any source. Bulletins on water quality, recharge and discharge are published each year.

A policy of cooperating with all Soil Conservation Districts where proposed improvements will add to the natural recharge has been adopted. Each project is judged on its merits, and financial participation by the District is based on the value of the increased water made available.

The District has participated in the Seco Creek Water-Shed Project in Medina, Uvalde and Bandera Counties, in Leona River Watershed Project in Uvalde County, and in the Dry Comal-Blieders Creek Project in Comal County on field surveys. The District has also assisted the San Antonio River Authority in the construction of the Salado Creek Project in Bexar County in order to increase the recharge.

Alamo Area Council of Governments. The Alamo Area Council of Governments (AACOG) is a regional planning organization whose headquarters are

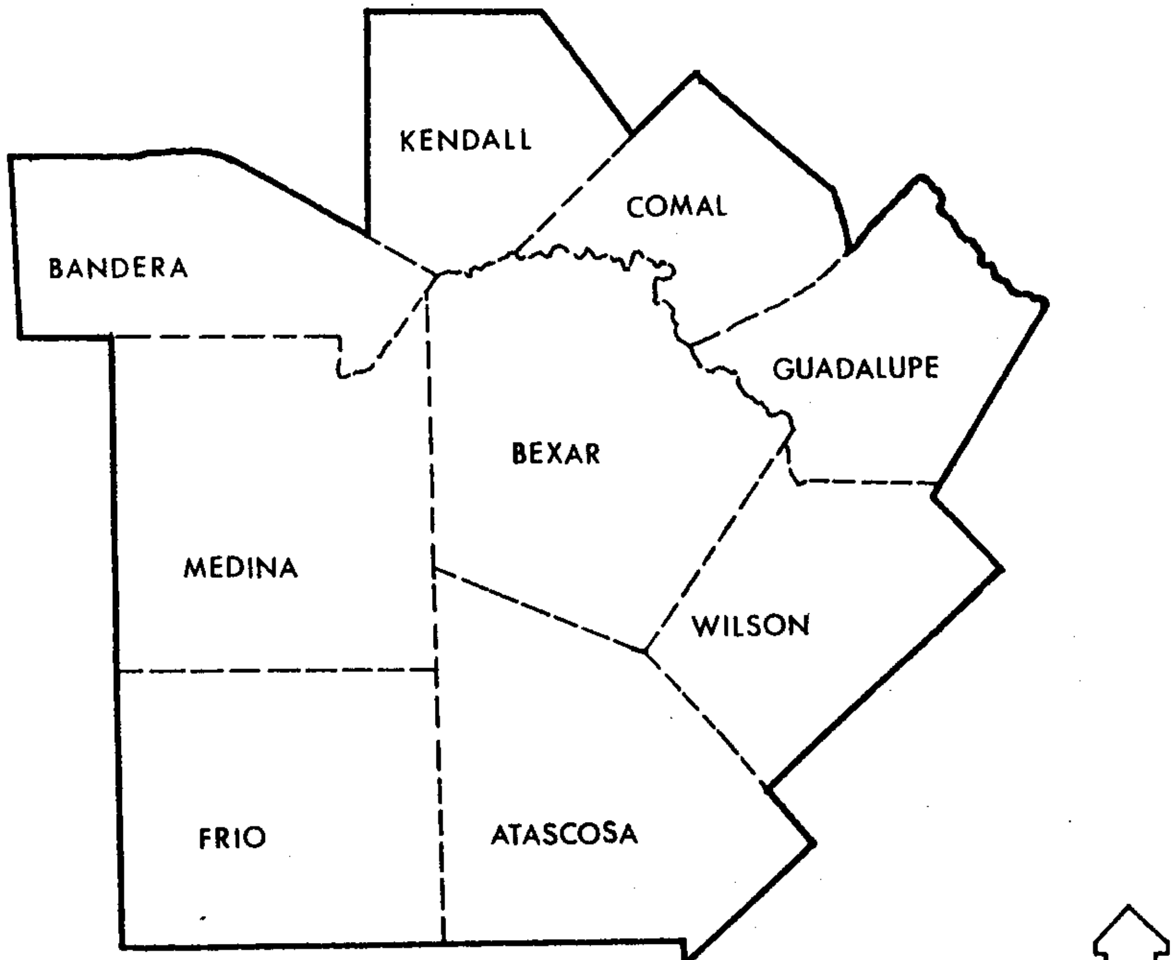


Figure 3.2
Alamo Area Council of Governments

located in San Antonio. The organization consists of ten member counties, each of which pays dues to support the organization. The ten member counties of AACOG are Atascosa, Bandera, Bexar, Comal, Frio, Guadalupe, Kendall, Medina, Uvalde, and Wilson (see Figure 3.2).

The general objectives of AACOG are to promote the general welfare of the citizens of the region through planning. The areas of interest of AACOG are general government, health, public protection, human resources, recreation, economy, housing, transportation and education.

AACOG has been especially active in studying the water resources of the area and in helping promote necessary programs aimed to improve the water quality. During the past year a Regional Waste Water Development Plan was completed. In addition a study was made for the recharge requirements and potential of the Edwards Aquifer. Due to the effort of AACOG, there is an efficient method to exchange data and information concerning both quantity and quality in water among government agencies of the region.

Bexar County. Bexar County is authorized to issue bonds for flood control, navigation, irrigation, and drainage improvement. The County can also levy ad valorem taxes as well as other authorized taxes for flood control improvements.

Soil Conservation Districts. Soil Conservation Districts are created and supervised by the State Soil Conservation Board. Each District is governed by an elected five-member Board of Supervisors. Each District serves an an independent subdivision of the state. Among other things, the Districts carry out control measures to prevent flood damage, and furnish equipment and other material that will assist farmers and ranchers in carrying out erosion control and water management. The Districts are also assigned the responsibility of cooperating with any other agency in order to prevent erosion and flood damage within the District.

The Texas Water Rights Commission. The Commission is composed of three full-time members that are appointed by the Governor, and an Executive Director who is chief administrative officer of the Commission.

The primary functions of the Commission are regulating and permitting use of public water of the state. Its general responsiblities include the protection of public safety and private property from damage which could occur from improperly designed dams and reservoirs. It also regulates the diversion and distribution of canals. Along these lines, any particular project may be decalred a public nuisance and ordered to be abated or removed if the project is found to be dangerous to public safety.

The Commission creates several kinds of water districts and approves the organization and feasibility of the water districts which propose to construct projects that are to be financed by the issuance of bonds. Most of the water districts and river authorities are subject to continuing supervision by the Commission.

The Commission recognizes and provides local interests with continuing opportunities to develop projects for local and regional needs; however, the Commission usually considers the State Water Plan as a guide for authorizing projects. Resolution of any conflict between the State Water Plann and private, local, and/or regional interests is vested in the Commission. Ultimate authority is vested in the courts (126).

The Texas Water Development Board. The Texas Water Development Board has been specifically charged with the preparation, development, and formulation of a comprehensive State Water Plan. This shall include a definition and designation of river basins and watersheds as separate units for purposes of water development, and inter-watershed transfers of water resources. In addition, the Board will assist and advise local governments in undertaking different water development projects.

The Texas Water Plan is to be used as a flexible guide to select policies for water resource development with the state. The Board also has the responsiblility to investigate all matters concerning the quality of gourndwater in the state and report its findings to the Texas Water Quality Board.

The Texas Water Development Board consists of six members, appointed by the Governor on six year terms with confirmation of the state Senate. Each Board member must have at least ten years of successful business or professional experience. The Governor has the power to designate the chairman of the Board.

In relation to the San Antonio area, the publications of the Board have proven to be an invaluable source of information. Published reports in the area of groundwater, quantity, quality and structural information are of particular importance. Also numerous studies defining and describing the surface water quantity and quality along with urban run-off and flood control studies are especially pertinent to the San Antonio area. The Systems Engineering Group of the Board has developed several mathematical models and stream simulation programs which aid in the study of description of the San Antonio River itself (128).

The Texas Water Quality Board. The Texas Water Quality Board replaced the Texas Water Pollution Control Board. It is composed of seven members chosen as follows: three are appointed by the Governor; the other four are the Executive Director of the Texas Water Development Board, the State Commissioner of Health, the Executive Director of the Parks and Wildlife Department and the Chairman of the Texas Railroad Commission.

The Board is the principal authority in the state on matters relating to the quality of water within the state. Under the Water Quality Act, the Board is to be informed on all aspects of water quality, specifically water pollution, its control and abatement. The Board is further directed to assist in resolving questions as to the respective authorities and duties of state agencies which have a vested interest in water quality control functions, and in doing so, to minimize duplication of activities so that state policy for controlling and maintaining the quality of the state's water can be achieved.

The General Land Office. The General Land Office is administered by the Land Commissioner who is elected by the people of Texas. It has several roles in the supervision and management of state water, namely: 1) the power to assist and supervise levee improvement and drainage districts, 2) the power to make and approve agreements or contracts for cooperating with any branch of the federal, state, county, or city governments, 3) the power to regulate oil and gas development of public lands, and to prevent pollution of waters in the areas where such development occurs.

Texas Soil Conservation Board. The Soil Conservation Board is a state agency delegated to perform the state-level administration of soil conservation district programs. The Board's activities are primarily directed along three lines: 1) district program planning and assistance, 2) education and promotion of conservation in general, and 3) approval or disapproval of applications for federal assistance in planning and implementing watershed protection and flood prevention projects as contemplated in Public Law 566 and 1018. The federal government, through the Board, provides the entire financial support for the improvements in flood prevention (126).

The Environmental Protection Agency. In an effort to rationally and systematically organize the activities of the Federal Government related to the environment, the Environmental Protection Agency (E.P.A.) was formed and given the responsibility to oversee the major Federal pollution control programs. The agency is headed by an Adminstrator and a Deputy Administrator appointed by the President.

The agency was formed to integrate the control and responsibility of different programs related to water, air, solid wastes and radiation pollution from the departments of Agriculture, Interior, Health, Education and Welfare, the Atomic Energy Commission and the Federal Radiation Council.

The principle functions of E.P.A. include: 1) the establishment and enforcement of environmental protection standards consistent with national environmental goals, 2) the conduct of research on the adverse effects of pollution and on methods and equipment for controlling it, 3) the gathering of information on pollution and the use of this information in strengthening environmental protection programs and recommending policy changes, 4) assisting the Council of Environmental Quality in developing and recommending to the President new policies for the protection of the environment, with particular reference to abating pollution by the establishment and enforcement of pollution control standard.

The establishment of the E.P.A. will permit quick response to environmental problems which were previously beyond the capability of individual pollution control programs. It will enable the establishment and enforcement of uniform standards not previously possible (101).

The U.S. Army Corps of Engineers. The Corps of Engineers is primarily responsible for navigation improvement of rivers and harbors and has the additional responsibility of undertaking flood control measures. The Corps is also concerned with the following: 1) drainage and soil conservation, 2) conservation of water for domestic, industrial and agricultural use, 3) hydro-electric power, 4) recreation, 5) public health and sanitation, 6) prevention of salt water intrusion, and 7) fish and wildlife preservation.

On December 23, 1970, President Nixon signed Executive Order 11574 which provides for the establishment of a federal permit program to regulate the discharge of waste in waters of the United States. The U.S. Army Corps of Engineers was designated as the responsible agency to administer this Executive Order. The Executive Order requires special permits to be issued before waste may be discharged in waterways in order to insure that water quality standards are being met. This program applies to both existing and new installations and a comprehensive enforcement mechanism is provided.

Bureau of Reclamation (Department of Interior). The Bureau of Reclamation is concerned not only with providing water facilities for irrigation, but also with water resource development in general. The Bureau is specifically concerned with the development of water resources for 1) generation of hydro-electric power, 2) drainage, 3) flood control

4) improvement of navigation, 5) silt control, 6) creation of recreational facilities, 7) wildlife refuge, and most importantly, 8) the provision of water supplies for municipal and industrial use.

The United States Geological Survey (USGS). The U.S. Geological Survey is responsible for determining, appraising and describing surface and underground water resources so as to aid in the solution of the nation's water problems. These investigations are under taken by the Water Resources Division of the USGS, and are financed on a federal-local matching fund basis. Within the San Antonio area the U.S. Geological Survey is specifically charged with studying the quantity and quality of the water of the Edwards Underground Aquifer. In addition, a continuing study of the structural conditions of this aquifer is pursued. The USGS also monitors eight stream gauging stations in the San Antonio River Basin.

Soil Conservation Service (Department of Agriculture). The Soil Conservation Service conducts exhaustive research into various aspects of soil erosion problems. It has the responsibility of administering the upstream watershed programs which provide assistance to local watershed groups for building flood control and erosion prevention structures when these programs are approved by Congress. As mentioned previously, the Service cooperated closely with the State Soil Conservation Board and the local Soil Conservation Districts in their respective activities.

The Public Health Service (Department of HEW). The Public Health Service collects data to show the degree of pollution of the nation's waterways, and conducts research to find more effective and efficient means of treating municipal and industrial wastes. In addition, the

Service conducts studies of the various state laws pertaining to pollution control. The service also provides the states with model statutes that can aid the states in their attempts to abate pollution.

Other Federal Agencies. Numerous other federal agencies, as well as congressional committees, have responsibilities for various aspects of water planning and development in the San Antonio area. They are the U.S. Weather Bureau, the Bureau of Mines, the Bureau of Census, the Federal Power Commission, the Forest Service, the Committees of Public Works on Interior and Insular Affairs, the Council on Environmental Quality and Water Resources Council. In reality, one may justifiably conclude that all agencies at every level of government have responsibilities for conserving and developing our water resources, for everything we do deals with some aspect of water (126).

Other Local Agencies. Among the various local organizations which help form San Antonio's Water resource policy is the River Walk Commission. The River Walk Commission is a seven member advisory commission appointed by the city council (99). The purpose of the commission is to preserve and promote the natural beauty of the area. The success of the River Walk is evident by tourist visitation numbering more than one million people in 1969. Other local agencies which help shape San Antonio's water policy are Department of Public Works, City Planning Department, San Antonio Parks and Recreation Department, and the San Antonio City Council.

In view of the overlapping and conjunctive responsibility and authority of different governmental agencies, the general description of the duties of each individual agency and its interface with other agencies is demonstrated in Table 3.1. It may be realized that the

Table 3.1. Important management agencies in San Antonio area

FUNCTION	FEDERAL	STATE	REGIONAL	LOCAL
WATER SUPPLY	Environmental Protection Agency Water Resources Council Bureau of Reclamation U. S. Geological Survey Public Health Service	Water Control and Improvement District Texas Water Development Board Texas Water Rights Commission	Edwards Underground Water District San Antonio River Authority	San Antonio City Water Board
SEWAGE DISPOSAL	Environmental Protection Agency Public Health Service Council on Environmental Quality	Water Control and Improvement District	San Antonio River Authority	Bexar Municipal Water District Sewer Division (Dept. of Public Works)
WATER QUALITY MANAGEMENT	Environmental Protection Agency Water Resources Council Public Health Service Council on Environmental Quality	Texas Water Development Board Texas Water Quality Board	Edwards Underground Water District San Antonio River Authority Alamo Area Council of Governments	San Antonio City
FLOOD CONTROL & DRAINAGE	Environmental Protection Agency U. S. Army Corps of Engineers Soil Conservation Service	Water Control and Improvement District Soil Conservation Service General Land Service Texas Soil Conservation Board	San Antonio River Authority	Bexar Metropolitan Water District Bexar County
WATERFRONT LAND USE	Environmental Protection Agency U. S. Army Corps of Engineers		Alamo Area Council of Governments	San Antonio River Walk Commission City Planning Department
RECREATION & OPEN SPACE	Environmental Protection Agency Bureau of Reclamation U. S. Army Corps of Engineers Council on Environmental Quality	Texas Parks And Wildlife	San Antonio River Authority	San Antonio Parks And Recreation Department
REGIONAL & CITY PLANNING	Urban Renewal Agency		San Antonio River Authority Alamo Area Counicl of Governments	San Antonio City Planning Department
MONITORING	U. S. Geological Survey Weather Bureau		San Antonio River Authority	San Antonio City

institutional barriers have become one of the most significant problems in the San Antonio area in terms of the formulation of optimum policy-making and administrative coordination for the effective implementation of different urban water resources tasks. A regional water resources management and planning system must be established to integrate and coordinate different activities concerning the augmentation of water supply, the protection and water quality of both surface water and groundwater, and the regulation of utilizing existing resources. The idea to establish a super-agency-type organization has been suggested for the overall management and development of groundwater resources of the Edwards Aquifer (UT's Report). However, the structural detail concerning the interagency cooperation and the future implementation and adaptability must be studied seriously.

Ground Water Resources.

Four major aquifers in the San Antonio River Basin can supply approximately 343,500 acre-feet of ground water annually. These aquifers are the Edwards-Trinity (Plateau), Gulf Coast, Carrizo-Wilcox, and the Edwards (Balcones Fault Zone) (82). These aquifers are shown in Figure 3.3. Other minor formations which are not shown in Figure 3.3 may provide limited quantities of water to supplement domestic and livestock supplies, and in some instances, to supply for small municipal, industrial, and irrigation uses.

The Edwards-Trinity (Plateau) Aquifer extends over Bandera county and part of the San Antonio River Basin. The aquifer is 400-500 feet thick and is composed of hard, massive, cherty, marly, and dolomitic limestone of the Edwards, Comanche Peak and Georgetown Formations. The water is found in channels and fractures in the rock under water-table conditions. Annual yields from wells in the Basin are generally small; however, if developed, it may yield as much as 25,000 acre-feet annually. The water of the Edwards-Trinity (Plateau) Aquifer is a calcium bicarbonate water having a hardness of more than 200 mg/l and 200 and 300 mg/l of dissolved solids. This aquifer is a minor source of the total groundwater available in the San Antonio River Basin (82).

The Gulf Coast Aquifer extends from the central part of Karnes County to the Gulf of Mexico. The aquifer consists of the Catahoula, Oakville, Lagarto, Goliad, Lissie, and Beaumont Formations. It is composed of interbedded sand and clay, and extends as deep as 1,800 feet below the surface. The net sand thickness of the aquifer ranges from 200-600 feet. The water is generally artesian, but a considerable amount of water leaks through the confining clay layers. Yields from large-capacity wells average about 800 gallons per minute, with some yields as large as 2,000 gallons per minute. Salt water intrusion of the Aquifer does not present a major problem at the present time; however, the southern edge contains a zone of transition between saline and fresh water. Water to the south of the zone generally contains at least 1,000 mg/l of dissolved solids (82).

The Carrizo-Wilcox Aquifer lies in southern Bexar County, Wilson County and the northern part of Karnes County. The aquifer is composed of coarse-to-fine-grained sand, sandstone, silt, and clay with a few thin beds of lignite. Thickness of the aquifer ranges from 800 to more than 2,000 feet in the downdip area. Water table conditions generally exists in the outcrop, with artesian conditions in the downdip. Yields

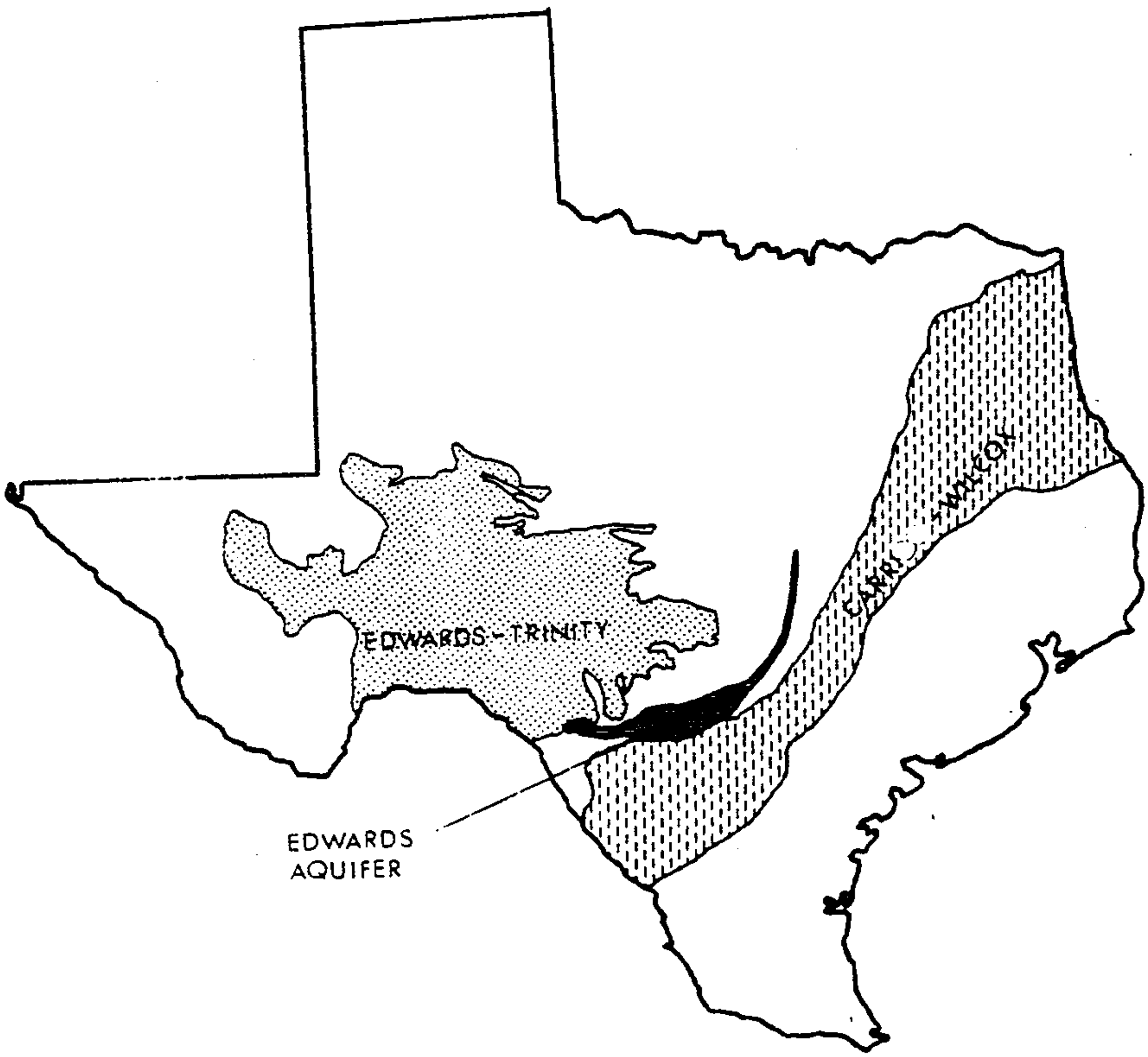


Figure 3-3
Geographic Location of the Three Major
Aquifers Which Influence the San Antonio Area.

from the large capacity wells average about 900 gallons per minute, and some reach as high as 1,800 gallons per minute.

Approximately 33,500 acre-feet of groundwater is available as an annual yield from the Carrizo-Wilcox Aquifer in the San Antonio River Basin. The water in the Aquifer varies from less than 500 mg/l dissolved solids to about 3,000 mg/l. In general, the water is suitable for most purposes, but excessive iron is found in and near the outcrop (82).

The principal aquifer of the San Antonio River Basin is the Edwards as shown in Figure 3.4. It supplies most of the water for municipal, industrial, irrigation, and domestic purposes (133). The aquifer extends across the central part of Bexar County and is composed of hard massive limestone, dolomitic limestone, and marly limestone of the Edwards, Comanche Peak, and Georgetown Formations. Thickness of the aquifer ranges from 400-900 feet with water in the interconnected solution cavities and fractures in the rock under artesian conditions. Yields from the large capacity wells average about 1,5000 gallons per minute, and some reach 9,000(gmp) (82).

The Aquifer yields approximately 260,000 acre-feet of water annually in the San Antonio River Basin. The water is a calcium bicarbonate type of very good quality, although very hard. Generally the water contains less than 500 mg/l dissolved solids, and increases very little in mineralization with depth. However, in the region where the formation is 1,000 feet or more below sea level, the water becomes brackish containing up to 10,000 mg/l of dissolved solids as shown in Figure 3.5.

The Edwards Aquifer hydraulically connects three river basins: Guadalupe, San Antonio, and Nueces. Springs in each of these river basins

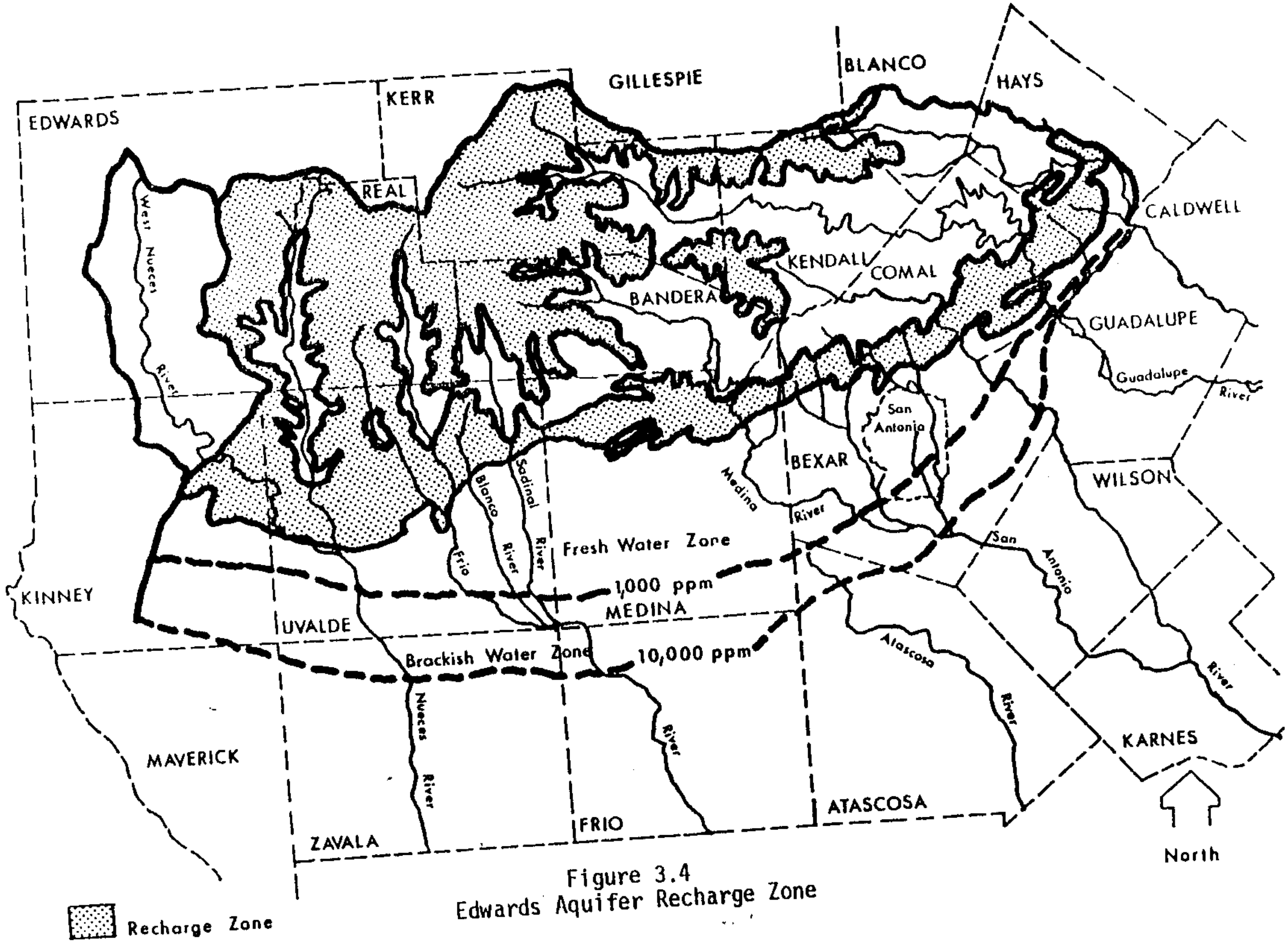


Figure 3.4
Edwards Aquifer Recharge Zone

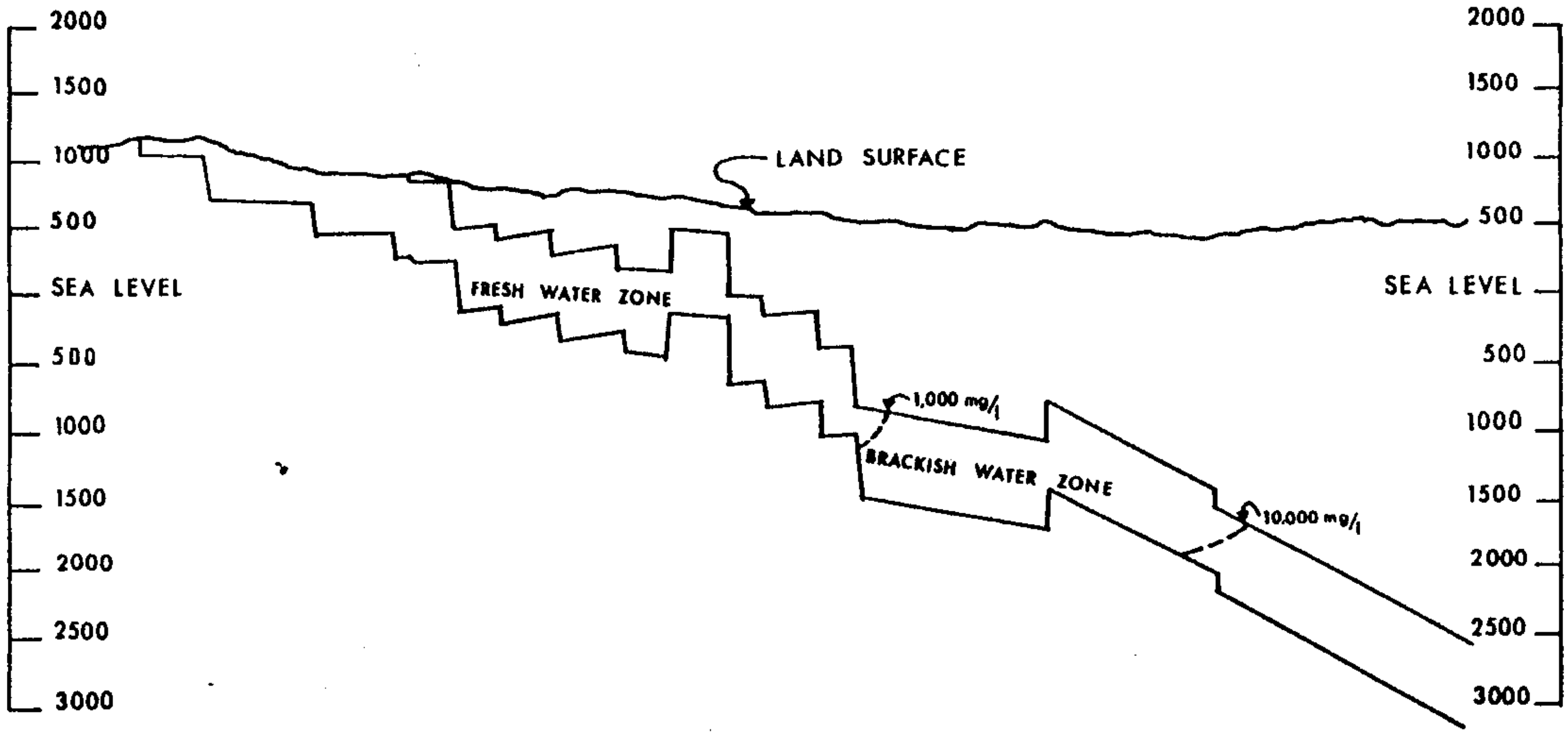


Figure 3.5.
Cross-Section, Edwards Aquifer

also discharge groundwater from this formation when water levels are sufficiently high. Two of the largest springs in Texas discharge water from this aquifer: Comal Springs at New Braunfels and San Marcos Springs at San Marcos. These springs provide the bulk of the dry-weather flow of the Guadalupe and San Marcos Rivers. Pumping from the Edwards results in declining water levels, and therefore inductions in spring discharges. Hence, groundwater use from the Edwards will affect the surface water supply of the lower part of the three river basins (82).

The Edwards Aquifer is the only source of water for the cities of Uvalde, Knippa, Sabinal, D'Harnis, Castroville, La Coste, San Antonio, New Braunfels, San Marcos, Kyle, and other smaller communities (32). Domestic, industrial, irrigation, stock, and other uses also are dependent on water from the aquifer which is the sole supply of water for nearly one million people (32). Because of the reliance of the San Antonio area on this aquifer, it will be discussed in more detail herein than the other three aquifers described above. Groundwater is discharged from the Edwards by both springs and wells. Prior to 1954 most of the discharge was from springs, although the discharge from wells showed an annual increase. In 1964, the discharge from wells exceeded that from springs and by 1956 approximately 80 percent of the discharge was from wells (42). This trend has continued although the discharge from wells was only 54.6 percent in 1970.

The principal springs in the San Antonio area are Leona River Springs near Uvalde, San Antonio and San Pedro Springs at San Antonio, and Comal Springs at New Braunfels. These springs issue along faults

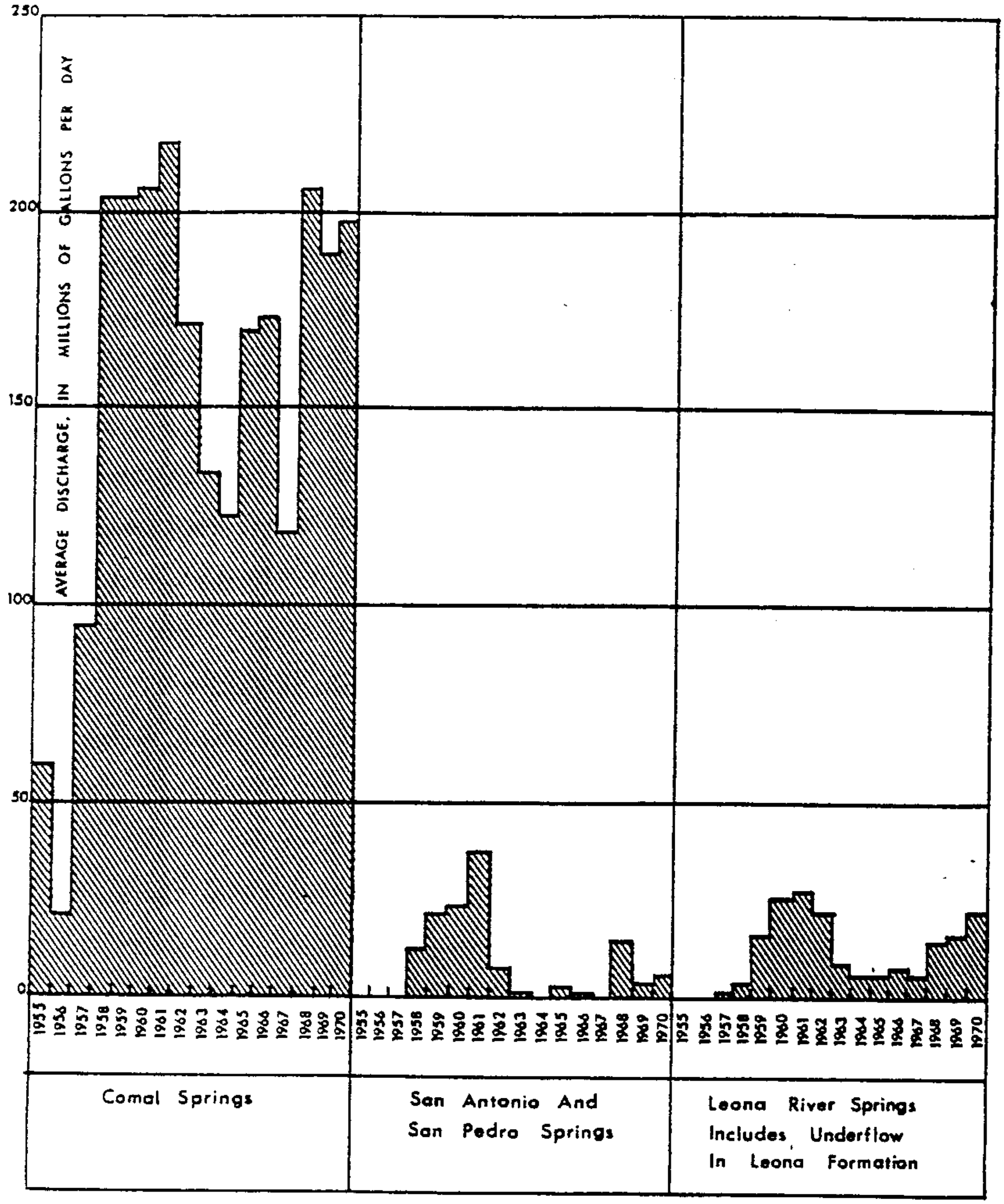


Figure 3-6
Springflow in the Region
1955-1970

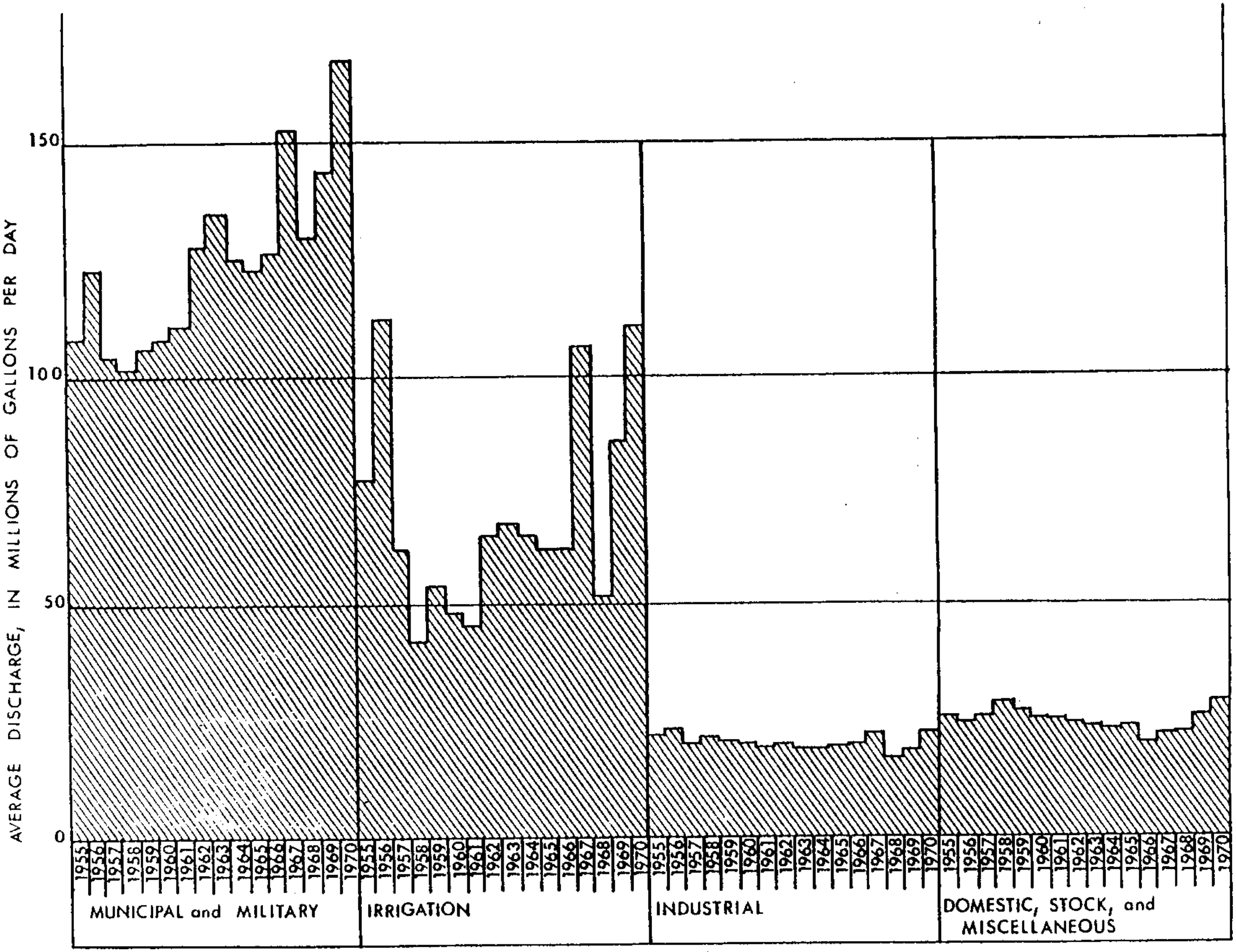


Figure 3.7 Water Use by Type in the Region 1955-1970

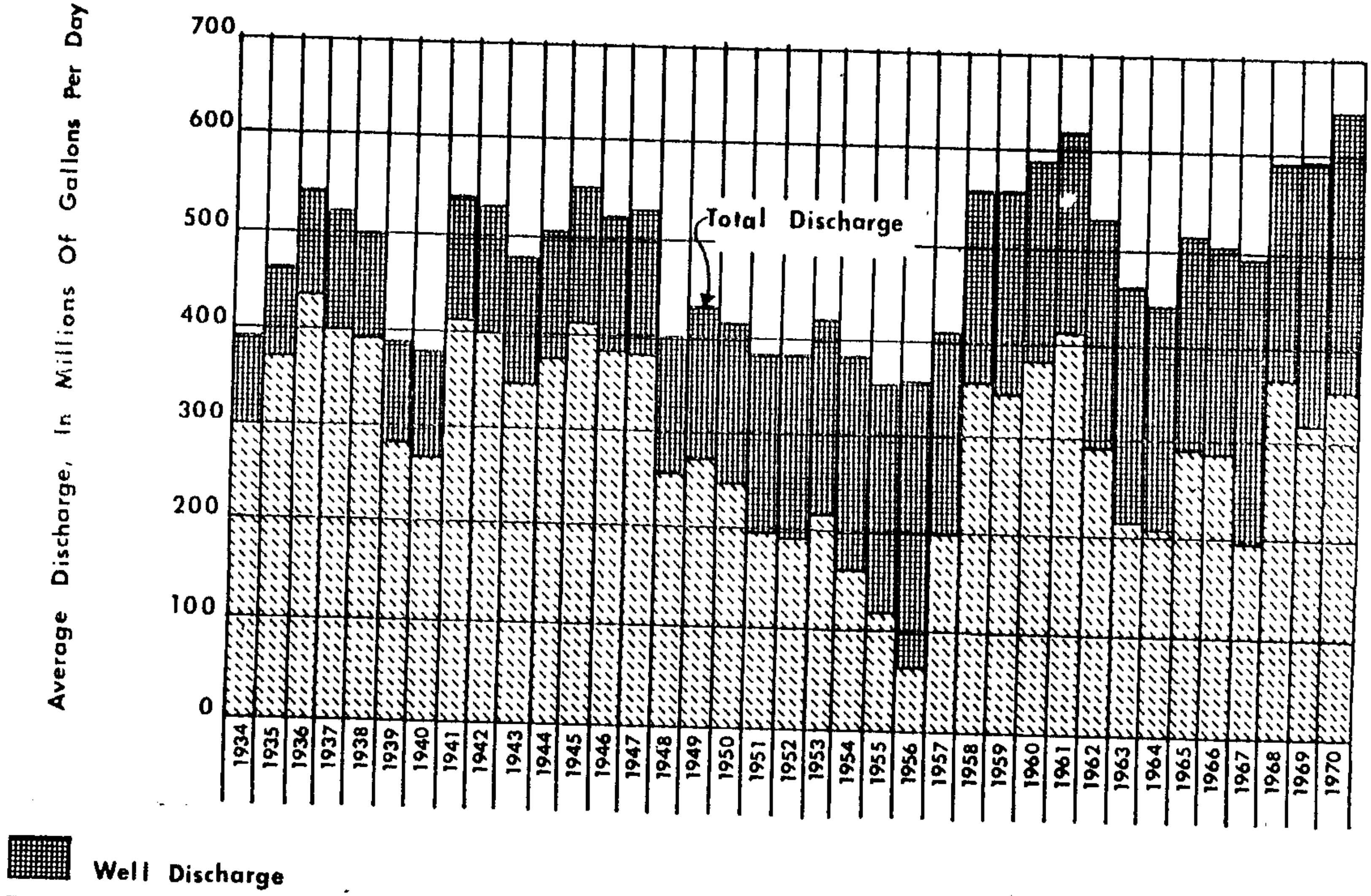


Figure 3.8
Average Discharge by Springs and Wells,
1934-1970

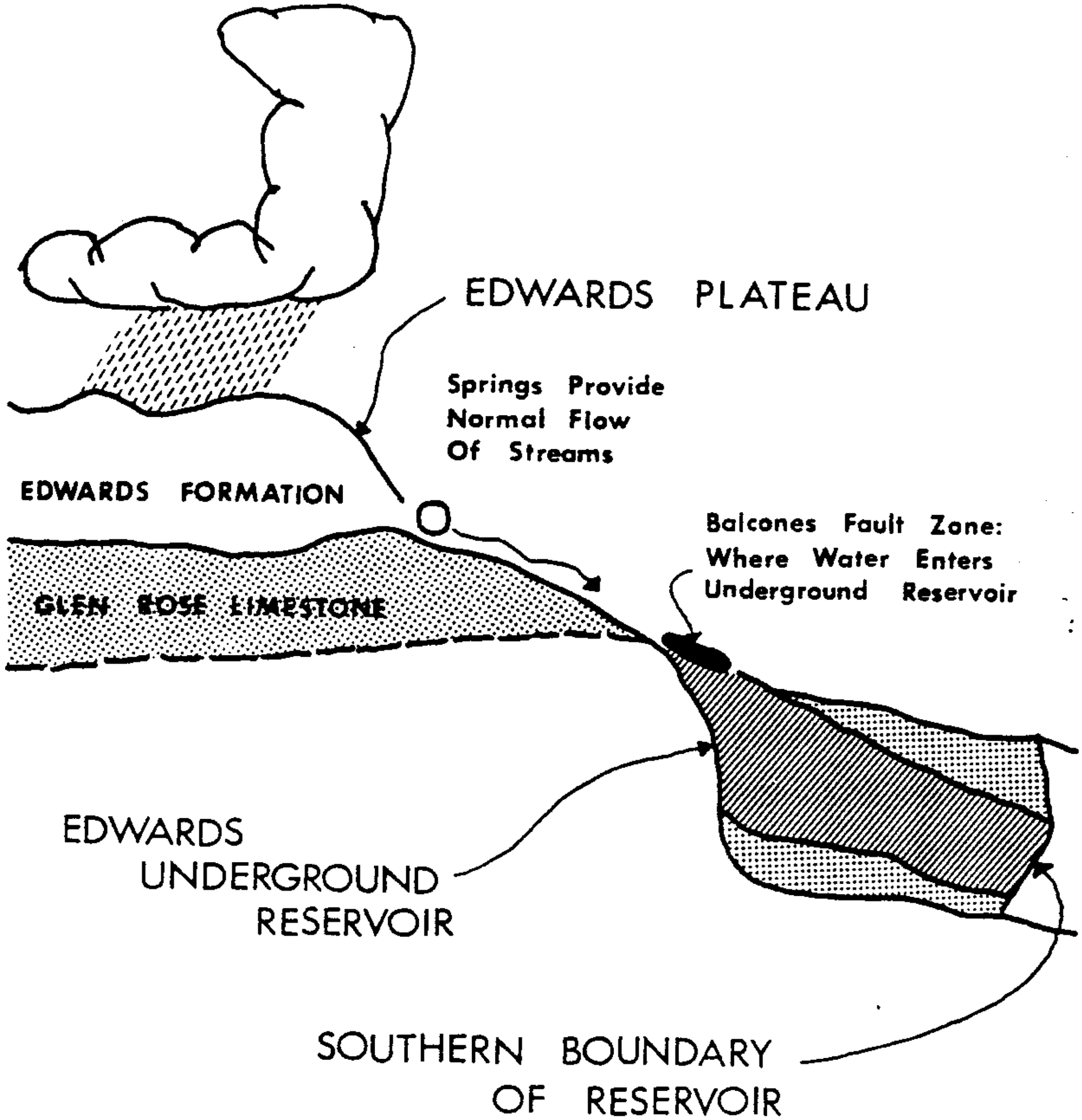


Figure 3.9
Recharge of the Edwards

that have developed into open cracks and solution channels as water discharges naturally from the aquifer (42).

Spring flow during the period 1955-1970 is shown in Figure 3.6. These three principal springs, San Antonio, San Pedro and Leona River, ceased flowing between 1955-1956. Comal Springs ceased flowing in 1956 for the first time on record (43).

The discharge from wells in terms of withdrawal from the Edwards for specific uses is shown in Figure 3.7. During the period between 1955-1970, one-half of the annual discharge from wells was used for municipal and military purposes. Out of that amount over 90 percent of this discharge is required for municipal and military purposes in Bexar County. Of this 90 percent, more than 70 percent is used by the city of San Antonio. Figure 3.8 also shows the total discharge from the Edwards including both springs and wells during the period 1934-1970.

Recharge to the Edwards in the San Antonio area is chiefly by seepage from streams that cross the outcrop of the aquifer in the Balcones fault zone, and to a lesser extent, by direct infiltration of rainfall on the outcrop (3). This recharging process is illustrated in Figure 3.9.

In general the method used to estimate the recharge of the aquifer is based on the assumption that recharge in each stream basin is the difference between total inflow above the infiltration area and total outflow below infiltration area. Hence seepage investigations made at different stages of the streams have helped in locating the infiltration areas, which generally follow the outcrop of the aquifer along the Balcones Fault Zone. That part of the inflow above the infiltration area in each stream basin is measured at a gauging station. The flood runoff determined at this gauging station is used to estimate the direct infiltration or runoff on the outcrop itself. Those stream losses due to evaporation and transpiration by vegetation are assumed to be proportionally the same in the area of the outcrop and above the ourcrop. The total outflow for each stream basin is measured at another gauging station below the outcrop (42). Generally, this method has worked well over long periods of time, probably because errors tend to balance out over such periods.

Because not all the streams in the recharge areas have been suitable for controlled gauging, assumptions concerning runoff in these and other areas have been made. Some areas having little or no runoff have been included either as part of the basis for which estimates of recharge have been made or as individual areas with assumed runoff characteristics similar to those in adjacent basins. For others an estimate of runoff is made by the following method. The runoff above the outcrop is usually applied to the outcrop area, except when rainfall records clearly indicate a wide variance of rainfall within the basin. In such cases, a correction factor based on rainfall, is applied to the runoff (42).

During the 1934-1970 period, the annual recharge to the aquifer ranged between the minimum of approximately 44,000 acre-feet in 1956 and the maximum of more than 1,700,000 acre-feet in 1958. The annual average recharge was 519,700 acre-feet (42). This data is shown in Table 3.2. The above discussion indicates that average annual discharge from the aquifer exceeds average annual recharge to the aquifer. In the past 25 years, annual recharge has exceeded annual discharge in only seven yearly periods, these being the years between 1957 and 1961, 1964 to

TABLE 3.2
ESTIMATED ANNUAL RECHARGE
1934-1971

Year	Nueces and West Nueces River basins	Frio and Dry Frio River basins	Sabinal River basin	Medina River basin	Cibolo and Dry Comal Creek basins	Blanco River basin and adjacent area	Area between Sabinal and Medina River basins	Area between Cibolo Creek and Medina River basins	Total
1934	8.6	27.9	7.5	46.5	28.4	19.8	19.9	21.0	179.6
1935	411.3	192.3	56.6	71.1	182.7	39.8	166.2	138.2	1,258
1936	176.5	157.4	43.5	91.6	146.1	42.7	142.9	108.9	909.6
1937	28.8	75.7	21.5	80.5	63.9	21.2	61.3	47.8	400.7
1938	63.5	69.3	20.9	65.5	76.8	36.4	54.1	46.2	432.7
1939	227.0	49.5	17.0	42.4	9.6	1.1	33.1	9.3	399.0
1940	50.4	60.3	23.8	38.8	30.8	18.8	56.6	29.3	308.8
1941	89.9	151.8	50.6	54.1	191.2	57.8	139.0	116.3	850.7
1942	103.5	95.1	34.0	51.7	93.6	28.6	84.4	66.9	557.8
1943	36.5	42.3	11.1	41.5	58.3	20.1	33.8	29.5	273.1
1944	64.1	76.0	24.8	50.5	152.5	46.2	74.3	72.5	560.9
1945	47.3	71.1	30.8	54.8	129.9	35.7	78.6	79.6	527.8
1946	80.9	54.2	16.5	51.4	155.3	40.7	52.0	105.1	556.1
1947	72.4	77.7	16.7	44.0	79.5	31.6	45.2	55.5	422.6
1948	41.1	25.6	26.0	14.8	19.9	13.2	20.2	17.5	178.3
1949	166.0	86.1	31.5	33.0	55.9	23.5	70.3	41.8	508.1
1950	41.5	35.5	13.3	23.6	24.6	17.4	27.0	17.3	200.2
1951	18.3	28.4	7.3	21.1	12.5	10.6	26.4	15.3	139.9
1952	27.9	15.7	3.2	25.4	102.3	20.7	30.2	50.1	275.5
1953	21.4	15.1	3.2	36.2	42.3	24.9	4.4	20.1	167.6
1954	61.3	31.6	7.1	25.3	8.8	10.7	11.9	4.2	160.9
1955	128.0	22.1	.6	16.5	3.3	9.5	7.7	4.3	192.0
1956	15.6	4.2	1.6	6.3	2.2	8.2	3.6	2.0	43.7
1957	108.6	133.6	65.4	55.6	397.9	76.4	129.5	175.6	1,143
1958	266.7	300.0	223.8	95.5	268.7	70.7	294.9	190.9	1,711
1959	109.6	158.9	61.6	94.7	77.9	33.6	96.7	57.4	690.4
1960	88.7	128.1	64.9	104.0	160.0	62.4	127.0	89.7	824.8
1961	85.2	151.3	57.4	88.3	110.8	49.4	105.4	69.3	717.1
1962	47.4	46.6	4.3	57.3	24.7	28.9	23.5	16.7	249.4
1963	39.7	27.0	5.0	41.9	21.3	16.2	10.3	9.3	170.7
1964	126.1	55.1	16.3	43.3	51.1	22.2	61.3	35.8	411.2
1965	97.9	83.0	23.2	54.6	115.3	66.7	104.0	78.8	623.5
1966	169.2	134.0	37.7	50.5	66.5	17.1	78.2	44.5	597.7
1967	82.2	137.9	30.4	44.7	57.3	19.0	65.0	30.2	466.7
1968	130.8	176.0	66.4	59.9	120.5	49.3	198.7	83.1	884.7
1969	119.7	113.8	30.7	55.4	99.9	46.6	84.2	26.6	576.9
1970	112.6	141.9	35.4	68.0	113.8	39.5	81.6	68.8	661.6
1971	263.4	212.4	39.2	68.7	82.4	22.2	150.3	81.4	920.0
Total	3,566	3,252	1,192	1,900	3,356	1,187	2,704	2,075	19,231
Average	96.4	87.9	32.3	51.4	90.7	32.0	73.1	56.1	519.7

1966 and 1970 (133). Figure 3.10 illustrates the relationship between annual recharge graphically.

If this imbalance between discharge and recharge should continue, the discharge deficit will continue to increase. It has been projected that huge springs at San Marcos and New Braunfels will cease to flow by the year 2000 (133). Another consideration is that at some point enough pressure would be taken off the fresh water zone of the aquifer to permit saline water intrusion as shown in Figure 3.5.

Along with the problem of discharge/recharge imbalance to water quantity is the increasing role of deterioration of the water quality along with time. Paramount to the problem of water quality of the aquifer is the face that many of the streams which flow over the recharge zone are also used as a medium for transporting sewage and other waste material from cities and communities in the area (133). It is easy to see that as the population of the region increases, the volume of waste will also increase. Consequently, this increase in waste material flowing across the recharge zone will generate serious pollution to the aquifer. To help combat this problem, an order was issued by the Texas Water Quality Board, July 31, 1970, which placed restrictions on the discharge of raw sewage or poorly controlled sewer effluent on the recharge zone of the Edwards Formation (133). It is too early at the present time to evaluate the effect of this order; however, it is definitely an applaudable move toward the water quality protection of the Edwards.

Currently, the fresh water zone of the aquifer is defined as water containing less than 1,000 mg/l of dissolved solids. The brackish zone is defined as water containing dissolved solids from 1,000 to 10,000 mg/l

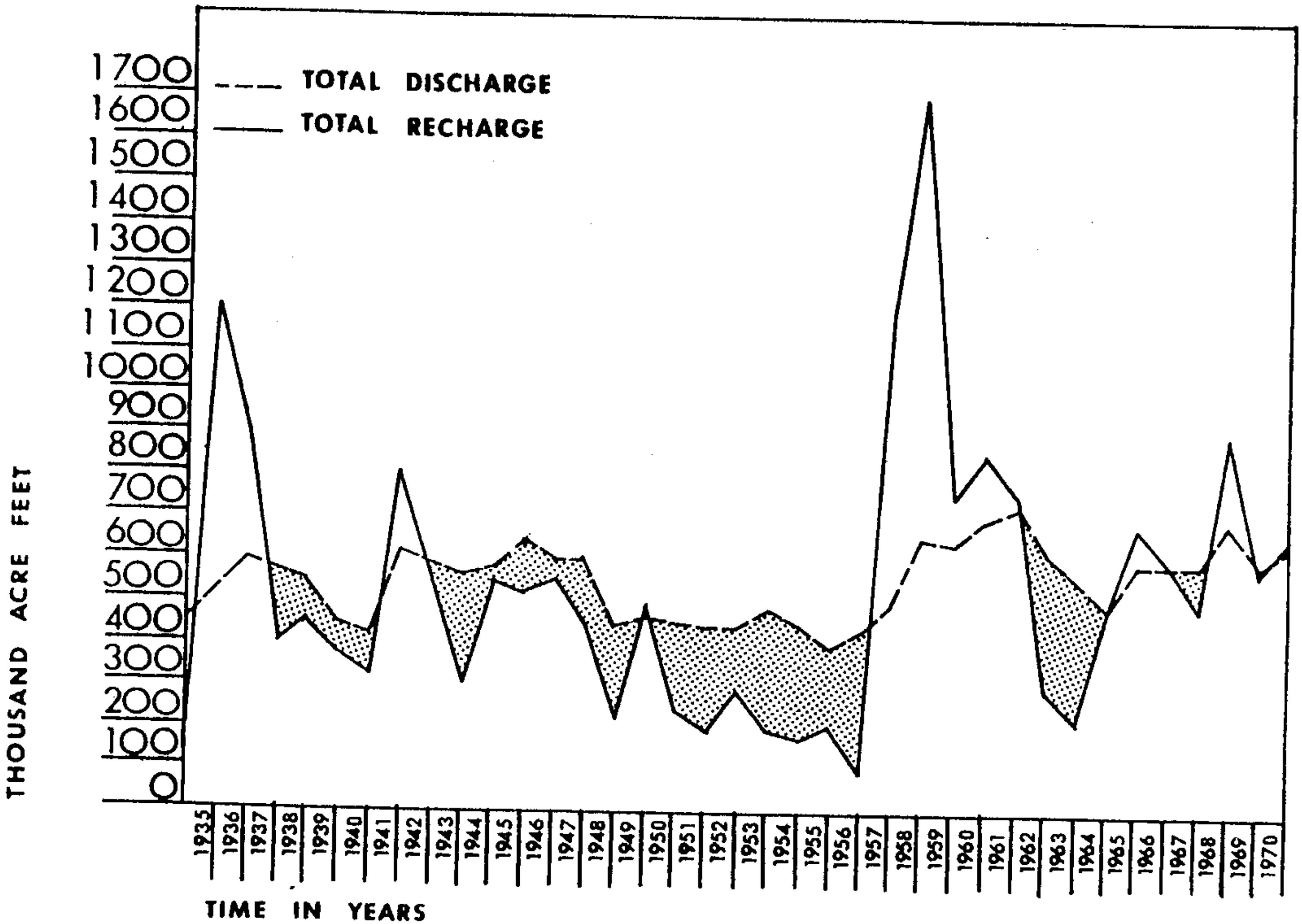


Figure 3:10
Comparison of Total Recharge to
Total Discharge to the Edwards Aquifer
1935-1970

as shown in Figure 3.5. The total dissolved solids in the aquifer increases from east to west (133).

Table 3.3 shows the composite chemical analysis of water from four San Antonio deep wells in the Edwards Aquifer. Notable amounts of chloride, sulphate, magnesium, nitrate, calcium, sodium, and bicarbonate are present. It is interesting to note that the total dissolved solids increased five percent over a four-year period in well No. 59. The total dissolved solids also increased in well No. 60 over a three-year period. The location of well No. 60 is in the northern portion of the city. This trend toward an increase in dissolved solids in all wells should be carefully observed and examined in the years to follow. If the trend increases, it could mean that some of the brackish water is beginning to move into the fresh water zone (133).

Several studies sponsored by the Edwards Underground Water District and the San Antonio City Water Board set what is considered to be a "safe" discharge from the Edwards in the San Antonio area. This "safe" discharge or recommended yield is that maximum amount of water withdrawal by wells from the aquifer so that it will not destroy or interrupt the spring flows. These "safe" discharge estimations vary between 235 MGD-300 MGD. The average recommended well yield from the studies amounts to 266 MGD. The average pumpage rates in 1968 were 225 MGD and it is estimated the 1970 pumpage rates were close to the "safe" yield of 266 MGD (32).

In 1959, the Texas Legislature created the Edwards Underground Water District for the purpose of "protection, conserving, and recharging the underground reservoir" (32). The District consists of all of Uvalde County, most of Medina and Bexar counties, and a small part of Comal and Hays Counties (see Figure 3.1).

TABLE 3.3

COMPOSITE CHEMICAL ANALYSIS
CHEMICAL CHARACTERISTICS

1964-69

		1964	1965	1966	1967	1968	1969
Iron	ppm	0.06	0.03	0.03	0.02	0.02	0.02
Maganese	ppm	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium	ppm	16.3	16.0	17.0	17.0	15.0	17.0
Chloride	ppm	13.9	13.0	15.0	14.0	14.0	13.0
Sulphate	ppm	23.5	22.0	25.0	23.0	25.0	25.0
Carbonate	ppm	0.0	0.0	0.0	0.0	0.0	0.0
Bicharbonate	ppm	250.0	253.0	256.0	257.0	262.0	263.0
Fluoride	ppm	0.18	0.29	0.29	0.29	0.27	0.31
Nitrate	ppm	4.9	5.1	5.1	6.0	5.0	5.6
Calcium	ppm	68.0	70.0	70.0	68.0	74.0	73.0
Sodium	ppm	8.3	7.0	7.0	8.0	7.0	8.0
Total Solids	ppm	320.8	387.0	394.0	393.0	402.0	403.0
Total Hardness	ppm	241.3	241.1	247.0	240.0	248.0	251.0
Total Hardness	gpg	14.1	14.1	14.4	14.0	14.4	14.6
Source: Deep Wells		59	61	60	56	59	60
pH		7.3	7.6	7.6	7.6	7.6	7.5
Aquifer: Edwards Limestone							
Temperature		75°F	75°F	75°F	75°F	75°F	75°F

Note: 1 milligram/liter equals 1 part per million
1 grain per gallon equals 17.12 parts per million

Supplemental surface water supplies are necessary in the San Antonio area and should be made available as soon as possible. To supply the projected municipal and industrial demand of Bexas County in the year 2020, it is estimated a minumum surface water supply of about 220,000 acre-feet will be required annually in addition to the available groundwater resources. To meet this additional water requirement, construction of two reservoirs is recommended in the Texas Water Plan. These reservoirs are to be located on the Sabinal and Frio Rivers (122).

In order to implement the proposed total water supply system, proper organizational, institutional, financial, administrative, and governmental cooperation is imperative among each entity in the area that it would benefit. A regional planning and development program of the Edwards and the surrounding surface waters is the most popular method to insure that future demands for water are met. This regional program should have two main goals: (1) the augmentation of the water supply and, (2) the prevention of pollution (30). It should be noted however, that the implementation of such a regional program would be extremely difficult due to the existing institutional factors within the area. There is an intricate and complex network of overlapping governmental units which have the responsibility of water policy formulation. In the San Antonio area alone there are seventeen such entities: two cities, one water district, eleven water control and improvement districts, and two non-supplying water districts. In addition, there are about thrity private water companies and several installations on military bases which are constructed and operated by the federal government. This situation may make it impossible to achieve a balanced, comprehensive water management policy (126).

As mentioned previously, the San Antonio region has been strictly dependent on groundwater for the fresh water supply. It is inevitable that future water resources must come from a conjunctive use of ground and surface water. There are several alternatives presently available which will supply the conjunctive water needed. Lake Medina has a surface water supply which could be utilized; however, water rights forbid its use as a water supply to the San Antonio area. Calaveral Reservoir and Cibolo Reservoir, which are planned, could be utilized. In addition, the Carrizo-Wilcox Aquifer adjacent to the city could also be utilized. The combination of these possible alternatives would create a surface/ground water resource base and should be studied and included in future planning programs.

The suggestion has been made that some type of regulatory agency be formed in which is vested the power to manage the entire San Antonio River Basin. This encompassing "super-agency" could either replace all existing agencies or act as a decision center whose approval is necessary before any subordinate agency could act. This is an idealistic approach, although at first glance it appears to be an alternative solution. Further investigation, however, reveals that this approach would be all but impossible to implement and the question arises if it is really necessary.

Institutional organizations develop through time. Once established, they become responsive to the needs of the people they serve. Although their basic structure does not change their immediate goals, objectives and means of obtaining these objectives do change. Often the various water management agencies in the area operate to fulfill competing objectives. This is in the best interest of the people as it provides a check and balance in local government so that one sector of the populus is not dominate. They are immediate in acting against developing problems since a minimum amount of time elapes before decisions are made. Neither of these would be possible in one agency. Not only would it become politically-oriented and disproportionally powerful, it would also become unwiedly with many levels of "red tape" which must be considered before a decision can be made. Due to the dynamic nature of San Antonio's water management problem, this would not be in the best interest of the citizens of the city. In addition, very few of the existing agencies operation in the River Basin could be utilized as subcomponents of the "super-agency" once their powers had been usurped and their organizational barriers would alone prohibit the establishment of such an agency.

But, assuming that these institutional and organizational barriers could be overcome, the problem then arises of legal implications of the new agency and the tax structure necessary to support it. Naturally these problems must be taken to the people who must approve any change at the polls. The current attitude of the populus toward taxes is not favorable and such a move would be extremely difficult to gain voter approval. Each agency currently operation in the Basin receives some type of revenue, either through taxation, or otherwise. This must all be changed and the details of distributing the tax equally over the Basin would be enormous. As it is, each region serviced by an existing agency is taxed. To change this, a formula must be developed which would allow taxation throughout the basin at an equitable rate for those who receive each service. This task would not only present a monumental problem at the outset of agencies' organization but it would continue to be a problem throughout its existence.

Finally the question of "is such an agency really necessary" must be answered. San Antonio and the surrounding area is unique in that there is a high degree of cooperation among all agencies. This includes transferal of data, mutual problem solving, and continuous communications among all agencies at each level. This is not to imply that the situation in San Antonio cannot be improved, but it should be emphasized that the formation of another agency to supervise the whole Basin is not a feasible solution to the problem and should not be considered as an alternative.

Surface Water Resources

The utility surface water resources, besides recreation, in the San Antonio area is almost non-existent. The beautiful stream flow of the San Antonio River found by Domingo Raman (58) back in 1716 had diminshed since the early years of the nineteenth century. The springs now flow only intermittently due to the pre-emptive pumpage of the Edwards Aquifer. Though the stream flow in the San Antonio River always consists of runoffs resulting from rainfall, spring-flow and return flows, the composition of these resources has been changed substantially in the last thirty years. Return flows have increased from negligible amounts to over 100,000 acre-feet per year whereas the spring flows have decreased from almost 100,000 acre-feet per year to nearly zero.

The principal utilization of the San Antonio River is thus becoming the drainage waterway carrying the return flows from urban water uses. The water quality is thus the most critical concern for the San Antonio

River. Meanwhile, the quality of the San Antonio River has degenerated from one of the crystal-clear spring waters to a murky oxygen deficient stream transporting essentially the diluted treated waste effluent from the San Antonio metropolitan area. The major source of pollution to the river is domestic sewage generated by nearly one million inhabitants of the area. Each day more than 400,000 tons of treated waste are dumped into the San Antonio River. It is equivalent to 40 tons of biochemical oxygen demands and eight tons of phosphate which is derived from the domestic detergents. Therefore, the downstream stretches of the San Antonio River have witnessed heavy algal growth as well as anaerobic biological growth.

The stream quality is found highly influenced by the reliability of wastewater treatment facilities. Data collected along stretches of the San Antonio River downstream of the wastewater outfalls over the past 50 years indicates that excessive algal growth, dissolved oxygen depletion, and dissolved solids contamination can be controlled through improved waste treatment operations. Existing wastewater treatment facilities in the region do not have the ability to remove the untrients and biochemical demands beyond that by secondary wastewater treatment. Though plans for advanced wastewater treatment have been envisioned, little progress has been made.

The total travel time of the river between San Antonio and the coast is approximately two weeks. This time period is not even adequate for the complete biological oxidation of those biodegradable pollutants which are discharged with treated effluents by natural purification processes. Therefore, stretches of the San Antonio River between San Antonio and the coast are constantly under polluted situations. The aesthetic value and the recreational activities along this 250 mile stretch of the San Antonio River, as well as the San Antonio Bay area, have been completely ruled out of consideration. Two studies have been conducted (20, 29) and both concluded that the major cause of this pollution effect is the discharge of pollutants by the treated waste effluent in Bexar County.

In order to increase the recreational or aesthetic values of the San Antonio River downstream from San Antonio to the estuaries of the Gulf Coast area, improvements for wastewater treatment and quality mangement for the Basin must be initiated immediately. The improvement of the treatment facility may be accomplished by the addition of advanced wastewater treatment processes or by the practice of domestic wastewater reclamation through industrial use, agricultural irrigation, and impoundment for power generation. The economic tradeoff between the benefits along with recreational use and the additional costs accrued by the supplementary treatment facilities must be studied in detail. The river basin quality management can also be improved with the utilization of the existing stochastic decision making procedures as well as the analysis for reliability of urban water quality control. Although tougher water quality standards may be the enforcement approach to facilitate or to push forward such improvements, the economic incentives associated with recreation, public response, and marine resources may be emphasized.

The Alamo Area Council of Governments presently has 43 domestic waste discharge facilities. The majority of these treatment facilities were built to service subdivision needs and treat less than one million gallons per day (MGD) of sewage. Over 90 percent of the sewage generated in the area is treated in a plant complex south of San Antonio composed of Leon Creek and Rilling Road facility (88). A regional sewage system is currently planned which will eliminate the majority of smaller disposal plants.

Planning for a regional sewage network must take into account a variety of problems, some have been resolved and some are still in the solution development stage. For example, the accurate prediction of population density is nearly impossible to attain. In addition, the types and amounts of wastes generated depend in part upon the state of current technology. As technology changes, types and amounts of wastes will change along with alternatives available to treat the waste effluent. The plan must be of a flexible nature so that alternative land use plans may be considered and the associated sewer costs may be evaluated.

Sewer systems generally follow the natural paths of streams. This is the case for the regional plan being developed. A regional stream numbering system was developed to aid not only the sewer plan but also the total water resource system of the are. This system is utilized to store and retrieve all water related data of the region. The system has been named the Storet Numbering System which was developed by EPA and will be described in the next chapter.

The San Antonio River Authority regularly (weekly) monitors the return flow quality for twenty-four treatment plants within the region. In addition, water quality at ten stream locations, eight of which are USGS stream gauging stations, are also monitored. In order to accomplish the monitoring program efficiently, the River Basin has been broken down into six regions.

As discussed previously, the availability of natural surface water resources varies from season to season. During the winter, a substantial amount of good quality water is available to dilute the sewage generated in the AACOG region. During the summer the available natural flow decreases to almost zero.

Another factor which influences the quality of the stream it ths temperature of the surface water. It was found that the stream assimilation capacity during winter is greater than that during summer in the San Antonio area.

In order to determine treatment requirements, a dissolved oxygen contour graph has been established by the Alamo Area Council of Governments for three stream conditions: summer, winter, and average (88). These contour graphs are used to predict the dissolved oxygen level at specific locations downstream due to specific levels of organic pollutants. It should be noted that the operation of waste treatment facilities constitute a very major portion of effective water resources management. Most treatment facilities are designed to remove ninety percent of the pollutants in wastewater. The present dissolved oxygen deficiency in river waters in the region indicates that treatment is not sufficient nor will it be in the future (88).

An analysis of stream quality at selected sampling points within the river basin was conducted and the results are shown in Figures 3.12-3.19. The sampling points selected were 52.00.00.00 and 52.06.00.00. Their approximate location in the river basin is illustrated by Figure 3.11. The water quality parameters examined were BØD, DO, PH and Temperature. The histograms and associated date in Figures 3.12-3.19 are a portion of the output from the data acquisition program developed in this project. The histograms graphically indicate the frequency distribution of each selected parameter per sample point for the past two years.

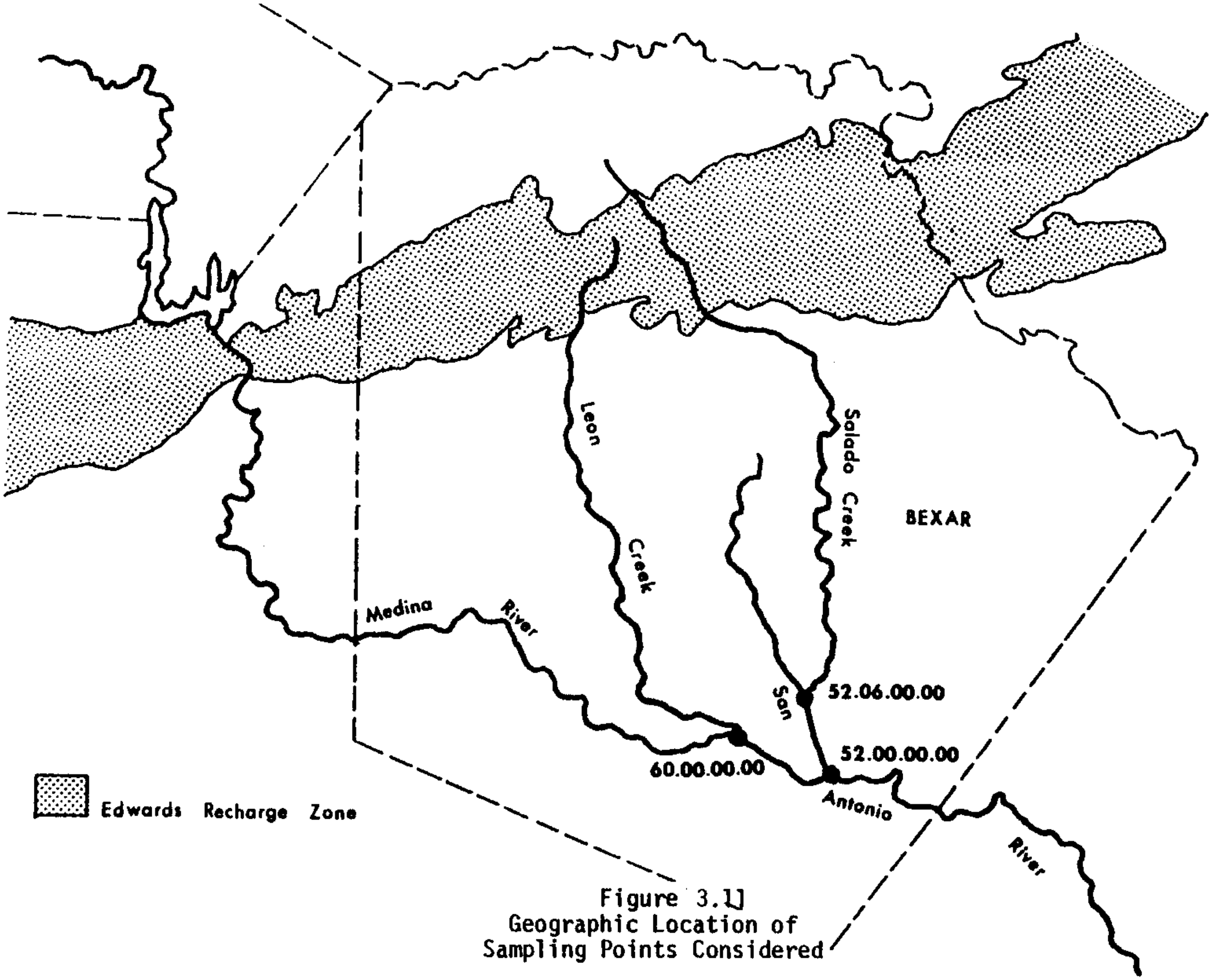


Figure 3.1]
Geographic Location of
Sampling Points Considered

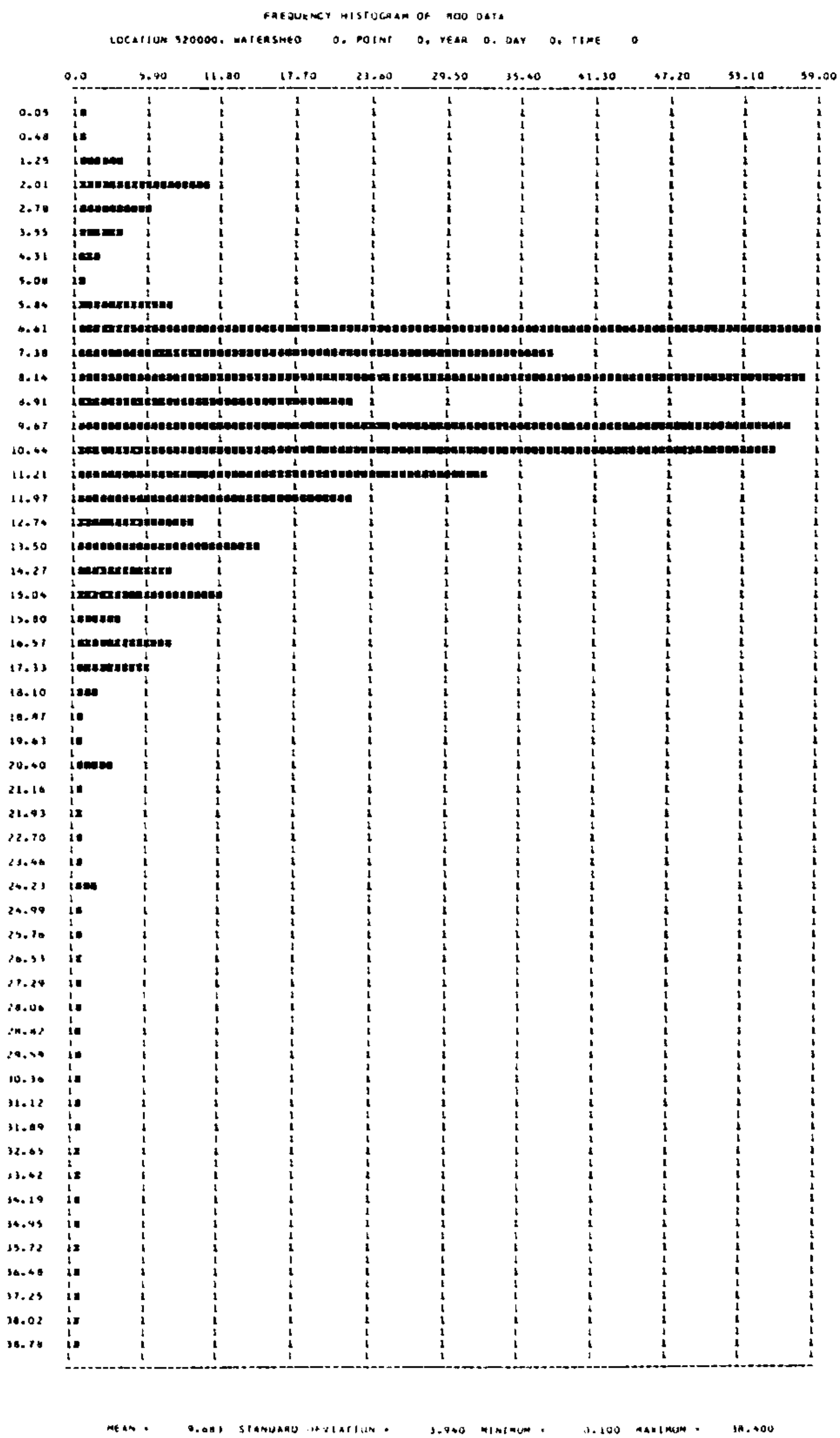
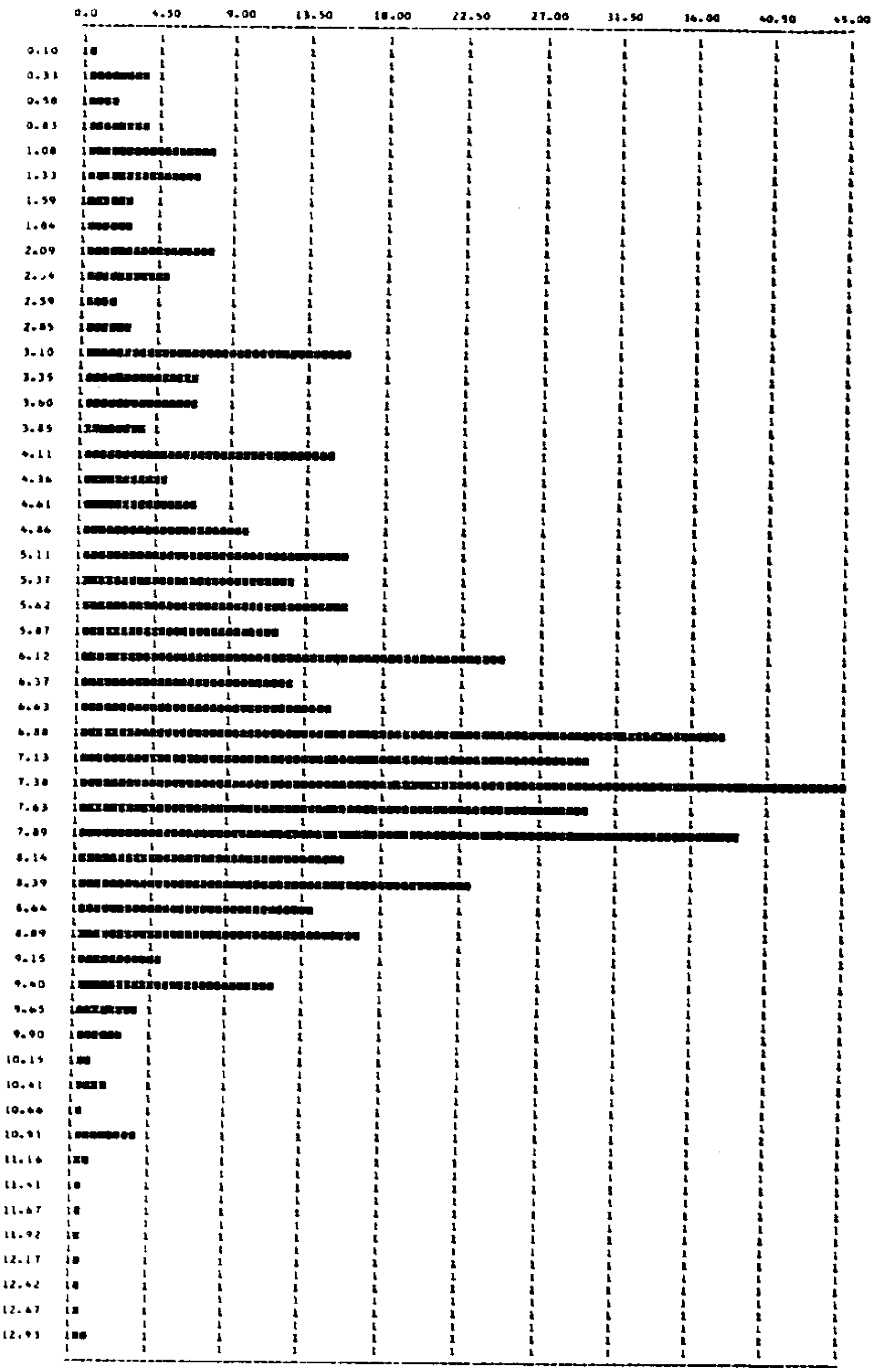

FREQUENCY HISTOGRAM OF ROO DATA
LOCATION 520000, WATERSHED 0, POINT 0, YEAR 0, DAY 0, TIME 0
0.0
5.90
11.80
17.70
23.60
29.50
35.40
41.30
47.20
53.10
59.00
0.05
0.48
1.25
2.01
2.78
3.55
4.31
5.08
5.84
6.61
7.38
8.14
8.91
9.67
10.44
11.21
11.97
12.74
13.50
14.27
15.04
15.80
16.57
17.33
18.10
18.87
19.63
20.40
21.16
21.93
22.70
23.46
24.23
24.99
25.76
26.53
27.29
28.06
28.82
29.59
30.36
31.12
31.89
32.65
33.42
34.19
34.95
35.72
36.48
37.25
38.02
38.78
MEAN = 9.683 STANDARD DEVIATION = 5.940 MINIMUM = 0.100 MAXIMUM = 38.400

FIGURE 3.12

FREQUENCY HISTOGRAM OF DO DATA

LOCATION 520000, WATERSHED 0, POINT 0, YEAR 0, DAY 0, TIME 0



MEAN = 6.347 STANDARD DEVIATION = 2.259 MINIMUM = 0.200 MAXIMUM = 12.600

FIGURE 3.13

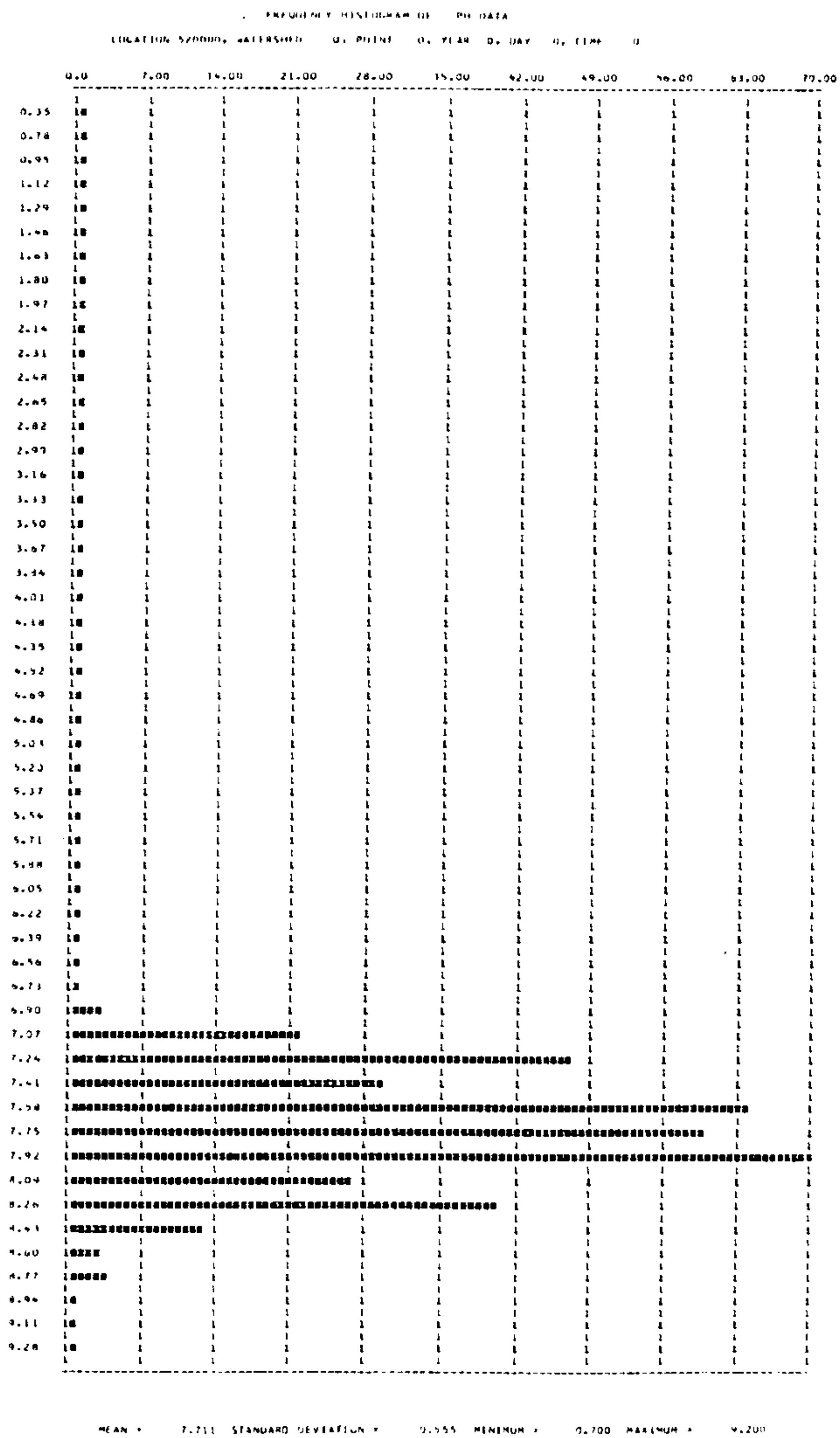

FREQUENCY HISTOGRAM OF PH DATA
0.0
7.00
14.00
21.00
28.00
35.00
42.00
49.00
56.00
63.00
70.00
MEAN = 7.711 STANDARD DEVIATION = 0.555 MINIMUM = 0.700 MAXIMUM = 9.200

FIGURE 3.14

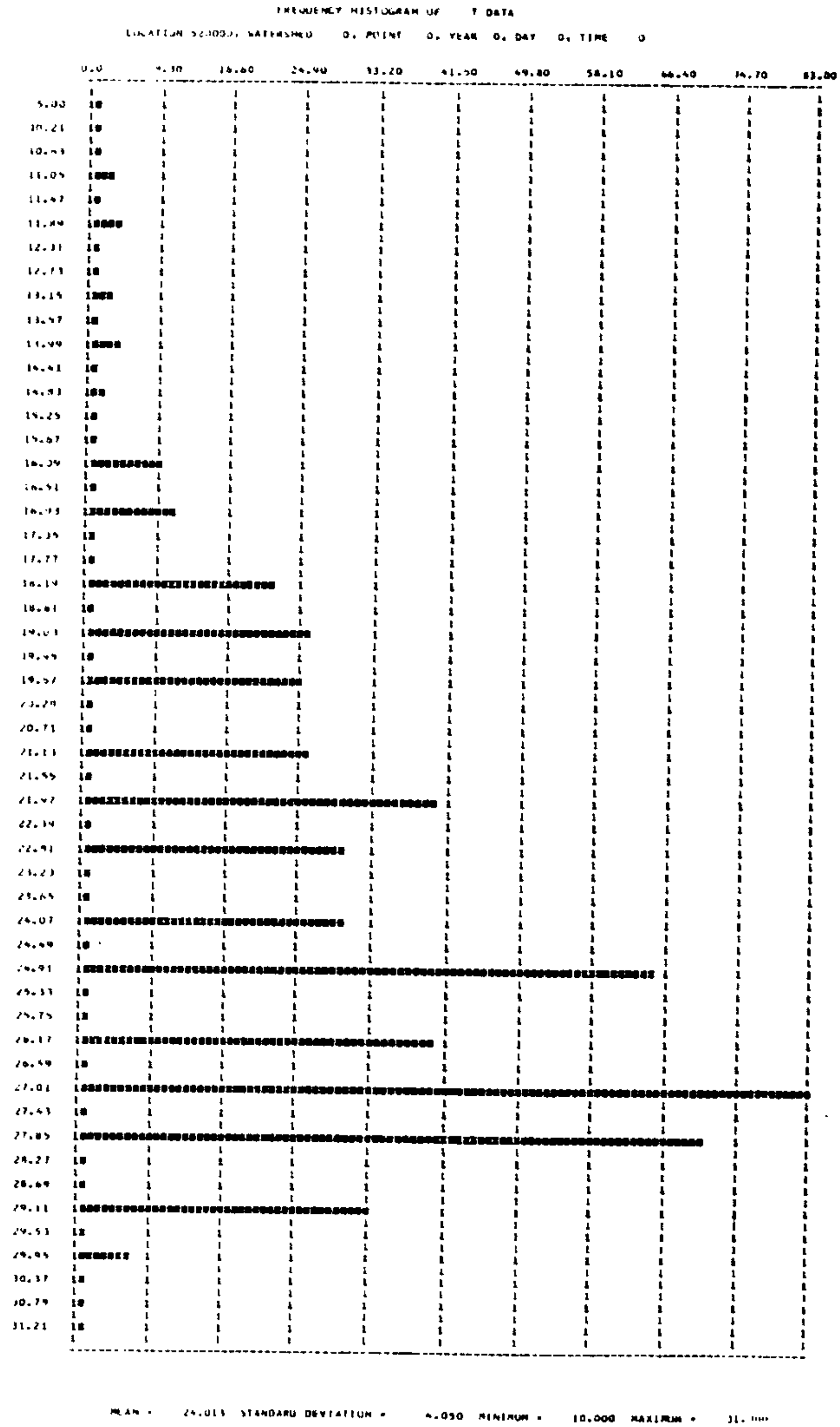


FIGURE 3.15

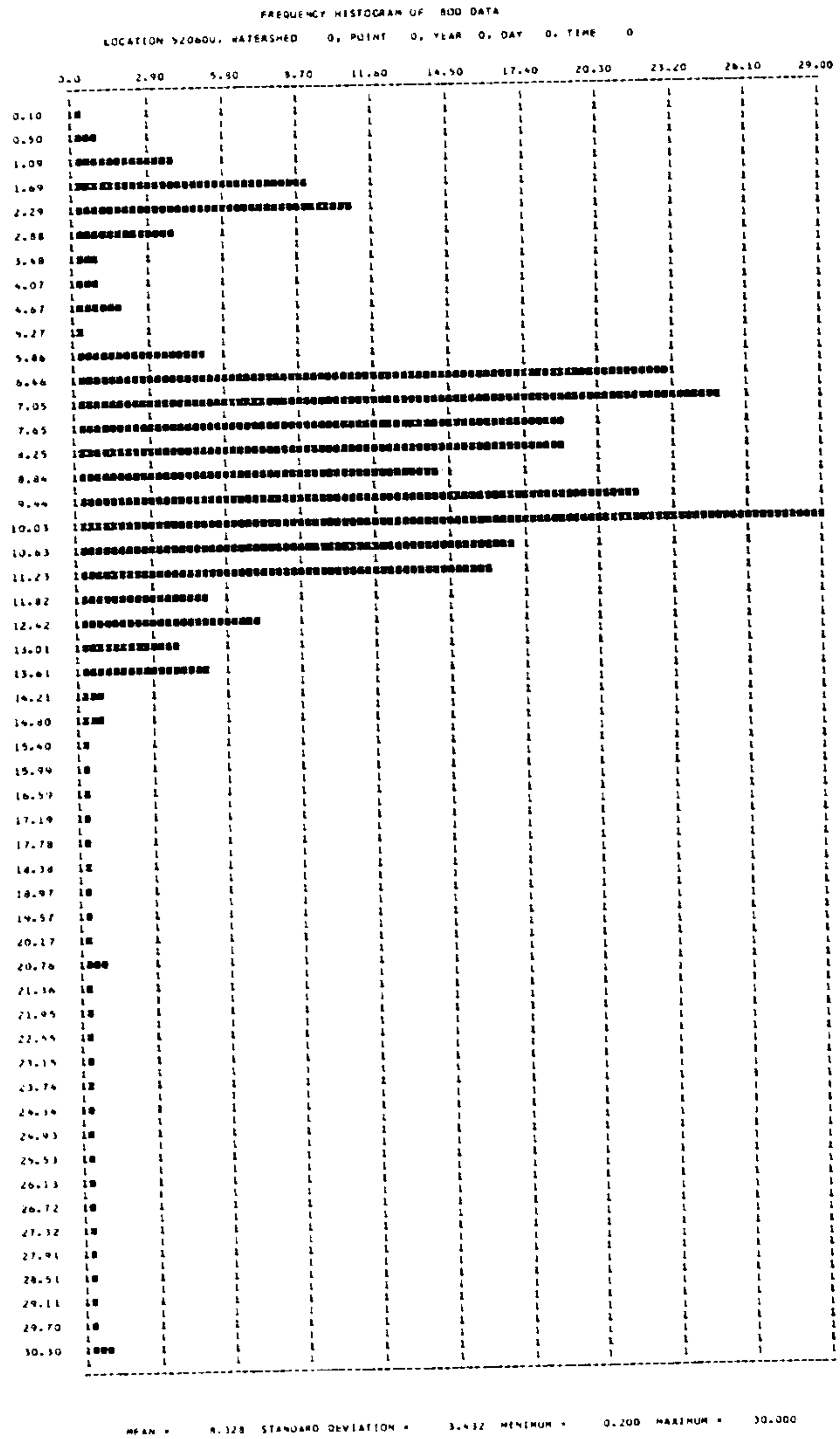
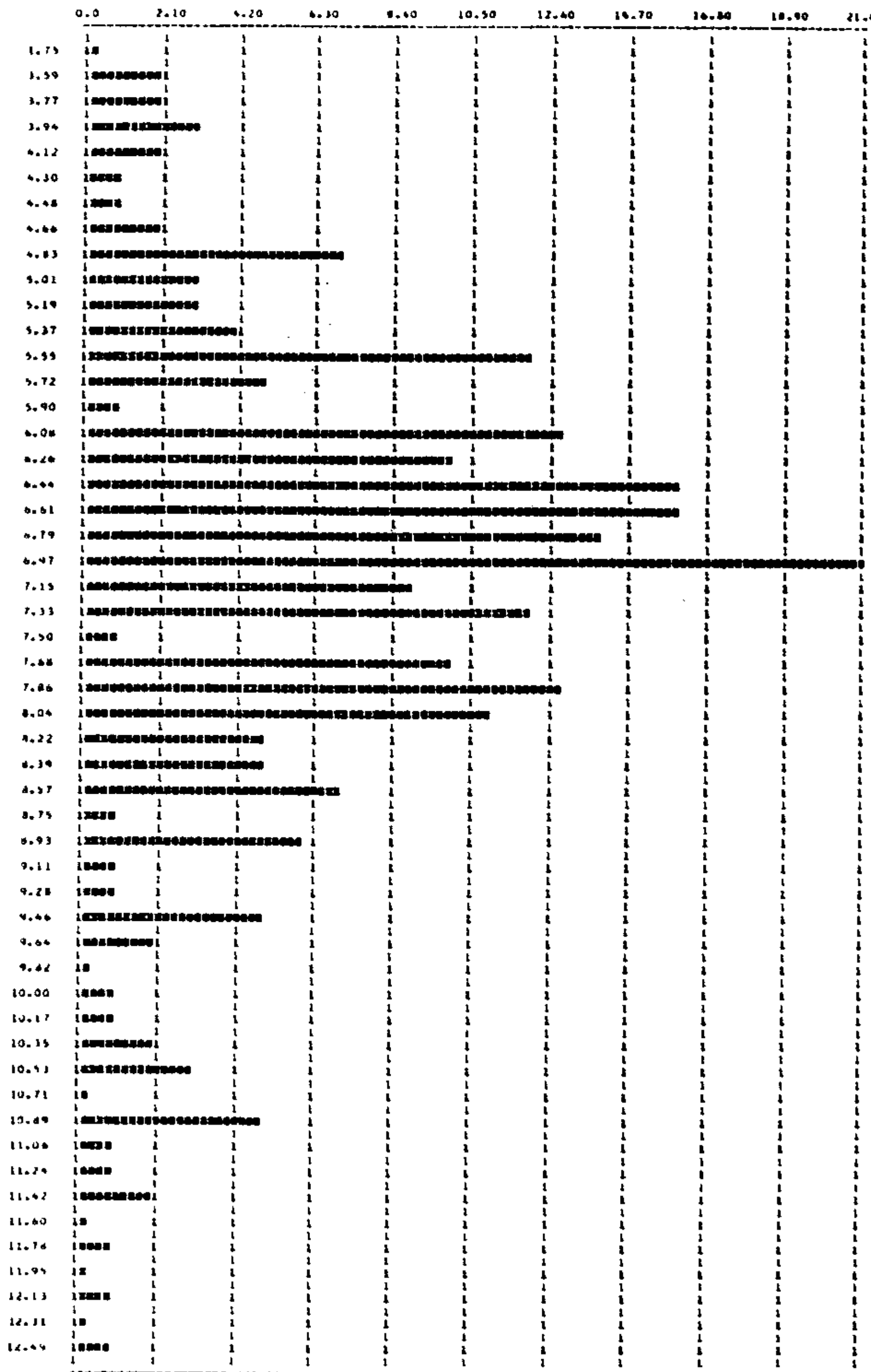

FREQUENCY HISTOGRAM OF 800 DATA
LOCATION 52060U, WATERSHED 0, POINT 0, YEAR 0, DAY 0, TIME 0
0.0 2.90 5.80 8.70 11.60 14.50 17.40 20.30 23.20 26.10 29.00
MEAN = 8.328 STANDARD DEVIATION = 3.432 MINIMUM = 0.200 MAXIMUM = 30.000

FIGURE 3.16

FREQUENCY HISTOGRAM OF UO DATA

LOCATION 520600, WATERSHED 0, POINT 0, YEAR 0, DAY 0, TIME 0

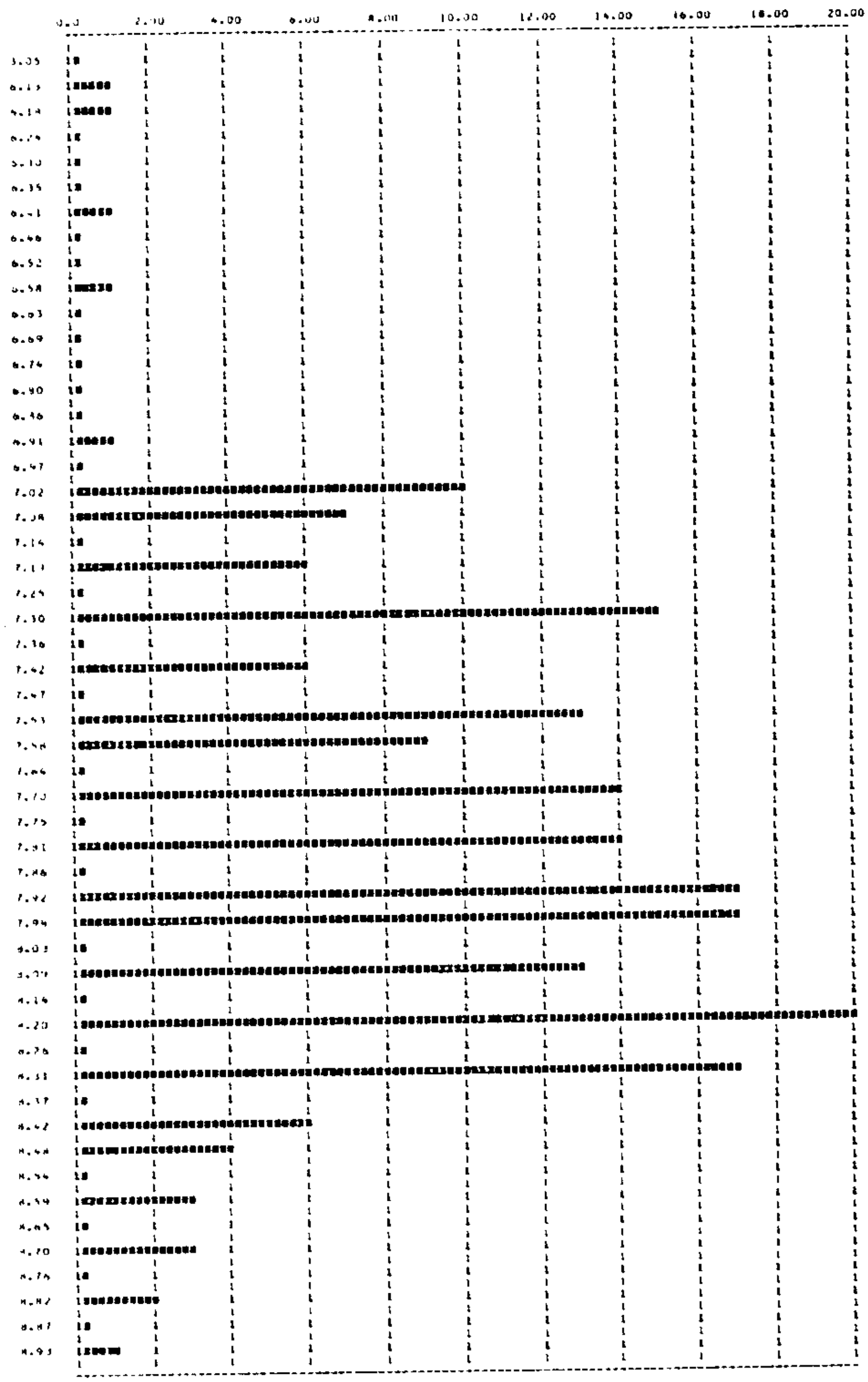


MEAN = 7.140 STANDARD DEVIATION = 1.662 MINIMUM = 3.500 MAXIMUM = 12.400

FIGURE 3.17

FREQUENCY HISTOGRAM OF [illegible] DATA

LOCATION 92000, WATERSHED 0, POINT 0, YEAR 0, DAY 0, TIME 0



NUMBER OF DATA OBSERVATIONS = 875 NUMBER OF CONTROL CARDS = 2

MEAN = 7.799 STANDARD DEVIATION = 0.495 MINIMUM = 6.100 MAXIMUM = 8.900

FIGURE 3.18

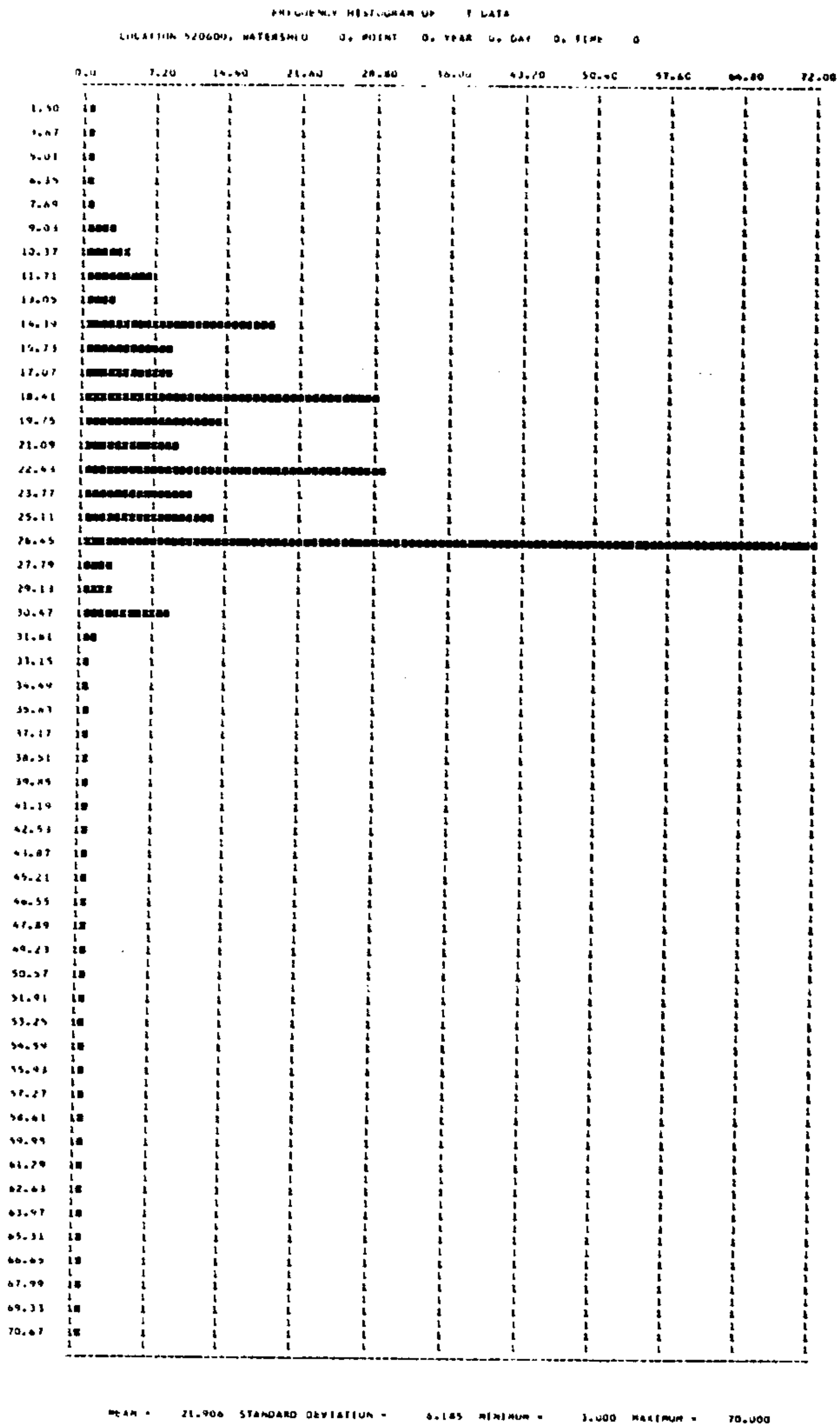

FREQUENCY HISTOGRAM OF T DATA
LOCATION 520600, WATERSHED 0, POINT 0, YEAR 0, DAY 0, TIME 0
0.0
7.20
14.40
21.60
28.80
36.00
43.20
50.40
57.60
64.80
72.00
MEAN = 21.906 STANDARD DEVIATION = 6.145 MINIMUM = 3.000 MAXIMUM = 70.000

FIGURE 3.19

PART II

Information Retrieval Progrmas for Urban Water Resources Management

CHAPTER IV

Information Retrieval Programs for Urban Water Resources Management

INTRODUCTION

The effective utilization of urban water resources has been highlighted as the primary factor for the enhancement of the quality of metropolitan living environment. In order to facilitate the achievement of this goal, comprehensive and updated information must be available to decision-makers so that appropriate policies may be formulated timely and accurately. Most water-related agencies have access to a large mass of data which can be used to describe the historical trend of the quantity and quality of urban water resources.

The key to effective management is to enable these agencies to draw upon their data files and determine the perspectives of the problems they may confront from time to time. Therefore, an information system possessing the capabilities of automatic file organization and manipulation, data reduction and statistical analysis is becoming the basic tool in urban water resources management.

In order to give room to final decision-making on water quality-quantity management, the information system for urban water resources must be broad-based, multi-parametric, and open-ended. The general functions included in a complete information system are detection, evaluation, diagnosis and guidance to actions. However, the latter two functions are usually varying with the needs of specific problems whereas the first two functions are generally common to all types of managerial problems. Thus, the initial task of effective management is to build a general data storage and retrieval system with the ability to categorize, organize, and conduct elementary statistical analysis on a massive volume of raw data. The objective of this paper is to present an effective data retrieval and analysis system developed for general use in urban water resources management. The application of the developed system will be illustrated by a practical example based on the implementation experience for the San Antonio River Authority in the state of Texas. The Storage and Retrieval Numbering Method (STORET) developed by the U. S. Environmental Protection Agency has been employed to organize the structure of stream networks. The basic principles and the logical relationships of the STORET numbering system will also be discussed and analyzed.

The information structure of stream network within a river basin can be expressed quantitatively in terms of stream order. The drainage patterns are usually classified as dendritic (treelike), rectangular or trellised, radial, and centripetal (56). Although the forms of drainage patterns are numerous, the numbering structure, which is based on specific ordinal numeric code, should be independent of the drainage patterns being represented.

Several different theories in defining the stream order numbers have been reviewed and are described below. Continental Europeans have been using a system based on branching or bifurcation. In this system, the largest, most branched, main or stem stream is designated as first order and the tributary streams are of higher orders (47).

Horton (56) developed a stream order which is the inverse of the European system. In this system, the main or stem stream is designated to be the highest order and unbranched fingertip tributaries are the lowest order. He states that unbranched fingertip tributaries are always designated as of order one and tributaries or streams of the second order receive branches or tributaries of the first order.

Third order streams must receive one or more tributaries of the second order but may also receive the first order tributaries. A fourth order stream receives branches of the third and usually of lower orders, and so on. Using this system the order of the main stream is the highest and should be denoted by the same ordinal number all the way to its headwaters. Horton suggested that one must be renumbered into the lower-order streams whenever two streams of equal order join together. Although Horton's work in the quantitative description of river morphology is rather cumbersone, it did pave the way for the advance in quantitative geomorphological research. Since then several modifications of Horton's original treatment have been developed.

Many river morphologists criticized Horton's method as being too subjective and difficult to follow a main stream headward. Strahler (112) redefined the term "order" into channel segments. He assumed that a higher order of channel will be formed where two channel segments of the same order join together (112). In Strahler's system, a high order stream will not extend back up stream as in Horton's classification. He also assumed that the channel network map includes all the intermittent and permanent flow lines located in clearly defined valleys.

The major setback of both Horton's and Stahler's stream numbering systems is the assumption that the stream order will increase by one if a stream is joined by another of the same order. This assumption may be meaningful if an idealized river system only consists of the confluence of streams of the same order all the time. However, actual stream systems are more complex. Many of them receive numerous tributaries of lower order. Thus, the lower order tributaries must be ignored under the ordering systems of Horton and

Strahler. Rzhanitsyn observed that changes in the characteristics of a stream of a given order into a higher order would increase the numerical values of the characteristics. For instance, in the case that two rivers of the third order enter consecutively into a river of the fourth order, the inflow of the second third order stream will change the river into a fifth order (100). Meanwhile, Scheidegger defined a consistent algebra of stream order numbers to relate the advance of stream order designations.

Comparing the stream order numbering system of these different river morphologists in terms of the adaptability to electronic data processing, all possess the same disadvantages. The data required for certain drainage areas can only be obtained through the use of maps. There is no systematic way to retrieve data for a certain drainage area. For example, if the user desires data for a certain segment of the fourth order stream the searching scheme must be performed with cross-reference to a map to locate the segments correctly. Thus, failure to construct a hierarchy system to represent the treelike stream system and failure to code the junction of two streams properly are the two major setbacks of these numbering systems.

In an attempt to simplify the retrieval scheme and to accommodate the needs of the information seeker, the Environmental Protection Agency (EPA) developed the STORET system. This is a hierarchical system which provides a base for the acquisition of the necessary data retrieval. The system and watershed numbers are represented by a standardized numbering code. It has been recognized that this uniform numbering system is extremely adaptable to EDP techniques.

<u>STORET NUMBERING SYSTEM</u>

The STORET numbering system is basically a systematic method to designate all streams and tributaries by sequential numbers according to their relative locations. All the streams in a basin are classified as major, first order, second order, etc.

The main stream of a river basin is designated by the number 00.00.-00.00.00-00 throughout the length. First order streams are all streams (longer than two miles) that are direct tributaries of the major stream. Each first order stream is given a progressively larger number than the first order stream immediately downstream from it. As one progresses upstream, tributaries which enter major streams from the right side are given even numbers and streams which enter from the lefthand side are given odd numbers. Second order streams enter first order streams. Third, fourth, fifth order streams, etc. are streams which enter the next lower order streams and the same systematic numbering system is applied (34).

Generally, a watershed is defined as a body of soil with definite boundaries around it, above it and below it. Therefore watersheds are delineated only at the junction of streams. The stream number is followed by a hyphen and the watershed number. Both stream numbers and watershed numbers are illustrated in the Figure 4.1. Because the STORET system designates streams by increasing order, each juncture is always made up of a tributary entering a lower order stream. Since every juncture, except the main stream, consists of a tributary, there will be as many decision points in a region as there are tributaries. Also every stream juncture constitutes the mouth of a higher order stream, the number of the higher order stream becomes a convenient number for each particular decision point. The following two relationships should be noted:

(1) By designating the number of the higher order stream as the number of the decision point, it is readily possible

to identify both the water shed number of the major stream above and also the watershed number of the tributary. This is illustrated in the following examples:

Decision Point	Tributary Watershed	Major Watershed Above
52.06.00.00.00	52.06.00.00.00-00	52.00.00.00.00-06
52.06.03.00.00	52.06.03.00.00-00	52.06.00.00.00-03
52.00.00.00.00	52.00.00.00.00-00	00.00.00.00.00-52

(2) At any decision point, the watershed number of both the tributary and the upstream watershed will always be greater than the down stream watershed. This is illustrated in the following example:

Decision Point	Tributary Watershed	Upstream Watershed	Downstream Watershed
52.06.00.00.00	52.06.00.00.00-00	52.00.00.00.00-06	52.00.00.00.00-(05 or 04)
52.06.03.00.00	52.06.03.00.00-00	52.06.00.00.00-03	52.06.00.00.00-(02 or 01)
52.00.00.00.00	52.00.00.00.00-00	00.00.00.00.00-52	00.00.00.00.00-(51 or 50)

These two relationships enable a systems description for streams without the constant referral to maps. Also it will not be affected by the morphological variation of stream-tree configurations.

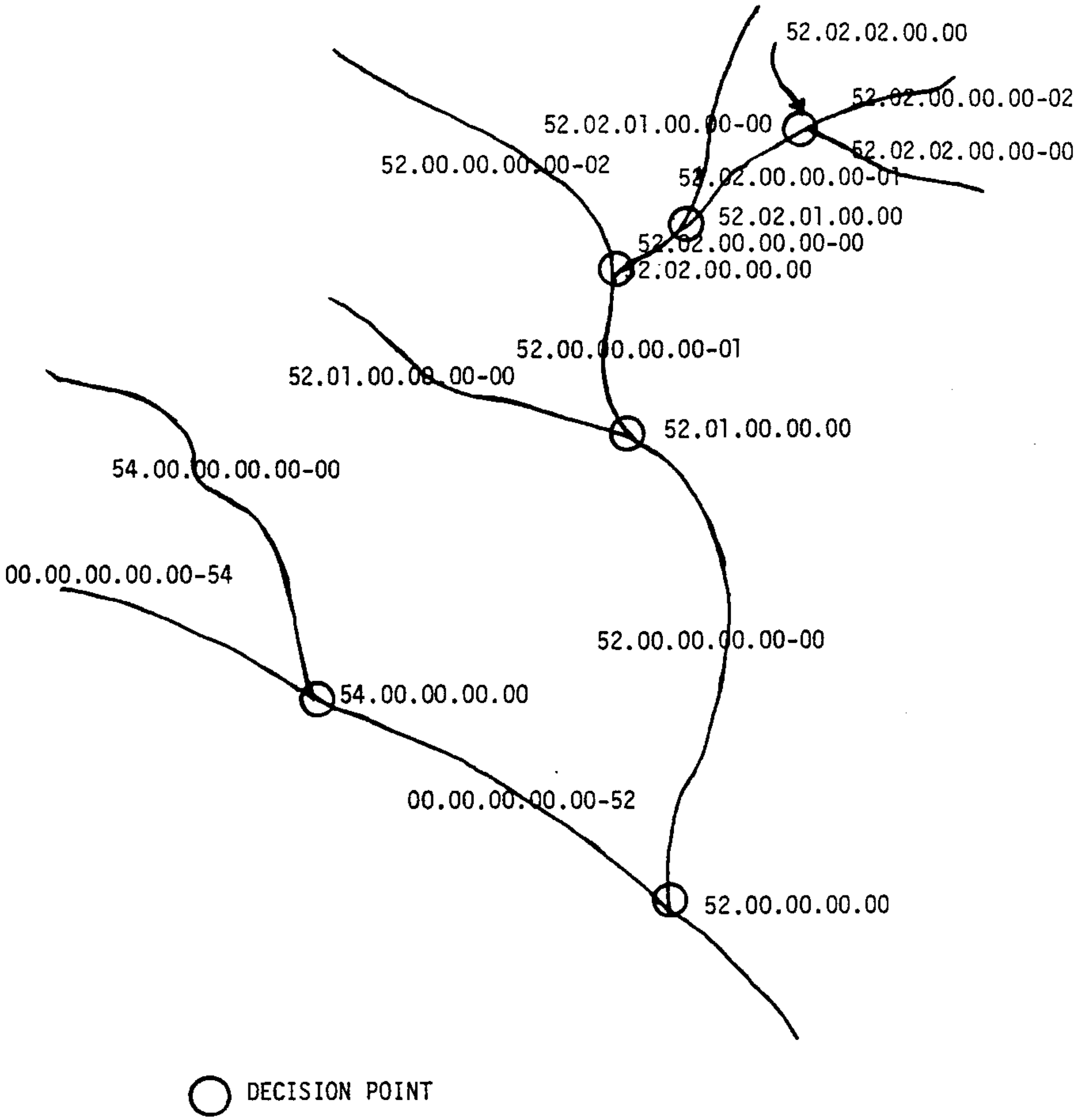
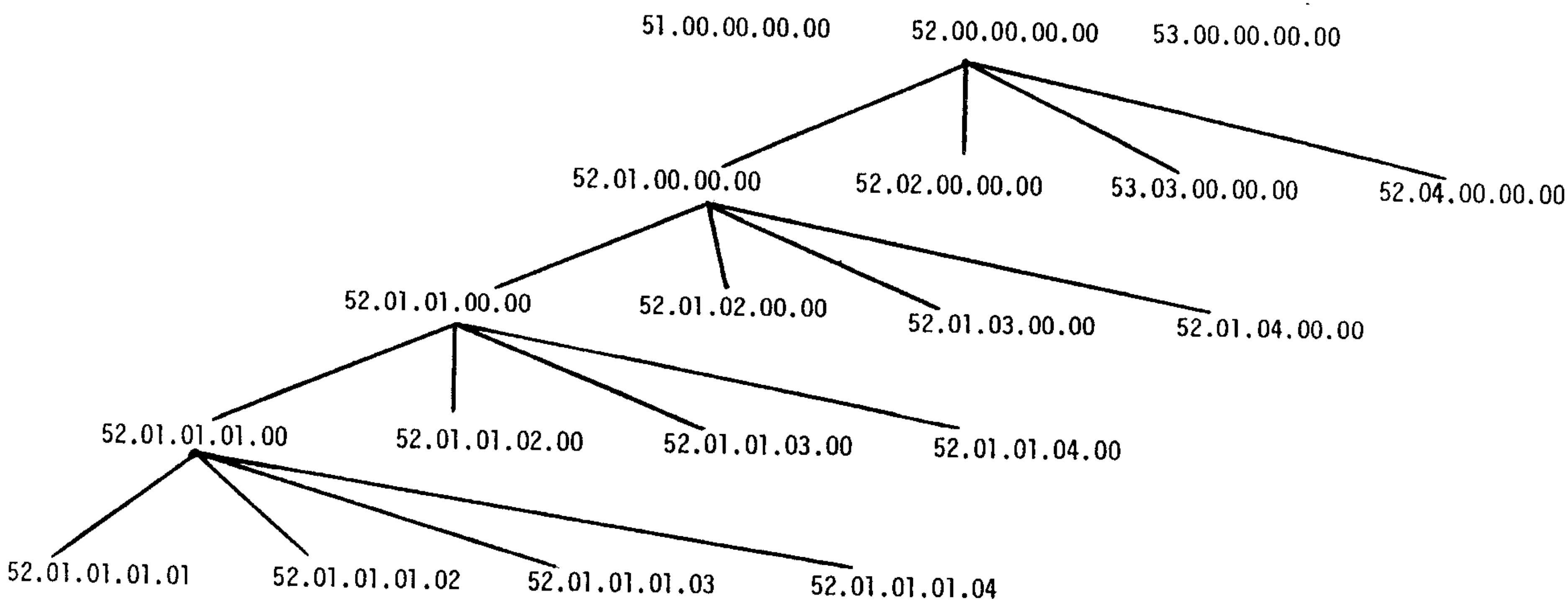


FIGURE 4-1 'STORET' STREAM NUMBERING SYSTEM



FIGUE 4-2 HIERARCHIC RELATIONSHIP

(STREAM NUMBER)

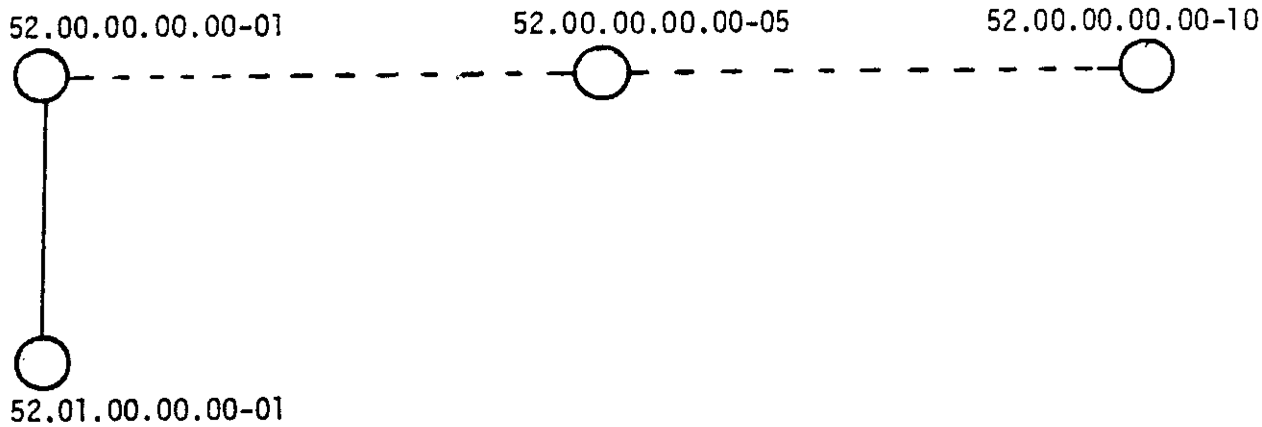


FIGURE 4-3 ASSOCIATIVE RELATIONSHIP
(STREAM SEGMENTS)

LOGICAL RELATIONSHIPS

The information structure of the STORET numbering system is based on two major logical relationships. The stream system is based on a hierarchic relationship, while the stream segments follow an associative relationship. Figure 4-2 and Figure 4-3 illustrate these relationships.

As shown in Figure 4-2, there is a record at the top which bears a superior hierarchical relationship to the second level records. Similarly, each of these are superior in the hierarchy to the next lower records. In this project, the hierarchy represented by a tree of five levels is considered. However, the number of levels can easily be extended when it is needed. Another property of hierarchic information structure, as illustrated by the bottom most record in the diagram, is that a given record may actually be shared in the hierarchy by more than one superior record.

In summary, there is a chosen relationship between different levels of records. For example, the third order record 52.01.01.00 has a specific information relationship in the hierarchy to the second order record 52.01.00.00.00, and this in turn has an information relationship to the first order record 52.00.00.00.00.

It is considered by the designers of this system to relate or associate all records, regardless of their position in the file hierarchy, that would contain the same identification key. This kind of relationship is called associative, and is represented in this diagram by broken lines. For instance the identification key may be the stream number 52.00.00.00.00 for the entire upstream shown in Figure 4-1. So that the records 52.00.00.00.00-00, 52.00.00.00.00.01..........52.00.00.00.00-10 might be associative. The other hierarchic relationships, if any, among these records is not important.

These information structures are very adaptable to electronic data processing techniques. For instance, if the investigator designates a location number of 52.01.00.00.00-00, the retrieval scheme upstream of that number can be conducted by using the hierarchic and associative relationships of streams and tributaries. A retrieval scheme can be considered hierarchically and associatively by including all the records of that hierarchy until the bottom most records are reached.

Since stream segments have an inverse relationship to tributaries, the stream number corresponding to the tributary 52.01.00.00.00-00 is 52.00.00.00.00-00. Streams are segmented by the increasing watershed numbers, i.e., 52.00.00.00.00-02, 52.00.00.00.00-3.....etc. of the same stream number 52.00.00.00.00. The retrieving scheme can be considered associatively starting from record 52.00.00.00.00-01 to the last record. In Figure 4-3, this is shown from 52.00.00.00.00-1 to 52.00.00.00.00-10. If the watershed numbers are arranged in ascending order, a network is established whereby one moves progressively upstream until the designated drainage area is covered.

An example of the application of the STORET system will be illustrated as follows. If the investigator desires to retrieve data from the drainage generated which is composed of streams and tributaries in ascending order. As is shown in Figure 4-4, the STORET stream numbering system starts at the first stream at location point 52.00.00.00.00-00. Instead of tracing individual watersheds from its tributaries which are upstream of the designated location point, the watershed table generated is based on key designators (keys).

Watershed Table

Sequence No.	Watershed No.
1	00.00.00.00.00-52
2	00.00.00.00.00-54
3	52.00.00.00.00-00
4	52.00.00.00.00-01
5	52.00.00.00.00-02
6	52.01.00.00.00-00
7	52.02.00.00.00-00
8	52.02.00.00.00-02
9	52.02.02.00.00-00
10	52.02.02.00.00-01
11	52.02.02.01.00-00
12	54.00.00.00.00-00

Given the specified order of the stream number, a retrieval scheme can be achieved by tracing the hierarchy downward until the bottom most record is reached. It will also retrieve the records of the same order which has an associative relationship. For instance, the location number specified is 52.00.00.00.00. The retrieved stream number will be started at 52.00.00.00.00-00 down to include all the records vertically and horizontally. According to the sequential watershed table and stream number, 52.00.00.00.00 is the first key. The corresponding sequence number will be key one, i.e., k1 = 3. While the second key in this case is the last record in the watershed table, 54.00.00.00.00. The corresponding sequence number will be key two, k2 =12. These two keys form the stream boundary

520000	71	0	0	0	DO	BOD

RETRIEVED DATA OF DO
****

LOCATION 520000, WATERSHED 0, POINT 71, YEAR 0, DAY 0, TIME 0

LOC	WS	PT	YR	DAY	TIME	DO
520000	0	71	70	5	1105	7.8
520000	0	71	70	7	1040	6.9
520000	0	71	70	12	1410	7.3
520000	0	71	70	19	1130	7.8
520000	0	71	70	20	1205	8.8
520000	0	71	70	21	1635	9.8
520000	0	71	70	22	1050	9.6
520000	0	71	70	26	1100	7.7
520000	0	71	70	27	1050	8.8
520000	0	71	70	28	1700	8.5
520000	0	71	70	29	1420	7.8
520000	0	71	70	30	1030	10.8

FIGURE 4-4 DATA LIST

in which the lower margin is k1, the higher margin is k2. All data falling within this range will be retrieved.

The second range is formed by the stream segments. Owing to the inverse relationship between tributaries and stream segments, the stream segment of the location 52.00.00.00.00 is 00.00.00.00.00-52. According to the associative structure, the identification key in this case is stream number 00.00.00.00.00 plus any combination of watershed numbers. Upstream of the segment 00.00.00.00.00-52 in this case starts from itself to the segment 00.00.00.00.00-54. These two margins create a second boundary. The lower margin is called the third key, while the higher margin is called the fourth key. A sequence number can be generated corresponding to the keys, k3 = 1, k4 = 2. All data falling within this range will be retrieved. Combining these two groups of the watersheds, the information concerning the upstream drainage area of the given location points can be linked and retrieved without referring to a map.

PROGRAM DEVELOPMENT:

The first segment of the retrieval program is designed to provide the user with information concerning selected water quality parameters from a predetermined data base. The retrieval scheme is initiated by a user command called a control statement. The control statement contains the following information.

1. sample location (STORET number)
2. date and time collected
    (a) year (two digit designation, i.e. 69,70)
    (b) day (julian date)
    (c) time (24 hour clock)

(3.) parameter (s) desired (one or more items below)

(a) dissolved oxygen (DO)

(b) biochemical oxygen demand (BOD)

(c) total suspended solids (TSS)

(d) volatile suspended solids (VSS)

(e) temperature (T)

(f) clorine demand (CL2)

(g) conductivity (COND)

(h) acidity (PH)

(i) alkalinity (ALK)

(j) ammonia nitrogen (NH3)

(k) nitrate (NO3)

(l) phosphate (PO4)

(m) chlorides (CL)

(4.) Output option (1,2,3,4,0)

The sample location information must be included, however a default check exists for date and time. That is, if any or all of the date and time parameters are ommitted (=0) data for all observations corresponding to location will be retrieved. The retrieval scheme is based on a sequential search routine. The data base may be stored on a sequential access device or a direct access device; however, the latter is much more efficient in terms of computation time than the former.

After the desired data is retrieved elementary statistics are performed and the following options are available as output.

0. all options below
1. data list

3. histogram

4. cummulative distribution function

Any or all options may be executed as desired. These options are entered in the control statement. A default of zero will provide the user with a quality of that section of the river basin in question. The quality is accomplished by means of a simulation model. The simulation model incorporated is a modified version of DOSAG-I originally developed by the Texas Water Development Board. The major modifications to the program were made in the input and output formats. DOSAG-I is designed to simulate the spatial and temporal variations of biochemical oxygen demand (BOD) and dissolved oxygen concentration (DO) under various conditions of temperature and headwater flow. DOSAG-I input formats were modified to conform with the STORET system in order to use the output from the data retrieval segment as direct input to the water quality profile segment.

DOSAG-I solves for the biochemical oxygen demand and dissolved oxygen profiles by the following relationships:

$$\frac{dL}{dt} = -K_1 L$$

$$\frac{dN}{dt} = -K_3 N$$

$$\frac{dC}{dt} = K_2 (C_{sat} - C)$$

where

t = time

L = carbonaceous biochemical oxygen demand concentration

c = dissolved oxygen concentration

C_{sat} = dissolved oxygen saturation concentration

N = nitrogenous biochemical oxygen demand concentration

K_1 = deoxygenation coefficient by carbonaceous BOD

K_2 = reaeration coefficient

K_3 = deoxygenation coefficient by nitrogenous BOD

The solution of the above equations gives the dissolved oxygen concentration at a point with travel time "t".

$$C(t) = C_{sat} + \frac{K_1 L_o}{K_2-K_3}(e^{-K_2 t} - e^{-K_1 t}) + \frac{K_3 N_0}{K_2-K_3}(e^{-K_2 t} - e^{-K_1 t})$$

$$-(C_{sat}-C_0)e^{-K_2 t}$$

where L_0 = initial carbonoreous BOD

N_0 = initial nitrogenous BOD

For the San Antonio region the effects of photosynthesis respiration of aquatic plants was found to be negligible and therefore is not considered in the model. However, the analysis suggested by O'Conner and Ditoro would be applicable if necessary.

At each change in a reach and at every junction a simple mass balance is performed to arrive at the biochemical oxygen demand and dissolved oxygen concentration in the next reach downstream. Thus the stream system is modled from its upper to its lower end in response to all the pollution loads imposed upon it. The output from the quality profile model is shown in Figures 4-8 and 4-10.

A macro flow chart for the retrieval and analysis system is illustrated by Figure 4-11.

WATER QUALITY PARAMETER BOD - SAN ANTONIO RIVER BASIN
SARA NUMBER 600 POINT NUMBER 1 YEAR 1970

CLASS INTERVALS		CLASS MARK	CLASS FREQUENCY	RELATIVE FREQUENCY	CUMMULATIVE RELATIVE FREQUENCY
***************		*********	*********	*********	***********
0.200	3.596	1.898	3	0.1285.01	0.128E-01
3.596	6.992	5.294	87	0.372E 00	0.385E 00
6.992	10.388	8.690	61	0.261E 00	0.645E 00
10.388	13.784	12.086	40	0.171E 00	0.816E 00
13.784	17.180	15.482	19	0.812E-01	0.897E 00
17.180	20.576	18.576	7	0.299E-01	0.927E 00
20.576	23.972	22.274	2	0.855E-02	0.936E 00
23.972	27.368	25.670	4	0.171E-01	0.953E 00
27.368	30.764	29.066	3	0.128E-01	0.966E 00
30.764	34.160	32.462	1	0.427E-02	0.970E 00
34.160	37.556	35.858	0	0.000E 00	0.970E 00
37.566	40.952	39.254	1	0.427E-02	0.974E 00
40.952	44.348	42.650	2	0.855E-02	0.983E 00
44.348	47.744	46.046	1	0.427E-02	0.987E 00
47.744	51.140	49.442	0	0.000E 00	0.987E 00
51.140	54.536	52.838	0	0.000E 00	0.987E 00
54.536	57.932	56.234	0	0.000E 00	0.987E 00
57.932	61328	59.630	0	0.000E 00	0.987E 00
61.328	64.724	63.026	0	o.000E 00	0.987E 00
64.724	68.120	66.422	1	0.427E-02	0.991E 00
68.120	71.516	69.818	0	0.000E 00	0.001E 00
71.516	74.912	73.214	0	0.000E 00	0.991E 00
74.912	78.308	76.610	0	0.000E 00	0.991E 00
78.308	81.704	80.006	0	0.000D 00	0.991E 00
81.704	85.100	83.402	1	0.427E-02	0.996D 00
85.100	88.496	86.798	0	0.000E 00	0.996E 00
88.496	91.892	90.194	0	0.000E 00	o.996E 00
91.892	95.288	93.590	0	o.000E 00	0.996E 00
95.288	98.684	96.986	0	0.000E 00	o.996E 00
98.684	102.080	100.382	0	0.000E 00	0.996E 00
102.080	105.476	103.778	0	0.000E 00	0.996E 00
105.476	108.872	107.174	0	0.000E 00	0.996E 00
108.872	112.268	110.570	0	0.000E 00	0.996E 00
112.268	115.664	113.996	0	o.000E 00	0.996E 00
115.664	119.060	117.362	0	0.000E 00	0.996E 00
119.060	122.456	120.758	0	0.000E 00	0.996E 00
122.456	125.852	124.154	0	0.000E 00	0.996E 00
125.852	129.248	127.550	0	0.000E 00	0.996E 00
129.248	132.644	130.946	0	0.000E 00	0.996E 00
132.644	136.040	134.342	0	0.000E 00	0.996E 00
136.040	139.436	137.738	0	0.000E 00	0.996E 00
139.436	142.832	141.134	0	0.000E 00	0.996E 00
142.832	146.228	144.530	0	0.000E 00	0.996E 00
146.228	149.624	147.926	0	0.000E 00	0.996E 00
149.624	153.020	151.322	0	0.000E 00	0.996E 00
153.020	156.416	154.718	0	0.000E 00	0.996E 00
156.416	159.812	158.114	0	0.000E 00	0.996E 00
159.812	163.208	161.510	0	0.000E 00	0.996E 00
163.208	166.604	164.996	0	0.000E 00	0.996E 00
166.604	169.812	168.303	0	0.000E 00	0.996E 00
169.812	173.396	171.689	0	0.000E 00	0.996E 00
173.396	176.792	175.094	1	0.427E-02	0.100E 00

MAX = 170.000 XBAR = 7.868 VAR = 193.894
MIN = 0.200 SD = 13.925

FIGURE 4-5 FREQUENCY DISTRIBUTION TABLE

WATER QUALITY PARAMETER BOD - SAN ANTONIO RIVER BASIN
SARA NUMBER 600 POINT NUMBER 1 YEAR 1970

```
                         O B S E R V E D   F R E Q U E N C Y
            0.00                          43.50                          87.00
              ...........................................................
       1.90 .XXXX                                                          .
       5.29 .XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX        .
       8.69 .XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX                       .
      12.09 .XXXXXXXXXXXXXXXXXXXXXXXXXX                                    .
      15.48 .XXXXXXXXXXXXX                                                 .
      18.88 .XXXXXXX                                                       .
      22.27 .XXXX                                                          .
      25.67 .XXXXX                                                         .
      29.07 .XXXX                                                          .
      32.46 .XXX                                                           .
      35.86 .                                                              .
      39.25 .XXX                                                           .
 C    42.65 .XXXX                                                          .
      46.05 .XXX                                                           .
      49.44 .                                                              .
 L    52.84 .                                                              .
      56.23 .                                                              .
      59.63 .                                                              .
 A    63.03 .                                                              .
      66.42 .XXX                                                           .
      69.82 .                                                              .
 S    73.21 .                                                              .
      76.61 .                                                              .
      80.01 .                                                              .
 S    83.40 .XXX                                                           .
      86.80 .                                                              .
      90.19 .                                                              .
      93.59 .                                                              .
      96.99 .                                                              .
 M   100.38 .                                                              .
     103.78 .                                                              .
     107.17 .                                                              .
 E   110.57 .                                                              .
     113.97 .                                                              .
     117.36 .                                                              .
 A   120.76 .                                                              .
     124.15 .                                                              .
     127.55 .                                                              .
 N   130.95 .                                                              .
     134.34 .                                                              .
     137.74 .                                                              .
     141.13 .                                                              .
     144.53 .                                                              .
     147.93 .                                                              .
     151.32 .                                                              .
     154.72 .                                                              .
     158.11 .                                                              .
     161.51 .                                                              .
     164.91 .                                                              .
     167.31 .                                                              .
     171.70 .                                                              .
     175.09 .XXX                                                           .
              ...........................................................
```

FIGURE 4-6 FREQUENCY HISTOGRAM

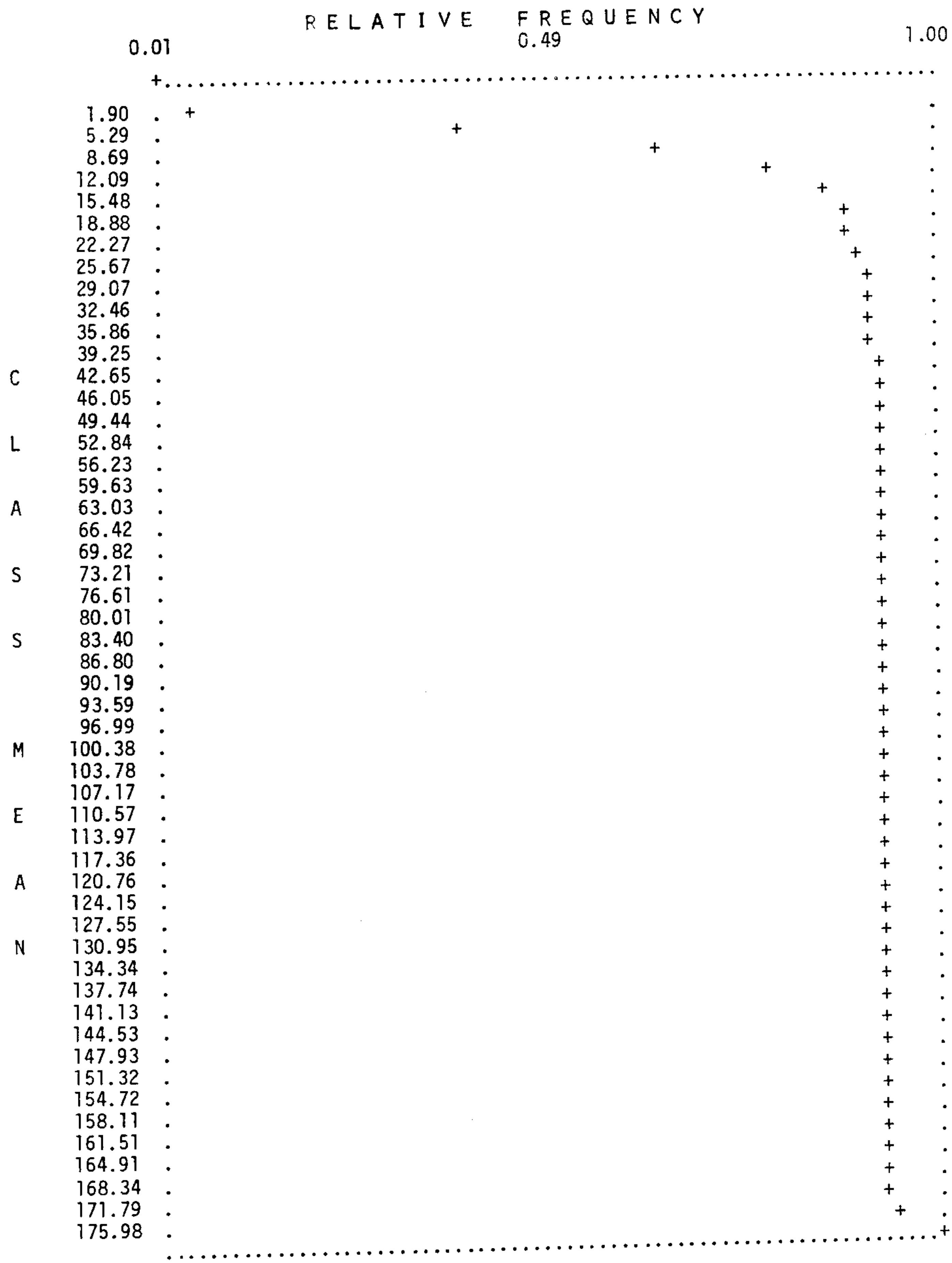


FIGURE 4-7 CUMULATIVE DISTRIBUTION FUNCTION

* * * * * F I N A L   S U M M A R Y * * * * *

SAN ANTONIO RIVER ANALYSIS - REVISED DOSAG-I VERSION

NUMBER OF RUN = 1
TREATMENT (C) = 0.00
SEASON OF YR. = JUN

NO. OF REACH	DECISION POINTS	CARBONACEOUS BOD AT START (MG/L)	CARBONACEOUS BOD AT END (MG/L)	NITROGENOUS BOD AT START (MG/L)	NITROGENOUS BOD AT END (MG/L)	K2 VALUE BASE E	TRAVEL TIME (DAYS)	MEAN VELOCITY (FPS)	MEAN DEPTH (FT)
1	66 0 0	1.00	0.93	0.00	0.00	5.802	0.150	1.22	1.4
2	66 0 0	10.23	8.81	0.00	0.00	5.699	0.331	1.29	1.5
3	5214 0	2.00	1.28	0.00	0.00	5.941	0.986	0.81	1.0
4	5211 0	46.12	40.09	0.00	0.00	4.465	0.310	1.96	2.4
5	52 0 0	27.18	24.10	0.00	0.00	1.166	0.266	0.92	3.9
6	50 0 0	24.10	22.57	0.00	0.00	1.200	0.145	0.84	3.5

FIGURE 4-8 FINAL SUMMARY-I

*****F I N A L   S U M M A R Y*****

SAN ANTONIO RIVER ANALYSIS - REVISED DOSAG-I VERSION

NUMBER OF RUN = 1
TREATMENT (C) = 0.00
SEASON OF YR. = JUN

TARGET D.O. LEVEL = 0.01
TREATMENT (N) = 0.00
MEAN TEMPERATURE = 27.50

NO. OF HEADWATER	NO. OF STRETCH	INITIAL FLOW (CFS)	FINAL FLOW (CFS)	AUGMENTATION REQUIRED (CFS)
1	66 0 0	60.6	60.6	0.0
2	5214 0	14.0	14.0	0.0

* * * JUNCTIONS * * *

NO. OF JUNCTION	NO. OF UPSTREAM STRETCH	NO. OF UPSTREAM STRETCH	NO. OF DOWNSTREAM STRETCH
1	66 0 0	5214 0	52 0 0

FIGURE 4-9 FINAL SUMMARY-II

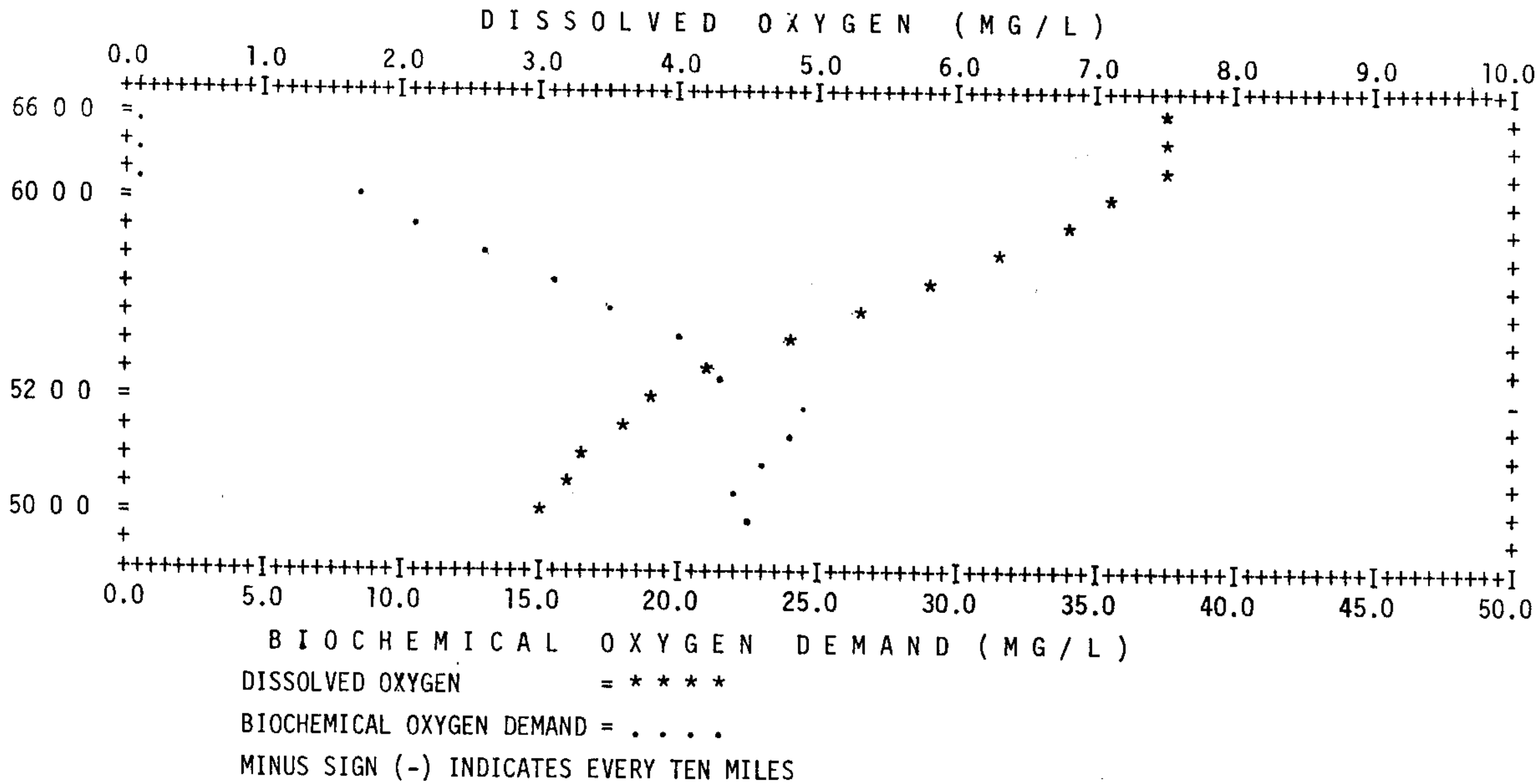


FIGURE 4-10 PLOT

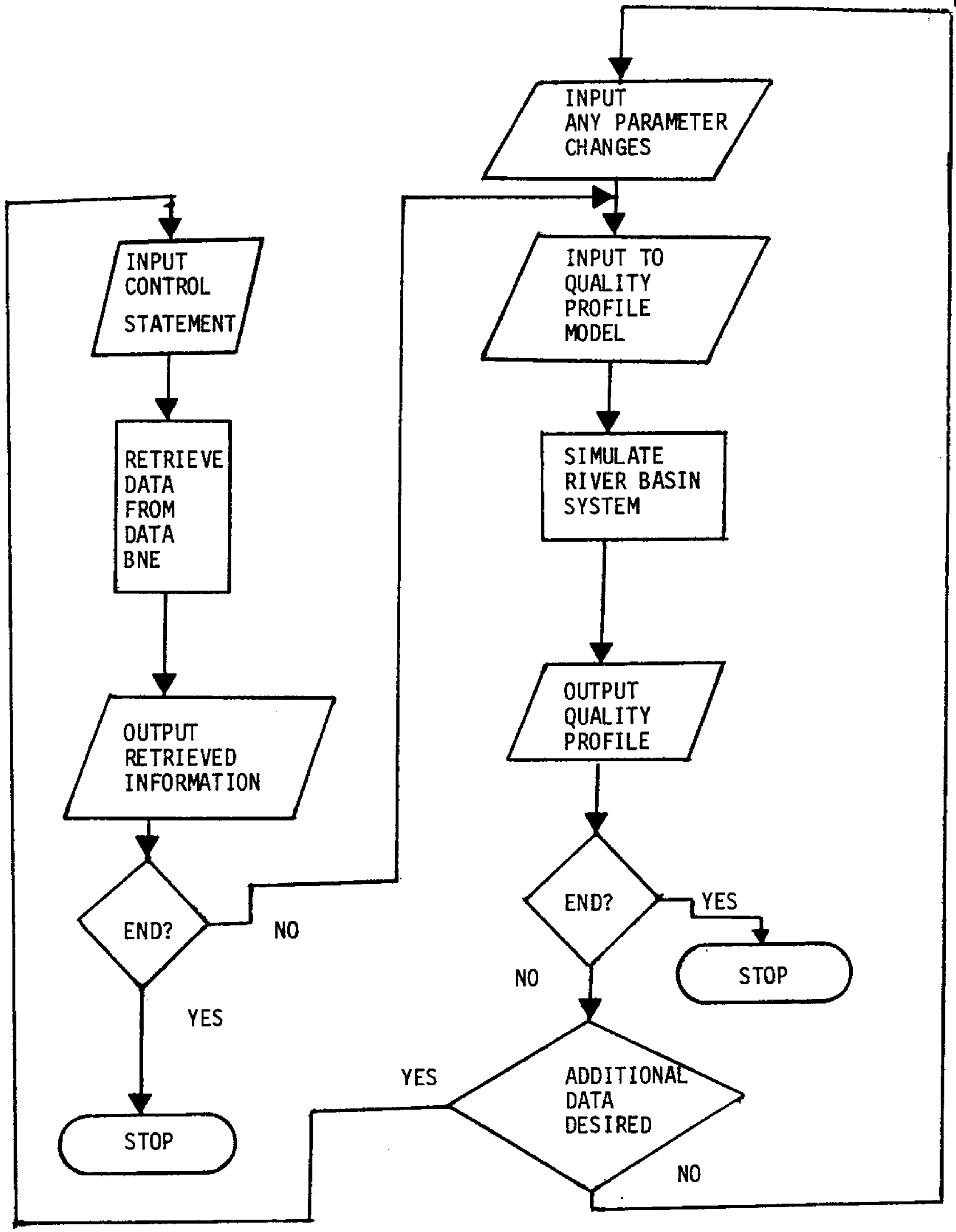


FIGURE 4-11 MACRO CHART

PART III

Reliability Analysis for Regional Water Quality Management

CHAPTER V

Reliability Analysis for Regional Water Quality Management

The development of techniques leading to the reduction of liability of pollution to our waterways has been considered as the major commitment of all elements of this society for this decade. The effective preservation and utilization of good quality water has also been recognized as an absolute necessity for the survial of mankind. The population explosion along with man's tendency to pollute water resources has added extra dimensions of difficulty to managerial decision-making. There is, therefore, a great need to devise a methodology for the assessment of uncertainty of goal achieving and control parameters variation for river basin quality management.

In establishing the managerial goals for an urban water quality management system, deterministic criteria are always employed. However, the probabilistic nature of different parameters characterizing the urban water quality management are also well-recognized. Thus, the attainment of managerial goals must exhibit the characteristics of uncertainty. For example, the quantity and quality of a specific section of a river are usually regulated based on certain predetermined requirements and concerning components are designed and operated accordingly. As the initial quality for individual components changes randomly, the resultant quality will also deviate randomly from predetermined requirements. Thus, there is a certain fraction of time, in which the resultant water quality will not be satisfied. But,

a) How can this uncertainty be assessed?

b) To what degree should this uncertainty be incorporated in legal regulations and managerial goals?

c) What type of economic trade-off relationships will be exhibited due to this uncertainty?

d) What are the optimum policies concerning this uncertainty in terms of effectiveness for water quality management?

e) What will be the practical and adaptive methods for the managers and laymen to determine optimal policies in terms of effective water quality management?

This paper is not attempting to present the answers for all these questions, but to suggest a parameter, reliability, and initiation of an attack on these problems.

BASIC CONCEPTS

Reliability is defined herein as the measure of effectiveness for the attainment of specific managerial goals in water quality preservation, i.e. the probability that the quality standard may be satisfied, and the percentage of time that a treatment facility is operated above the expected efficiency, etc. Variability of the water quality of streams receiving return flows has often been blamed as the cause of surprising or disheartening results in regional water quality management. Besides the qualitative and quantitative fluctuations occuring in urban runoff, a large fraction of the water quality variability of streams is attributed to the quality variations of return flows, especially when the fresh water inflow is insignificant. Thus, the established managerial goals based on deterministic criteria become either inadequate or too simplistic to handle the probabilistic nature of regional water quality. Reliability analysis is therefore suggested for the assessment of the uncertainty associated with the performance of goal achieving on regional water quality management.

The objective of this paper is to present the concept of reliability and an optimization model developed for the analysis of optimal regional water quality management with uncertainty. The criteria utilized in the systems optimization is to minimize the total costs required to operate the major water pollution control facilities. The variability of each treatment facility is characterized by a normally distributed random variable whereas the quality standard and reliability requirement are represented by a chance-constraint. Using the newly developed chance-constrained quadratic programming method coupled with parametric analysis, a solution approach for the model is devised. A case study based on the actual situation and problems encountered in the San Antonio River Basin is investigated. With the results of sensitivity analysis, the implication due to reliability concepts on practical water quality management problems is discussed.

Through the decade of the 1960s, system reliability has become increasingly important in the design and implementation of industrial and military systems. During World War II, the importance of reliability was emphasized by analyzing the consequences of unreliability of the military equipment. In both the industrial and domestic applications, reliability is closely associated with preference and acceptance of the individual product.

Unreliability normally generates consequences in cost, manpower, and inconvenience; and thus, in pollution abatement, the degradation of the environmental quality must be added. In industrial applications, the requirement of reliability may differ from one system to another, even for the same product. An excellent example is the transistor whose reliability in a ballistic missile is tenfold or more than required for a portable radio. This same analogy may readily be drawn for wastewater treatment; to operate treatment facilities at different levels of reliability corresponding to different receiving stream conditions, influent quality, or even seasons of the year.

The specific causes of unreliability are numerous but the heart of the problem lies in the dynamic complexity of systems concurrent with budgetary restrictions. The complexity of system reliability lies in the problem of system component or subsystem reliability which, when coupled together, must operate at an acceptable level. Consideration must also be given to the complexity of the managerial organization whose duty is to oversee the successful operation of this system and consideration must also be given, of course, to the facilities of human error. In view of the regional water quality management agency, the concept of reliability can be used to an economic advantage by adjusting the system in terms of the requirements of overall water quality and operating individual facilities at optimum control levels to maintain the satisfactory stream quality at minimum costs. On the other hand, if the reliability of waste treatment facilities is not recognized and the total time average is the basis of the operations policy of individual facilities, some irreparable damage may result to the stream systems due to unsatisfactory operation for an extended period of time. Therefore, this concept of reliability applied to treatment facilities as well as to river basin systems must be emphasized. The economic gain due to the water quality criteria and reliability can thus be identified.

It has been reported in literature (124, 125, 108) that the performance of water pollution control facilities often exhibits seasonal or random oscillation with time. This oscillation is an indication of the failure to meet specific pollution control objectives a percentage of the time. Reliability, then, is a measure of the percentage of time of satisfactory operation of a pollution control facility. Basically, the reliability of a water pollution control plant depends upon the variability of process efficiency and is affected by the performance of equipment, plant design, degree of automation, ability of operators, and attitudes of management and plant maintenance. It has been found that the reliability of a waste treatment facility may be closely associated with the size of the plant. This may be explained by the fact that larger plants normally have better trained operators, more standby equipment, higher degrees of automation, and superior process and engineering design (106). Therefore, in order to handle the random nature of wastewater characteristics and the performance of pollution control processes, system optimization must be performed in conjunction with some type of stochastic analysis.

Numerous probabilistic methodologies have been developed based on linear, non-linear, and dynamic programming techniques (26, 36, 59). Most of these, however, have emphasized the influence of hydrologic risk or managerial policies. Few have included the interaction between water quality and water quantity (6). Some models have been developed for total water quality and quantity, but these are designed for deterministic variables only (109).

Loucks (68) presented a variety of stochastic linear, non-linear, and dynamic programming methods for the preliminary selection of alternative system design and operating policies. Water quality control by wastewater treatment and flow augmentation was examined, and hydrologic risk is again emphasized. Loucks (64) also investigated a probabilistic approach to stream quality standards. In addition, he developed a Markov model (67) to examine the risk evaluation in sewage plant design. The model was developed to predict the probability of having less than some specified dissolved oxygen concentration downstream from a waste treatment plant. Thayer and Krutchkoff (121) presented a stochastic model for pollution and dissolved oxygen in streams. Given stream parameters and initial conditions, the model predicted the mean amounts of pollutants and dissolved oxygen at any point downstream.

Although these and many other approaches have included probabilistic analytical procedures, none have applied the technique of stochastic programming. The analytical solution approach based on the chance-constraint programming technique seems readily adaptable and preferable to the problem of water quality management. The chance-constrained programming method was originated by Charnes (16) with extensions and refinements by Hillier (53). The general solution technique for stochastic quadratic programming utilized herein is innovated by Curry and Rice (24).

Chance-Constrained Quadratic Programming

A chance-constrained programming problem is one in which certain constraints have probabilistic coefficients. Since these parameters are not explicitly known, it may be unrealistic to require that these constraints be satisfied all of the time. Instead, it will be sufficient to specify some reliability that these constraints are satisfied. Thus, each stochastic constraint is written in terms of a probability statement for its satisfaction. This statement takes the form:

$$P \{\sum_{j=1}^{n} a_{ij}x_j \leq b_i\} \geq \alpha_i$$

where α_i is the probability that the ith constraint is satisfied, and the a_{ij} coefficients are independent and normally distributed random variables with known means and variances.

The problem of reliability optimization for regional water quality management consists of minimizing a convex quadratic objective function subject to a set of linear constraints. One of these constraints is a chance-constraint. Thus, the general problem can be formulated as:

(1) minimize $\underline{cx} + \underline{x}^T\underline{Dx}$

subject to:

(2) $\sum_{j=1}^{n} a_{ij}x_j \leq b_i \quad i = 1,\cdots,m$

(3) $\underline{x} \geq \underline{o}$

and for some i

(4) $P\ \{\sum_j a_{ij}x_j \leq b_i\} \geq \alpha$.

The first step in solving this problem is to convert the chance-constrainted equation (4), to a deterministic equivalent. This is accomplished by obtaining the distribution of the random variable $\gamma = \sum_{j=1}^{n} a_{ij}x_j$ where the x_j's are considered as parameters. The random variable γ is normally distributed with a mean,

$$E[\gamma] = \sum_{j=1}^{n} E[a_{ij}]\ x_j$$

and variance,

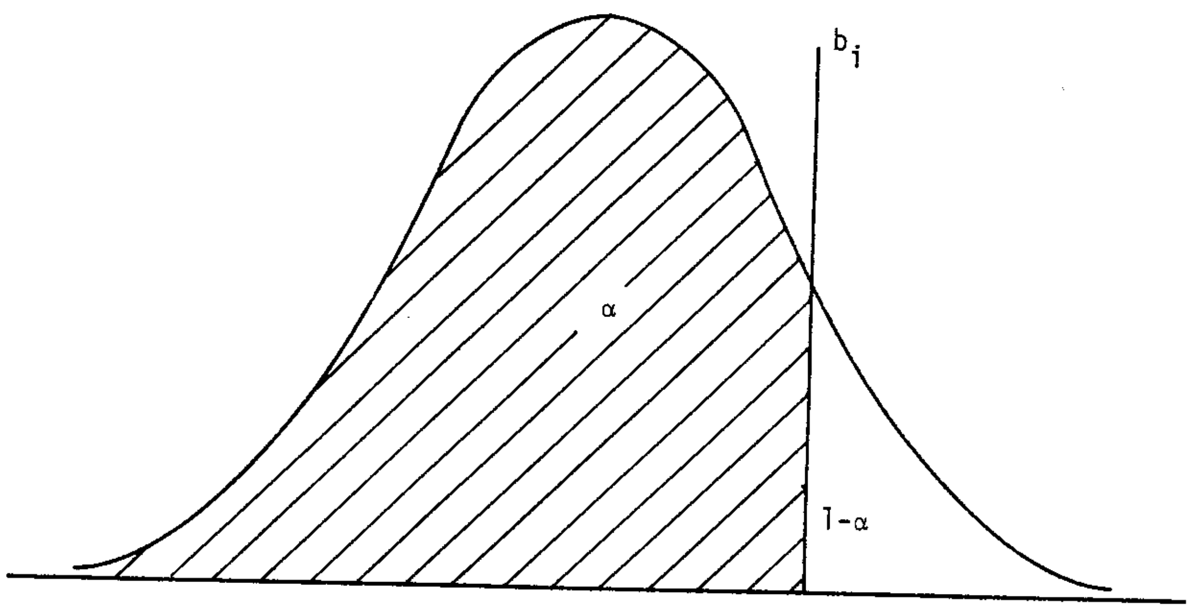
$$\alpha^2[\gamma] = \sum_{j=1}^{n} \alpha^2[a_{ij}]\ x_j^2\ .$$

Since b_i is a constant, the chance-constraint is satisfied 100α percentage of the time if the distribution of γ is such that area under the curve from $-\infty$ to b_i is less than or equal to α. This is picturally represented in Figure 5-1

The distribution of the random variable γ is a function of the decision variables $\underline{x}$. Thus, the variables must be chosen such that,

(5) $$\sum_{j=1}^{n} E[a_{ij}]\ x_j + k_\alpha \sum_{j=1}^{n} \sigma_j^2[a_{ij}]x_j^2\ {}^{1/2} \leq b_i\ ,$$

and k_α is the number of standardized normal deviations associated with the confidence limit α. The problem now becomes one of minimizing equation (1) subject to constraints (2), (3) and (5).



Area Under Curve to Left of b_i is Less Than α.

Figure 5-1

The deterministic equivalent problem is a nonlinear constraint problem. One approach to solving this problem is to use the procedure developed by Hillier (53). In this approach an approximation to constraint (5) is utilized and then the problem is solved by separable convex programming. However, this procedure is only good for the quadratic problem if there are no interproduct terms in the matrix $\underline{D}$. Also, linear approximations are made to the objective function and the chance-constraint. This greatly increases the number of variables in the problem.

Another solution technique and the one being utilized for the solution of the problem discussed in this paper is that of Curry and Rice(24). This procedure consists of first solving equations (1), (2), (3) and (6) parametrically for all feasible values of θ, where θ is an arbitrary number varying from zero to plus infinity.

(6) $$\sum_{j=1}^{n} E[a_{ij}]\ x_j \leq b_i - \theta$$

The parametric solution $\underline{x}^*(\theta)$ is thus a function of θ and can be readily obtained by an extension of Wolfe's(134) procedure designed for parametric analysis of the objective function in quadratic programming.

The original problem is then solved by setting,

(7) $$\theta^2 = k_\alpha^2 \sum_{j=1}^{n} \sigma_j^2\ [a_{ij}]\ [x_j^*\ (\theta)]^2$$

and solving equation (7) for the smallest value of θ which satisfies it. The sensitivity of the solution to the chance-constraint can also readily be studied without reiteration for $\underline{x}^*(\theta)$ by merely resolving equation (7) for various values of k_α and lower limits on θ.

Model Formulation

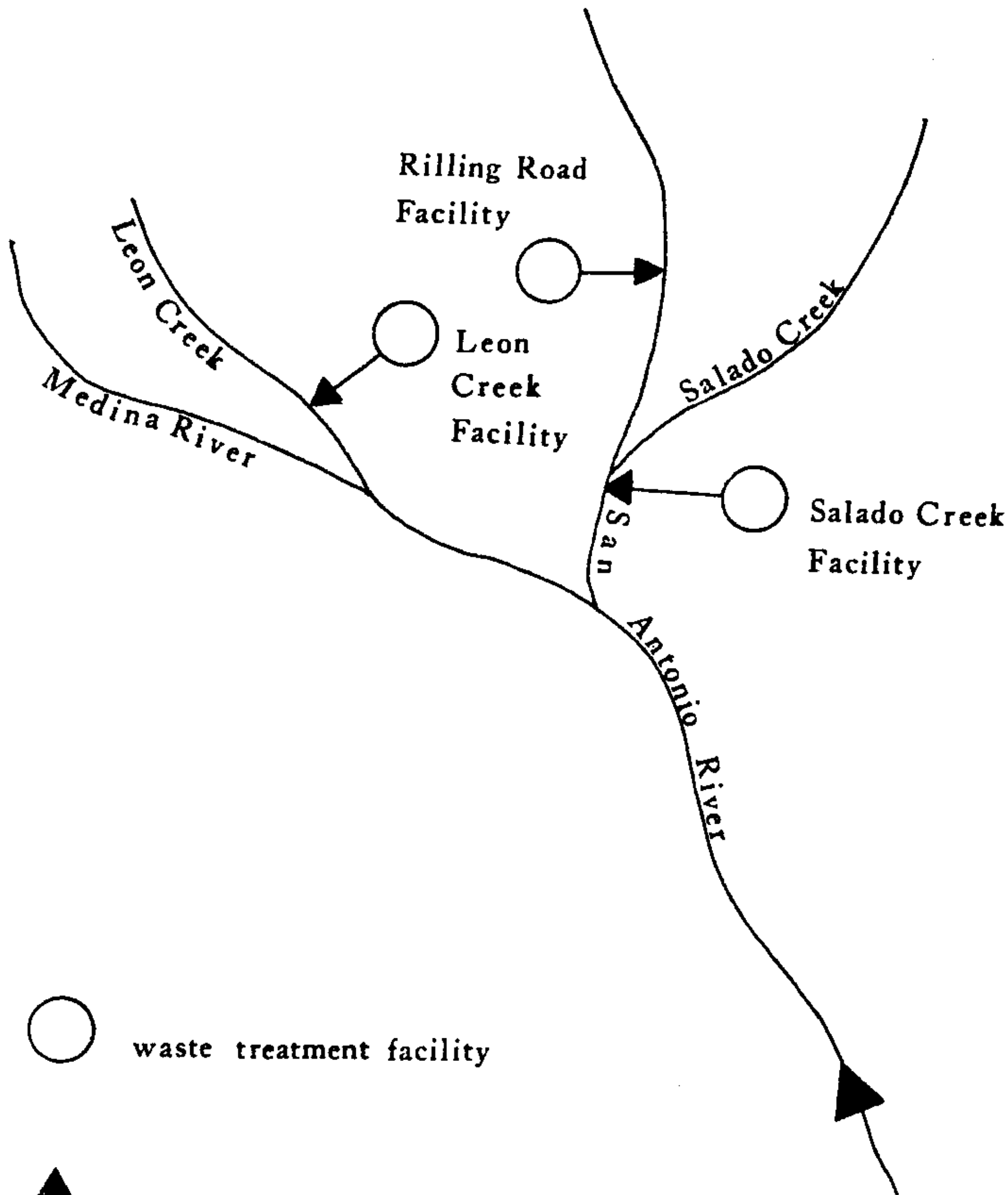
The regional waste treatment system to which the quadratic chance-constrained programming method will be applied is the San Antonio River Basin, Texas. Figure (5-2) is a schematic diagram of the primary elements considered in the system.

The San Antonio River Basin is located in the southern portion of the State of Texas near the Gulf of Mexico. The metropolitan area of San Antonio is located within the basin and it is this area which is of primary interest. The three major treatment facilities of the San Antonio region are the Salado, Leon, and Rilling Road plants. Their permit capacities are shown below.

Plant	Flow
Rilling Road Waste treatment facility	94.0 MGD
Salado waste treatment facility	24.0 MGD
Leon Creek treatment facility	12.0 MGD
	130.0 MGD

Included in the system is a water quality sampling station located at Elemandorf (See Figure 5-2).The water quality of the basin must comply with the standards set forth by the Texas Water Quality Board. For this particular region the state requires that the water quality should not exceed 10 mg/l BOD.

The cost functions in terms of BOD removal for each of the three major pollution control facilities were found to be those shown below:



Primary Elements in the San Antonio River Basin Regional System.

Figure 5-2

Rilling Road:

$$C = w_1\ (4x_1^2 - 110\ x_1 + 17900)$$ and due to physical limitations $30 \geq x_1 \geq 10$.

Salado:

$$C = W_2\ (7x_2^2 - 480x_2 + 25100) \text{ and, } 30 \geq x_2 \geq 10.$$

Leon:

$$C = W_3\ (2x_3^2 - 20x_3 + 21050) \text{ and } 30 \geq x_3 \geq 5.$$

where:

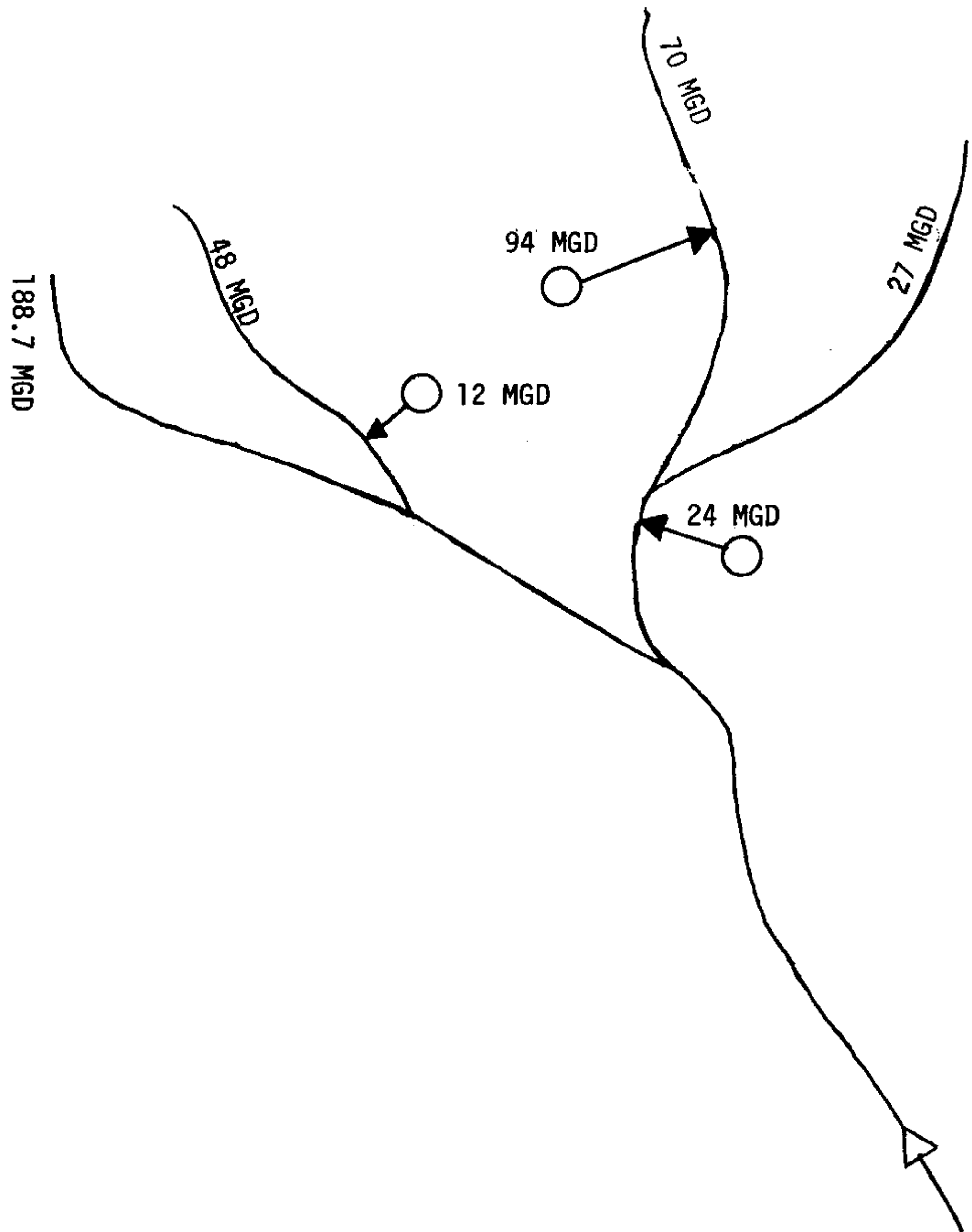
w_i = throughput of the ith treatment facility in MGD

x_i = effluent BOD of the ith treatment facility in mg/l.

The average stream flow above each waste treatment facility and other conference points in the system is as follows (See Figure 5-3)

Stream	Flow
San Antonio River	70 MGD
Salado Creek	27 MGD
Leon Creek	48 MGD
Medina River	188.7 MGD

Incorporating the dilution effects of stream runoff, the water quality at the downstream control point is thus limited to be less than or equal to some desired level of BOD set by the stream quality standard. Meanwhile, there remains, the inclusion of reliability of each waste treatment facility and its effects on quality managerial policies. Specifically, the reliability must also be considered in the constraint for quality management requirement. Though urban stream runoff may play a very important role in determining the reliability of



STREAM AND WASTE TREATMENT FLOW

FIGURE 5-3

stream water quantity, the quantity resulting from local drainage compared with that collected by combined sewer lines is insignificant for the area included in this study. However, the probabilistic nature of the urban storm runoff has been included in the computation for the reliability of individual wastewater treatment facilities. Therefore, in its final form, the quality management requirement constraint is,

$$P\left\{ \sum_{i=1}^{n} d_i \sum_{j=1}^{m} i\left(\frac{w_{ij}}{w_{ij}+f_{ij}}\right) x_{ij} r_{ij} f_{ij}\ (t_{ij}) \leq L_{max} \right\} \geq R$$

$i = 1,2 \; . \; . \; . \; . \; , n$

$j = 1,2 \; . \; . \; . \; . \; , m_i$

Where x_{ij} = target value of BOD concentrates in the treated - effluent of jth facility along the ith stream

r_{ij} = reliability of jth treatment facility along jth stream

d_i = dilution factor for the ith stream flow toward the flow at the control point

m_i = total number of wastewater treatment plants on jth stream

$g(t_{ij})$ = the BOD decay function of jth treated waste effluent in ith stream, while t_{ij} is the travel time to the control point

w_{ij} = flow rate of jth treated waste effluent on ith stream

f_{ij} = flow rate of ith stream upstream at the outfall of jth treated waste effluent

$f_i{}^o{}_j$ = fresh water inflow between jth and (j+1)th treated waste effluent

and $f_{ij} = f_{i(j+1)} + W_{i(j+1)} + f_i{}^o{}_j$

d_i may be a very perplexing term in its symbolic expressions because it depends upon the ith stream flow and the flow rate of the stream which the ith stream is discharging into, as well as the order of tributary of ith stream in the tree branches of streams systems. In general, d_i may be represented by Equation (2)

$$d_i = \prod_{k=1}^{p} \left(\frac{f_k}{f_k + f_m{}^k}\right) \quad (2)$$

$$f_i = f_{io} \quad (3)$$

$$f_{k+1} = f_m + \sum_{j=1}^{q} (f_{mj}^{0} + w_{mj}) \quad (4)$$

where

f_k = flow rate of the kth tributary at the confluence point with its main stream

$f_m{}^k$ = flow rate of the main stream at the confluence point with the kth tributary

p = the order of the tributary of ith stream

$f^o{}_{mj}$ = jth freshwater inflow between the kth and (k+1)th confluence points on (p-k)th order stream.

w_{mj} = jth treated waste effluent flow rate between kth (k+1)th confluence points, on the (p-k)th order stream

q = total number of reaches between kth and (k+1)th confluence points on the (p-k)th order stream.

The reliability of each pollution control facility is approximated by a normal distribution in the critical region. As an illustration of computing each r_i consider the Rilling Road facility. From collected data of effluent sampled over a period of time the cumulative distribution was computed. Based on this distribution, three key relationships relating to the efficiency and the reliability of the waste treatment facility were found as,

$$P(BOD_{eff} \leq 30) = .68$$

$$P(BOD_{eff} \leq 66) = .95$$

$$P(BOD_{eff} \leq .5) = .0042$$

where BOD_{eff} is the level of biochemical oxygen demand contained in the discharged effluent. The above distribution may readily be normalized with respect to the design target yielding,

$$P(r_1 \leq 1) = .68$$

$$P(r_1 \leq 2.2) = .95$$

$$P(r_1 \leq .5/30) = .0042$$

where r_1 is the ratio between the actual treatment efficiency and expected treatment efficiency. The $P(\gamma_1 \leq .5/30) = .0042$ may be disregarded as it begins to approach zero on the lower end of the distribution. Since the .95 level is 1.65σ and the .68 percent level is $.47\sigma$ the mean and standard deviation for the random variable r_1 which characterizes the performance of Rilling Road treatment facility were computed as,

$$\sigma = \frac{2.2 - 1}{1.65 - .47} = 1.0$$

$$\mu = 1 - (0.47)\sigma = .53.$$

Thus $r_1 \sim N(0.53,1.0)$. Using the above method the reliability of the other regional facilities were found to be,

$r_2 \sim N(0.225, 0.69)$, and

$r_3 \sim N(0.200, 0.5)$.

From the data presented above the problem can be formulated as follows:

$$\text{Min:} \quad C=376x_1^2 + 48x_2^2 + 84x_3^2 - 27260x_1 - 3600x_2 - 5760x_3 + 2880600$$

$$\text{S.T:} \quad \{0.10743789x_1r_1 + 0.0116455x_2r_2 + 0.0051758x_3r_3 \leq q\} \geq R$$

$$10 \leq x_1 \leq 30$$

$$10 \leq x_2 \leq 30$$

$$5 \leq x_3 \leq 30$$

where q = water quality criteria in terms of BOD desired, and

R = probability that the constraint will not be violated, i.e., reliability of the Regional Water Quality control system.

The above problem was solved for different combinations of R and q. For each R considered, q was initially set at 10 mg/l and reduced to a minimum value of 2 mg/l. These results are shown below in Tables 5-1 through 5-5.

Analysis of Results

Tables 5-1 through 5-5 indicate, as would be expected, that as the reliability of the system increases, the cost also increases. This relationship may also be realized from Figure 5-4. It was found that the optimum operating cost for the regional system is increasing at an accelerated rate with the improvement of reliability at each level of water quality criteria desired. Generally, the effects of water quality requirements on the

Table 5-1: Optimal Management Policies and Associated Costs
System Reliability = .80

quality Criteria q BOD mg/1	Total Cost C (dollars)	Effluent discharge policy (BOD mg/1)		
		Rilling Road facility x_1	Salado facility x_2	Leon Creek facility x_3
10	2,239,200	30.0	30.0	30.0
8	2,239,200	30.0	30.0	30.0
6	2,297,652	22.7	25.9	30.0
4	2,411,478	14.8	19.3	29.7
3	2,487,989	10.8	15.9	28.8
2*	-	-	-	-

* Constraint violated, no feasiable solution

Table 5-2 Optimal Management Policies and Associated Costs
System Reliability = :85

quality Criteria q BOD mg/l	Total Cost C (dollars)	Effluent discharge policy (BOD mg/l)		
		Rilling Road facility x_1	Salado facility x_2	Leon Creek facility x_3
10	2,239,200	30.0	30.0	30.0
8	2,258,462	26.8	29.5	30.0
6	2,331,892	19.9	23.6	30.0
4	2,445,218	12.9	17.7	29.3
3	2,544,294	10.0	10.0	15.8
2*	-	-	-	-

* Constraint violated, no feasiable solution

Table 5-3:Optimal Management Policies and Associated Costs
System Reliability = .90

quality Criteria q BOD mg/l	Total Cost C (dollars)	Effluent discharge policy (BOD mg/l)		
		Rilling Road facility x_1	Salado facility x_2	Leon Creek facility x_3
10	2,240,844	29.7	30.0	30.0
8	2,288,446	23.5	26.7	30.0
6	2,367,283	17.4	21.5	30.0
4	2,477,247	11.4	16.4	28.9
3*	-	-	-	-
2*	-	-	-	-

* Constraint violated, no feasible solution

Table 5-4: Optimal Management Policies and Associated Costs
System Reliability = .95

quality Criteria	Total Cost	Effluent discharge policy (BOD mg/l)		
		Rilling Road facility	Salado facility	Leon Creek facility
q BOD mg/l +	C (dollars)	x_1	x_2	x_3
10	2,273,964	24.9	27.9	30.0
8	2,332,363	19.8	23.6	30.0
6	2,412,804	14.7	19.2	29.6
4	2,550,670	10.0	10.0	13.8
3*	-	-	-	-
2*	-	-	-	-

* Constraint violated, no solution

Table 5-5: Optimal Management Policies and Associated Costs
System Reliability = .99

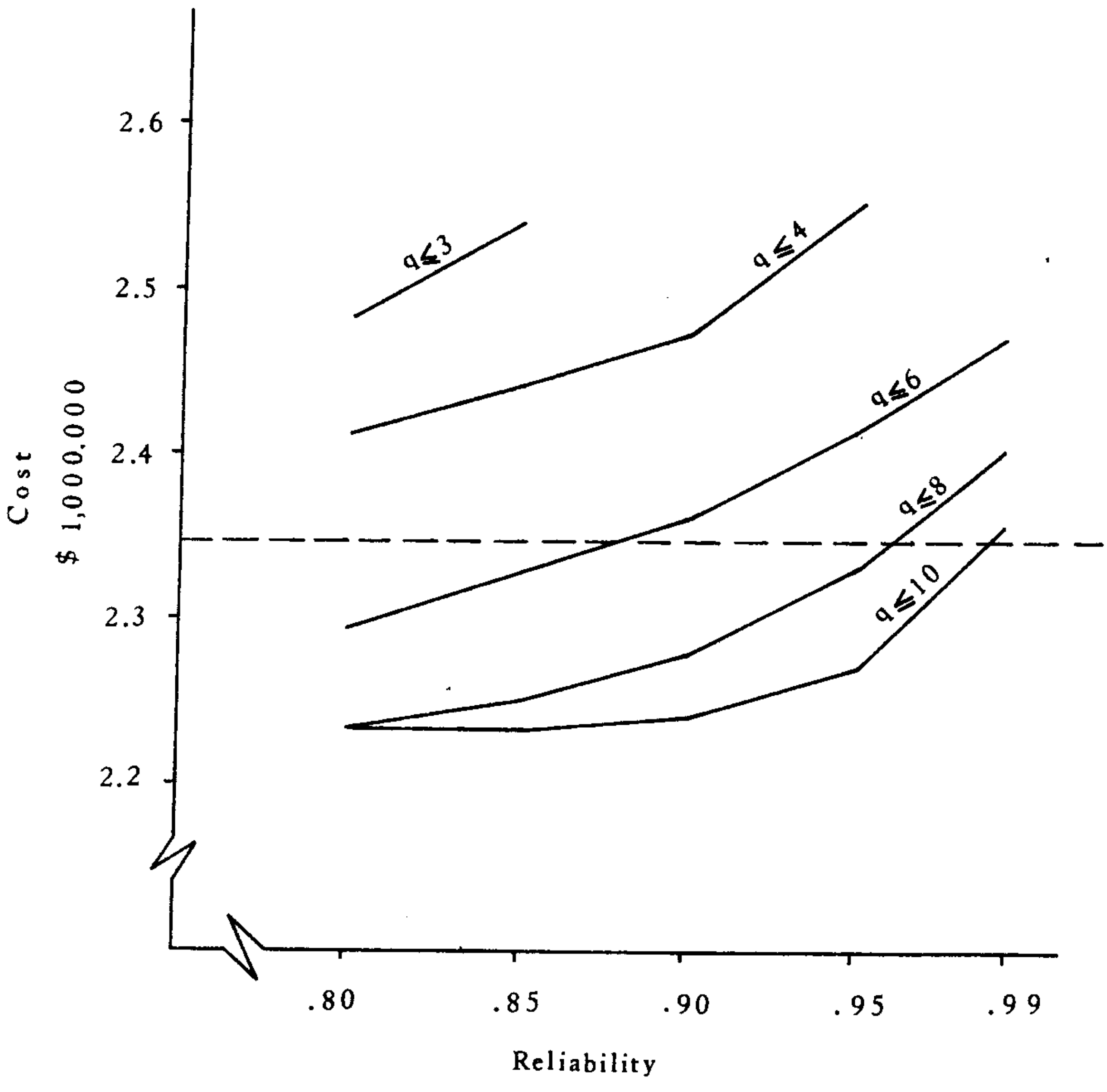
quality Criteria	Total Cost	Effluent discharge policy (BOD mg/l)		
		Rilling Road facility	Salado facility	Leon Creek facility
q BOD mg/l	C (dollars)	x_1	x_2	x_3
10	2,339,313	19.3	23.1	30.0
8	2,401,396	15.3	19.8	29.8
6	2,477,081	11.4	16.4	28.9
4*	-	-	-	-
3*	-	-	-	-
2*	-	-	-	-

* Constraint violated, no feasible solution

rate of change is insignificant, especially at the upper range of reliability. It was also found that there are no feasible solutions when the water quality criteria becomes too tight, (i.e. BOD concentration in stream water lower than that 3 mg/l and the reliability requirements higher than 0.85). As indicated by Figure 5-4, the cost curves are near parallel and the difference resulting from the tightening of the water quality criteria is also increasing at an accelerated rate.

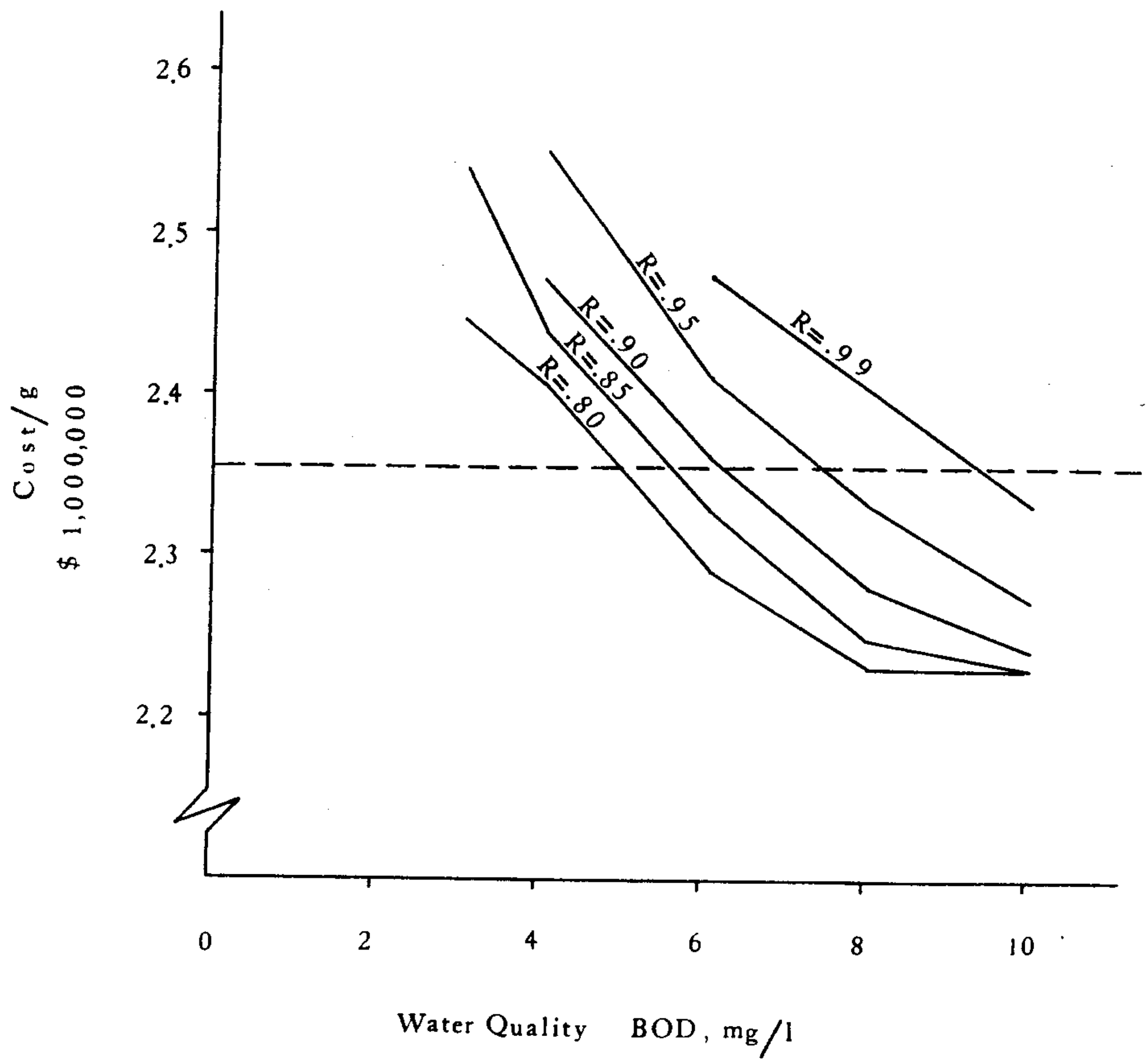
If it is assumed that an annual budget for the regional system be allocated to $2,350,000, various managerial operating policies could be conceived from the relationships demonstrated in Figure 5-4. The dash line on Figure 5-4 represents this hypothetical budget line, thus it can be realized that the system can maintain the stream water quality to such a level that the BOD concentration in stream water at a central point is equal to or less than 10 mg/l and the reliability is at 0.99. Meanwhile, the same cost will also achieve such a water quality managerial goal that the BOD concentration in stream water is equal or less than 8 mg/l and the reliability is about 0.96. However, during certain periods of the year, seasonal variations in both influent quality and receiving stream conditions would dictate a higher quality of effluent be produced. There is, then, a tradeoff between producing a better effluent but at a lower reliability. Therefore, as the need arises for better effluent, a tradeoff between water quality and reliability must be recognized if there is no budgeting change for the operation of the system.

Figure 5-5 shows the water quality criteria and total cost relationship at different levels of reliability. It was found that the costs for optimum management policies will decrease with stream water quality requirements at the same approximate rate for all levels of reliability. There also appears



Reliability vs. Cost

Figure 5-4



Water Quality Criteria

vs.

Cost

Figure 5-5

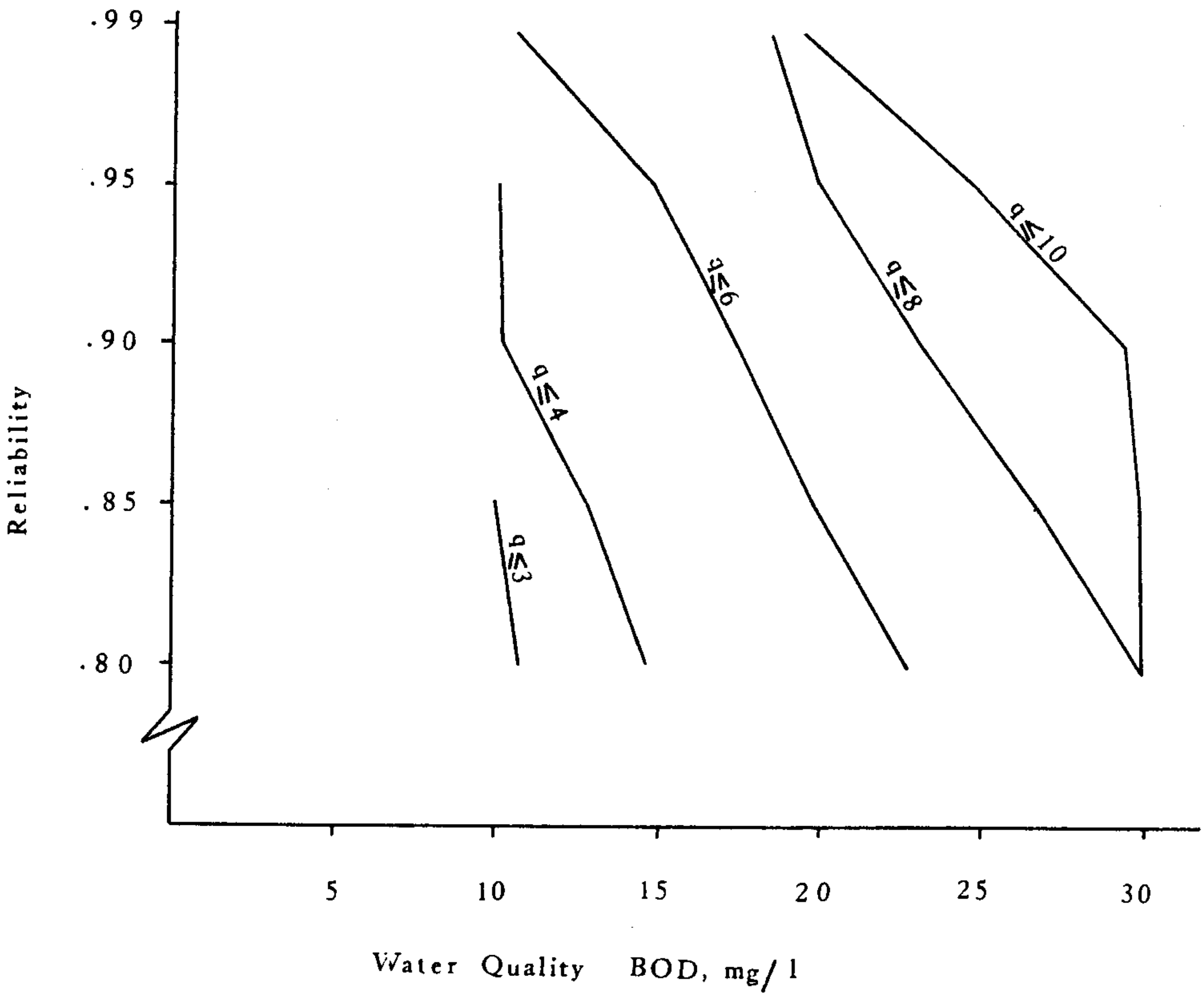
to be a proportional shift upwards as reliability is increased. Again a hypothetical budget line can be drawn at $2,350,000 per year to illustrate the possible tradeoffs between cost and desired water quality at various levels of system reliability.

Figures 5-6 through 5-8 show the optimal effluent level for each treatment plant in the system as it relates to total system reliability. The Rilling Road (x_1) facility is the largest and also the oldest of all the regional water pollution control facilities considered. The treated effluent of the Rilling Road plant is discharged into a stream of moderate flow so the flow augmentation process of improving water quality does not act in favor of the system. When the plant operates at its top performance level, the effluent centering 10 mg/l of BOD may be produced. However, the overall system reliability can only reach as high as 0.85 and 0.95 for the stream quality criteria of less than 3 mg/l and less than 4 mg/l of BOD, respectively, as shown in Figure 5-6. Since this facility discharges more than 70% of the total treated water to the system, the quality of its treated waste effluent affects the overall system reliability and the stream quality most significantly. In contrast, Figure 5-8 is for the Leon waste treatment facility which is the smallest and the newest of the three treatment plants. In addition, the effluent from the Leon treatment plant is discharged into a stream with higher fresh water inflow. Thus, the effects of the quality of the Leon plant effluent on overall stream quality are considerably dampened through the flow augmentation by the fresh water inflow in Leon Creek. Thus, the Leon facility may operate at a relaxed target level, i.e. 16 mg/l of BOD in the effluent, and still achieve the stream quality requirements of less than 3 mg/l and less than 4 mg/l with reliability of 0.85 and 0.95, respectively. Meanwhile, the Salado waste treatment facility,

Figure 5-7, is a medium-sized plant of moderate age and its reaction to change in the system constraint are also moderate, as expected.

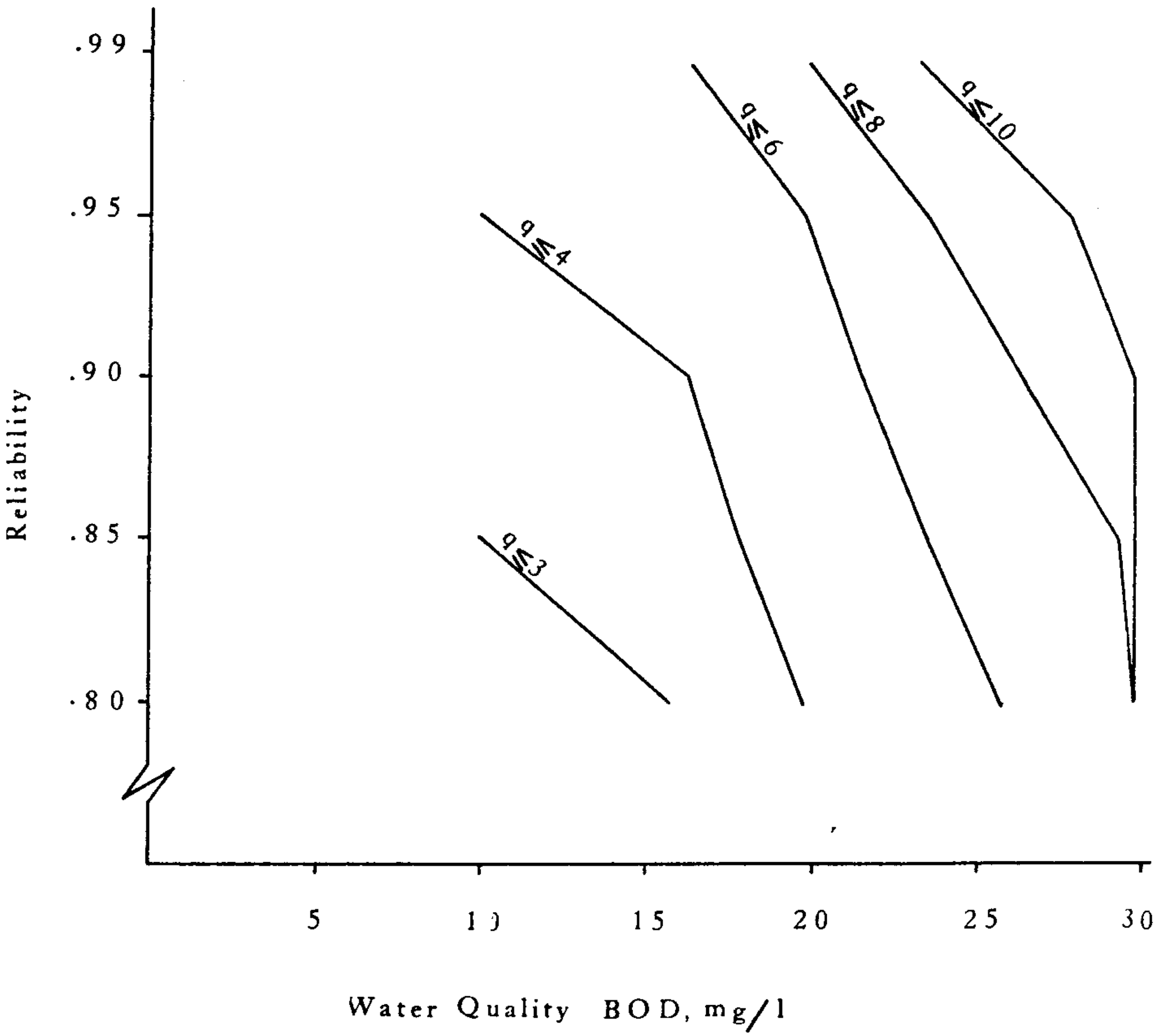
At a reliability level of 0.85 or lower and water quality criteria of 10 mg/l, the regional wastewater treatment facility in operation with minimum cost requirement produces the effluent containing 30 mg/l of BOD as cited in Figures 5-4, 5-6, 5-7, and 5-8. The same minimum total costs may be derived from a reliability of 0.80 and water quality criteria of less than 8 mg/l. If the reliability is increased to 0.90 with a water quality criteria of 10 mg/l BOD, only a slight cost increase will result since the constraint on Rilling Road facility becomes active while the other facilities may continue to operate at maximum allowable levels. Therefore, in the case that the water quality criteria is 10 mg/l (such as that required by the Texas Water Quality criteria), there would be only a slight economic gain to the regional management to operate the facilities at an overall reliability of less than 0.90 and none at all to reduce the reliability level below 0.85.

It is also evident that the Rilling Road facility is the most dominant and the most sensitive component in terms of system reliability of this regional water quality system. Thus, the quality control porgram for the Rilling Road plant must be more strict than that for the other plants in the overall regional water quality managerial system. By using this approach, an economic tradeoff among different facilities can also be estimated for optimum quality control policies under the constraint of meeting the reliability and stream water quality criteria set for a river basin. Furthermore, it can be realized that the uniform standard for effluent quality may not follow on an equitable basis in view of the impacts of different facilities on the reliability of regional water quality management.



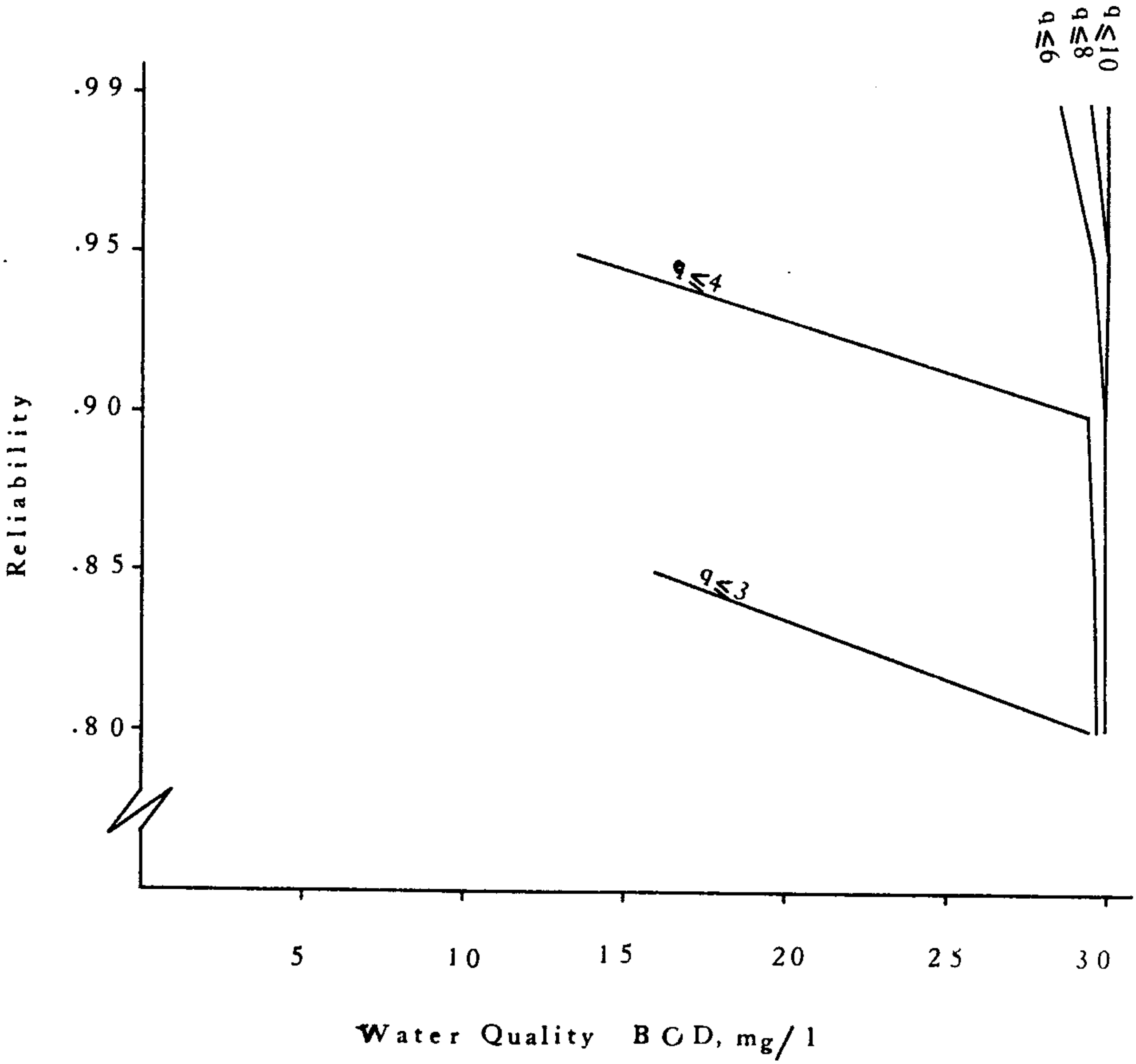
Optimal Treatment Policy of Rilling Road Plant (x_1)
vs.
Reliability

Figure 5-6



Optimal Treatment Policy of Salado Plant (x_2)
vs.
Reliability

Figure 5-7



Optimal Treatment Policy of Leon Creek Plant
vs.
Reliability

Figure 5-8

CHAPTER VI

Discussion

The problems concerning the urban water resources planning and management for the greater San Antonio area have been identified. It may be recognized that most of these problems are derived from the multiplicity of governing organizations, the decentralization of data and information, the over-simplification in quality standards controlling the surface water resources, and the lack of regulations protecting the groundwater resources.

Effective water quality-quantity management is realized to be highly dependent upon the availability and accessibility of the adequate objective information for accurate subjective decision analysis. The retrieval systems developed in this study will essentially solve most of the problems faced by water resource managers. With the utilization of a teletype processing service and a real time computer facility, the information retrieval programs developed in this study can readily be applied for urban water resources agencies. In San Antonio, the River Authority has applied the retrieval system to conduct the studies in water quality management and planning. Of course, only water quality and quantity information will by no means be sufficient to furnish the data base for the problems normally faced by urban or public affairs managers. The information concerning population, housing, education, socio-economic status, employment opportunities, and economic development as well as wealth distributions, etc. must be mapped together with all of the community utility services and the water resources information to form an integrated urban information and analysis system.
A study involving the integration of the U. S. 1970 Census data, the geographic information related to planning, and the water resources information has also been completed at Texas A&M University. It is anticipated that the

information mapping method based on X-Y planning grids may be a readily applicable information integration approach to serve the needs of future urban problems.

Subjective decision-making will eventually play a very important role in furthering the utilization of the objective information as well as complementing the intuitive approach for the practical manager. However, the availability of totally integrated, systematically, and statistically analyzed objective information will certainly improve the results of subjective decision-making. Also, with the objective analysis of historical trends, it will provide the concrete foundation for the projection of the future as well as the judgemental assessment of the uncertainties. Nevertheless, a sound information storage and retrieval system can always bring up-to-date the present status of urban water resources and bridge the gap between history of the past and the predictions of the future.

Meanwhile, the retrieval systems developed in this study are based on the STORET numbering system. As has been discussed, the STORET numbering system will not be limited by specific morphological patterns of the stream networks. With proper numbering assignments for each significant tributary, any river or stream system may become readily adaptable to the retrieval programs developed in this paper. Though the data organization in sequential form may consume some effort, in file organization, the enhancement of the efficiency for the retrieval of specific data or information will provide adequate justification. The sequential search technique has been used for this retrieval program, any other search technique such as binary research or block search methods may readily be substitutable with improvement of the search efficiency in the future.

However, the protection of the Edwards Aquifer is an urgent problem which will require immediate attention from a multi-disciplinary team and large amounts of resources. In addition to the studies concerning the institutional realignment, some immediately extensive research effort must be devoted to, but not limited to, the following investigations:

1. The analysis for socio-economic tradeoffs between urban development and the Edwards Groundwater Aquifer protection.
2. The accumulation and infiltration behavior of pollutants in the soil and limestone formation.
3. The hydrologic and hydrodynamic characteristics of the Edwards Aquifer.
4. The decision alternatives review and evaluation for the Edwards Aquifer utilization and augmentation.
5. The development of supplementary water resources for the San Antonio area.
6. The identification of legal requirements for the control of raw or treated wastes discharged over the Edwards Aquifer.
7. The legislative measures for the appropriate protection and conservation of groundwater resources.
8. The improvement of surface water quality for better utilization of the available resources in the San Antonio area.

Finally, it must be pointed out that the existing legal regulations pertaining to the Basin quality management are deficient in the sense of system reliability. Besides, there are often several separate agencies authorized to manage the water quality within a region. By their very nature, many water pollution control facilities in a region are often operating at conflicting goals and interests. Again, the analysis points out that the burden imposed on various treatment facilities based on uniform effluent quality requirements will result in an unequitable distribution economically. In general, a larger plant discharges more mass of pollutants into the receiving stream. In addition, a larger plant usually has a higher degree of automation and better trained personnel. The economic scaling effects thus will provide smaller incremental costs for larger plants in respect to the tightening of regional water quality criteria and reliability. Therefore, the water quality criteria outlined by regional standards must consider the realism of the probabilistic nature of water pollution control processes, and incorporate the concepts of reliability on future standard revisions. Besides, the water quality standards containing uniform criteria may also need some re-evaluation with regard to the equity of economic burden and the maintainability of specific overall regional water quality requirements.

The concept of system reliability as explained in this report should then be utilized by management as a decision-making device and also in the overall operation of the system. By using this type of analysis, both the economic considerations of the basin as well as the water quality standards may be examined in the light of optimum managerial goals.

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