HOW MUCH UNDERGROUND WATER STORAGE CAPACITY DOES TEXAS HAVE?[1]

by

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Abstract

Water imported into Texas under the Texas Water Plan must be stored in surface or underground reservoirs. The advantages of underground storage include: (1) an abundant supply of underground reservoirs located in the right areas, (2) the lack of surface reservoir sites in some areas, (3) a built-in distribution system, although this is limited by transmissibility in some aquifers, (4) more constant temperature of the water, and (5) elimination of evapotranspiration losses.

Ground-water levels are being drawn down heavily in many parts of Texas. This is causing a shift of much water from a surface- to a ground-water environment. Many springs which formerly flowed copiously,such as Comanche Springs, are now dry. The lowering water tables have resulted in a great reduction in wastage of water through evapotranspiration and spring and well flow. The trend is therefore considered to be in part beneficial.

The methods used in estimating the quantities of underground storage capacity available in Texas are discussed. An estimated 620 million acre-feet of storage capacity is now occupied by recoverable fresh and slightly saline ground water in the seven major, seven minor, and other aquifers discussed in this paper. Sixty-six percent of this quantity is found in two ground-water reservoirs: the Ogallala and Gulf Coast.

Dewatered storage capacity is estimated to be 85 million acre-feet, chiefly in the Ogallala Formation of the High Plains. Twenty-one percent of the Ogallala Formation has now been dewatered. In the opinion of the author, irrigation of cropland will essentially cease in an area when the remaining saturated thickness in the underlying reservoir is less than

30 feet. In some parts of the High Plains this will likely take place between 1970 and 1980.

The total underground storage capacity available is about 710 million acre-feet.

Some problems will be encountered in the use of dewatered underground storage capacity by artificial recharge. These include: (1) the low transmissibility of some aquifers, (2) compaction of aquifers when water is withdrawn, (3) air entrapment, and (4) clogging of aquifers with muddy recharge water. In spite of these difficulties, probably 60 to 70 percent of the dewatered storage capacity of Texas aquifers can be reused for ground-water storage. Most of this capacity is located where it can be used in conjunction with the Texas Water Plan.

The estimated 1968 ground-water use in Texas was 13.4 million acre-feet. Seventy-five percent of this was from the Ogallala ground-water reservoir. 1968 surface-water use was about 5.2 million acre-feet. Seventy-two percent of all water used in Texas in 1968 was ground water.

The estimated 710 million acre-feet of underground storage capacity does not include reservoirs of fresh and slightly saline ground water below 400 feet depth or the large reserves of more saline ground water. Neither does it consider the limitations of ground-water recharge, which reduce the effective capacity available for storage. The dewatered underground storage capacity of 85 million acre-feet compares with a total storage capacity of 103 million acre-feet for the 157 existing and 67 proposed major surface reservoirs of Texas.

Introduction

As the Texas Water Plan (1968) states, Texas does not have within its own boundaries enough water to meet its increasing requirements, and will pass from a water surplus area to a water shortage area by the year 2000. To compensate for this shortage the Texas Water Plan contemplates the importation of 12 to 13 million acre-feet of water annually. This water is essential to sustain the economy of West and South Texas, and to strengthen the agricultural and industrial base of the entire State.

If, as it appears, it will be desirable to import water during the spring season and to store it until it is needed, the question naturally arises: Should this water be stored in surface reservoirs or underground? The writer suggests that underground reservoirs should be used to the maximum possible extent for the storage of both imported water and treated sewage effluents. The advantages of underground water storage have been enumerated in many technical papers. To mention only a few:

1. Texas has been blessed with an abundant supply of underground storage reservoirs.
2. In many areas such as the High Plains, feasible surface reservoir sites are scarce.
3. Underground reservoirs have a built-in distribution system, although this is limited in some cases by the transmissibility of the aquifers.
4. Ground water is uniform in temperature.

5. Evaporation and transpiration losses are largely eliminated in underground storage. In the High Plains, for example, net evaporation averages 60 inches per year. At the present cost of water in this area ($20 per acre-foot), each square mile of surface reservoir loses $64,000 worth of water per year to evaporation.

This paper attempts to quantify all of Texas' underground storage capabilities. Texas' ground-water reservoirs are complex and varied. They range from unconsolidated sands to hard sandstones and cavernous limestones and gypsums. In age they span the period from Cambrian to Holocene. Some are artesian, some are unconfined, and others are both artesian and unconfined. Some contain enormous volumes of high-quality water and others are very limited in volume. Some, such as the cavernous Edwards (Balcones Fault Zone) reservoir, have the capability of distributing water quickly over large areas. Others such as the Trinity, because of their low transmissibility, could not be used for distribution. In the Trinity reservoir at Fort Worth, for example, low transmissibility and heavy pumping caused an artesian pressure decline of 770 feet from 1892 to 1954 (Leggat, 1957), and led to the abandonment of many wells. An attempt has been made in preparing this paper to include even relatively small ground-water reservoirs, in order to arrive at a more accurate estimate of Texas' total underground storage capability.

Ground-water levels are being drawn down excessively by heavy pumping in many parts of Texas. This is in part beneficial in that it reduces waste of water. Where mesquite and brush formerly used large amounts of water, the water table has in many cases lowered so that the ground-water reservoir is beyond the reach of such losses. As the ground-water reservoirs are developed to their fullest capacity, especially in arid West Texas, the base flow of many streams, and hence the surface water supply, will be reduced (Peckham, 1967). With declining water tables many streams which were formerly "effluent" are now "influent". Surface water which was formerly rejected as ground-water recharge is more and more being accepted.

Guyton (1957) has ably described this change, particularly with reference to the Carrizo-Wilcox and Edwards (Balcones Fault Zone) ground-water reservoirs. Banks (1967) advocates that this drawdown process be accelerated artificially in many cases in order to save large amounts of water which are now being wasted.

Many flowing springs and wells are gradually disappearing. An example is Comanche Springs at Fort Stockton (Figure 1). These springs, issuing from the Edwards-Trinity (Plateau) ground-water reservoir, formerly flowed as much as 48,000 acre-feet per year, and served the Comanche Indians for uncounted thousands of years. The springs were the basis for an irrigation district which irrigated 6,200 acres of cropland. Heavy pumping of the aquifer lowered the water table so that the spring discharge began to fall off in May 1947 (U.S. Bureau of Reclamation, 1956). By March, 1961, the flow had entirely ceased. [1/]

In the author's opinion, the net result is that increasing quantities of water in Texas are shifting from a surface- to a ground-water environment. The indications are that long-term past surface-water records are often not indicative of surface-water quantities that will be available in the future. This changing picture should be kept in mind when deciding on the merits of surface as compared with underground storage.

[1/] This is also a good illustration of Texas ground-water law, which affirms that the surface landowner owns the underground water unless it can be shown that the source is a subterranean stream or stream underflow. This is usually very difficult to prove. The irrigation district sought an injunction in 1954 restraining pumping which interfered with the normal flow of Comanche Springs. The injunction was denied by the courts and the springs ceased to flow (Yarbrough, 1968).

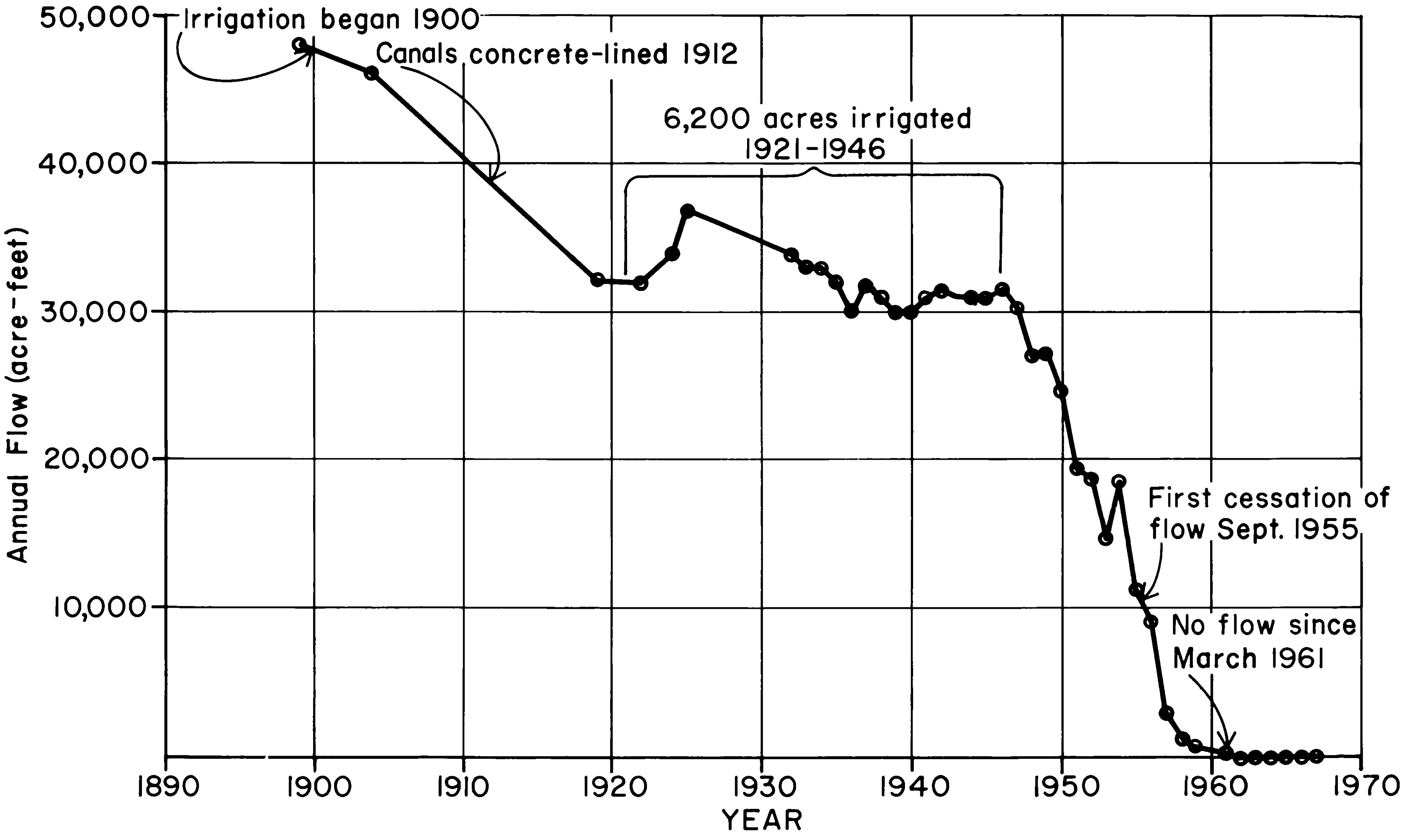

Figure 1

THE DEMISE OF COMANCHE SPRINGS, FORT STOCKTON, TEXAS

Admittedly, of course, there are legal problems as to the ownership and control of underground reservoirs which must be solved before these reservoirs can be used for artificial receipt, storage, and discharge of waters. We need to start thinking of ground water and underground reservoirs as a public resource rather than as private property.

Methods of Study and Findings

Figures 2 and 3 show the areal extent of the seven major and seven minor aquifers or ground-water reservoirs of Texas. Many of these aquifers extend into neighboring states. This paper is confined to the portions in Texas.

Only fresh and slightly saline ground water was considered. Winslow and Kister's general classification of water based upon dissolved solids content (1956) was used, which describes fresh and slightly saline water as having 3,000 milligrams per liter or less of dissolved solids.

The more saline waters were considered only insofar as they are reducing or threatening to reduce the aquifer capacities available to fresh and slightly saline ground water. For example, the Gulf Coast ground-water reservoir's capacity is being reduced in places by the intrusion of sea water because of heavy pumping. In the Salt Basin in West Texas the capacities of the Alluvium and the Victorio Peak ground-water reservoirs are being threatened by intrusion of salt water from beneath the Salt Lakes. In many areas in Texas, ground-water reservoir capacities are being reduced by careless oil-field brine disposal and defective casings. Open-pit disposal of oil-field brines is in general no longer permitted in Texas. However, much damage to ground-water quality and reservoir capacities continues to be caused by disposal pits constructed in the past. Admittedly an aquifer's capacity is not "destroyed" by salt-water intrusion, but the process of removing intruded salt water is usually long and expensive.

Figure 2

MAJOR AQUIFERS

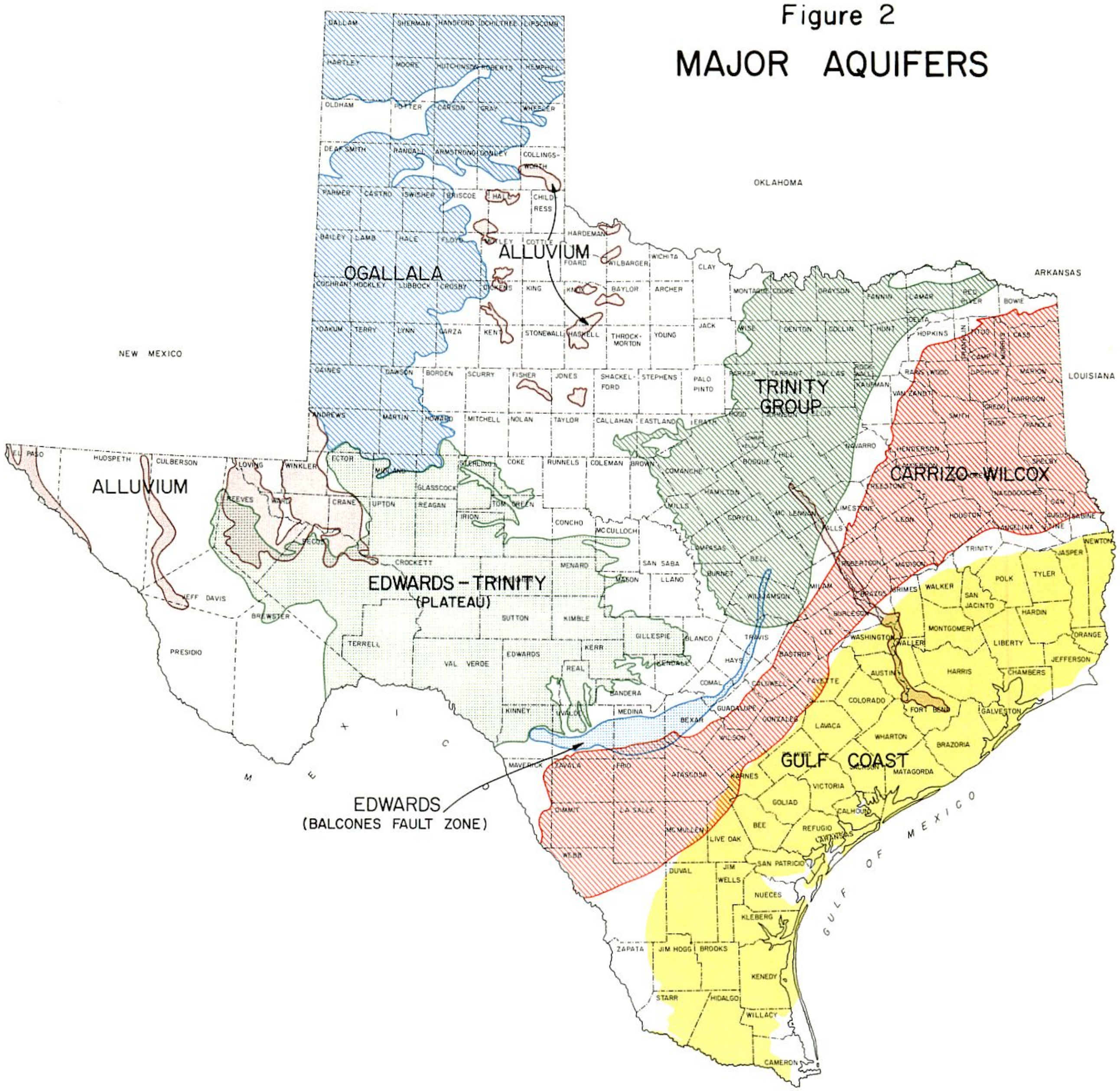

Figure 3

MINOR AQUIFERS

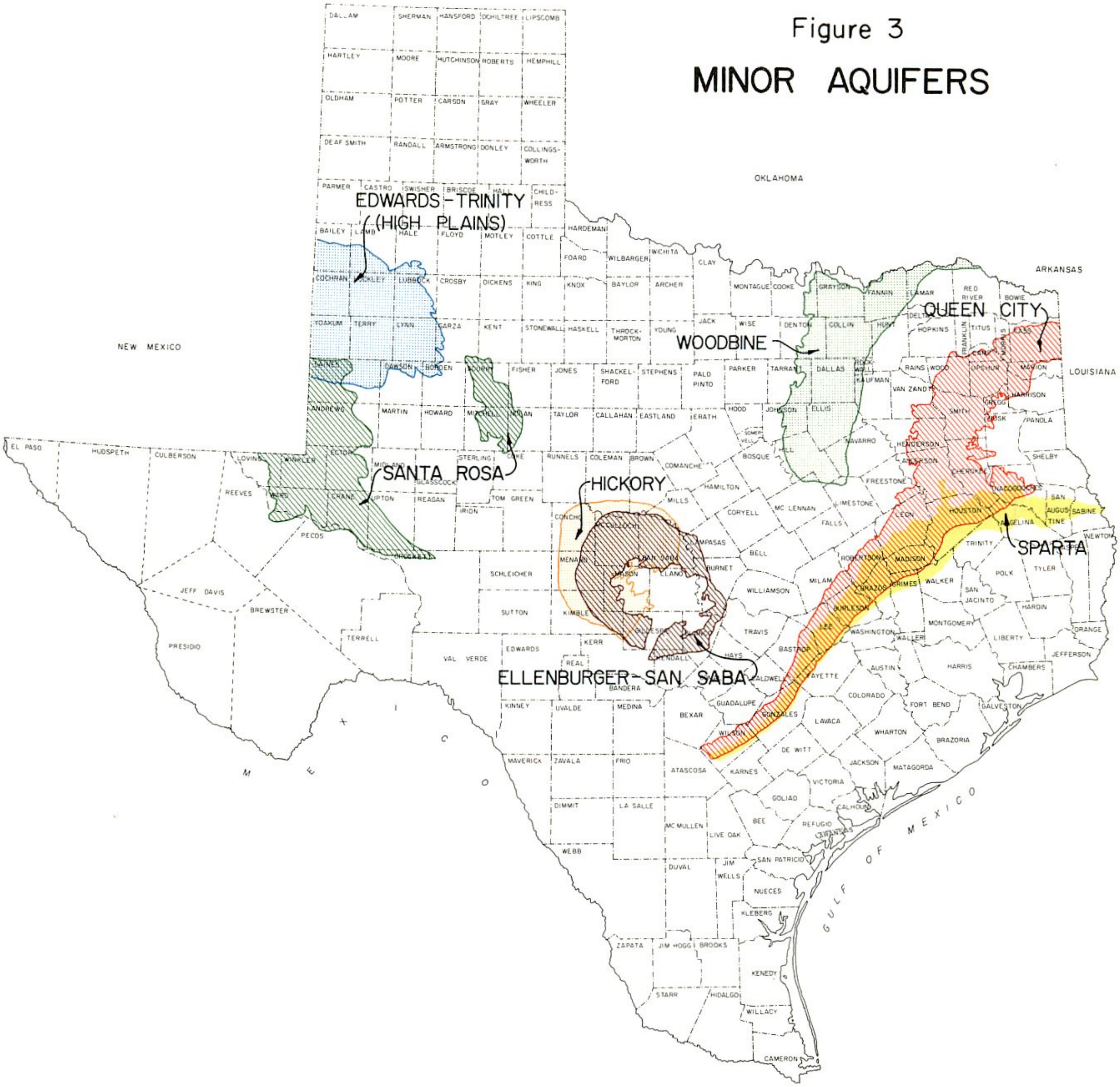

Table 1 describes the aquifers or ground-water reservoirs and gives the approximate characteristics which affect their use. Table 2 summarizes annual withdrawals of ground water, recharge, volumes of fresh and slightly saline ground water recoverable from storage, and dewatered storage capacity for each aquifer. The values have for the most part been rounded to two significant figures, because the basic data do not warrant greater accuracy.

A number of small aquifers have been combined under the heading "Other" in these tables. These include primarily the following:

Tertiary
    Lava flows and breccias
Eocene
    Jackson Group
    Yegua Formation
    Cook Mountain Formation
    Reklaw Formation
Cretaceous
    Nacatosh Sand
    Blossom Sand
    Austin Chalk
    Purgatoire-Dakota Sandstone
Permian
    Rustler Formation
    Delaware Mountain Formation
    Victorio Peak Limestone
    Bone Spring Limestone
    Blaine Gypsum

Table 1

APPROXIMATE CHARACTERISTICS OF TEXAS GROUND-WATER RESERVOIRS

1	2	3	4	5	6	7	8	9	10	11	12
			Area (Thousands of Square Miles)					Dip			
Ground-Water Reservoir	Age	Material	Outcrop	Downdip	Total	Average Present Thickness of Saturated Reservoir (Feet)	Greatest Depth of Fresh and Slightly Saline Water (Feet)	Slope (Ft/mile)	Direction	Permeability Gallons/Day/Sq/Ft)	Transmissibility (Gallons/Day/Ft)
					MAJOR RESERVOIRS						
Ogallala	Pliocene	Sand, gravel	35		35	140	900			170	30,000
Alluvium	Pliocene-Holocene	Sand, gravel, silt	9.6		9.6	390	1,600			170	67,000
Edwards-Trinity (Plateau)	Cretaceous	Vugular limestone, sand	34		34	250	3,000	35	SE	1/	1/
Edwards (Balcones Fault Zone)	Cretaceous	Cavernous limestone	0.1	2.2	2.3	500	2,500	30	SE	1/	1/
Trinity Group	Cretaceous	Sand, gravel	6.2	19	25	350	4,000	60	SE	31	11,000
Carrizo-Wilcox	Eocene	Sand	11	25	36	790	4,500	75	SE	48	38,000
Gulf Coast	Oligocene-Pleistocene	Sand	44		44	550	3,000	55	SE	140	79,000
					MINOR RESERVOIRS						
Woodbine	Cretaceous	Sand	1.5	5.9	7.4	250	2,400	65	SE	10	2,500
Queen City	Eocene	Sand	7.1	4.8	12	150	1,500	75	SE	55	8,300
Sparta	Eocene	Sand	1.6	4.5	6.1	100	2,000	80	SE	230	23,000
Edwards-Trinity (High Plains)	Cretaceous	Sand, gravel, limestone	0.6	5.7	6.3	30	400	10	SE	1/	1/
Santa Rosa	Triassic	Sand, gravel	0.7	6.6	7.3	190	2,000	20	Various	74	14,000
Ellenburger-San Saba	Cambrian-Ordovician	Vugular Limestone, dolomite	1.1	4.0	5.1	600	3,000	100	Various	1/	1/
Hickory	Cambrian	Sandstone	0.28	4.9	5.2	125	4,700	100	Various	230	29,000
Other	Ordovician to Eocene	Sand, vugular limestone, gypsum, marl, chalk, lava flows, breccias	23	12	35	450	4,000	Various	Various	1/	1/

1/ Not applicable. All or partly turbulent flow in subterranean channels.

Table 2

ESTIMATED YIELDS AND STORAGE CAPACITIES OF TEXAS GROUND-WATER RESERVOIRS

1	2	3	4	5	6	7	8	9	10
Ground-Water Reservoir	Estimated 1968 Withdrawal 1/ (Thousands of Acre-Feet)	Annual Recharge 2/ (Inches)	(Thousands of Acre-Feet)	Estimated Net 1968 Loss of Stored Ground Water (Thousands of Acre-Feet)	Porosity (%)	Specific Yield (%)	Fresh and Slightly Saline Ground Water Recoverable from Storage (Millions of Acre-Feet)	Dewatered Storage Capacity (Millions of Acre-Feet)	Total Storage Capacity (Millions of Acre-Feet)
				MAJOR AQUIFERS					
Ogallala	9,800	2.0	3,800	6,000	30	15	280	75	360
Alluvium	870	0.5	270	600	30	16	81	10	91
Edwards-Trinity (Plateau)	230	0.4	650		2	1	12		12
Edwards (Balcones Fault Zone)	250	4.1 3/	500		3	2	9		9
Trinity Group	74	0.2	70	4	30	15	13	Trace	13
Carrizo-Wilcox	560	1.0	580		30	14	52		52
Gulf Coast	1,300	1.0	2,400		33	10	130		130
				MINOR AQUIFERS					
Woodbine	10	0.3	25		30	15	1		1
Queen City	5.2	0.1	25		30	15	8		8
Sparta	5.9	1.1	95		30	15	1		1
Edwards-Trinity (High Plains)	4.9	0.1	42		10	5	2		2
Santa Rosa	86	0.3	100		30	15	3		3
Ellenburger-San Saba	1.6	0.4	25		2	1	2		2
Hickory	12	3.0	45		20	10	1		1
Other	200	0.2	190	10	7	3	20	Trace	20
TOTAL	13,400		8,800	6,600			620	85	710

1/Excluding spring flow

2/Including irrigation deep percolation

3/Recharge is principally from surface streams which drain the area west of the outcrop, crossing the fault zone

Pennsylvanian

Marble Falls Limestone

Ordovician

Marathon Limestone

Transmissibility and permeability as well as annual rainfall were considered in estimating recharge rates. The transmissibility and permeability figures given in Table 1 are based chiefly on horizontal permeability. It was recognized that vertical permeability in the outcrop areas, where natural recharge takes place, may be much lower than the horizontal permeability. However, the hydraulic gradient may be much greater (often vertical) in the outcrop area as compared with the downdip area of artesian aquifers. This increased gradient counteracts the lower vertical permeability as compared with horizontal permeability.

It was also necessary to consider that the recharge area of some underground reservoirs is covered with material of low permeability. The Ogallala, for example, has an average transmissibility of about 30,000 gallons per day per foot. Its natural recharge capacity, however, is severely limited because it is mostly covered by clay and caliche.

In estimating the volumes of fresh and slightly saline ground water recoverable from storage (Table 2, Column 8), the following procedure was used. The outcrop area and average saturated thickness (Table 1, Columns 4 and 7) were used to compute the volume of saturated reservoir in the outcrop area. The volume of saturated reservoir was multiplied by the specific yield (Table 2, Column 7) to determine the quantity of ground water in storage.

This figure was further reduced by multiplying by the percent of that portion of the water in storage estimated to be recoverable. This percentage, which is based to a large extent upon judgment, was determined by considering three factors. These are:

1. The depth of the underground reservoir in the outcrop area. The percentage of fresh and slightly saline water which is within presently recoverable depths (usually 400 feet) was computed with the aid of geologic cross-sections through each reservoir.

2. The transmissibility of the aquifer. Low transmissibility requires wide spacing of wells, results in severe drawdown and high water tables between wells, and consequently limits the amount of ground water that is economically recoverable.

3. The portion of the ground-water reservoir which is fresh to slightly saline. For example, 50 percent of the water in the Blaine Gypsum reservoir contains more than 3,000 milligrams per liter of dissolved solids. Although this moderately saline water is used for irrigation, it was excluded from consideration in this paper. The use of this type of water may eventually build up such a concentration of salts that the land will no longer be usable for crops.

These three factors combined make up the recoverability factor, which was the final factor applied in arriving at the quantities of fresh and slightly saline water recoverable from storage (Table 2, Column 8).

The Ogallala (Figure 4) has been dewatered to a far greater extent (about 21 percent) than any other Texas ground-water reservoir. This is due to the accelerating pumpage of ground water for irrigation in the High Plains, and the very limited amount of natural recharge that can reach the reservoir. Its dewatered capacity was determined from Cronin's 1969 study. If a natural recharge of 5 percent of the precipitation and a deep percolation of 20 percent of the irrigation pumpage are assumed, the dewatered capacity of 75 million acre-feet shown in Figure 4 agrees closely with Cronin's data. Havens (1966) assumed 17 percent deep percolation from irrigation in adjoining Lea County, New Mexico. A small amount of underflow also enters the reservoir from

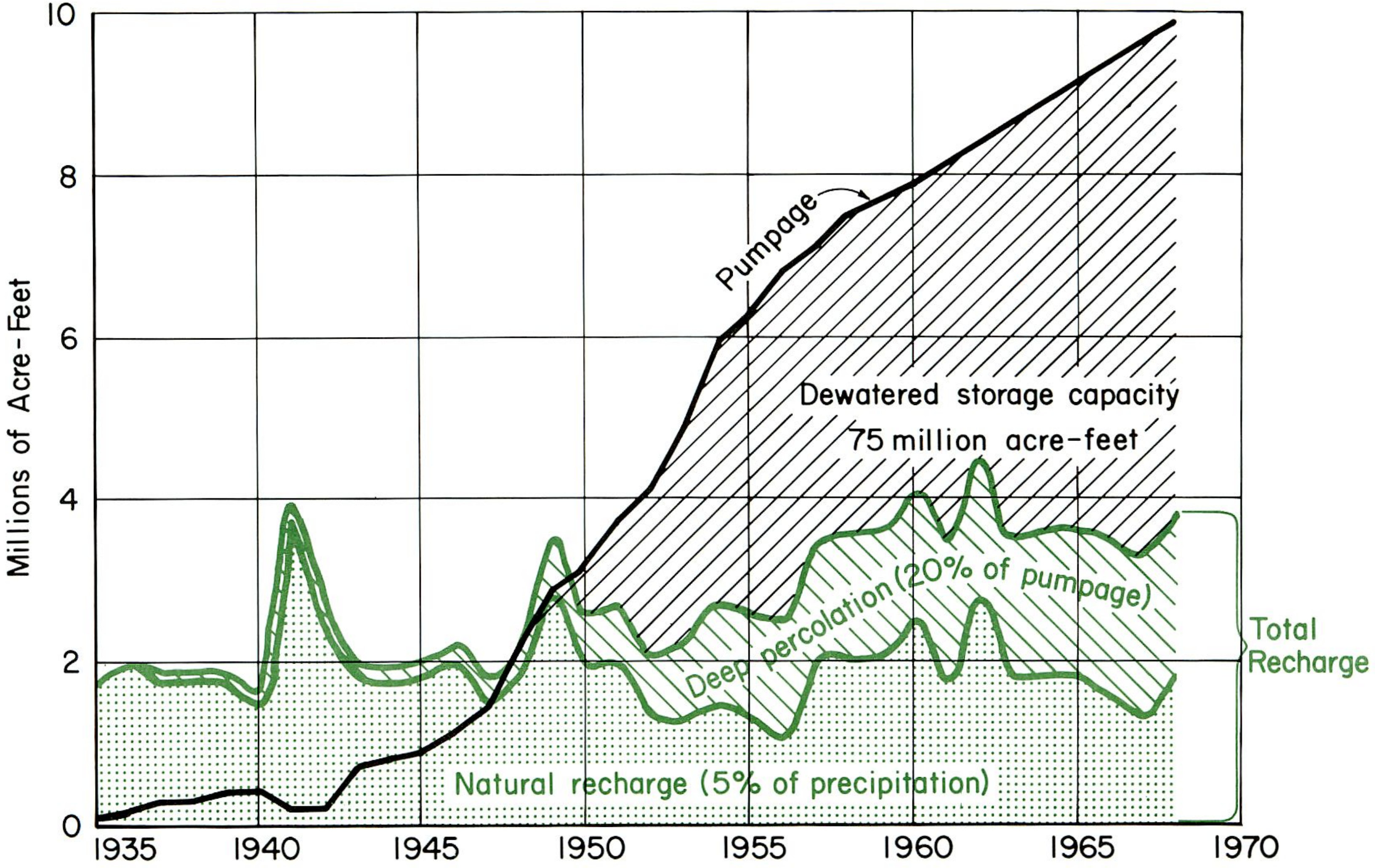

Figure 4

DEWATERING OF THE OGALLALA
GROUND-WATER RESERVOIR

New Mexico, and a small amount leaves it through seeps and springs along the High Plains escarpment or by downward flow into the underlying Permian and Triassic formations.

Irrigation has ceased because of lack of ground water in the Ogallala in portions of the High Plains of New Mexico. Many wells have had to be deepened and pumps reset in parts of the Texas High Plains because of declining water levels and yields. Figure 5 portrays the expected time periods when the saturated thickness of the Ogallala ground-water reservoir in the South High Plains will be reduced to 30 feet. This map is based upon data given by Cronin (1969) and the Twenty-Twenty Water Study Committee (1965). It assumes that the annual deficit between discharge and recharge of the Ogallala will continue at the 1968 rate of 6.0 million acre-feet. As the yields of individual wells decline with the decreasing saturated thickness of the reservoir, additional wells are expected to be drilled to maintain the overall pumpage rate as long as possible.

The time when the saturated thickness of the underlying reservoir reaches 30 feet is believed by the author to be roughly the time when an area will go out of irrigated crop production, unless additional water is imported. Note that in some parts of the South High Plains this time is expected to be between 1970 and 1980.

The Alluvium is also undergoing significant depletion of storage. Its depletion is taking place primarily in the Cenozoic alluvium and bolsons of West Texas. Although the transmissibility of these deposits is high, the rainfall in this area is low. Consequently, natural recharge has been unable to keep pace with discharge.

The Trinity Group reservoir is beginning to be dewatered, as shown in Table 2, Column 9. Most of the large drawdowns encountered in this reservoir to date, however, represent declines in artesian pressure rather than

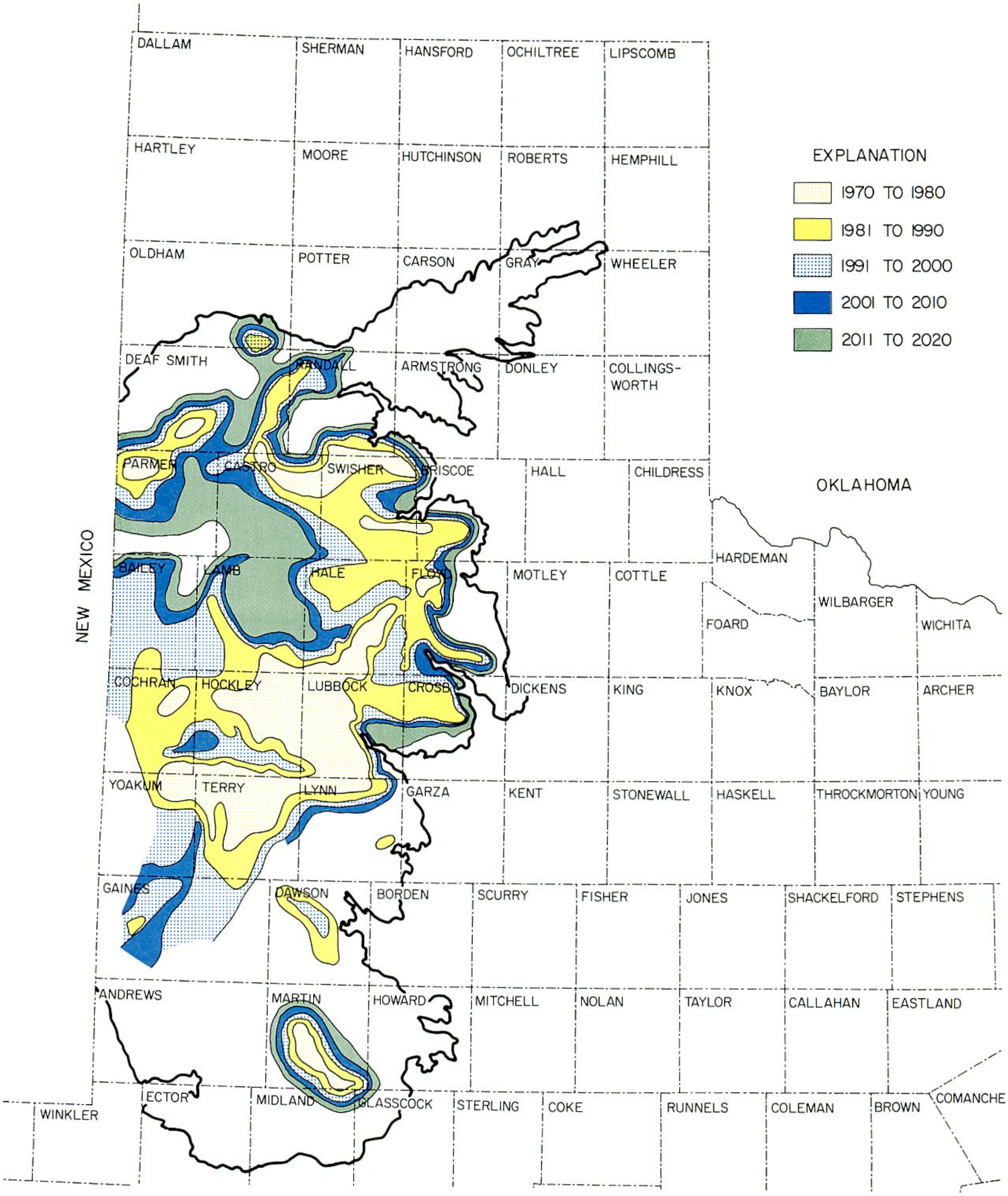

Figure 5

PERIOD WHEN THE SATURATED THICKNESS OF THE OGALLALA FORMATION WILL LIKELY BE REDUCED TO 30 FEET, SOUTH HIGH PLAINS dewatering.

The Bone Spring-Victorio Peak reservoir in West Texas is suffering an annual overdraft of 50,000 acre-feet, and is gradually being dewatered.

The Blaine Gypsum reservoir in the Childress area is at present in equilibrium, but will probably undergo depletion in the near future. This aquifer in the counties of southwestern Oklahoma has already been overdeveloped and is being depleted (Steele and Barclay, 1965).

DISCUSSION

The total underground storage capacity available in Texas is shown in Table 2, Columns 8 through 10, and Figure 6. An estimated 620 million acre-feet of storage capacity is now occupied by recoverable fresh and slightly saline water. Two reservoirs, the Ogallala and the Gulf Coast, account for 66 percent of this storage capacity. Dewatered storage capacity is estimated to be 85 million acre-feet. Eighty-eight percent of the dewatered storage capacity is in the Ogallala and 12 percent in the Alluvium reservoir. The total underground storage capacity available is approximately 710 million acre-feet. Most of this is located where it can be used in conjunction with the Texas Water Plan.

This storage capacity does not include the large amounts of fresh and slightly saline water below 400 feet in depth. Much of this will probably be economically recoverable someday. Also available are the huge reserves of moderately and very saline ground water. Although these saline waters have not been included in this paper, they are already being utilized through municipal desalting plants at Dell City, Port Mansfield, and Plains, and through several industrial desalting plants.

On the other hand, it should be kept in mind that there are problems connected with the use of dewatered storage capacity for ground-water storage

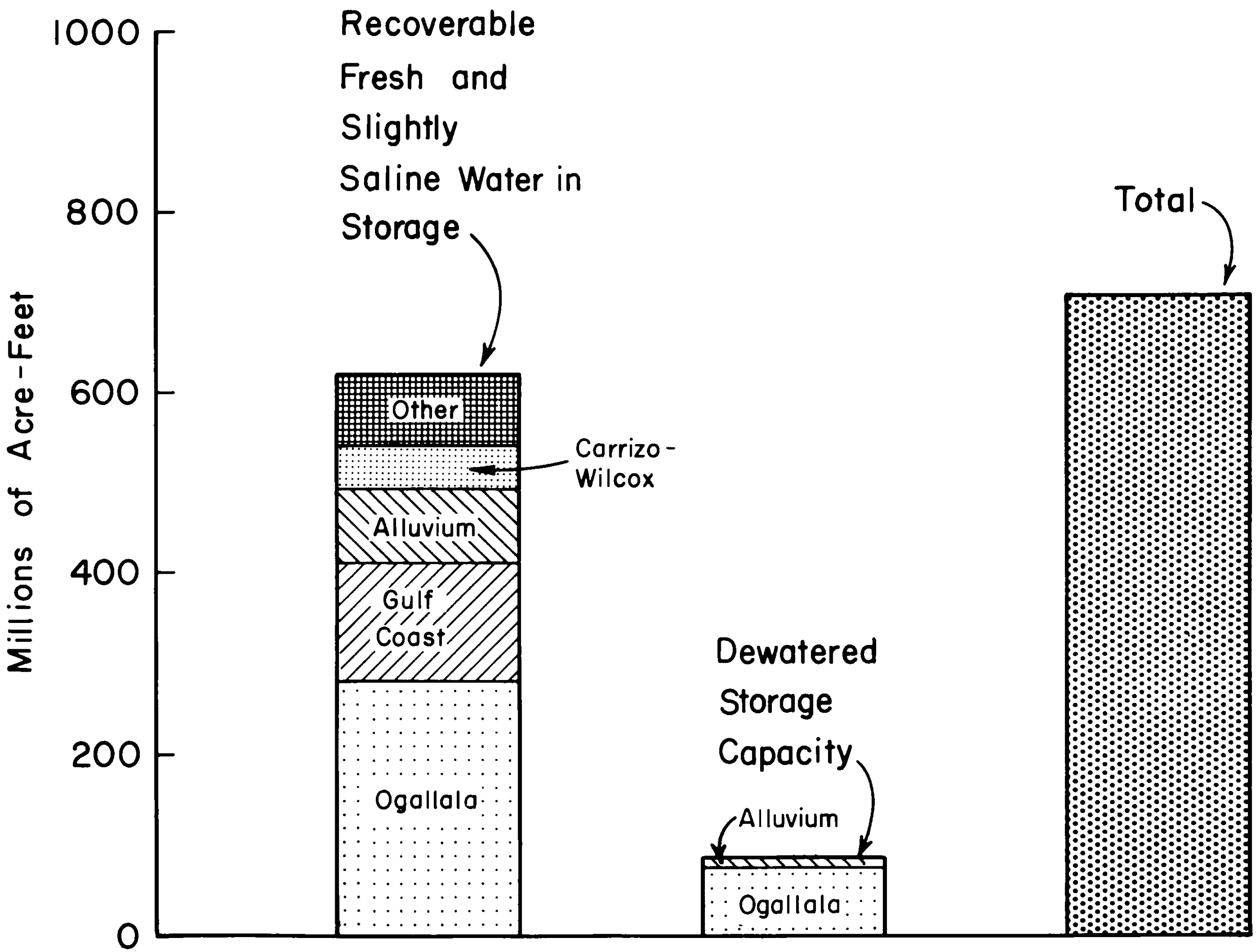

Figure 6

GROUND-WATER STORAGE CAPACITY IN TEXAS

by artificial recharge. These apply also when artificial recharge is used to form a salt-water barrier. Although a detailed discussion of artificial recharge is beyond the scope of this paper, some of these problems are:

1. Aquifers with low transmissibility, especially below 30,000 gallons per day per foot, cannot be used for efficient distribution of water. However, local storage and withdrawal of water at the same points might be practicable in such aquifers.

2. Compaction of underground reservoirs when the water is withdrawn reduces their storage capacity. In the Gulf Coast aquifer near Houston, land subsidence of as much as 1.3 feet per 100 feet of water-level decline has been measured (Gabrysch, 1967). This is equivalent to a compaction of the aquifer of 1.3 percent. All of the compaction must be absorbed by the pore space, because the individual aquifer particles do not change in volume. If the original porosity of a reservoir is 30 percent, a 1.3 percent compaction would reduce this porosity to 28.7 percent. The specific yield would probably be reduced to a greater extent.

3. Air entrapment may cause problems when water is injected into dry underground reservoirs. Signor, Hauser, and Jones (1968) found that in the Ogallala reservoir this caused the build-up of an abnormally high ground-water mound during recharge. However, it is possible to partially dissipate this mound and remove entrapped air by fluctuating the recharge head. It is also possible to use an airtight system for the recharge water to help prevent air entrainment, oxidation of iron, and growth of algae.

4. Aquifers can be clogged by using muddy recharge water. The work of Hauser and Lotspeich (1968) on treatment of playa lake water for recharge into the Ogallala Formation is encouraging. However, the recharge potential of the 16,700 High Plains playa lakes is relatively small, about 220,000

acre-feet per year (Grubb and Parks, 1968), as compared with the annual pumpage of 9.8 million acre-feet. Hence it is obvious that the bulk of the recharge water for the High Plains must be imported. Clogging of cavernous aquifers such as the Edwards Limestone or the gypsum of the Blaine Formation with sediment is much less of a problem than clogging of sand aquifers. The caverns constantly enlarge themselves by solution, counteracting the effect of sediment (Brune, 1966).

In spite of these and other recharge difficulties, the writer believes that 60 to 70 percent of the dewatered storage capacity of Texas' underground reservoirs can be reused for water storage.

The estimated 85 million acre-feet of dewatered underground storage capacity available compares with a total surface storage capacity of 103 million acre-feet for the 157 existing and 67 proposed major reservoirs in Texas.

The estimated 1968 Texas ground-water use of 13.4 million acre-feet (excluding spring flow) is shown in Table 2 and Figure 7. Note that 73 percent of this amount is being taken from the Ogallala ground-water reservoir of the High Plains. This use of ground water in Texas compares with an estimated 1968 use of surface water of 5.2 million acre-feet. Seventy-two percent of the present water use is from ground water. Seventy-five percent of all water used goes for irrigation, 22 percent for municipal and industrial use, and 3 percent for mining and other uses.

The figures given in this paper are the best estimates available at this time. It must be emphasized that they are based partly on judgment. Undoubtedly they will be refined in the future as the ground-water investigation program of the Texas Water Development Board explores these problems more thoroughly.

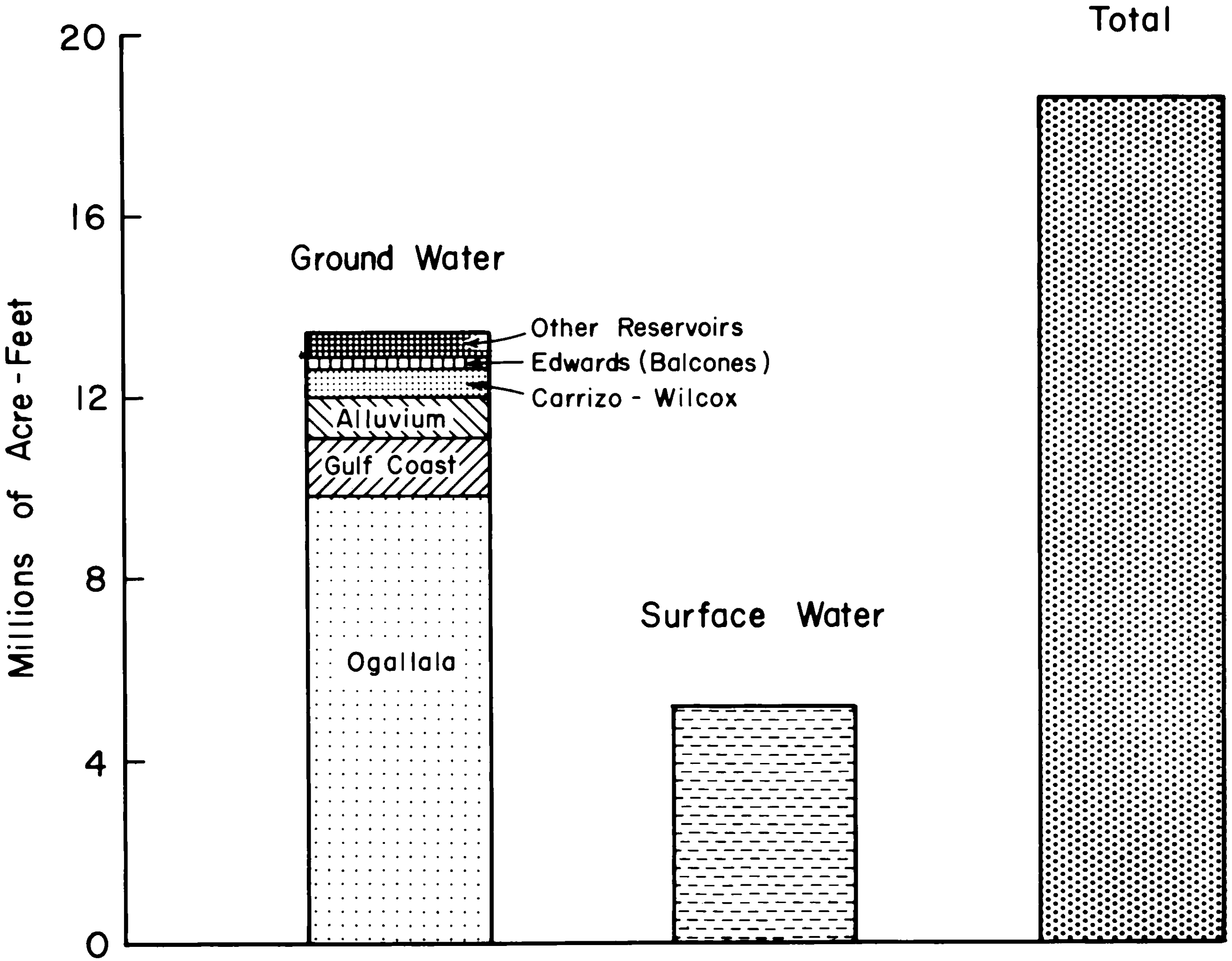

Figure 7

1968 WATER USE IN TEXAS

The best interests of Texas will of course be served by the conjunctive use of both surface and ground water. The purpose of this paper is to point out the advantages of making maximum use of our ground-water resources.

Acknowledgments

Most of the basic data used were taken from the Texas Water Development Board's reports of reconnaissance investigations of ground-water resources (1960-1967) and from its numerous reports of detailed ground-water investigations. Klug (1963) has ably discussed this program of investigations. Also drawn upon heavily was Peckham's (1967) study of the role of ground water in the Texas Water Plan.

References

Banks, Harvey O., 1967, Sixth biennial conference on ground-water recharge, development, and management, Summary of conclusions by panel moderators: California State Department of Water Resources, Sacramento, California.

Brune, Gunnar, 1966, Recharge of the Edwards Limestone reservoir, Texas: Presented at the annual meeting of the Association of Engineering Geologists, Anaheim, Calif. Box 12386, Austin, Texas 78711.

Cronin, J. G., 1969, Ground water in the Ogallala Formation in the Southern High Plains of Texas and New Mexico: Hydrologic Investigations Atlas HA-330, U. S. Geological Survey, Washington, D.C.

Gabrysch, R. K., 1967, Development of ground-water in the Houston district, Texas, 1961-1965: Texas Water Development Board Report 63, Box 12386, Austin, Texas 78711.

Grubb, H. W., and D. L. Parks, 1968, Multipurpose benefits and costs of modifying playa lakes of the Texas High Plains: Department of Agricultural Economics, Texas Technological University, Lubbock, Texas.

Guyton, W. F. and Associates, 1957, Report on ground-water conditions in Nueces River Conservation and Reclamation District: 221 E. 11 St., Austin, Texas 78701.

Hauser, V. L., and F. B. Lotspeich, 1968, Treatment of playa lake water for recharge through wells: Transactions, American Society of Agricultural Engineers, v. 11, n. 1, p. 108-111, St. Joseph, Mich.

Havens, John S., 1966, Recharge studies on the High Plains in northern Lea County, New Mexico: Water-Supply Paper 1819-F, U. S. Geological Survey, Washington, D.C.

Klug, Mervin L., 1963, Ground water in Texas: Proceedings, Journal of Hydraulics Div., ASCE, v. 89, n. HY3, 2,500 S. State St., Ann Arbor, Mich. 48104.

Leggat, E. R., 1957, Geology and ground-water resources of Tarrant County, Texas: Texas Water Development Board Bull. 5709, Box 12386, Austin, Texas 78711.

Peckham, Richard C., 1967, The role of ground water in the Texas Water Plan, <u>in</u> Additional technical papers on selected aspects of the preliminary Texas Water Plan: Texas Water Development Board Report 38, Box 12386, Austin, Texas 78711.

Signor, D. C., V. L., Hauser, and O. R. Jones, 1968, Ground-water recharge through modified shafts: Presented at meeting of American Society of Agricultural Engineers. Southwestern Great Plains Research Center, Bushland, Texas 79012.

Steele, C. E., and J. E. Barclay, 1965, Ground-water resources of Harmon County and adjacent parts of Greer and Jackson Counties, Oklahoma: Oklahoma Water Resources Board Bull. 29, 2241 NW 40 St., Oklahoma City, Oklahoma 73112.

Texas Water Development Board, 1960-1967, Reconnaissance investigations of ground-water resources (10 reports, as follows: Canadian River Basin, Bull. 6016; Red River, Sulphur River, and Cypress Creek Basins, Bull. 6306; Sabine River Basin, Bull. 6307; Neches River Basin, Bull. 6308; Trinity River Basin, Bull. 6309; Brazos River Basin, Bull. 6310; Colorado River Basin, Report 51; Guadalupe, San Antonio, and Nueces River Basins, Bull. 6409; Rio Grande Basin, Bull. 6502; and Gulf Coast region, Bull. 6305, Box 12386, Austin, Texas 78711.

Texas Water Development Board, 1968, The Texas Water Plan. Box 12386, Austin, Texas 78711.

Twenty-Twenty Water Study Committee, 1965, High Plains Water, 1970-2020: Unpublished report, Texas Water Development Board, Box 12386, Austin, Texas 78711.

U. S. Bureau of Reclamation, 1956, Reconnaissance report on Fort Stockton Project, Texas, USBR, Region 5, Box 1609, Amarillo, Texas.

Winslow, A. G., and L. R. Kister, 1956, Saline water resources of Texas: U. S. Geological Survey Water-Supply Paper 1365, 300 E. 8th St., Austin, Texas 78701.

Wyatt, A. Wayne, 1968, A general discussion accompanied by hydrological maps pertaining to the ground-water resources in the South Plains Underground Water Conservation District No. 4: Progress Report 1, Box 232, Brownfield,

Yarbrough, Donald, 1968, Laws and programs pertaining to water and related land resources: Texas Water Development Board Report 89. Box 12386, Austin, Texas 78711.