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WATER BUDGET AND QUALITY OF WATER STUDIES OF HUBBARD CREEK RESERVOIR, TEXAS 1963-67 WATER YEARS

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TABLE OF CONTENTS

TABLES

FIGURE

WATER BUDGET AND QUALITY OF WATER STUDIES OF HUBBARD CREEK RESERVOIR, TEXAS 1963-67 WATER YEARS

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ABSTRACT

This report presents the results of a water budget and chemical quality of water study of Hubbard Creek Reservoir. Data collected in the study permitted computation of watershed precipitation, inflow to and outflow from the reservoir, evaporation, and chemical analysis of water in the reservoir. The losses due to transpiration are insignificant.

Small losses were attributed to saturation of alluvium in the reservoir basin during the initial filling of the reservoir, but because there are no ground-water aquifers of importance in the watershed, and because the sediments within the drainage basin are relatively impermeable, no large amounts of water are lost by infiltration.

Evaporation causes a significant loss from the reservoir contents. During the period 1963-67, about 110,000 acre-feet of water was lost by evaporation. This amount represents about 30 percent of the capacity of the reservoir at normal operating level.

Water-sample analyses from tributaries passing through oil fields indicate that industrial waste contributes to mineralization of the reservoir water.

Stratification of the mineralized water in the reservoir has not occurred as anticipated; therefore, efforts to selectively release mineralized water containing undesirable concentrations of dissolved constituents during periods of substantial runoff have not been successful.

WATER BUDGET AND QUALITY OF WATER STUDIES OF HUBBARD CREEK RESERVOIR, TEXAS 1963-67 WATER YEARS

INTRODUCTION

A water budget is an accounting for the water that enters and leaves a watershed. The determination of the factors in the water budget of a reservoir and its drainage area should extend over a representative climatic cycle that includes an extended drought, extreme flood flows, and periods of normal runoff.

This study does not extend over a complete climatic cycle, but meaningful information has been compiled from analyses over a period of five years.

Equally important as the water-budget studies are the quality of water studies. Without potable water for municipal and industrial use, quantity is unimportant. Some figures on chloride content are cited to emphasize the importance of controlling the increasing mineralization of water in the reservoir.

Purpose and Scope of This Report

This report analyzes quantitatively the surface-water losses and gains in Hubbard Creek Reservoir for water years 1963-67, following impoundment which began in September 1962. These losses and gains are related to ground- and surface-water exchange, where significant, and to the change in the chemical quality of water in the reservoir.

Location and Physical Features

Hubbard Creek Reservoir is 6 miles northwest of Breckenridge, Texas. Most of the surface area of the lake is in Stephens County, but at spillway level the Hubbard Creek arm of the reservoir extends into Shackelford County. Hubbard Creek is a tributary of the Clear Fork Brazos River, which is a tributary of the Brazos River.

The dam forming Hubbard Creek Reservoir is an earth-filled structure 15,150 feet long with a height of 112 feet above the streambed. Elevation of the top of the dam is 1,208.0 feet above mean sea level. The shoreline at elevation 1,183.0 feet above mean sea level is 100 miles long. Other pertinent data are given in the following table:

FEATURE	ELEVATION (FEET ABOVE MEAN SEA LEVEL)	RESERVOIR CAPACITY (ACRE-FEET)	RESERVOIR SURFACE AREA (ACRES)
Top of dam	1,208.0	–	–
Top of earth fuse plug	1,197.0	579,400	22,000
Crest of emergency spillway	1,194.0	515,800	20,500
Top of gates of service spillway	1,185.0	349,200	–
Normal operating level	1,183.0	317,800	15,250
Crest of service spillway	1,176.5	227,400	12,300
Invert of 5- x 7-foot gate	1,138.0	5,580	–
Invert of 48-inch valve	1,133.8	1,720	–
Invert of 48-inch outlet pipe	1,111.0	0	0

The main outlet is a circular-shaped, drop-inlet concrete structure, 69.3 feet in diameter, with gate control. Discharge is into a 22-foot diameter concrete conduit through the dam with the invert at an elevation of 1,108.0 feet above mean sea level. The crest of this outlet is 1,176.5 feet above mean sea level, but the gates raise normal water level to 1,183.0 feet above mean sea level. After construction was completed, an additional 5- by 7-foot opening was cut with the invert at elevation 1,138.0 feet above mean sea level, with a gate control to facilitate release of stratified water.

Drainage Area

The drainage area above Hubbard Creek Reservoir is 1,107 square miles and lies in Stephens, Shackelford, Eastland, and Callahan Counties. The principal streams that flow into the reservoir are Hubbard Creek and its tributaries and Big Sandy Creek and its tributaries.

McCarty Lake (capacity 2,600 acre-feet), about 6 miles southwest of Albany on Salt Prong Hubbard Creek, has a drainage area of 42 square miles at the dam. It furnishes water for the city of Albany. In the 1966 water year, the city of Albany diverted 754 acre-feet of water from McCarty Lake for municipal use. During the period of this investigation, McCarty Lake effectively controlled the runoff from its drainage area above the dam and little if any water spilled from the reservoir.

Figure 1 shows the stream gages on various streams that flow into Hubbard Creek Reservoir. In 1963, the gage on Salt Prong Hubbard Creek was located downstream from the confluence of North Fork Hubbard Creek and Salt Prong Hubbard Creek, but was moved to the present location before the beginning of the 1964 water year.

Lake Cisco (capacity 25,600 acre-feet), on upper Big Sandy Creek about 4 miles north of Cisco in Eastland County, has a drainage area of 26 square miles. Runoff from this small drainage area is insufficient to furnish enough water for the city of Cisco, and spill from the lake is rare. Consequently, little if any runoff from the drainage area above Lake Cisco ever reaches Hubbard Creek Reservoir.

The discovery of oil and gas in the early 1920's has caused intensive development on much of the watershed, and salt water produced along with the oil, much of which has been carelessly disposed of, has caused "vegetation kills" in numerous places on the drainage area.

Low rolling hills are predominant over most of the drainage area; however, west of U.S. Highway 283 the hills are higher and the relief is more pronounced. Along the southern boundary, there are outcrops of Cretaceous limestone and sand, but because these rocks are thin at the outcrop, very little ground water is found in the area. Most of the drainage area is composed of sediments and sedimentary rock of such a nature as to preclude any ground-water aquifers of significance.

Elevation of the drainage area ranges from about 1,200 feet above mean sea level near Hubbard Creek Reservoir to about 2,000 feet above mean sea level on the south and west boundaries of the watershed.

Climate

The climate of the area is subhumid. The mean temperature for July is about 29°C (84° F), but a temperature of 44°C (112°F) has been recorded. The mean temperature for January is about 7°C (44°F), but minimum temperatures near -18°C (0°F) have been recorded. The frost-free season, which averages about 226 days, extends from the last of March to early November.

Precipitation recorded by four U.S. Weather Bureau stations on or near the perimeter of the watershed averages 25.81 inches annually for the period of record, but an inspection of the yearly totals at the stations indicates that precipitation is local and may vary as much as 30 percent annually between stations. For example, in 1966, Baird, in the southwestern part of the watershed, reported a yearly total of 24.90 inches, while Breckenridge, in the northeastern margin of the watershed, reported 32.91 inches. Table 1 gives the monthly and yearly totals for the period of study and the average yearly rainfall for the period of record.

One of the climatic factors most adversely affecting Hubbard Creek Reservoir is evaporation. Not only is water lost from the reservoir in significant amounts, but soluble minerals are left as a residue, thereby increasing the dissolved-solids concentration in the remaining water. Lines of equal evaporation rate indicate that average annual gross lake-surface evaporation for Hubbard Creek is between 70 and 80 inches (Kane, 1967, p. 25); therefore, average evaporation is about three times the average rainfall. An extreme evaporation-precipitation ratio occurred in 1956 when the estimated gross lake-surface evaporation in the Hubbard Creek area was 95 inches while the average rainfall at Albany and Breckenridge was about 12 inches. Because of the poor infiltration characteristics of most of the soils and rock outcrops, most of the rainfall runs off or is lost to evaporation and transpiration.

Table 1.—Monthly and Yearly Precipitation for the Period of Study, and Average Yearly Precipitation for the Period of Record, From U.S. Weather Bureau Records at Stations On or Near the Watershed of Hubbard Creek Reservoir

(Precipitation in Inches)

WATER YEAR	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	TOTAL
						Albany							
1963	1.44	1.06	1.19	.04	.31	.08	3.43	4.78	2.90	.98	1.67	1.74	19.62
1964	.91	6.09	.60	2.58	2.77	1.51	1.47	3.71	1.50	.05	3.29	3.69	28.17
1965	.87	3.83	.32	1.75	1.66	.48	4.53	7.99	2.41	.22	1.97	3.82	29.85
1966	3.19	.22	1.56	1.76	.79	1.49	6.98	2.73	1.50	.41	6.34	4.87	31.84
1967	1.24	.38	.09	.00	.29	.85	1.52	5.19	2.54	1.21	1.43	6.72	21.46
					Average yearly precipitation for period of record (37 calendar years)								26.57
						Baird							
1963	3.38	1.51	.72	.01	.28	.90	.85	5.70	3.32	.68	1.16	.73	19.24
1964	.35	4.24	2.61	2.32	1.47	1.32	1.90	.45	2.46	.00	4.02	2.98	24.12
1965	1.06	8.39	.30	1.36	1.30	.70	1.63	8.65	2.04	.00	.89	3.53	29.85
1966	3.21	3.20	1.94	.85	1.55	.08	7.98	.75	3.11	.81	4.12	3.90	31.50
1967	1.75	.00	Trace	.00	.61	1.21	1.54	2.18	2.39	1.91	.89	5.62	18.10
					Average yearly precipitation for period of record (23 calendar years)								24.42
						Breckenridge							
1963	1.30	1.19	1.58	.09	.27	.14	4.59	4.81	3.72	1.32	1.22	1.54	21.77
1964	3.75	4.65	.48	2.37	1.79	1.11	1.15	2.61	.64	.98	4.44	5.19	29.16
1965	.56	5.33	.31	2.21	1.49	.45	2.82	9.61	1.61	.38	1.62	2.81	29.20
1966	2.44	.38	2.26	1.16	1.13	.56	7.75	1.24	4.87	1.30	4.88	8.56	36.53
1967	.90	.49	.07	.00	.54	.85	1.07	2.44	2.24	2.43	.20	5.21	16.44
					Average yearly precipitation for period of record (44 calendar years)								25.30
						Eastland							
1963	3.48	1.13	1.05	.67	.22	.81	2.47	6.66	1.32	.11	3.41	3.84	25.17
1964	1.65	5.84	.36	2.48	2.00	1.00	2.27	.85	.66	.69	5.81	4.79	28.40
1965	1.02	3.38	.39	2.10	2.10	.54	1.16	8.48	1.22	.00	1.33	4.06	25.78
1966	3.44	1.79	1.61	1.35	1.62	.11	6.81	2.45	6.59	.34	4.13	2.88	33.12
1967	1.03	.24	.05	.20	.74	1.15	2.74	4.91	5.17	3.98	.00	5.18	25.39
					Average yearly precipitation for period of record (57 calendar years)								26.95

PHYSIOGRAPHY AND GEOLOGY

Hubbard Creek Reservoir and its drainage area are in the Osage Plains, a subdivision of the Central Lowland province. The Osage Plains in Texas extend from the foot of the High Plains, east to the Cretaceous exposures, north of the Llano Uplift in central Texas, and mostly south of the Red River (Sellards, Atkins, and Plummer, 1932, p. 101).

In the Hubbard Creek area, the exposed Pennsylvanian and Permian formations dip west and northwest into the Permian Basin. In the southern part of the area, the Callahan Divide, which locally separates the drainage area of the Brazos and Colorado Rivers, is capped by sand of the Trinity Group. The sand on the surface creates excellent recharge conditions for ground water, but the deposit is too thin to function as an important aquifer. The underlying formations are not permeable enough to be good aquifers.

The Bend Flexure, an anticlinal feature extending from the Llano Uplift northward almost to the Red River, is the major structural feature affecting the formations in the study area. The axis of the flexure trends north from the Llano Uplift across central Brown County, and western Stephens County. Paleozoic deposits east of the axis dip in an easterly direction and those west of the axis dip westerly and northwesterly at 40-50 feet per mile. Cretaceous formations overlying the Paleozoic beds dip southeasterly toward the Gulf of Mexico.

In the Hubbard Creek area, the Pennsylvanian and Permian formations are composed predominantly of shale and thick limestone with lenticular deposits of sandstone and conglomerate. Thick evaporite beds, characteristic of Permian formations in the Permian Basin farther west, are absent in the reservoir drainage area. South of the Hubbard Creek drainage area in Brown and Coleman Counties, Terriere (1960) reports broad shallow channels cut during Pennsylvanian and early Permian times. These channels, which are now filled with sandstone and conglomerate, may be small aquifers, but few, if any, have been mapped in the Hubbard Creek drainage basin. Figure 1 is a geologic map of the watershed.

WATER BUDGET

The water budget for Hubbard Creek Reservoir, evaluated by computing values for the terms in the following basic equation, as used by Gilbert (1970) is:

$$Q_i = Q_o \pm \Delta S + L \text{ (all terms in acre-feet).}$$

Q_i = inflow, which is the runoff at several gaging stations on streams within the watershed plus estimates of runoff from ungaged areas. It consists specificallyof (1) flow measured at Big Sandy Creek near Breckenridge, (2) flow measured at Hubbard Creek near Albany, (3) flow measured at Salt Prong Hubbard Creek at U.S. Highway 380 near Albany, (4) flow measured at North Fork Hubbard Creek near Albany, (5) three-year record of flow at Snailum Creek near Albany, and (6) estimated flow from the ungaged area based on unit runoff from the gaged area. Rainfall on the reservoir surface is accounted for as an inflow term by using net evaporation in the outflow term.

Q_o = outflow, which is the flow measured at the gaging station Hubbard Creek near Breckenridge less a small adjustment for the 4 square miles of drainage area between the reservoir dam and the gaging station. All released water passes this gage and is included in the flow at the station. No known diversions were made from the reservoir during this study period (October 1, 1962 to September 30, 1967).

ΔS = the annual net change in the reservoir contents for each water year.

L = water loss or gain from the reservoir, consisting of evaporation, seepage (if any), or any other unaccounted loss or gain. The results of the computation are presented in Table 2.

Limits of accuracy for terms in the water-budget equation will vary. The annual streamflow records at the gaging station are considered accurate within 5 percent. The annual change in contents of the reservoir is probably accurate within 2 to 5 percent. Any error in the reservoir content can be neglected because differential values are used to compute the annual change.

Net evaporation rates from the reservoir surface for the period 1940-65 were computed from values given by Kane (1967). Net evaporation rates for 1966 and 1967, which were computed by methods similar to those of Kane, were determined from evaporation measured by the U.S. Weather Bureau at Proctor Reservoir in Comanche County about 60 miles south of Hubbard Creek Reservoir and from rainfall records at Breckenridge. According to Kane (1967, p. 25), both Proctor and Hubbard Creek Reservoirs have about the same evaporation rate. Accuracy of the net annual evaporation is considered to be within 10 percent.

Anderson (1954), in his conclusions from energy-budget studies at Lake Hefner, indicates that an accuracy of plus or minus 5 percent of the mean energy-budget evaporation requires that all terms in the energy-budget equation be evaluated with utmost accuracy. Kohler (1954) suggests that annual lake evaporation can probably be estimated within 10-15 percent (on the average) by applying an annual coefficient to pan evaporation, provided lake depth and climatic regime are taken into account in selecting the coefficient.

The item in the water-budget calculations most subject to error is the estimate of inflow from the ungaged area between the stream-gaging stations and the reservoir, about 20 percent of the total inflow. The estimates are based on computed unit runoff at the streamflow stations within the drainage area and applied proportionately to the ungaged drainage areas. Even though the gaged and ungaged areas are similar in climate and physiography, the variation in rainfall over comparatively short distances may cause errors.

Fairly accurate adjustments for rainfall variation could be made if enough data were available from a number of rain gages located within the drainage area. Adjustments based on the available rainfall records indicated that differences in the total gains and losses during the study period varied less than 5 percent from the unadjusted records; therefore, no adjustment for rainfall differences appeared to be justified. As the surface area of the reservoir increased with the impoundment of water, adjustments were made to

Table 2.—Water Budget for Hubbard Creek Reservoir, 1963-67 Water Years

BUDGET ITEMS (ACRE-FEET)	WATER YEAR (OCTOBER 1 TO SEPTEMBER 30) 1963	1964	1965	1966	1967	PERIOD OF STUDY 1963-67
Inflow Big Sandy Creek near Breckenridge, Station 8-863	20,600	24,040	38,340	33,420	16,760	133,000 3/
Inflow Hubbard Creek near Albany, Station 8-861	12,810	11,600	49,860	29,570	11,180	115,000
Inflow Salt Prong Hubbard Creek at U.S. Highway 380 near Albany, Station 8-861.2	886	474	2,480	322	58	4,220
Inflow North Fork Hubbard Creek near Albany, Station 8-861.5	483 1/	1,010	3,610	3,560	627	9,290
Inflow Snailum Creek near Albany, Station 8-862.1 2/	—	535	1,950	1,150	—	3,640
Total gaged inflow	34,779	37,659	96,240	68,022	28,625	265,000
Estimated from ungaged drainage area	9,782	11,089	25,588	17,567	8,166	72,200
Total inflow (Q_i)	44,561	48,748	121,828	85,589	36,791	338,000
Outflow Hubbard Creek near Breckenridge adjusted for estimated runoff for drainage area between dam and gage, Station 8-865	33,157	20,916	516	1,348	38	56,000
Net evaporation from reservoir	8,229	9,168	23,774	20,711	48,000	110,000
Total outflow (Q_o)	41,386	30,084	24,290	22,059	48,038	166,000
Change in reservoir contents (ΔS)	- 1,520	+15,770	+ 84,410	+69,500	- 11,400	+157,000
Net unaccounted loss (L)	4,695	2,894	13,128	- 5,970	- 153	14,600

1/ One month estimated for 1963 water year.
2/ Snailum Creek ungaged in 1963 and 1967.
3/ Period totals rounded to three significant figures.

reduce the ungaged drainage area above the dam for the principal tributaries used in the computations of unit runoff for each area.

No attempt was made to estimate transpiration loss from the reservoir. Prior to the closing of the reservoir gates, most of the vegetation had been cleared from the bed of the reservoir, and probably the only transpiration loss occurred from grasses around the shore line; therefore, transpiration is considered to be so small that it is probably unimportant.

In January 1962 (U.S. Geological Survey, 1962), a series of measurements were made along Hubbard Creek from a county road 2-1/2 miles north of Sedwick (10 miles southeast of Albany) in Shackelford County to the gaging station Hubbard Creek near Breckenridge (a distance of 24 miles) to determine gains or losses in the base flow of the stream. This low-flow investigation showed that most of the flow came from alluvium along the lower end of the reach. This suggests that alluvium in the reservoir basin is thick enough and will store enough water to sustain base flow.

Assuming an unsaturated thickness of 10 feet of alluvial fill in the reservoir basin prior to inundation and a porosity of 25 percent for the alluvium, 13,000 acre-feet of water could have been absorbed by the alluvium by the end of the 1965 water year when water covered approximately 5,200 acres of the basin. About 7,000 acre-feet of this amount would have been lost to the alluvium during the first two years after the gates were closed and impoundment began.

The net gain shown in the 1966 water year is probably attributable to the wide variation in rainfall over the drainage area during the year. The total rainfall at Breckenridge during the 1966 water year, which is the site of the rain gage nearest to the reservoir, was 36.53 inches. At Baird, on the southwest side of the drainage area, the total rainfall for the 1966 water year was 31.50 inches; at Albany on the northwest part of the drainage area, the rainfall was 31.84 inches. Based on the areal variation indicated by these records, the calculated gain of 5,970 acre-feet in 1966 is not considered significant.

No gain or loss of significance was noted for the 1967 water year. The reservoir area increased approximately 15 percent during 1967, but evaporation caused a net loss in content before the end of the water year. Most of the alluvium had been saturated by the end of the 1966 water year, so very little additional water was lost to the alluvium.

Conselman and others (1962), in their report to the West Central Texas Municipal Water District, show by the geologic map of the drainage area that Hubbard Creek Reservoir is on the outcrop of the Pueblo Formation of the Lower Permian Wolfcamp Series. Stafford (1960a) described this formation as consisting of a series of shale and limestone beds with thin lentils of siltstone and sandstone. No permeability data are available for the Pueblo Formation, but shale and limestone generally have low permeability and do not transmit water readily. Bayha (1964) shows only a few water wells in western Stephens County, most of which are shallow dug wells producing from thin deposits of sand or sandstone. Cronin and others (1963) indicate that aquifers in the area of Hubbard Creek Reservoir are unimportant.

From the type of sediments and sedimentary rock underlying the Hubbard Creek Reservoir, and from the absence of any known ground-water aquifers of significance in the area, it is concluded that little if any water is lost through ground-water recharge other than that to the alluvial and terrace deposits along the stream channels. This conclusion is supported by the small net losses over the period of record.

EFFECT OF EVAPORATION ON WATER QUALITY

After impoundment began in Hubbard Creek Reservoir, a water-quality monitoring program was established to determine salt loads of streams that contribute water to the reservoir. Most analyses indicate that pollution of the reservoir is predominantly a result of industrial waste from oil fields in the drainage area and leakage of saline ground waters from saline aquifers underlying the area through unplugged or inadequately plugged oil and gas tests and improperly completed oil or gas wells.

Water evaporated from the reservoir leaves its mineral constituents, thereby increasing the dissolved-solids content of the remaining water. During extended dry periods, evaporation may increase to such an extent that the water will be undesirable for most uses. In the area of Hubbard Creek Reservoir, the climatic conditions are such that evaporation exceeds the rainfall by about three times. On the basis of the weighted annual-average concentrations of chloride and of the evaporation records, 27,120 tons of chloride have accumulated in the reservoir during the period of study as a result of evaporation.

Assuming that the average chloride concentration at the monitoring station near the dam is representative of the chloride concentration in the reservoir, there were 28,250 tons of chloride in Hubbard Creek Reservoir on September 30, 1967 (contents, 166,200 acre-feet), an increase of 3,370 tons since September 30, 1966 (contents, 177,660 acre-feet). Records indicate that between September 30, 1962, and September 30, 1967, 7,880 tons of chloride were removed from the reservoir through released water. A special outlet structure at the dam provides for selectively releasing mineralized water if the lake should become stratified. However, as of September 30, 1967, the water had not become sufficiently stratified to successfully release the more mineralized water.

CONCLUSIONS

During the initial filling of Hubbard Creek Reservoir, insignificant quantities of water were lost to the alluvial and terrace deposits underlying the reservoir. Seepage losses through or around the dam have been very small, and the soil underlying the lake has low permeability, thereby insuring excellent water-holding characteristics. The largest natural loss of water was the result of evaporation. The net evaporation from Hubbard Creek Reservoir was about 110,000 acre-feet for the period of study (1963-1967). The evaporation results in an increase in dissolved-solids content which could eventually render the water unsuitable for human consumption. As of September, 1967, water in the lake had not become stratified to the extent that proposed remedial measures for reducing mineralization of water in the reservoir by selective release during periods of substantial streamflow could be successfully carried out.

Chemical analyses of water samples from streams flowing into the reservoir indicate that saline waters resulting from oil and gas operations are the greatest hazard to its useful life as a source of water for municipal and industrial uses.

Establishment of an evaporation station at or near the reservoir and the addition of several gages, strategically located on the watershed, would provide additional accuracy to reservoir water-budget development.

Streamflow and reservoir-content records appear to be ample and should be continued for water-budget studies in the future.

The quality of water data are extremely important and data collection should be continued as long as industrial wastes continue to contaminate the water in the reservoir. Studies of stratification phenomena should be continued.

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