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LAND USE IN RELATION TO SEDIMENTATION IN RESERVOIRS, TRINITY RIVER BASIN, TEXAS

ALEXIS N. GARIN AND L. P. GABBARD

Division of Farm and Ranch Economics,
Texas Agricultural Experiment Station, and the Soil Conservation Service, United States Department of Agriculture, Cooperating

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T. O. WALTON, President

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In this bulletin the relationships of land use to erosion and sedimentation are critically examined. The feasibility of controlling the water flow and silt transportation by a systematic treatment of watershed lands is discussed, and the benefits to be derived are indicated.

The rates of reservoir sedimentation have been excessively increased by unsound land use. Soil loss from upland fields not only reduces soil productivity, lowers land values, and reduces farm income, but its deposition in reservoirs greatly increases the cost of water storage.

The total annual damage caused by siltation in all the reservoirs in the Trinity River Basin without upland erosion control was found to be approximately $165,000 a year. It is estimated that $90,000, or more than one-half of this damage, could be prevented if approved erosion control practices were applied to approximately two-thirds of the total land area of the reservoir watersheds.

Soil erosion causes not only the siltation of reservoirs with resultant loss of storage capacity and destruction of reservoir values, but pollution from soil erosion brings with it an added burden of water treatment for industrial and domestic uses. This represents, in the aggregate, serious economic loss to the public. Both of these erosion damages can be reduced greatly by the application of known methods of erosion control on reservoir watersheds. For example, it has been found that the Kaufman Lake is silting at the rate of 6.6 acre-feet per year. On the basis of data available from soil and water conservation experiments, it is estimated that at least one-half of this siltation damage could be prevented if the Soil Conservation Program were applied to as much as 90 per cent of the watershed area. As a result, the life of this lake would be increased from 37 to 74 years, or doubled.

It is apparent from this study that substantial benefits may be expected from an erosion control program in reservoir watersheds by both farmers and townsmen. For example, the annual farm benefits of a complete erosion control program in the watershed of the Kaufman Lake are estimated at $810 and the benefits of the town at $425—a total of $1,235. The total initial cost of a complete erosion control program for the Kaufman Lake Watershed, including increases in annual maintenance, is estimated at $5,000. The combined benefits of farm and town benefits of $1,235 would amortize the $5,000 at a 6 per cent interest in five years. This looks like a good investment for both farmers and townsmen.

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Alexis N. Garin[1] and L. P. Gabbard[2]

Division of Farm and Ranch Economics, Texas Agricultural Experiment Station, and the Division of Economic Research, Soil Conservation Service, United States Department of Agriculture, cooperating.

The purpose of this publication is two-fold: first, to indicate the extent and cost of siltation damages to reservoirs in the Trinity River Basin of Texas; and second, to determine the relationship of such damages to land use in the watersheds involved.

In the present phase of the study, the problem of land conservation and use are seen to be closely related to water conservation and use. Erosion is more than a problem of the individual landowner, for it respects neither fence lines nor property lines, and damage caused by erosion affects society as a whole. The reservoir site like the soil itself is a basic natural resource which is not only destructible but economically irreplaceable in the long run. To be sure, it is physically possible to dredge or otherwise remove the silt deposits from a reservoir just as it is possible to haul the soil back to the watershed where it originated. This is unsound economically however except to temporarily restore special-purpose reservoirs where there is no alternative.

The reservoir drainage areas studied present, generally speaking, compact problem areas where erosion causes appreciable damage to reservoirs and to public water systems and where the general benefits of improved land-use can be immediate and real. In view of the large direct capital losses to the public resulting from soil erosion, it is apparent that these costs, as well as the economic losses on individual farms and ranches, should be assessed against soil erosion and considered in the question of "costs and benefits" of erosion control. In most watersheds it would seem to be sound economics to control erosion in critical areas of sediment production to a greater degree than the present agricultural interests justify solely on the basis of protecting the value in the land itself. This is especially so because of the present financial limitations of the farming population, regardless of the needs of the future.

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[1]Project Supervisor, Division of Economic Research, Soil Conservation Service, United States Department of Agriculture.

[2]Chief, Division of Farm and Ranch Economics, Texas Agricultural Experiment Station.

DESCRIPTION OF THE WATERSHED

The Trinity River Watershed, comprising a total of approximately 11,286,400 acres, lies wholly within the eastern half of Texas. The river, as shown in the map "Major Soil Group Areas", flows successively through seven physiographic divisions; namely, West Cross Timbers, Grand Prairie, East Cross Timbers, Blackland Prairie, Gulf Coastal Plain, Coastal Flatwoods and Coastal Prairie. Each of these physiographic divisions comprises a complex of physical and economic conditions quite different from the other. Within these divisions several more or less homogeneous land-use type areas are to be found. In general, with the exception of the Coastal Plains and Prairies which are characterized by a predominance of woodland and forest interspersed with small irregularly shaped cultivated fields, the eastern two-thirds of the watershed is devoted to general farming, with cotton as the principal cash crop. The northwestern part is dominated by the grazing and ranching type of land-use.

The portion of the watershed west of Fort Worth lies in the sub-humid climatic zone, while the remainder of the watershed becomes progressively more humid toward the Gulf Coast. The annual rainfall varies from about 28 inches on the extreme northwest to around 50 inches on the coast. Periods of deficient rainfall occur at 8 or 10 year intervals in the upper portions of the watershed. The growing season varies from 200 days in the headwaters to 300 near the mouth of the river.

The watershed generally presents an appearance of smooth plains with more or less distinct escarpments facing the northwest and increasing in prominence toward the headwaters where the topography is somewhat rougher.

The western extremity of the basin is approximately on the boundary between the two great soil groups of the United States; namely, (1) the Pedocals, or lime-accumulating soils, to the west, and (2) the Pedalfers, or soils being leached of lime, to the east. The sandy prairies of the West Cross Timbers are characteristic of the transition between these two soil groups.

The dominant soils of the Grand and Blackland Prairies are brown to black and mostly of heavy grassland types, such as Houston Black Clay and Denton Clay, but in the other groups soils are generally sandy and have a natural hardwood, pine, or mixed pine and hardwood forest growth.

The significant factor regarding erosion is the predominance of heavy and largely avoidable soil losses. On the basis of recent erosion surveys it has been estimated that the average annual soil loss is approximately 15 tons per acre. On the uplands this varies from an average of about 7 tons per acre in the rangeland area of the West Cross Timbers to 27 tons per acre in the most severely eroded cultivated portion of the same province[1]. Local differences in land-use and cover conditions normally

[1]These figures are based upon the best available data, but they must be regarded as but rough approximations.

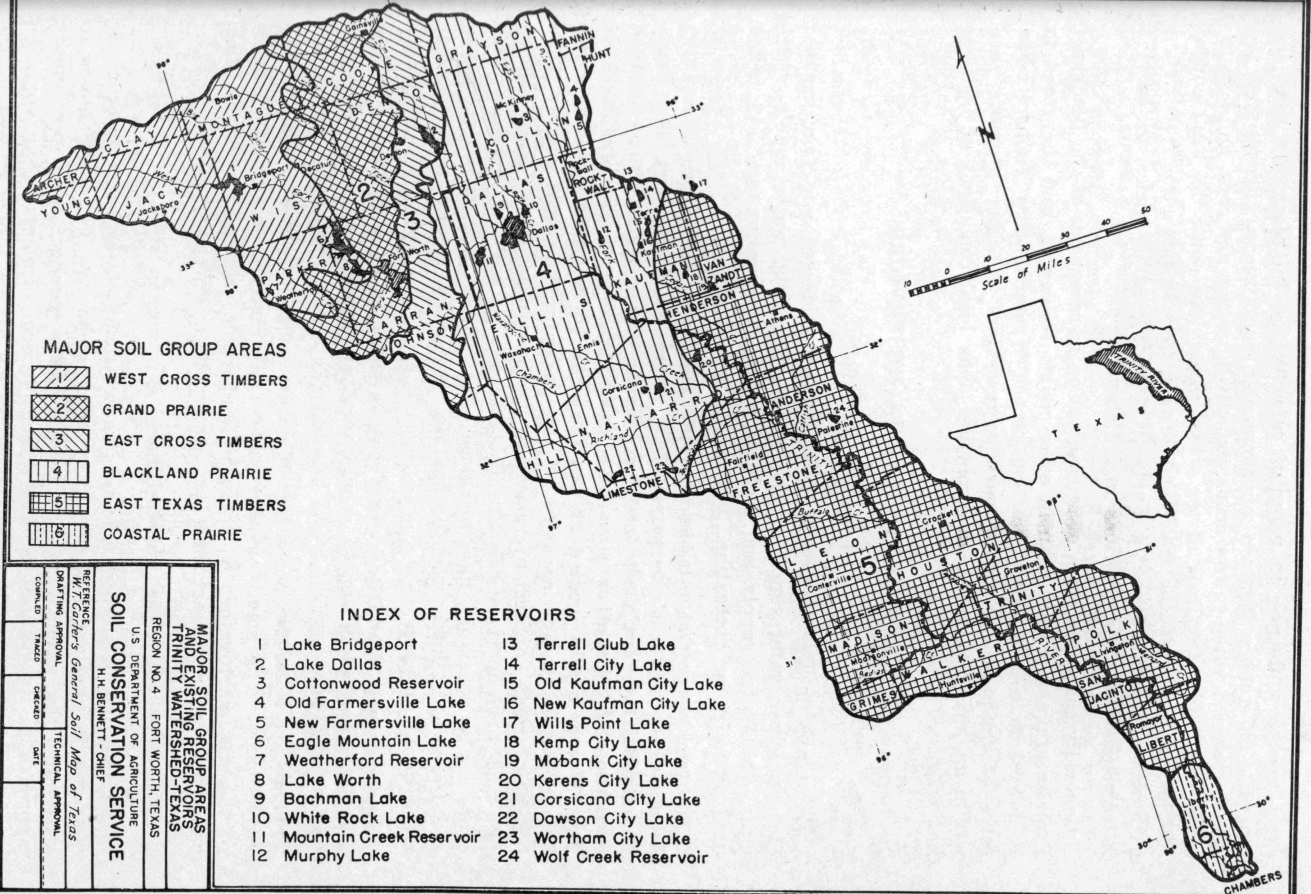

Fig. 1. Major soil group areas and existing reservoirs, Trinity Watershed, Texas

exert greater influence on rates of capacity loss in reservoirs than the inherent differences between physiographic subdivsions. Because of the large acreage devoted to row-crops, principally cotton and corn, and because of the low infiltration rate of the waxy, impervious soils, the total annual soil loss is higher in the Blackland Prairie than in any other subdivision as a whole. In this area the finely-divided clay soil particles are carried in suspension for long periods and distances.

Generally speaking, rates of sedimentation in reservoirs of the Blackland Prairies are also higher than in other major soil areas, and they tend to be lowest in the rangeland portion of the Western Cross Timbers. The rates of capacity loss in comparable reservoirs of other provinces are within an intermediate range depending upon local conditions of land-use and erosion.

SEDIMENTATION IN RESERVOIRS

Types of Reservoirs

Reservoirs in the Trinity Watershed can be classed into four groups: (1) Municipal water supply reservoirs, (2) Industrial water supply reservoirs, (3) Water supply and multiple purpose reservoirs, and (4) Lakes used entirely for recreation.

Fourteen towns and cities and two industrial concerns secure their water supply from surface reservoirs. Two reservoirs, Bridgeport and Eagle Mountain Lake, are used for Fort Worth water supply, flood control, recreation and for other purposes. Although the water supply intake of Fort Worth is still located at the Lake Worth dam, the city no longer depends upon storage capacity of this lake for its water supply. The latter is largely supplied by release of water as needed from Eagle Mountain and Bridgeport reservoirs. The city has permitted the Lake Worth shore to be developed into residence sites, public park areas, et cetera, and the lake is much used for boating, swimming, fishing, and for other recreational purposes.

Bachman and White Rock reservoirs in the suburbs of Dallas have been abandoned as water supply sources and are at present used solely for recreational purposes.

There are no water power developments on the streams of the Trinity River basin. The small average yield, the erratic character of the flow of the streams together with the high economic value of water for other purposes render impracticable any water power development.

The Physical Basis of Appraisals

An appraisal of siltation damages is an attempt to estimate an economic loss due to physical depletion of reservoir capacity. The first step is to determine the extent and character of this damage as a preliminary approach to its evaluation. The direct physical elements of an appraisal of reservoir property intended primarily for water supply consist of the amount and quality of the water. The indirect elements are damages to scenic and recreational values. The physical elements of an appraisal of reservoir property for recreational purposes consist of the capacity and surface area of the lake.

The shoaling, swamping, decreased accessibility to open water, odor, unsightliness, and other injurious effects of sediment accumulations will gradually create a nuisance, will disturb or prevent the enjoyment of the public and the riparian owners, and will lower surrounding property values.

Annual sediment accumulations in reservoirs, with consequent reduction in storage capacities, are shown in Table No. 1. Original capacities and figures on silting rates for Lake Dallas, White Rock, Weatherford, Wills Point, and Lake Worth reservoirs are based on detailed sedimentation surveys. With the exception of Lake Worth, which was surveyed by Dean T. U. Taylor, of the University of Texas, during the summer of 1928, the surveys were made by the Division of Sedimentation Studies, Soil Conservation Service.

The corresponding figures on all the other reservoirs are based on reconnaissance tests by sedimentation specialists of the Soil Conservation Service. A very wide range of capacity loss rates is indicated. The rates of sediment accumulation per unit of watershed vary according to the physiographic divisions and according to local differences in land use. Apparently, the local differences in land use or unfavorable ratios of reservoir capacities to watershed area can cause greater differences in rates of sediment production and capacity loss than variations between major soil divisions.

It was assumed that the total accessible and useful capacity of reservoirs would vary between 38 to 85 per cent (see Table No. 1, Column 5) of the original capacity of the reservoir. That is, when the useful capacity is destroyed the remaining capacity will not be sufficient to supply the primary services and the reservoir would be replaced. With the exception of Bridgeport and Eagle Mountain, the capacities which remain at the end of reservoir life have assumed to have no value. This minimum requirement is necessary as a safety factor to furnish the services through the dryest periods of deficient rainfall and low or no run-off. (See the detailed calculations under "Sedimentation Damage to Bridgeport Reservoir, Lake Dallas, and Mountain Creek Reservoirs.") In addition to the run-off or the inflow into the lake during dry periods, and the water taken from these lakes for use, other factors must be considered; such as, (1) evaporation from the surface of the lake, (2) seepage under the dam or into the ground, (3) water which will be inaccessible, as all water cannot be drawn from reservoirs. In other words, unless the capacity of any storage reservoir is such as to afford an additional quantity of water supplemental to the inflow, less evaporation, seepage and other losses sufficient to tide over periods of deficient rainfall and run-off, normally the reservoir would have no economic value.

Appraisal Based on Cost of Replacement

The estimated cost of replacement is the cost of construction of reservoir on alternate sites where available. Where costs of alternative reservoirs were not available, the original per acre-foot cost of the present storage was used with recognition given to the fact that normally it is probably a minimum cost as the most favorable sites would be utilized first. The replacement cost includes the cost of construction of the dam and the value of the land actually under water at spillway level. The cost of accessories and other equipment needed to make impounded waters available for use was excluded. Siltation of reservoirs does not ordinarily influence the life of such accessories, but they suffer relatively rapid losses of value arising from ordinary wear and tear. These costs and other maintenance costs, it was assumed, would be the same for both the existing reservoirs and the alternate reservoir to be constructed; these costs should, therefore, be excluded from replacement costs. The cost of reservoirs used for both flood control and water supply was allocated in the same proportion as storage allocation for the two purposes.

The Rate of Interest

Capital is a commodity, the use of which is bought and sold. The price for the use of this commodity, money capital, is the rate of interest. Because of the existence of interest, a dollar now is worth more than the prospect of a dollar at some later date. On the supply side, most people have a low present estimation of the utility of future goods, and must be compensated in order that they postpone deriving immediate satisfaction from use of money now. On the demand side, interest is possible because capital is productive. By investing money in plant and machinery, in the fixed-capital goods of business enterprise, it is possible to obtain more and higher quality goods and services in return. There was a time, before the rise of modern capitalistic industry, when most borrowing was for unproductive consumption, but now borrowing for productive purposes is by far the more important and the one which exercises the predominant influence upon the demand side of the loan market. Whether specific capital goods in a given set of circumstances promise to be productive enough to earn a certain return is a problem in economy. Each situation must be examined with respect to the specific rates which probably apply to the given circumstances. As the purpose of this study is not to elucidate economic theory beyond what is needed for understanding the meaning of terms to be used here, there is no need to enter into further analysis of the question of why interest should exist. Interest, or the time value of money, is an economic fact, regardless of whether or not money is to be borrowed. If ownership funds are available, or if the money is obtained by taxation, it may not be necessary to pay out interest to any creditor. Nevertheless, interest is a cost just as truly as if its expenditure were required. There is always the alternative of lending money at some rate of interest both for the government and for the citizen who pays the taxes.

The question of interest arises in connection with all forms of human activity which involve an exchange of present income for future. Being a price, the interest rate does not remain stable but is constantly changing. It fluctuates rather sharply in short run periods and has a tendency to rise in the wake of rising prices during the "prosperity" phase of the business cycle and to fall to a low point during the subsequent reaction. The rate is especially sensitive to conditions of civil disorder and international war. But all these short term fluctuations are lost in a uniformity of trend over long run periods as is exhibited by no other price, and the testimony of history as to the stability of the interest rate is impressive. The trend on the whole has been downward direction during periods of history when security of private property has been undisturbed by civil disorder and when equilibrium of the loan market has been unaffected by heavy military expenditures. The rate has been slightly more than three per cent since the 17th century. Although predictions as to the future of the interest rate are extremely hazardous, it is possible to speak of general forces which will control. The productivity of capital conforms to a law of diminishing marginal productivity, whether viewed from the standpoint of society as a whole or from that of the individual business undertaken. Present income of the average man is larger than it has been at any time in the world's history, and a surplus exists above his vital needs. Also, education and general enlightenment tend to increase the foresight of the common man regarding the desirability of saving for the future, and increasingly larger amounts of present income are being set aside for exchange against the income of the future. The supply of loan funds will increase, and as the supply of capital becomes more and more plentiful it can increasingly be turned to uses where its marginal productivity is low.[1] This is recognized as a sign of improving social welfare.

The most common fallacy appearing in economic discussions dealing with long life public works projects is the assumption that compound interest over long periods is the economic and mathematical equivalent of simple interest at that rate paid currently on loans. This assumption has led to the use of relatively high compound interest rates, of from 3.5 to 6 per cent, over long periods of time. It is true that interest upon invested capital, when paid, may in theory be promptly reinvested and will in turn earn interest, thus becoming incorporated as part of the principal capital. This capital sum thus increases annually at a rate represented by a geometric progression whose factor or multiple is 1 plus the rate of interest (or let us say 1.06; $1+\frac{6}{100}=1.06$). But, its continuance requires not only the continuance but the constant expansion of the field of industrial activity at any equal rate, *which does not happen.* The fact that cannot be overlooked is the tremendous increase in capital which

[1]The productivity of capital should not be viewed as an explanation of the existence of interest; it is time preference which by limiting the supply of present capital available for loans creates and perpetuates the phenomenon of interest.

is the requisite of an uninterrupted accumulation at a given rate of compound interest if extended over a long period of time. A mathematical possibility which may apply only to the exceptional individual who would permit his money capital to accumulate uninterruptedly and without periodic withdrawal of interest, and only then in case the majority of others pursue a contrary and hence balancing course, does not establish the validity of the economic equality between 5 per cent simple interest, for instance, and the same rate of compound interest.

The reader will recall that in the present-day capitalistic industry borrowing for productive purposes exercises the predominant influence upon the demand side of the loan market and that productiveness of capital, meaning its power to increase the output of goods per unit of labor expended, conforms to a law of diminishing marginal productivity. The amount of capital the individual enterpriser-borrower can advantageously use, at any given time, varies inversely with the rate of interest and is such that the marginal productivity of the capital thus obtained is equal to the rate of interest paid, i. e., he will borrow when the productivity of capital under his management exceeds the interest rate and he will continue to borrow until the productivity of capital and the interest rate equate. The tendency of all enterprisers to act in the same manner results in distributing the capital supply of society among the different business undertakings so that the marginal productivity of capital tends to be approximately the same everywhere. The importance attached in this discussion to the long-run productivity of capital is due to the fact that some of the reservoirs, the Bridgeport and Eagle Mountain for instance, will have a much longer useful life than any of the public borrowing obligations issued to finance these projects. In such instances, it will be necessary to determine the expected rate of return throughout the entire life of the reservoir as compared to investments in other productive enterprises as a basis for determining the economic advantage of outlays to increase the life of the reservoirs. The shorter the life of a project the less the difficulty of comparing the returns with more familiar investments. The basic rate of compound interest to be used in capitalizing and discounting future values, whether income or cost, must be made to depend primarily on the length of the period involved and must take into account the essential difference between simple and compound interest as previously noted. In certain great industries such as farming and forestry the long run return on the capital investment is not over 2 per cent annually, and for industry as a whole it is about 2½ per cent compounded. This suggests that by and large the enterpriser's gain is non-existent for industry as a whole, and the only reward for capital is in the form of interest as earned by industry. But this is the long run and average effect only. The rate fluctuates very greatly in short run periods and different rates of interest appear in the market at the same time, each rate applying to a particular type of loan transaction. Also, a certain class of enterprise under certain conditions earns profits greatly exceeding the average rate of interest, while

Table No. 1.—Estimated D

Name of Reservoir	Drainage Area	Original Storage Capacity: Total	Original Storage Capacity: Depleted Annually		Estimated per cent depletion of original capacity which terminates useful life of Reservoir[2]	Actually useable capacity of reservoirs; % Column 5 is of Column 2	Useful Life of Reservoir at Present Rate of Silting: Date construction plus Column 8	Useful Life of Reservoir at Present Rate of Silting: Column 6 ÷ Column 3	Rem Life Rese in 1
	(1) Sq. Mi.	(2) Acre-Feet	(3) Acre-Feet	(4) Per Cent	(5) Per Cent	(6) Acre-Feet	(7) Period	(8) No. of Years	(9 No Ye
Bridgeport	1,051.00	292,000	817.6	0.28	70	204,400	1932–2182	250	
Eagle Mountain	824.00	211,000	1,012.8	0.48	70	147,700	1934–2080	146	
Lake Worth	94.00[4]	47,177	47.2[4]	0.10	....	....	1914– —	....	Inc
Lake Dallas	1,174.00	180,759	1,301.5	0.72	55	99,417	1928–2004	76	
White Rock	99.10	18,158	156.1	0.86	....	....	1911– —	....	Inc
Bachman Lake	15.00	2,300	20.9	0.91	....	....	1903– —	....	Inc
Mountain Creek Res.	251.00	36,000	684.0	1.90	60	23,258	1937–1971	34	
Weatherford	9.00	311	4.7	1.51	60	187	1930–1970	40	
Old Farmersville	1.56	200	5.9	2.95	38	76	1922–1935	13	....
New Farmersville	1.87	500	5.0	1.00	60	300	1935–1995	60	
Murphy Lake	2.88	397	15.6	3.93	70	278	1922–1940	18	....
Cottonwood Reservoir	6.10	29	2.8	9.40	85	25	1912–1921	9	....
Terrell City Lake	10.00	3,000	41.4	1.38	60	1,800	1921–1964	43	
Old Kaufman	1.50	300	4.2	1.40	65	195	1903–1949	46	....
New Kaufman	0.94	445	4.1	0.91	50	222	1936–1991	55	
Kemp City Lake	1.48	376	5.9	1.57	60	226	1926–1964	38	
Mabank City Lake	0.55	295	1.8	0.61	50	148	1926–2008	82	
Lake Halbert	15.80	7,350	39.0	0.53	60	4,410	1921–2034	113	
Dawson City Lake	1.20	650	13.0	2.00	60	390	1937–1967	30	
Kerens City Lake	8.82	900	9.5	1.06	60	540	1935–1992	57	
Wortham City Lake	0.31	275	1.1	0.40	50	138	1922–2047	125	
Wolf Creek Reservoir	5.00	222	1.1	0.51	60	133	1919–2040	121	
Wills Point Reservoir	1.83	396	5.1	1.29	60	238	1914–1961	47	
Totals	3,615	803,040	....	....	....	....	....	....	....

[1]The damages shown in Columns 22 to 24 are based on the assumption sedimentation rates are not reduced through application of su
[2]Based on the experience of local water works engineers and on the basis of special considerations which existed in each case; the size a
is reached.—See text "Sedimentation Damage to Lake Dallas."
[3]The price of money, or the interest rates, are: 1 to 25 years 4¼ per cent, 26 to 100 years 3½ per cent, and for periods longer than 1
[4]Total drainage area of 1969 sq. mi. above Lake Worth was reduced to 918 sq. mi. following the construction of Bridgeport Reservoir a
[5]Damages based on the estimated cost of dredging.—See text "Sedimentation Damage to Lake Worth, White Rock and Bachman L
[6]On the basis of an annual silt inflow of 6.63 acre-feet or 4.36 acre-feet of sediment per square mile of watershed.

Table No. 1.—Estimated Damage from Silting of Specified Storage Reservoirs in the Trinity River Watershed, Texas[1]

Actually useable capacity of reservoirs; % Column 5 is of Column 2	Useful Life of Reservoir at Present Rate of Silting: Date construction plus Column 8	Useful Life of Reservoir at Present Rate of Silting: Column 6 ÷ Column 3	Remaining Life of Reservoirs in 1940	Remaining Capacity in 1940: Total	Remaining Capacity in 1940: Actually Useable Col. 2—Col. 10=X Col. 6—X=Col. 11	Original Cost of Capacity Remaining in 1940: Total Capacity: Per acre-foot	Original Cost of Capacity Remaining in 1940: Total Capacity: Total Column 12 X Column 10	Original Cost of Capacity Remaining in 1940: Actually useable capacity Column 12 X Column 11	Replacement Cost of Capacity Remaining in 1940: Total Capacity: Per acre-foot	Replacement Cost of Capacity Remaining in 1940: Total Capacity: Total Col. 15 X Column 10	Replacement Cost of Capacity Remaining in 1940: Actually useable capacity Col. 15 X Column 11	Capacity of Reservoir to be Restored and Cost of Such Restoration at End of Useful Life: Total capacity in Column 10 and total cost in Column 16 assuming no value for capacity remaining at end of reservoir life		Capacity of Reservoir to be Restored and Cost of Such Restoration at End of Useful Life: Useable capacity in Col. 11 and total cost in Col. 17 assuming capacity remaining at end of reservoir life need be supplemented and not abandoned		Estimated Future Annual Siltation Damage[3]: Annual sinking fund to accumulate value in Col. 19 or in Column 21	Estimated Future Annual Siltation Damage[3]: Annual value of lost reservoir services	Estimated Future Annual Siltation Damage[3]: Total Damage
(6) Acre-Feet	(7) Period	(8) No. of Years	(9) No. of Years	(10) Acre-Feet	(11) Acre-Feet	(12) Dollars	(13) Dollars	(14) Dollars	(15) Dollars	(16) Dollars	(17) Dollars	(18) Acre-Feet	(19) Dollars	(20) Acre-Feet	(21) Dollars	(22) Dollars	(23) Dollars	(24) Dollars
204,400	1932–2182	250	242	285,459	197,859	2.84	...	561,920	17.50	...	3,462,533	...	...	197,859	3,462,533	...	2,669	2,669
147,700	1934–2080	146	140	204,923	141,623	5.26	...	744,937	23.00	...	3,257,329	...	...	141,623	3,257,329	...	8,928	8,928
...	1914– —	...	Indef.	28,664	...	36.03	...	...	500.00	...	...	...	...	...	...	...	...	14,402[5]
99,417	1928–2004	76	64	165,141	83,799	27.41	...	...	27.41	4,526,515	...	165,141	4,526,515	...	...	29,009	...	29,009
...	1911– —	...	Indef.	13,475	...	25.00	...	...	500.00	...	...	...	...	...	...	...	...	64,496[5]
...	1903– —	...	Indef.	1,527	...	17.39	...	...	500.00	...	...	...	...	...	...	...	...	6,700[5]
23,258	1937–1971	34	31	33,948	21,206	48.75	1,654,965	...	48.75	1,654,965	...	33,948	1,654,965	...	...	30,406	...	30,406
187	1930–1970	40	30	264	140	257.23	67,909	...	257.23	67,909	...	264	67,909	...	...	1,315	...	1,315
76	1922–1935	13	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
300	1935–1995	60	55	475	275	80.00	38,000	...	80.00	38,000	...	475	38,000	...	...	236	32	268
278	1922–1940	18	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
25	1912–1921	9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1,800	1921–1964	43	24	2,213	1,013	46.67	103,281	...	46.67	103,281	...	2,213	103,281	...	...	2,477	386	2,863
195	1903–1949	46	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
222	1936–1991	55	37[6]	574	246	49.00	28,126	...	60.00	34,440	...	574	34,440	...	...	469	187	656
226	1926–1964	38	24	293	143	58.00	16,994	...	58.00	16,994	...	293	16,994	...	...	408	49	457
148	1926–2008	82	68	270	123	50.85	13,730	...	60.00	16,200	...	270	16,200	...	...	60	40	100
4,410	1921–2034	113	94	6,609	3,669	44.90	296,744	...	55.00	363,495	...	6,609	363,495	...	...	522	444	966
390	1937–1967	30	27	611	351	50.77	31,020	...	50.77	31,020	...	611	31,020	...	...	709	58	767
540	1935–1992	57	52	853	493	86.67	73,930	...	86.67	73,930	...	853	73,930	...	...	519	54	573
138	1922–2047	125	107	255	118	72.73	18,546	...	72.73	18,546	...	255	18,546	...	...	36	49	85
133	1919–2040	121	100	199	110	180.18	35,856	...	180.18	35,856	...	199	35,856	...	...	42	97	139
238	1914–1961	47	21	263	105	63.13	16,603	...	63.13	16,603	...	263	16,603	...	...	492	41	533
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	66,700	13,034	165,332

on rates are not reduced through application of suitable control measures. For detailed computations see text under "Sedimentation Damage to Larger Reservoirs."
nsiderations which existed in each case; the size and character of drainage area, minimum inflow during dry periods, evaporation, seepage and the use of the reservoir. In some cases supplementary storage to meet water demand will be needed long before this degree of depletion

years 3½ per cent, and for periods longer than 100 years 2½ per cent, compounded annually.
lowing the construction of Bridgeport Reservoir and to 94 sq. mi. following the completion of Eagle Mountain Reservoir. The annual siltation rate of 2.25 per cent or 1,061.5 acre-feet established by Dean Taylor was reduced to 0.1 per cent or 47.2 acre-feet during the same period.
ge to Lake Worth, White Rock and Bachman Lake."
per square mile of watershed.

others suffer losses and may be squeezed out altogether. There is no one correct and uniform rate of interest equally applicable to all periods of time encountered in this study. It would seem that a reasonable approach would be to use the rate of interest actually being paid on the capital borrowed for as long a period as the term of existing borrowing obligations and in lieu of a better basis to adopt the rate paid by government securities in time of peace and stability or the average long run return on the capital investment in industry as the maximum rate for periods longer than those on which specific information is available. On this basis the time value of money is estimated at 4½ per cent for periods from 1 to 25 years, 3½ per cent for periods from 26 to 100 years, and 2½ per cent for periods longer than 100 years.

Equivalence

Equivalence calculations are necessary for a comparison of different money time series. The concept that payments which differ in total magnitude but which are made at different dates may be equivalent to one another is an important one in a study such as this. Any future payment or series of payments which will exactly repay a present sum with interest at a given rate is equivalent to that present sum; all such future payments which will repay the present sum are equivalent to one another. The present sum is the present worth of any future payments or series of payments which will exactly repay it with interest at a given rate.

Two money time series may be compared by converting them into equivalent uniform annual series (annual cost method). They may also be compared by converting them into equivalent single payments (present worth method). Still another method for comparing two money time series is on the basis of capitalized cost. A capitalized cost of a reservoir, for instance, is that sum of money the interest from which will provide for restoring the lost capacity of the reservoir at stated intervals indefinitely.

In other words, the computations of siltation damage and of erosion control benefits may be accomplished by (1) annual cost method, (2) by present worth method or (3) by capitalized cost method. The annual cost method appears to be used by engineers and economists somewhat oftener than the present worth or the capitalized cost methods. Yet, because of the different annual utility loss series and capacity replacement series without and with control measures, the damages and benefits are probably as difficult to interpret by annual cost method as by present worth or capitalized cost method.

SEDIMENTATION DAMAGE TO LARGER RESERVOIRS

Sedimentation Damage to Bridgeport Reservoir

1. The reservoir, completed in 1934, is located 43 miles above Fort Worth, on the West Fork of the Trinity River. It is the most recent one in a series of three reservoirs on the West Fork. The dam is an earthen

embankment, protected on the upstream slope with stone paving. The spillway is constructed of concrete. The design provides for regulation of the overflow by Stoney crest gates. The spillway has an elevation of 826 feet, and its total net length is 75 feet which is divided into 3 bays or openings, each 25 feet wide. Two of the openings are equipped with Stoney crest gates 25 feet wide by 31 feet high. No gate has been installed in the remaining opening, but recesses have been left in the masonry for stop-logs and for the installation of a third Stoney crest gate if desired. The service outlets, to feed the water to Eagle Mountain and to Lake Worth reservoirs downstream consist of four 48-inch cast iron pipes. The service outlets are laid in a concrete tunnel which passes through the bottom of the dam.

The original capacity of this reservoir at the spillway level was 292,000 acre-feet. The original surface area of this conservation pool, at the spillway level, covered about 11,400 acres. The reservoir was built by the Tarrant County Water Control and Improvement District No. 1. The purposes of the conservation storage below spillway level were to augment the municipal water supply of the city of Fort Worth and to supply other beneficial public uses. The capacity above spillway level, approximately 524,000 acre-feet, was designed to detain flood waters for the protection of Fort Worth and adjacent territory. By installing an additional Stoney gate at the dam or by using stop-logs, the flood storage can be converted into conservation storage to the extent desired. The maintenance of the proper capacity for flood protection, however, will limit the amount of flood storage that may be thus converted into conservation storage. This reservoir is believed to completely dominate the run-off of the West Fork above it.

2. The entire watershed of the West Fork above Lake Bridgeport Dam is located within the West Cross Timbers, as shown on the map "Major Soil Group Areas." The western nine-tenths of the watershed may be classed as range land. This portion of the watershed is identified by a series of discontinuous, steep, wooded ridges interspersed with broad smooth prairies. The ridges, composed of resistant sandstone and limestone strata, are covered with a thin mantle of sandy soils from the slopes of which a considerable amount of soil has been washed by intense rains. The prairies, on the other hand, have developed deep soils from exposed parent materials of shale and clays. The natural vegetation though seriously depleted by improper livestock management and burning has inhibited run-off and soil loss to a marked degree.

In the most severely eroded, eastern portion of the Western Cross Timbers, in which the reservoir basin is located, the topography is rough and the soils are sandy. Here sheet erosion has removed much of the top soil from cultivated fields, and gullies have completely dissected large areas of both pasture and woodland as well as cultivated and abandoned areas. The beds of pack-sand underlying this severely damaged by erosion area are friable and induce severe gullying.

About 80 per cent of the upland area of this watershed is in range and pasture, and 16 per cent is in cultivation, most of which is in the eastern part in the immediate vicinity of the lake. In the flood plain, 12 per cent is in cultivation and 77 per cent in pasture. Because most of the land is devoted to range, run-off and erosion have not been as accelerated in this watershed as in most others. Yet, considerable erosion has taken place, particularly in the eastern uplands where there is a large proportion of cultivated land. The average annual soil loss in the range land area has been estimated at 7 tons per acre as compared to 29 tons per acre in the cultivated uplands. Although a considerable amount of this eroded material is deposited on lands in the flood plain, especially in the eastern part of the watershed, a high percentage of the silt and clay from the range land area is carried as suspended sediment load and is deposited in Lake Bridgeport, thereby reducing its storage capacity. Reconnaissance measurements of sediment in Lake Bridgeport indicate that about 78 acre-feet of material per 100 square miles of watershed accumulate annually in its basin. On this basis, the original storage capacity of Bridgeport Reservoir is being depleted annually at the rate of 0.28 per cent.

3. As indicated previously, this is a multiple-purpose reservoir. It is used for: (1) flood control, (2) public water supply, (3) improvement of sanitary conditions of public water supply in Lake Worth by furnishing increased water for dilution of wastes and sewage, (4) recreation, (5) improving sewage disposal by contributing to the low water flow of the river which will aid health and reduce odor nuisance, (6) wild life, (7) providing a silting basin which will increase the lives of Eagle Mountain and Lake Worth reservoirs downstream, (8) increasing the scenic and property values of the area, and (9) maintaining relatively constant stages in Eagle Mountain and Lake Worth reservoirs, thereby protecting their recreational and scenic values.

The Fort Worth city water supply intake is located at the Lake Worth dam. Since Lake Worth, as well as the Eagle Mountain Reservoir immediately above it, are used for swimming and recreation by thousands of people and since the shores of both these lakes are occupied by extensive concessions, camp sites, and permanent residences, the sanitary protection afforded by the additional dry weather flow from Lake Bridgeport is exceedingly important. Although all three of the reservoirs are operated as a unit, the operations of Bridgeport Reservoir are different from those of the other two reservoirs in that its water stage is normally permitted to fluctuate widely in order to keep the water level in the other two reservoirs relatively constant. This fact will tend to retard or prevent very intensive development of recreational and residential possibilities at Bridgeport. As the lake is drawn down, any silt deposits will become objectionable because of unsightliness, odor, and decreased accessibility.

Proper consideration of the service which a storage reservoir of given capacity will render must take into account periods of small rainfall and low run-off. The longest period of deficient rainfall and consequent low discharge was for the years 1909 to 1912, inclusive. During this 4-year period the annual run-off was approximately 70,000 acre-feet. Obviously, the capacity of any storage reservoir must be such as to afford an additional quantity of water supplemental to the inflow, less evaporation, seepage, and other losses, sufficient to tide over periods of deficient rainfall and run-off.

After allowing for the rainfall on the lake surface (23 inches annually in 1909-1912), the net evaporation from the reservoir area is estimated at about 3 feet per year. At spillway level this would be 32,700 acre-feet (10,800 acres × 3 feet = 32,700 acre-feet). Assuming an average water surface of the lake of about 7,500 acres, the average annual evaporation loss would be 22,500 acre-feet. In addition to this loss, some allowance must be made, perhaps at least 20,000 acre-feet annually, for losses through seepage under the dam and into the ground and for the water losses which must invariably occur during dry weather periods in the more than 25 miles of open, meandering stream channel between Bridgeport and Eagle Mountain reservoirs. Furthermore, a certain percentage, perhaps at least 15 per cent of the capacity of the reservoir when originally constructed, or about 44,000 acre-feet, will be inaccessible, as all water cannot ordinarily be released or drawn from the reservoir.

The main conclusion to be drawn from this discussion is that during a 4-year dry period like that of 1909-1912, the total water losses would amount to about 216,000 acre-feet. With the reservoir capacity of about 200,000 acre-feet at the beginning (on the basis of past operation of the reservoir, this seems a maximum capacity to be expected), plus the total expected run-off from the watershed or the total inflow into the lake of about 280,000 acre-feet during the period, the reservoir would have a net available capacity of approximately 264,000 acre-feet at the end of such a dry period. From this amount, at least 60,000 acre-feet must be deducted for the minimum net release of water to Lake Eagle Mountain. In other words, about 204,000 acre-feet is all that could be filled in with silt before replacement of the reservoir becomes necessary. This is about 70 per cent of the original capacity, as figured in Table 1, Column 5.

4. Siltation will not rapidly reduce the flood control storage capacity of this reservoir. Since only that capacity above spillway level is used for flood control storage and since siltation does not ordinarily occur above spillway level, this capacity would not be seriously depleted. Tangible damage will, therefore, occur only to that portion of the reservoir used for water conservation and serving the purposes enumerated previously. The cost of flood control storage above spillway level was, therefore, excluded from the computations of siltation damage to this reservoir. The total cost ($2,317,000) of the reservoir, which is used for both flood control and water conservation, was allocated in the same proportion as storage allocation for the two purposes. It is entirely possible that, as the

water supply becomes threatened, the spillway level will be periodically raised to offset the conservation storage capacity lost by depletion. In such cases, the capacity available for flood control storage will be reduced.

5. The lapse of time since the construction of this reservoir has been too short to make a fair estimate of its value for recreation and for other purposes. The lake is still in the early stage of development. Moreover, the reservoir is publicly owned and operated and will not be developed on a commercial basis, and the loss of utility cannot, therefore, be expressed through loss of income or decline in the market value of the reservoir. Also, to segregate the damage inflicted by sedimentation to the different public values which are provided by the reservoir as a unit is difficult, if not impracticable. It seems reasonable to assume, however, that since the public voted bonds and state and local officials approved plans for the reservoir, the project as a whole is economically justifiable. If people of Tarrant County are willing to pay taxes to provide for this reservoir, they must believe that the returns, or the combined utility, would be sufficient to justify the construction.

Annual services of the reservoir (or its total utility) should, therefore, be worth at least what it cost to provide them, i. e., the sum of (1) annual sinking fund depreciation cost to replace the reservoir at the end of useful life,[1] (2) 2½ per cent annual interest on original investment (or on first cost) in reservoir capacity furnishing the services,[2] and (3) average annual long-run cost of reservoir operation and maintenance, estimated at $10,000.

There is some uncertainty as to the actual time when depletion of the capacity of the reservoir begins to cause actual decline in utility, or the decline in the amount of annual services. It is reasonably clear, however, that the principal services of the reservoir depend on a continuing storage for their existence and that the total utility of the reservoir for all purposes (excepting flood control) will decline in some direct relationship to capacity depletion.

This reservoir is situated in a region devoted primarily to grazing and, except for some 7,700 acres of the total of 21,000 acres owned by the District along the south side of the reservoir, accessibility to the reservoir is not now readily available to the public. The District has leased a number of 1- and 2-acre tracts at $50 to $200 per year cash in advance for docks, fishing camps, et cetera. Few permanent improvements, however, and the period of time since the construction of the reservoir has been so short that not much road construction has been possible.

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[1]That is, annual payments into depreciation sinking fund to accumulate, at 2.5%, the $3,462,533 required to restore the lost capacity at the end of 242 years. (See Table No. 1.) Financially, this would be the most economical policy to follow. For other reasons, however, the District may find it impracticable to set up a sinking fund and may replace the reservoir by a new bond issue when needed.

[2]Although the actual cost of borrowed money to the water District is approximately 5 per cent, including all the costs incidental to the borrowing, it is believed that a long period time value of money should not be figured at more than 2.5 per cent. Perhaps it should be figured even at a lower rate.

Considering these and other factors, it has been estimated that for the next 20 years the services of the Bridgeport Reservoir will not be affected, to any appreciable degree, by sedimentation. After that date, however, and continuing over the estimated remaining life of the reservoir, the net annual utility of the reservoir has been assumed to decrease gradually, year by year, as its capacity is replaced by silt. That is to say, the decline in the value of annual reservoir services is estimated to take place during the 222 years, 1960-2182.

6. Original cost of the 197,859 acre-feet conservation storage capacity of the reservoir, which will be depleted in an estimated period of 242 years,[1] 1940-2182, is $2.84 per acre-foot or a total of $561,920. This includes the cost of construction of the dam and the value of the land actually under water at spillway level.

7. Replacement cost of the lost conservation storage capacity of 197,859 acre-feet is estimated at $17.50 per acre-foot or a total of $3,462,533.

NOW,

Let \$R = Value of services rendered annually at the beginning.

Then, the amount at the end of 242 years of all the services rendered equals $\$R\ S_{242}$ at .025[2] less the amount at the end of 242 years of the losses in revenue or services due to silting.

i. e., $$\$R\ S_{242} \text{ at } .025 - \frac{R}{222}[S_1 \text{ at } .025 + S_2 \text{ at } .025 + S_3 \text{ at } .025 + \text{---} S_{222} \text{ at } .025]$$

Now the amount at the end of 242 years of all the services rendered =

$$\$R\ (\$15,708^3) - \frac{R}{222}(\$383,521^4) =$$

$$\$R\ (\$15,708) - \$R\ (\$1,728^5) = \$13,980\ R$$

$$\$13,980\ R = \$220,665,984^6 + \$157,080,000^7 + \$3,462,533^8 = \$381,208,517$$

$$R = \$24,268^9$$

Having determined the value of R, we can compute the amount at the end of 242 years of the losses in reservoir services due to silting.

[1]Assuming the 88 acre-feet capacity remaining at the end of the present estimated life of the reservoir need be supplemented and not abandoned. (See Table 1, Cols. 20-21.) By itself, this 88 acre-feet capacity will have no service value at that time.

[2]S_{242} at $.025 = \frac{(1+.025)^{242}-1}{.025}$, see "Compound Interest and Annuity Tables" by F. C. Kent and M. E. Kent, McGraw-Hill Book Co., N. Y., 1926, Table III entitled The amount of 1 per annum at compound interest in which $S_n = \frac{(1+i)^n-1}{i}$. The Kents' table was extended from 100 to 242 years by the authors of this bulletin.

[3]The amount of \$1 per annum at 2.5% compound interest for 242 years.

[4]The sum of the amounts of \$1 per annum at 2.5% compound interest for 222 years.

[5]The sum of compound amount factors of \$383,521 ÷ 222 years = \$1,728.

[6]Original cost of \$561,920 × .025 = \$14,048; \$14,048 × \$15,708 = \$220,665,984.

[7]Average long-run annual cost of operation and maintenance of \$10,000 × \$15,708 = \$157,080,000.

[8]Replacement cost of lost capacity. [9]\$381,208,517 ÷ \$15,708 R = \$24,268.

This is

$$\frac{R}{222}\,[S_1 \text{ at } .025+S_2 \text{ at } .025+\text{———}S_{222} \text{ at } .025]^1 =$$

$$\frac{R}{222}\,(\$383,521) =$$

$$\frac{\$24,268}{222}\,(\$383,521) = \$41,926,516$$

At 2.5 percent, the present value of this loss is =

$$\frac{\$R}{222}\,[S_1 \text{ at } .025+S_2 \text{ at } .025+\text{———}S_{222} \text{ at } .025]\quad (1.025)^{-242\,2}$$

$$\$41,926,516\ (1.025)^{-242} = \$41,926,516\ (0.0025399^{3}) = \$106,489$$

The *equivalent* annual loss of reservoir services during the 242 year period is[4]

$$\$106,489\ \frac{1}{A_{242} \text{ at } .025}\,{}^{5} = \$106,489\ (0.025063^{6}) = \$2,669$$

Sedimentation Damage to Eagle Mountain Reservoir

1. This reservoir, completed in 1932, is located some 11 miles above Fort Worth on the West Fork of the Trinity River. The dam is an earthen embankment, protected on the upstream slope with stone paving. The spillway is constructed of concrete. The design provides for regulation of the overflow by Stoney crest gates. The spillway has an elevation of 649 feet, and its total net length is 100 feet, which is divided into 4 bays or openings, each 25 feet wide. Three of the openings are equipped with Stoney crest gates 25 feet wide by 31 feet high. No gate has been installed in the remaining opening, but recesses similar to those at Bridgeport have been left in the masonry so that an additional gate can be installed. The service outlets, to feed the water to Lake Worth below it, consist of four 48-inch cast iron pipes. The service outlets are laid in a concrete tunnel which passes through the bottom of the dam.

The original capacity of this reservoir at the spillway level was 211,000 acre-feet. The original surface area of this conservation pool at the spill-

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[1]This may be written $\frac{R}{222}\sum_{n=1}^{222} S_n$

[2]This may be written $\left[\frac{R}{222}\sum_{n=1}^{222} S_n\right](1.025)^{-242}$

[3]The present value of $1 at 2.5%, for 242 years.

[4] $\left[\frac{R}{222}\cdot\sum_{n=1}^{222} S_n\right](1.025)^{-242}\cdot\frac{1}{A_{242} \text{ at } .025}$

[5] $\frac{1}{A_{242} \text{ at } .025} = \frac{.025}{1-(1.025)^{-242}}$; see Kents' Table VI.

Annuity whose present value at 2.5% compound interest is $1 for 242 years.

way level covered about 9,850 acres. Like Bridgeport, the reservoir was built by the Tarrant County Water Control and Improvement District No. 1. The conservation storage below spillway level was for the purpose of augmenting the municipal water supply of the city of Fort Worth, providing recreational facilities, and for other beneficial public uses. The capacity above spillway level (457,000 acre-feet) was designed to detain flood water for the protection of Fort Worth and adjacent territory. By installing an additional Stoney gate at the dam or by using stop-logs, the flood control capacity can be converted into conservation storage to the extent desired. But the maintenance of proper provision for flood protection will limit the amount of flood storage that may be thus converted into conservation storage.

2. The severely eroded area of the West Cross Timbers described under Bridgeport Reservoir comprises about four-fifths of the total drainage area of Eagle Mountain Reservoir, the rest being in the Grand Prairie Rangeland and in the West Cross Timbers Rangeland. Most of the land is in range and pasture uses, although much in the eroded area is now or has been at one time in cultivation. It is significant that over half of the crop land in this watershed has been abandoned. Damaging sediment deposition has occurred on most of the valley bottoms, and many of the stream channels have been completely choked with sand. It is likely that the rate of siltation in this lake will increase considerably if erosion continues unabated in the upland areas since, with the channels already clogged with sediment, a greater proportion of the future silt loads will be deposited in the lake. Reconnaissance measurements of sediment in Eagle Mountain Reservoir indicate that about 100 acre-feet of material per 100 square miles of watershed accumulates annually in its basin. On this basis the original storage capacity of Eagle Mountain Reservoir is being depleted annually at the rate of 0.48 per cent.

3. This is also a multiple-purpose reservoir, and it provides nearly the same services as the Bridgeport Reservoir described earlier. The step--to-step computations of siltation damage are therefore essentially the same as those explained under Bridgeport. The Eagle Mountain Lake shores are rapidly being developed into extensive residence sites, and the lake is much used for boating and recreation. On the adjacent uplands are some of the finest residential improvements. Much of the publicly owned areas around the lake are leased for camps, residences, concessions, et cetera.

As at Bridgeport, all of the land secured by the Tarrant County Water Control and Improvement District No. 1 for the construction of Eagle Mountain Reservoir was bought by agreement. Condemnation, that is, purchase from an unwilling owner by legal action based on public necessity, was not resorted to. (Note: Consequently, the land probably cost more than its agricultural worth.) For Eagle Mountain Lake, there was bought in fee about 9,000 acres of flood plain lands and about 3,700 acres of uplands, the latter usually to avoid suits for damage to remainder. On about 1,700 acres the District has a perpetual easement. About 70 per cent of the water frontage is owned by the District.

The average value paid by the District for Eagle Mountain lands and improvements was $54 per acre. Competent authorities estimate that the hilly, rolling upland prairie lands adjacent to the lake on the east were worth some $15-$20 per acre before the lake was built, while the loamy bottom lands were worth $50 to $65. The sandy cross timber uplands along the west side of the lake were worth some $15-$20, while the attendant bottom lands varied from $45 to $55.

A few of the original land owners were far-sighted enough to retain title to their lands situated between spillway and extreme flood limit elevations. In such cases, the District took only flood easements. Only a few such owners are selling water frontages. There are two owners who are now selling, and they are ordinarily securing $80-$100 per acre for tracts of less than 20 acres with narrow frontage on the water front. However, each has sold choice tracts at $500-$1,000 per acre. It is reported that 13 acres on the west shore, a mile or so above the west end of the West Dam or "levee," sold for $1,000 per acre. Some of the choice lands are leased for $50-$100 annually for 3-acre tracts, one acre wide and 3 acres deep.

The District does not sell any of its land. It leases lands in choice locations at $50-$100 per acre annually. Such tracts are usually not over 2 acres. Around the upper end of the reservoir the District now leases at $5-$10 per acre annually. It was found hardly practicable to ascertain the average selling value or the average lease value of all the land, as the presence of small sandy beaches, rock bluffs, et cetera cause wide fluctuations. Accessibility is also a primary consideration, and the period of time since the lake construction has been so short that not much road construction has been possible. In fact, the road extending entirely along one side of Lake Worth has been completed only within the last three years. A somewhat extensive development of recreational facilities was completed along one side of Lake Worth at the same time, while such facilities, including a large park area, are just now being planned for Lake Eagle Mountain. No doubt, the property, scenic, and recreational values of this lake will continue to increase at a rapid rate for some time to come in spite of a loss of reservoir capacity by silting. It is quite obvious, however, that some parts of the lake, especially in the vicinity of the entrance channel, the head of the lake, and the several inlets, will be the first ones to become a nuisance and disturb the enjoyment of the public and of the riparian owners and will decline or lose their value because of silt deposits. Because of the newness of the lake, which now is at a development stage, and because of insufficient funds and personnel for this study, no satisfactory estimate could be obtained concerning the probable long-run decline in surrounding property, recreational, and other values which will result from the gradual silting of the reservoir. Moreover, the Eagle Mountain Reservoir, like the Bridgeport and the Lake

Worth reservoirs, is not operated on a commercial basis, and all of its services cannot be expressed in money. Extensive park, picnic, barbecue, fishing, swimming, and other recreational facilities are offered free of charge to the public. It has been estimated that some 175,000 people make use of these facilities annually. The siltation damage to this reservoir will therefore be computed in a manner similar to that explained under Bridgeport. The decline in the services of this reservoir has been estimated to start after a 10-year period from 1940 instead of after the 20-year period used for Bridgeport.

4. The construction and the maintenance of this lake is assumed to represent prudent public investment, and the annual services of the reservoir are therefore worth at least what it cost to provide them; i. e., the sum of (1) annual payments into depreciation sinking fund to accumulate the amount estimated to be necessary to replace the lost capacity at the end of the 140-year life of the reservoir ($3,257,329), (2) annual interest, 2.5 per cent, on original investment in reservoir capacity furnishing the services, and (3) average annual long-run cost of reservoir operation, necessary improvements, and upkeep, estimated at $12,000.

5. Annual services of the reservoir are estimated to decline concurrently with annual reduction of reservoir capacity through silting. This decline is estimated to start after about 10 years from 1940; i. e., the decline in the value of annual reservoir services is estimated to take place during the 130 years, 1950-2080.

6. Original cost of the 141,623 acre-feet conservation storage capacity of the reservoir, which will be depleted in an estimated period of 140 years, is $5.26 per acre-foot or a total of $744,937. (See Table 1.)

7. Replacement cost of this capacity is estimated at $23 per acre-foot or a total of $3,257,329.

NOW,

Let \$R = Value of services rendered annually at the beginning.

Then, the amount at the end of 140 years of all the services rendered equals $\$R\ S_{140}$ at .025 less the amount at the end of 140 years of the losses in revenue or services due to silting.

i. e., $\$R\ S_{140} \text{ at } .025 - \frac{R}{130}[S_1 \text{ at } .025 + S_2 \text{ at } .025 + S_3 \text{ at } .025 + \text{———} S_{130} \text{ at } .025]$

Now the amount at the end of 140 years of all the services rendered =

$$\$R\ (\$1{,}229^1) - \frac{\$R}{130}(\$33{,}799^2) =$$

$$\$R\ (\$1{,}229) - \$R\ (\$260^3) = \$969\ R$$

[1]The amount of \$1 per annum at 2.5% compound interest for 140 years.
[2]The sum of the amounts of \$1 per annum at 2.5% compound interest for 130 years.
[3]The sum of the compound amount factors of \$33,799 ÷ 130 years = \$260.

$969 R = $22,887,667[1] + $14,748,000[2] + $3,257,329[3] = $40,892,996
R = $42,201[4]

Having determined the value of R, we can compute the amount at the end of 140 years of the losses in reservoir services due to silting.

This is

$$\frac{R}{130}\,[S_1 \text{ at } .025 + S_2 \text{ at } .025 + \text{——} S_{130} \text{ at } .025]^5 =$$

$$\frac{R}{130}\,(\$33,799) =$$

$$\frac{\$42,201}{130}\,(\$33,799) = \$10,971,155$$

The present value of this loss is

$$\frac{\$R}{130}\,[S_1 \text{ at } .025 + S_2 \text{ at } .025 + \text{———} S_{130} \text{ at } .025]\ (1.025)^{-140\,6}$$

$$\$10,971,155\ (1.025)^{-140} = \$10,971,155\ (0.0315253^7) = \$345,869$$

The *equivalent* annual loss of reservoir services during the 140 year period is

$$\$345,869\ \frac{1}{A_{140} \text{ at } .025} = \$345,869\ (0.0258138^8) = \$8,928$$

Sedimentation Damage to Lake Worth

1. The dam forming Lake Worth is located on the West Fork of the Trinity River about 4 miles west of Fort Worth. It was built by the City of Fort Worth in 1914 to impound water for municipal purposes. The dam is an earthen embankment with a fixed concrete spillway 700 feet long. The crest of the spillway is at elevation 594.3. The embankment has a freeboard of 12 feet above the spillway crest. The original capacity of this reservoir at the spillway level has been estimated at 47,177 acre-feet. The original surface area at spillway level was probably about 3,770 acres. Since this reservoir was put into service, silting has occurred which has considerably reduced both its surficial area and capacity. On the

[1]Original cost of $744,937 × $.025 = $18,623; $18,623 × $1,229 = $22,887,667.
[2]Average annual long-run cost of operation and maintenance of $12,000 × $1,229 = $14,748,000
[3]Replacement cost of lost capacity.
[4]$40,892,996 ÷ $969 R = $42,201.

[5]This may be written $\frac{R}{130} \sum_{n=1}^{130} S_n$

[6]This may be written $\left[\frac{R}{130} \sum_{n=1}^{130} S_n\right] (1.025)^{-140}$

[7]The present value of $1 at 2.5%, for 140 years.
[8]Annuity whose present value at 2.5% compound interest is $1, for 140 years.

basis of the best available data, it has been estimated that the present capacity of the lake is approximately 60 per cent of the original capacity, or 28,000 acre-feet, and its surface area free from vegetative growth and swamping, 3,200 acres. These figures must be regarded as but rough approximations.

Fort Worth no longer depends upon storage capacity of Lake Worth for its water supply. The latter is largely supplied by release of water as needed from the Eagle Mountain and the Bridgeport reservoirs. The city has permitted the Lake Worth shore to be developed into residence sites, public parks areas, et cetera, and the lake is much used for boating, swimming, fishing, and for other recreational purposes. The water surface is seldom drawn down more than 3 to 4 feet below the spillway level, and the residents along its shores and the general public have become accustomed to a fairly uniform stage. Because of these considerations and because of the considerable silt deposits in the lake, especially in the vicinity of the upper end and in the many tributary bays, it will be highly undesirable to draw heavily upon the storage of this lake except in a great extremity.

2. With the construction of Eagle Mountain and Bridgeport reservoirs, the silt-contributing tributary drainage area above Lake Worth Dam was reduced from 1,969 square miles to 94 square miles, and the annual silt inflow was reduced from an estimated 1,062 acre-feet to approximately 47 acre-feet. It has been pointed out that the remaining useful life of the present Eagle Mountain Reservoir is only 144 years. Considering the location and the worth of that lake and its surrounding property, however, it seems reasonable to assume that the capacity which will be destroyed by silt at Eagle Mountain will be restored through the conversion of its present flood control storage into conservation storage, reconstructing the existing flood storage in another site above the present one. Consequently, as far as can be foreseen at this time, Eagle Mountain Reservoir will continue to act as an effective settling basin for silt originating in its drainage area and, thus, will protect the capacity of Lake Worth for a very long time to come, perhaps for several hundred years. For all practical purposes, the present estimated 47.2 acre-feet silt inflow into Lake Worth Reservoir will therefore be expected to continue for a similar period.

3. Lake Worth, like Bridgeport and Eagle Mountain reservoirs, is a multiple-purpose reservoir. Like the others, it is not operated on a commercial basis, and the loss of its utility by silting cannot be accurately estimated through loss of monetary income. Extensive park, picnic, barbecue, fishing, swimming, and other recreational facilities are offered free of direct charge to the public. It has been estimated that some 300,000 people make use of these facilities annually. Much of the water frontage is owned by the city which uses it for park purposes or leases it for camps, residences, concessions, et cetera. Large areas of water frontage are cut into tracts about 75 feet in width on the lake by 175 feet in depth. These ordinarily lease for $0.50 to $1.00 per front foot annually with

option to renew. The city has some 400 lessees of such tracts and concessions which annually pay in $25,000-$30,000. This income hardly covers the annual expenditure for parks and road improvements, sewage disposal service, and operation and maintenance of the lake. The gross yearly income to storekeepers, concessionnaires, amusement places, boat owners, clubs, camps, et cetera is probably twenty times the annual gross revenue to the city.

In addition to the publicly owned land, there are thousands of acres in the vicinity which are privately owned and are being much sought after for residential uses because of the lake vistas. All land within a mile of the lake has doubled or trebled in value, at least. Where values were $10 to $50 per acre, there is little or none that can be bought for less than $100 to $500, while higher values are not unusual.

This increase in land values has taken place in spite of the 40 per cent loss of original capacity of the lake. Apparently sedimentation has had less effect than location of the lake in determining its value. Yet, because of the shoaling and swamping effects of sediment accumulation, there are now large areas in the upper end of the lake and in the several side inlets that are rapidly becoming a liability rather than an asset to the lake as a whole. It was found impracticable either to determine the present actual aggregate value of all the services provided by this lake or to estimate what the value of these services would have been if the lake now had its original capacity. It is probable, however, that the present land values in the vicinity of the entrance channel, the head of the lake, and the several side inlets would have been at least $300,000 higher if it were not for the shoaling, swamping, and odor effects of present silt deposits.

Furthermore, it is probable that land values at the present rate would decline at least $3,000,000 in the vicinity of the lake if the latter were destroyed. Yet, it has not been possible to estimate how, in the absence of sedimentation control, this decline in the value of land would be distributed over a future period of years.

4. There is no satisfactory and infallible method of determining the actual public utility or the actual value of the services provided by this lake and of estimating the siltation damage to each of the various uses. Even though a large but indeterminate part of the total services provided by the lake are not expressible in exact money terms, it is pertinent to estimate how many people are using the facilities, what the effects are on surrounding property, and what is the long run cost of reservoir ownership and operation. In many respects the irreducibles in a public project of this character create problems of judgment similar to those which arise in personal economy studies. The best that an individual can do in dealing with his personal problems of economy may be to note the satisfaction that will come from particular expenditures and to consider them in the light of their long-run costs and in the light of his capacity to pay.

A similar analysis may be applied to such a public works project as the one under consideration here. Considering the already existing shoaling, swamping, odor, unsightliness, and other injurious effects of present silt deposits in many parts of the lake, it is believed that any substantial further silt deposition will both create a serious nuisance and will disturb, or prevent in some places at least, the enjoyment of the public and of the riparian owners and will lower property values to the extent that the combined injurious effects of siltation will be more than the annual cost of maintaining the existing capacity by dredging. The actual dredging operations are not contemplated at present, but it is believed that these cannot economically be postponed for more than 20 years. Assuming an 8-inch hydraulic dredge similar to that now used for dredging White Rock Reservoir and considering the availability of silt disposal areas and other conditions of the Lake Worth project, it is estimated that the cost of silt removal from this lake will average not less than $500 per acre-foot. On this basis it would cost approximately $23,600 annually to remove the yearly silt inflow of 47.2 acre-feet. The annual cost of silt removal, or the annual siltation damage, can thus be computed as follows:

At 2.5 per cent, the present value of $23,600 each year indefinitely beginning 20 years hence =

$$\frac{\$23{,}600}{.025}(1.025)^{-20} = \$576{,}096$$

$$\text{i. e., } \frac{\$23{,}600}{.025} = \$944{,}000;\ \$944{,}000\ (0.6102709^{1}) = \$576{,}096$$

The *equivalent* uniform annual siltation damage beginning immediately and continuing indefinitely =

$$\$576{,}096\ (.025) = \$14{,}402$$

Sedimentation Damage to Lake Dallas

1. Lake Dallas Dam is located on the Elm Fork of the Trinity River about 26 miles above the city of Dallas. The reservoir was completed in the fall of 1927 and put into service in 1928. It was originally known as Garza Lake. This reservoir was built by the city of Dallas to impound water for municipal purposes. The dam is an earthen embankment, slightly more than 2 miles in length, protected on the upstream face with stone paving. The service spillway is a concrete structure with a clear length of 551 feet. The elevation of the spillway crest is 525 feet. The embankment has a freeboard of 15 feet above the spillway level. The spillway has a broad top and a substantial section resting on a sandstone foundation. There are no crest gates and no provision has been made for installing them. Possibly, 3-foot flashboards could be installed on the spillway to increase the storage capacity.

[1]The present value of $1, at 2.5% for 20 years.

Back water at crest stage extends about 10½ miles up the valley. The area of the lake at this level is 10,900 acres with an average depth of 18 feet and the original capacity 180,760 acre-feet. The water supply outlet is through two concrete conduits 465 feet long. Two 48-inch gates are provided into each conduit and an additional 18-inch gate into one of the conduits. The water from Lake Dallas flows by means of the small, meandering, open stream channel to the Filter Plant at Bachman Lake. In addition to Lake Dallas, there are three small channel reservoirs on the Elm Fork between Lake Dallas and the city: Carrollton Dam, 18 miles from Dallas, California Crossing Dam, 8½ miles from Dallas, and Record Crossing Dam, 3½ miles from the city. The latter is 1½ miles downstream from Bachman pumping station and maintains the storage pool from which the supply is delivered to the low-lift pumps at Bachman pumping station. The combined storage of the Carrollton, California Crossing, and the Record Crossing reservoirs at their spillway levels is less than 300 acre-feet.

2. The watershed of Lake Dallas is 1,174 square miles upon which the average rainfall is 34 inches. The drainage basin is of moderate relief and lies in four physiographic divisions (see map "Major Soil Group Areas"); namely, Grand Prairie (50%), East Cross Timbers (27%), Blackland Prairie (14%), and West Cross Timbers (8%). The principal use of land in the upland area is for crop production, although much of the land is in cleared and woodland pasture. Approximately 85 per cent of the floodplain is in cropland. Sheet erosion generally and moderate gully development locally are in evidence. Erosional waste from East and West Cross Timbers includes much sand, and flood flows from Grand and Blackland Prairies, especially from the latter, are generally turbid with considerable charges of suspended silt and clay. Much of the coarse sediment originates in the Critical areas of the East and West Cross Timbers, and the fine sediments come largely from the Blackland Prairie and Grand Prairie farmland areas. Approximately 113 acre-feet of sediment for each 100 square miles of drainage area are deposited annually in Lake Dallas. It is probable that unless land use practices in the upland areas of the tributary are corrected, this rate of siltation will increase from year to year.

3. Dallas has a dual water supply. Dallas proper and outlying sections east of the river are supplied with surface water from Lake Dallas which has been aerated, coagulated, filtered, and chlorinated before it is supplied to the city. While treated water may be supplied to the Oak Cliff section east of the river, under normal operating conditions Oak Cliff is supplied by deep wells, driven about 2,750 feet to the Trinity sands. During the 10-year period, 1928-1938, the yearly amount of water filtered has increased from 5.2 billion gallons in 1927-28 to 8.5 billion gallons in 1937-38.[1] If the past increase should continue in the future, the present demand would be expected to double in about 25 years.

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[1]The amount treated in 1936-37 reached 9.1 billion gallons.

The important consideration of the service which a storage reservoir of given capacity will render must take into account periods of small rainfall and low or no run-off. No reliable detailed records of the run-off of the Elm Fork above Lake Dallas Dam have been available for our use. Reliable records of run-off for the 2,650 square miles of watershed above Record Crossing Dam were readily available, however, for the period 1907-1937. While it is expected that the run-off from the smaller Lake Dallas watershed will be greater proportionately than from the larger watershed above Record Crossing, no information was available to show how great the difference might be. It was necessary, therefore, to assume that the area above Lake Dallas Dam will take its proportionate part of the run-off corresponding to the ratio of that area to the whole area above Record Crossing. Thus, the run-off at Lake Dallas damsite might be expected to be 44% of that at Record Crossing. The longest period of low run-off was for the three years 1909-1911, inclusive, for which the average at Lake Dallas damsite was 7.2 billion gallons.

The mean evaporation from the reservoir area has been estimated at about 60 inches per year. After allowing for rainfall of 23 inches on the lake surface during the critical dry period, the annual net loss would be about 3 feet. At spillway level this would be 32,700 acre-feet (10,900 acres $\times$ 3 feet $=$ 32,700 acre-feet). Assuming an average lake area of about 8,500 acres, the average annual evaporation loss would be 25,000 acre-feet or 8.1 billion gallons. In addition, a substantial allowance must be made for seepage under the dam and into the ground and the water losses through evaporation and seepage which must invariably occur during dry weather periods in the more than 40 miles of open, meandering, stream channel between Lake Dallas and the waterworks plant at Bachman Lake. This loss may be as much or more than the average annual evaporation loss from lake surface. Furthermore, a certain percentage of the storage will always be inaccessible, as all water cannot be drawn from the reservoir. Also, no precise estimate can be formed of the probable frequency or lengths of such low run-off periods in the future, against which a water storage must be provided. The 1909-1911 period gives us an idea of at least what may be expected to occur. In a case of public water supply, ordinarily some additional allowance should be made as a safety factor.

The main conclusion to be drawn from this discussion is that when the reservoir has lost about 55 per cent of its original storage capacity by silting, the storage pool of about 81,000 acre-feet remaining at that time either would become empty at the end of a dry season similar to 1909-1911 or would allow an annual draft so small as to make it uneconomical to operate the reservoir, even as a supplementary supply. In other words, the entire project would become economically worthless as a source of city water supply. At the present rate of siltation it would take an additional 64 years to reach this degree of depletion. If it were not for siltation, the reservoir could be used for water supply purposes for a very long time as a unit in the waterworks system, perhaps indefinitely, as far as our ability to foresee things is concerned. Needless to say, the city would need to supplement at periodic intervals its total raw water storage because of growth in water demand. If the past increase in the use of water will continue in the future, the annual water demand would be not less than 35 billion gallons by the time Lake Dallas will have lost 55 per cent of its original capacity by silting. Obviously, Lake Dallas alone will not be sufficient to meet the total water demand of the city for any such length of time as 64 years. This number of years has been estimated to represent the maximum economic life of Lake Dallas for water supply purposes. It is not the life of the lake as a sole source of Dallas water supply. It is probable that in about 35 years the then depleted capacity of Lake Dallas must be replaced by new storage facilities, but the entire lake need not be abandoned before the end of 64 years. Because of the cost of dual sources of supply, the total cost of water to the city will probably increase after the first replacement of Lake Dallas capacity 35 years hence. The exact amount of this resulting increase in annual cost of water operations is difficult to estimate before the exact source of new supply and its operating conditions become known. If the new reservoir will be constructed at an available damsite on the Elm Fork downstream from Lake Dallas, the general operating conditions will remain about the same.

Lake Dallas was constructed as a source of municipal water supply. Although the lake is used for boating, swimming, and for other recreational purposes, these services provided by the reservoir are not well developed and are purely incidental. As the recreational possibilities of the lake are little developed, it is doubtful that their values will be greatly affected by siltation for a very long time to come. Up to the present, the completion of Lake Dallas has not materially increased land values, except those that front on the lake or lie within a quarter of a mile thereof. According to competent authorities, about 1925 the real value of agricultural lands around the Lake Dallas site was about $35 per acre, including the attached bottom lands which had greater agricultural values. All of the land secured by the city for construction of Lake Dallas Reservoir was bought by agreement. Condemnation, that is, purchase from an unwilling owner by legal action based on public necessity, was not resorted to, and the City of Dallas paid an average of about $80 per acre. In general, this land is now worth about that.

In the light of the foregoing discussion, the siltation damage to Lake Dallas may now be computed as follows:

a. The depleted capacity to be replaced at the end of first 35-year period, 1940-1975, is 45,555 acre-feet, i. e., annual depletion of 1,301.5 acre-feet multiplied by 35 years.

b. The capacity to be replaced at the end of the 64-year useful life of the reservoir is 119,586 acre-feet, i. e., the total reservoir capacity of 165,141 acre-feet in 1940 less the 45,555 acre-feet capacity which was depleted during the first 35-year period of reservoir life.

c. Replacement cost is estimated to be \$27.41 per acre-foot, or the same as the original per unit cost of Lake Dallas. Thus, the total cost of first replacement =

45,555 acre-feet × \$27.41 = \$1,248,663 and the total cost of the final replacement =

119,586 acre-feet × \$27.41 = \$3,277,852

NOW,

(1) At 3½ per cent, the present value of an outlay of \$1,248,663, 35 years hence =

$$\$1{,}248{,}663\ (1.035)^{-35} = \$1{,}248{,}663\ (0.2999769) = \$374{,}570$$

(2) At 3½ per cent, the present value of \$3,277,852, 64 years hence =

$$\$3{,}277{,}852\ (1.035)^{-64} = \$3{,}277{,}852\ (0.1106159) = \$362{,}583$$

(3) The total present value of both replacements =

$$\$374{,}570 + \$362{,}583 = \$737{,}153$$

(4) At 3½ per cent, the equivalent uniform annual cost of replacement, or siltation damage, during the 64-year period, 1940-2004 =

$$\$737{,}153 \frac{1}{A_{64} \text{ at } .035} = \$737{,}153\ (0.0393531^{1}) = \$29{,}009$$

Sedimentation Damage to White Rock Reservoir

1. The dam forming White Rock Reservoir is located on White Rock Creek within the corporate limits of the city of Dallas, some 4 miles northeast of the city hall. It was built by the city in 1911, following a severe water famine, to provide water for municipal purposes. The use of this supply has been discontinued since the construction of Lake Dallas and the adjacent filter plant is not used. The reservoir is now maintained for aesthetic, park, and recreational purposes. These values far exceed the initial investment for constructing the reservoir. In a great extremity the reservoir could be used as a possible reserve supply. The dam is an earthen embankment with a concrete facing on the upstream side and with a fixed concrete spillway 450 feet long. The spillway has a long, broad, concrete apron carrying the overflow to the channel several hundred feet below the dam. The crest of the spillway is at an elevation of 457.45 feet above sea level. This corresponds to the 138.5 contour (local datum).

The original capacity of this reservoir at the spillway level was 18,158 acre-feet and the corresponding original surficial area 1,254 acres. Since the reservoir was put into service, silting has considerably reduced both its surficial area and capacity. On the basis of a survey made in 1935, it has been estimated that the present capacity of the lake at crest stage

[1]Annuity whose present value at 3.5% compound interest is \$1, for 64 years.

is approximately 13,475 acre-feet and its surface area, free from vegetative growth and swamping, about 950 acres.

2. The entire 99 square mile watershed lies within the Blackland Prairie province (see map "Major Soil Group Areas"). Approximately 70 per cent of the watershed is in cropland, 16 per cent in pasture, 6 per cent in farmsteads and urban areas, 5 per cent in woodland, and 3 per cent in idle land. Over four-fifths of the upland area is in cultivation, with cotton and corn as the principal crops, although truck farming is of considerable importance. Livestock production is limited to home consumption and a supply for local markets. Only about one-third of the floodplain is in cultivation.

The stream channel is wide and free of debris and obstructions, except in the extreme lower portion where cottonwood and willow have invaded areas already ruined for other uses by the delta deposits. Considerable above-crest deposits have been laid down in a 5-mile stretch of valley extending upstream from the reservoir. In general, the stream channel, therefore, permits flood waters to recede rapidly. The lake sediment, which has accumulated at the rate of about 156 acre-feet annually, has been deposited almost entirely during flood periods and originates from the erosion of practically all the upland portions of the watershed. Since the reservoir is too small to retain all the run-off from its watershed during floods, and since a large portion of the sediment load is clay and is held in suspension, a substantial portion of the total sediment inflow into the reservoir is normally carried over its spillway. In spite of this factor, White Rock Lake, of all the major reservoirs of the Trinity Basin, has the highest rate of deposition per unit of area of watershed, namely, 160 acre-feet annually per 100 square miles.

It is typical of reservoirs exceeding 10,000 acre-feet in the Blackland Prairie province, and probably represents average conditions in it. Therefore, it is reasonable to expect that without upland erosion control measures deposition rates in future major reservoirs which may be constructed in the Blackland province will range from 150 to more than 200 acre-feet annually per 100 square miles of watershed.

3. Despite the abandonment of White Rock Lake as a source of public water supply, the utility of the reservoir has increased rather than decreased, inasmuch as it now supplies a great need for recreation. Being in the suburb of Dallas it has easy accessibility for a large number of people, and important urban development has taken place near the lake. On the adjacent uplands are some of the finest residential improvements of Dallas.

The original value of the land around this lake has been estimated at something like $35 per acre in 1910. Land values along the two sides of the lake to a depth of approximately one-quarter mile will now average $4,000 per acre. Land within one-fourth to three-fourths of a mile of the lake will average $2,000 per acre, while property from three-fourths to 2 miles from the lake will average $1,000 to $1,500 per acre.

The approximately 2,215 acres of land owned by the city of Dallas, principally bottom lands, is valued at $3,000 to $4,000 per acre. Some of this is leased in small tracts, and some is in free public park and recreational areas.

The Columbian Club on the east side of the lake about one-fourth mile away, but overlooking the lake, recently was rendered at $60,000 to $75,000 for 20 acres.

In 1939, a 42-acre undeveloped tract somewhat closer to the lake sold for $65,000.

In 1938, there was sold on the west shore a 10-acre tract home for $69,000 which, with new improvements, is now estimated to be worth $8,000 per acre.

Land values within 2 miles of the lake shore amount to approximately $20,000,000. Were White Rock Lake destroyed by siltation, it is estimated that these values at present rates would decline about $8,000,000.

It has been estimated that from 800,000 to 1,000,000 people and about 300,000 cars visit the lake annually. The city spends over $35,000 annually for recreational facilities at White Rock Lake. A comprehensive improvement program is now under way at the lake, particularly the dredging program to reclaim the larger delta area at the upper end of the lake. Since the dredging operations were started in the fall of 1937, a total of some $65,000 has been spent on the operation of the dredge and the dragline, which is operated in conjunction with the dredge. Most of the material is moved by an 8-inch hydraulic dredge of which the operating cost (not including supervision, administration, interest, or depreciation) is probably around 12¢ or 13¢ per cubic yard. Some material is removed by a dragline, which is also used to throw up dykes for retention of dredged material. Much contribution has been made to this silt removal project by the White Rock C. C. C. Camp.

Including all expenses the present total cost of dredging is probably around 25 cents per cubic yard or approximately $400 per acre-foot. Considering the availability of silt disposal areas and other conditions of the White Rock project, it is believed that the average long-run cost of silt removal from this lake will average not less than $500 per acre-foot. On this basis, it would cost approximately $78,000 annually to remove the yearly silt inflow of 156.1 acre-feet and to maintain the lake as its present capacity. Considering the present worth of the lake, this expenditure seems fully justified.

For several reasons, however, the city authorities feel that such an annual expenditure could not be made at present. Due to swamping and shoaling effects of silt deposits, the continual depreciation of the aesthetic value, recreational facilities, and property developments will soon make the permanent maintenance of the capacity of this lake feasible. On the basis of the best available information, it is estimated that the city will continue to spend about $25,000 a year for dredging for the five-year period 1940-1945, $40,000 a year for the ten-year period 1945-1955, and $78,000 a year indefinitely after that.

On this basis, the equivalent uniform annual cost of siltation or annual siltation damage, beginning immediately and continuing indefinitely, would be computed as follows:

a. At 2.5 per cent, the present value of $25,000 a year for 5 years =

$$\$25{,}000\ A_5 \text{ at } .025^{1} = \$25{,}000\ (4.6458285^{2}) = \$116{,}146$$

b. At 2.5 per cent, the amount at the end of 15 years of the annual cost of $40,000 a year during the 10-year period 1945-1955 =

$$\$40{,}000\ (11.2033818^{3}) = \$448{,}135$$

The present value of this loss =

$$\$448{,}135\ (0.6904656^{4}) = \$309{,}422$$

c. At 2.5 per cent, the present value of the cost of $78,000 a year indefinitely beginning 15 years hence =

$$\frac{\$78{,}000}{.025}(1.025)^{-15} = \$2{,}154{,}253^{5}$$

d. $116,146 + $309,422 + $2,154,253 = $2,579,821

e. At 2.5 per cent, the *equivalent* annual cost of dredging, or of siltation damage, beginning immediately and continuing indefinitely=

$$\$2{,}579{,}821\ (.025) = \$64{,}496$$

Sedimentation Damage to Bachman Lake

This lake is located on Bachman Branch near the confluence of this small tributary with Elm Fork. It was built by the City of Dallas as a unit in the waterworks system in 1903 and was used as such for several years. The Dallas waterworks is still located on this reservoir even though the lake is not now used except for recreational purposes. It may have some small water supply value as a reserve storage. It is estimated by reconnaissance measurements of the sediment that by 1940, Bachman's original capacity of 2,300 acre-feet had been depleted approximately 35 per cent by sedimentation. The watershed area is about 20 square miles. The rate of deposition is approximately one acre-foot per square mile of watershed annually.

At the time the reservoir was built, and for many years thereafter, the adjacent land was devoted to agriculture. Values were about $25 or

[1] A_5 at $.025 = \frac{1-(1.025)^{-5}}{.025}$

[2] The present value of $1 per annum at 2.5% compound interest, for 5 years.

[3] The amount of $1 per annum at 2.5% interest, for 10 years.

[4] The present value of $1 at 2.5%, for 15 years.

[5] That is, $78,000 ÷ .025 = $3,120,000; $3,120,000 (0.6904656) = $2,154,253. The factor 0.6904656 = present value of $1. at 2.5%, for 15 years.

$30 per acre. Only during the last 5 or 6 years has there been much residential development north and northwest of the lake. Most of the watershed is still in agricultural use. Just southeast of the lake, an Army flying field was established in 1917, and this same area since has gradually been developed as an industrial area. The municipal airport, Love Field, is also located here. Between this area and the city there has been much residential improvement of a medium quality in the last 20 years. Doubtless, the presence of the lake has had much to do with the recent residential development. Selected areas for subdividing the immediate uplands around the lake are probably worth now from $600 to $1,500 per acre.

Only during the last few months has the improvement of the publicly-owned areas around the lake been started in accordance with a definite plan of development for recreational uses. Practically all the park, picnic, barbecue, and other recreational facilities are offered free of direct charge to the public. According to city officials, the existing property values near the lake and its aggregate public recreational utility will not permit the abandonment of this lake site. Since it is considered not to be in the public interest to allow this lake to be destroyed by silt and to reconstruct it at an alternate site, the lake capacity can be maintained only by dredging. However, considering the character of the services provided by this lake, the various other community needs, the outlays needed for other community projects, et cetera, it seems unlikely that any dredging work would be feasible until considerable further silting has taken place, which will create a serious nuisance and will prevent the enjoyment of the public and of the riparian owners. Considering these and other factors, it is believed that a permanent pool in Bachman Reservoir of about half the original capacity of the lake would be adequate for the limited recreational and property value maintenance purposes. At the present rate of silting, it will take an additional 18 years to reduce the lake capacity to this degree of depletion. Should the cost of sediment removal average $500 per acre-foot, it would take approximately $10,450 a year to remove the annual silt inflow of 20.9 acre-feet.[1] The annual cost of silt removal, or the annual siltation damage, can thus be computed as follows:

At 2.5 per cent, the present value of $10,450 each year indefinitely beginning 18 years hence =

$$\frac{\$10{,}450}{.025}(1.025)^{-18} = \$268{,}000^{2}$$

At 2.5 per cent, the *equivalent* uniform annual cost, or siltation damage, beginning immediately and continuing indefinitely =

$$\$268{,}000\ (.025) = \$6{,}700$$

[1]It may be that it will prove impracticable to dredge the small annual inflow each year and that the job may be done periodically. This should not alter materially the average annual cost.

[2]That is, $\frac{\$10{,}450}{.025} = \$418{,}000$; $418,000 (0.6411659) = $268,007. The factor 0.6411659 = the present value of $1, at 2.5%, for 18 years.

Sedimentation Damage to Mountain Creek Reservoir

1. The dam forming this reservoir is located on Mountain Creek about 10 miles southwest of the City of Dallas. The reservoir was built in 1932, but the gates were not closed until March 23, 1937. It was constructed under a permit granted by the Board of Water Engineers for the State of Texas. The purpose of the dam is to impound water for cooling and condensing in connection with the generation of electric power. The permit grants an annual use of 15,000 acre-feet. The dam is an earthen embankment about 8,700 feet long protected on the upstream face with stone paving. A concrete spillway is provided in the central section of the dam. The outflow is controlled by 6 Tainter gates 34 feet long by 26 feet high. The gates sills are placed at elevation 431 feet, the top of the gates at elevation 457 feet, and the top of the earthen embankment at elevation 467 feet. The original capacity of this reservoir at elevation 457 (the top of the gates) was approximately 36,000 acre-feet. The original area of the water surface at that elevation was approximately 3,150 acres. The capacity remaining in 1940 was about 34,000 acre-feet.

2. This reservoir has a tributary watershed of 289 square miles. As shown in the map "Major Soil Group Areas," the principal portion of the drainage basin lies in the Blackland Prairie province (77%) and a lesser part in the East Cross Timbers province (21%). Crop production is the major land use in the uplands. Approximately one-fourth of the area is in pasture and woodland. In the flood plain, 88 per cent of the area is in cropland. Considering the small area which this watershed drains, the soil losses from erosion are relatively high. The principal portion of this eroded soil is made up of clay which is held in suspension until it reaches Mountain Creek Lake. Only a small amount of the eroded soil is deposited on valley lands. Preliminary measurements of the sediment indicate that the original 36,000 acre-foot storage is being reduced at the rate of 684 acre-feet or 1.90 per cent annually. This would correspond to an average of approximately 237 acre-feet of sediment contribution from each 100 square miles of drainage area.

3. For the proper design of a storage reservoir for any purpose it is essential to know the run-off from the contributory drainage area for a long period of years—the longer the better. This information is essential not only that the capacity of the reservoir may be proportioned to the average quantity of water available, consideration being given to the purpose the reservoir is to serve, but also that for periods of minimum flow the reserve storage may be adequate for the supply needed. It is also essential that quite definite information regarding the maximum rates of run-off shall be had in order that proper spillway provisions may be made so that the safety of the dam and its appurtenances may never be jeopardized.

On the basis of best available data, the annual run-off will probably average about 54,000 acre-feet and will vary with the rainfall from a probable minimum of not more than 13,000 acre-feet during such low run-off periods as the three years 1909-1991[1] to an ordinary maximum of 100,000 acre-feet. Obviously, the reservoir is not large enough to regulate entirely the run-off of its watershed. If the reservoir is operated solely in the interest of its owners, there will be no outflow from the lake except during flood periods. Although the State permit grants an annual use of 15,000 acre-feet, it is believed that under the present operating conditions a permanent pool accessible for use of only about 8,000 acre-feet capacity would actually be needed for cooling and condensing purposes. This does not mean that the reservoir in 1940 had an excess capacity of 26,000 acre-feet. After allowing for the rainfall on the lake surface, the mean net evaporation from the reservoir area is estimated at about 3 feet per year. At spillway level this would be 9,450 acre-feet. Assuming an average water surface of the lake of about 2,700 acres, the average annual evaporation loss would be 8,100 acre-feet. In addition to this loss, some allowance must be made, perhaps at least 5,000 acre-feet annually, for losses through water use and seepage under the dam and into the ground. Furthermore, a certain percentage, perhaps at least 12 per cent of the capacity of the reservoir when originally constructed or 4,300 acre-feet, will be inaccessible, as all water cannot ordinarily be drawn from the reservoir.

The main conclusion to be drawn from this discussion is that during a three-year dry period like that of 1909-1911 the total water losses would amount to about 43,600 acre-feet for the period. With the reservoir full at the beginning (or 34,000 acre-feet on the basis of its 1940 capacity), plus the total expected run-off from the watershed or the total inflow into the lake of about 39,000 acre-feet during the period, the reservoir would have a net available capacity of approximately 29,400 acre-feet at the end of such a dry period. Of this amount 21,400 acre-feet are in excess of actual need. At the present rate of silt inflow of 684 acre-feet annually, the useful life of the lake would be 31 years before replacement becomes necessary.

In a program of planned reservoir development, the question usually arises of how far an owner should go in providing excess storage capacity over present water needs. A private public utility company, like the Dallas Power and Light Company, will base its decision concerning reservoir capacity on an engineering and economy study made for the purpose of: (1) determining the minimum capacity needed from the standpoint of satisfactory quantity and quality of water and (2) calculating the most economical, long-run reservoir unit and the size of investment in present excess capacity (considering also the probable increase in water demand) which will probably be recovered in future savings. Obviously, it would be uneconomical to construct a reservoir with capacity sufficient this year and a few years after to make an addition and so on, in piecemeal, hand-to-mouth fashion. The problem, therefore, is to determine the most eco-

[1]This includes periods of several months duration of no run-off.

nomical period for which to provide excess capacity in advance. It is believed that insufficient consideration was given to the silt problem when the present Mountain Creek Reservoir was built. Probably a somewhat larger lake than the present one would have been most economical in the long run.

In the light of the foregoing discussion, the siltation damage to Mountain Creek Reservoir may now be computed as follows:

(a) Replacement cost of the present 33,948 acre-foot storage, 31 years hence, is estimated to remain the same as its original per unit cost, i. e., $48.75 per acre-foot or a total of $1,654,965.

(b) At 3.5 per cent, the present value of an outlay of $1,654,965, 31 years hence =

$$\$1,654,965\ (1.035)^{-31} = \$1,654,965\ (0.3442303) = \$569,689$$

(c) At 3.5 per cent, the *equivalent* uniform annual cost of replacement, or siltation damage, during the 31-year period, 1940-1971 =

$$\$569,689 \frac{1}{A_{31} \text{ at } .035} = \$569,689\ (0.0533724) = \$30,406$$

NOTE: The same average annual cost would result if the company should follow the policy of establishing a depreciation sinking fund in order to accumulate the $1,654,965 needed to replace the reservoir at the end of 31 years. In that case, the necessary annual payments into the sinking fund depreciation account to replace the reservoir would be:

$$\$1,654,965 \frac{1}{S_{31} \text{ at } .035} = \$1,654,965\ (0.0183724) = \$30,406$$

SEDIMENTATION DAMAGE TO RELATIVELY SMALL MUNICIPAL RESERVOIRS

There are thirteen relatively small municipal water supply reservoirs for which the method of calculating sedimentation damage is very much the same. In order to avoid the repetition of the step-to-step computations only one, the Farmersville City Reservoir, will be treated in detail. The Farmersville will be used to illustrate the method; for the other reservoirs only such basic data will be presented as are essential if one wishes to check the calculations which have been summarized in Table No. 1, Columns 22-24.

Sedimentation Damage to Farmersville City Reservoir

The Farmersville City Reservoir was constructed in 1935 with an original capacity of 475 acre-feet, at a cost of $38,000.

1. At 3½ per cent, the present value of an outlay of $38,000 to replace the reservoir at the end of its useful life, 55 years hence =

$$\$38,000\ (1.035)^{-55} = \$38,000\ (0.150758^{1}) = \$5,729$$

[1]The present value of $1 at 3.5%, for 55 years.

At 3½ per cent, the *equivalent* annual cost of replacement during the 55-year period, 1940-1995 =

$$5{,}729 \frac{1}{A_{55} \text{ at } .035} = \$5{,}729\ (0.0412132^{1}) = \$236$$

NOTE: The same annual cost would result if the city should follow the policy of establishing a sinking fund in order to accumulate the $38,000 needed to replace the reservoir at the end of 55 years. Assuming the sinking fund can be invested with safety at 3½ per cent, the necessary annual payments into sinking fund would be:

$$\$38{,}000 \frac{1}{S_{55} \text{ at } .035} = \$38{,}000\ (0.0062132^{2}) = \$236$$

2. As the relatively small capacity of the reservoir decreases, the reservoir will become less effective as a settling basin and the turbidity will gradually increase at the water supply intake, requiring heavier application of chemicals in the settling tanks and more frequent flushing of the tanks. This refers principally to alum which is used as a coagulant (from 0.8 to 4.0 grains per gallon according to turbidity) by the addition of chlorinated lime. The present average cost of chemicals is approximately $8.00 per million gallons of water treated.[3] It is estimated that after about 40 per cent of the usable (or effective) capacity of the reservoir which remains in 1940 is replaced by silt (40% of 275 acre-feet = 110 acre-feet), the operating cost for chemicals and the power and water for flushing the tanks will increase, on the average, $4.00 per million gallons of water treated over the remaining life of the reservoir;[4] i. e., the increase in cost is estimated to start with 23rd year from 1940 and to continue during the remaining 33 years of reservoir life, 1963-1995, inclusive. This estimate is based upon the best available data, but it must be regarded as a rough approximation, for the available information on hour to hour and day to day fluctuations in turbidity and the corresponding amounts of chemicals used is extremely limited and of doubtful accuracy.

3. The amount of water treated in 1939-40 was approximately 14,600,000 gallons. Assuming 2 per cent annual increase for the next 22 years and stationary water demand after that,[5] the average annual amount of water treated during the 33-year period, 1963-1995, would be 21,020,000 gallons. The increased annual expense, due to increase in cost of water treatment, would be $84.08.

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[1]Annuity whose present value at 3.5% compound interest is $1, for 55 years.

[2]Annuity whose accumulation at 3.5% compound interest is $1, for 55 years.

[3]The total cost of delivered water is approximately $700 per million gallons, including all distributing expenses and fixed charges on the capital investment. If the latter are excluded, the cost is about $450 per million gallons.

[4]Because of capacity depletion through silting the reservoir will have to be replaced at the end of an estimated period of 55 years. (See Table 1.)

[5]At present, the per capita use of water is approximately 20 gallons a day which is expected to increase very considerably in the future even if the total population will not increase.

4. The amount in 1995 of the increase in cost of water treatment =

$$\$84.08\ S_{33} \text{ at } .035 = \$84.08\ (60.341210^1) = \$5{,}073$$

The present value of this increase in cost =

$$\$5{,}073\ (1.035)^{-55} = \$5{,}073\ (0.1507581^2) = \$765$$

The equivalent annual expense of increase in cost for the 55-year period =

$$\$765 \frac{1}{A_{55} \text{ at } .035} = \$765\ (0.0412132^3) = \$32$$

Summary:

Annual cost to replace the reservoir at the end of useful life..	= $236
Annual expense of increase in cost of water treatment.......	= 32
Total annual damage due to silting of the reservoir.....	= $268

Terrell City Reservoir

The Terrell City Reservoir, which had an original storage capacity of 3,000 acre-feet, was built in 1921 to furnish the municipal water supply. It is estimated that after about 50 per cent of the usable (or effective) capacity of the reservoir which remains in 1940 is replaced by silt (50% of 1,013.4 acre-feet = 506.7 acre-feet), the operating cost for chemicals and flushing the tanks will increase, on the average, $3.00 per million gallons over the remaining life of the reservoir; i. e., the increase in cost is estimated to start with 13th year from 1940 and to continue during the remaining 12 years, 1953-1964, inclusive.[4]

The amount of water treated in 1939-40 was approximately 255,000,000 gallons. Assuming 3 per cent annual increase for the next 12 years and stationary water demand after that, the average annual amount of water treated during the 12-year period, 1953-1964, would be 346,800,000 gallons. The increased annual expense, due to increase in cost of water treatment, would be $1,040.40.

Kaufman City Reservoir

The Kaufman municipal water supply is provided by two reservoirs on the same stream, built in 1903 and 1936. Their combined capacity remaining in 1940 was 574 acre-feet.

The present cost of delivered water is approximately $160 per million gallons, not including fixed charges on the capital investment. Of this, the cost of chemicals is about $11.00 per million gallons of water treated. It is estimated that the cost of chemicals and the power and water for flushing the settling tanks will increase, on the average, $5.00 per million

[1]This is the amount of $1 per annum at 3.5% compound interest, for 33 years.
[2]The present value of $1 at 3.5% compound interest, for 55 years.
[3]The annnuity whose present value at 3.5% compound interest is $1, for 55 years.
[4]The present total cost of water after all charges is approximately $165 per million gallons, the cost of chemicals being about $8.00 per million gallons.

gallons of water treated after 40 per cent of the usable reservoir capacity which remains in 1940 is displaced by silt.

The amount of water treated in 1939-40 was approximately 56,000,000 gallons. The average annual amount of water treated during the 22 years, 1955-1977, over which period the increase in cost of treatment is calculated, is estimated at 85,000,000 gallons. The increased annual expense, due to increase in cost of water purification during this period, is therefore $425.

Kemp City Reservoir

The present cost of delivered water is approximately $265 per million gallons, not including fixed charges on the capital investment. Of this, the cost of chemicals, the cost of flushing the settling tanks, pumping, et cetera is approximately $42 per million gallons of water treated. It is estimated that the cost of chemicals and flushing the settling tanks will increase, on the average, $4.00 per million gallons of water treated after 40 per cent of the usable (or effective) reservoir capacity which remains in 1940 is displaced by silt (it takes 10 years at the present rate of silting).

The amount of water treated in 1939-40 was approximately 22,000,000 gallons. The average annual water demand during the 14 years, 1951-1964, over which period the increase in cost of water purification is calculated, is estimated at 27,000,000 gallons. The increased annual expense, due to increase in cost of water purification during this period, is therefore $108.

Mabank City Reservoir

It is estimated that the present cost of chemicals and flushing the settling tanks will increase, on the average, $4.00 per million gallons of water treated during an estimated period of 41 years, 1968-2008.[1]

The amount of water treated in 1939-40 was approximately 18,000,000 gallons. The average annual water demand during the 41-year period of increased cost of water purification is estimated at 30,000,000 gallons. The increased annual expense, due to increase in cost of treatment during this period, is therefore $120.

Corsicana City Reservoir (Lake Halbert)

Lake Halbert, the Corsicana municipal water supply, was built in 1921 with an original capacity of 7,350 acre-feet.

It is estimated that the present cost of chemicals[2] and flushing the filters will increase, on the average, $4.50 per million gallons of water treated during an estimated period of 56 years, 1979-2034.[3]

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[1]The present cost of delivered water is approximately $158 per million gallons not including fixed charges on the capital investment. Of this, the cost of chemicals is approximately $10 per million gallons of water treated.

[2]In this case soda ash, by the addition of lime, is used as a coagulant.

[3]The present cost of delivered water is approximately $100 per million gallons, not including fixed charges on the capital investment. Of this, the cost of chemicals is about $9.00 per million gallons of water treated.

The amount of water treated in 1939-40 was approximately 380,000,000 gallons. The average annual water demand during the 56-year period of increased cost of water purification is estimated at 410,000,000 gallons. The increased annual expense, due to increase in cost of treatment during this period, is therefore $1,845.

Dawson City Reservoir

It is estimated that after 40 per cent of the usable (or effective) capacity of the reservoir which remains in 1940 is replaced by silt, the operating cost for chemicals and flushing the settling tank will increase, on the average, $6.00 per million gallons of water treated during the remaining 16 years of reservoir life, 1952-1967. This includes the construction of a new settling tank.

The amount of water treated in 1939-40 was approximately 16,000,000 gallons. The average annual water demand during the 16-year period of increased cost of water purification is estimated at 20,000,000 gallons. The increased annual expense, due to increase in cost of purification during this period, is therefore $120.

Kerens City Reservoir

It is estimated that after approximately 40 per cent of the usable (or effective) capacity of the reservoir which remains in 1940 is replaced by silt (21 years at present rate of silting), the operating cost for chemicals and flushing the settling tanks will increase, on the average, $4.00 per million gallons of water treated during the remaining 31 years of reservoir life, 1962-1992.

The amount of water treated in 1939-40 was approximately 28,000,000 gallons. The average annual water demand during the 31-year period of increased cost of water purification is estimated at 35,000,000 gallons. The increased annual expense, due to increase in cost of purification during this period, is therefore $140.

Wortham City Reservoir

It is estimated that after approximately 40 per cent of the usable (or effective) capacity of the reservoir which remains in 1940 is replaced by silt (this will occur in 43 years at the present rate of silting), the present operating cost for chemicals and flushing the settling tanks of approximately $17 per million gallons will increase, on the average, $4.50 per million gallons of water treated during the remaining 64 years of reservoir life, 1984-2047.

The amount of water treated in 1939-40 was approximately 26,000,000 gallons. Assuming 1 per cent annual increase for the next 43 years and stationary water demand after that, the average annual amount of water treated during the 64-year period of increased cost of water purification would be approximately 37,000,000 gallons. The increased annual expense, due to increase in cost of water treatment during this period, would thus amount to $166.50.

Palestine City Reservoir (Wolf Creek Reservoir)

It is estimated that after approximately 40 per cent of the usable (or effective) capacity of the reservoir which remains in 1940 is replaced by silt (this will occur in 40 years at the present rate of silting), the present operating cost for chemicals, flushing the rapid sand filters, and for wash water of approximately $20 per million gallons[1] will increase, on the average, $6.00 per million gallons of water treated during the remaining 60 years of reservoir life, 1981-2040.

The amount of water treated in 1939-40 was approximately 22,000,000 gallons. Assuming 2 per cent annual increase for the next 40 years and stationary water demand after that, the average annual amount of water treated during the 60-year period of increased cost of water purification would be approximately 39,600,000 gallons. The increased annual expense, due to increase in cost of water treatment during this period, would thus amount to approximately $237.60.

Wills Point City Reservoir

Wills Point Reservoir, although outside of the Trinity drainage basin, is in an area typical of a large part of the basin.

It is estimated that after approximately 40 per cent of the usable (or effective) capacity of the reservoir which remains in 1940 is replaced by silt (this will occur in 8 years at the present rate of silting), the operating cost for chemicals and flushing the settling tanks will increase, on the average, $2.00 per million gallons of water treated during the remaining 13 years of reservoir life, 1949-1961.[2]

The average annual amount of water treated during the 13-year period of increased cost of water purification is estimated at 40,000,000 gallons. The increased annual expense, due to increase in cost of water treatment during this period, would thus amount to approximately $80.00.

REMEDIAL MEASURES: EFFECT OF LAND USE ON EROSION AND SEDIMENTATION

Methods of Control

Two methods of overcoming excessive wearing down of the surface soil are available. One attempts to keep the land covered with vegetation; the other plans to reduce the velocity of the water flowing over the surface of the land through the aid of such mechanical practices as contour cul-

[1]The present combined cost for treating and pumping is approximately $40 per million gallons. The cost of $20 for chemicals and for flushing the filters is an estimated approximate cost. Normally the alum dosage varies from 0.2 to 1.25 parts per million according to turbidity.

[2]Due to the relatively coarse sandy deposits the turbidity in this reservoir is not expected to increase as much as in most of the other reservoirs studied.

tivation, terraces, and check dams. In upland areas of this watershed the farmer or the rancher, of course, is also interested in conserving as much of the rain water as possible. Any steps taken to retard the velocity of run-off, therefore, are beneficial in that they allow more time for the water to percolate into the ground. A combination of the two schemes of erosion control is essential in most of the reservoir watersheds because the personal economy problems of most farm operators do not permit any violent shift in cultivation, although considerable changes in land-use patterns and in the crop organization are often necessary to the achievement of a practical erosion control system. Results of the past five or six years in the several widely distributed demonstration areas of the Soil Conservation Service in the Trinity Watershed indicate, however, that a gradual transition to such farming practices as employment of winter cover crops, strip cropping, contour cultivation, terracing, pasture improvement, and retirement from cultivation of those eroded lands which are incapable of improvement to the level of profitable row-crop use have stabilized the destructive trends and have greatly reduced the soil and water losses in these areas. To be sure, the Federal Government has contributed materially toward the more expensive types of erosion control practices, such as terraces, sodded waterways, gully control, etc., some of which otherwise would not have been possible solely on the basis of cost and return acre by acre. It seems safe to say that in many of the watersheds some public assistance may be necessary to retard erosion in such critical areas of sediment production as badly eroded hillside pastures, abandoned fields, and other waste land, where the costs of control are not commensurate with the immediate returns solely on the basis of protecting the land itself. In regard to some types of erosion control the "Will it pay?" situation for the individual may thus have to be changed through financial cooperation of the downstream interests involved or through some sort of remedial action by governments. Before anything can be said as to how far an owner of a reservoir can afford to go in helping to finance a soil erosion control program, it is necessary to know the facts concerning the benefits to be expected.

Particularly insidious among the factors which cause the waste or the ineffective use of soil resources is the lack of the data essential for clear reasoning as to financial differences between alternative land uses. The actions of farmers working for what they believe to be self-interest may run counter to actual facts—in part, at least—because of ignorance of the consequences of wasteful agriculture.

Much of the work of the United States Department of Agriculture, State Agricultural Colleges, and Agricultural Experiment Stations in all States has been directed to acquire and diffuse useful information on subjects intended to accomplish the degree of conservation which is in the farmers' interest, and the Soil Conservation Service is now actually demonstrating the immediate (as well as future) economic advantage of certain soil and water control measures. Needless to say, these governmental activities have furnished a great many useful facts upon which a farm operator may intelligently base his own plans. Yet, some of the information has not been used by the farmers because it was too general to be applicable to individual parcels of land or because insufficient account was taken of a certain immobility in the factors of production which would prevent timely readjustment. With the advent of the Soil Conservation Service demonstration program, real progress has been made on a wide scale.

Effects of Remedial Measures on Silt Movement

The quantitative evaluation of the influence of such erosion control measures as have been used in the several Soil Conservation Service Demonstration Areas in Texas on erosion and silt movement has been difficult because of the lack of any significant local investigations. The anticipated effectiveness of the agronomic and structural control measures which have been used must necessarily be founded on data obtained from carefully controlled experiments, investigations, or carefully evaluated practical experience. The best sources of such local data are the intensive experiments carried on for the past several years at the Soil and Water Conservation Experiment Stations located at Tyler and at Temple. In addition to these stations, the Division of Watershed and Hydrologic Studies of the Soil Conservation Service has recently established an Experimental Watershed near Waco, a 5,600-acre area known locally as the Brushy Creek Watershed.

In comparison with the Temple and Tyler Stations, where the run-off and erosion experiments are confined to relatively small plots or fields of from 1/100th of an acre to a few acres in area, some of the records at the Brushy Creek Experimental Watershed are being obtained from subwatersheds of considerable sizes—up to 5,600 acres in extent.

Terracing.—Terracing has proved to be a very effective soil conservation measure.

Table No. 2. Soil Losses from *Terraced and **Unterraced Fields by Individual Storms. 1938, Tyler Station. (Pounds of dry soil per acre in run-off water.)

Date	Total Rain in Inches	Gauging Station No. 4 Unterraced Cultivated Watershed 5.75 Acres 7.5% Slope			G. S. C-12 Terraced Cultivated Field 0-3 inches per 100 feet, 2.46 Acres 7.45% Slope		
		In Suspension	Bedload	Total	In Suspension	Bedload	Total
1/23.....	3.46	2,712	1,768	4,480	2,390	716	3,106
3/27–28 .	2.96	1,165	546	1,713	696	427	1,123
4/7......	1.11	200	205	405	55	11	66
6/1......	1.57	4,985	5,235	10,220	695	396	1,091
8/10.....	1.53	731	1,341	2,072	25	37	62
10/3.....	1.52	1,795	1,182	2,977	467	94	561
10/6.....	1.30	1,767	1,243	3,010	401	279	680
11/22-26..	1.79	293	704	997	159	172	331
Totals..	....	13,648	12,224	25,872	4,888	2,132	7,020

Cover: Cowpeas, Winter Oats.
*Soils: Nacogdoches 51%, Kirvin 41%.
**Soils: Bowie 59%, Nacogdoches 32%, Kirvin 9%.

The total soil loss during the 8 storms as given in the preceding table was 7,020 pounds of soil per acre from the terraced land as compared to 25,872 pounds per acre for the unterraced land, or a saving of about 73 per cent. The corresponding savings for the soil in suspension and for the bedload were 64 and 83 per cent, respectively. No doubt, the differences of soil movement between terraced and unterraced fields would have been even greater if the fields were entirely in clean tilled or row crops and cultivated in the usual manner and without winter cover crops. The figures given are, of course, for soil that is completely lost to the fields. In the case of the unterraced land, this soil loss represents closely the over-all erosion from the field. For the terraced land, however, it does not represent that portion of the soil that is eroded from between the terraces and deposited in the terrace immediately below, but represents only that amount of inter-terrace erosion that is carried through the terrace to the measuring point.

The effectiveness of terraces in checking soil movement has been proven also at the Temple (or Blackland) Station. On fields devoted to cotton and corn and cultivated in the usual manner, losses of 54 tons per acre per year have been cut to 3.75 tons per acre per year by terracing. It is believed that the use of strip cropping with terracing will cut this 3.75 ton loss still lower, possibly to 2.50 tons per acre, but it is recognized that regardless of the amount which the latter loss is reduced, the reduction will not be nearly so important as that obtained by changing cultivation from up and down the hill to terraced land farming which reduces the soil loss from 54 to 3.75 tons per acre per year (a saving of 93 per cent). In the Blackland area, however, where the clay soils stay easily in suspension, the relative effectiveness of terraces is not as great in reducing the suspended load as it is in reducing the bedload. This is because the erosion control measures such as terracing do not cause all of the fine particles to be deposited out of water. In order for this to be done it would be necessary for the water to be held in a quiet position for a long period of time. The most important consideration is rainfall intensity directly affecting the rate of run-off, which in turn has a direct bearing on the quantity of soil carried in suspension. On the average, 40 per cent saving of soil in suspension at downstream locations can be expected in the Blackland, because of terraced land, which is devoted to row crops.

Cover Crops.—The cover crops recommended for erosion control purposes may be divided into three groups: (1) permanent perennial cover crops (such as bluegrass, Bermuda grass, buffalo grass, rye grass, and alfalfa), (2) permanent annual cover crops (such as bur clover, annual blue grass, the common annual brome grass, and wild barley), and (3) winter cover crops (such as Hairy vetch and small grains).

The principle of using permanent vegetation for erosion control on critical areas as pasture or hay crops is believed well established on the basis of economy and effectiveness. The degree to which soil is conserved will depend on the quality and quantity of the vegetative cover. The following plant-cover experiments conducted at the Blackland Experimental Watershed and at the Tyler and Temple Stations indicate the effectiveness of various types of cover in reducing soil losses.

Table No. 3. Average Annual Rainfall and Soil Loss in Run-off from Plots and Fields of Different Sizes Under Various Covers

Date	Plot or Field	Slope (Per cent)	Cover	Rainfall (inches)	Soil loss in run-off per acre (tons)
A. Blackland Experimental Watershed:					
3/28/38	SW No. 12 2.974 acres	3.8	Native grass	1.10	0.0013
3/28/38	SW No. 13 3.192 acres	2.9	No cover; corn planted March 15	1.10	0.3211
3/28/38	SW No. 16 3.168 acres	2.2	No cover; corn planted March 11	1.10	0.3618
B. Tyler Experiment Station:					
Annual average 1931–1936	1/100 acres	8.75	Continuous cotton	40.82	27.95
1931–1936	1/100 acres	8.75	Bermuda grass	40.82	0.12
C. Temple Experiment Station (rows down slope):					
Annual average 1931–1938	1/100 acre	4.00	Corn in rotation	31.59	20.65
1931–1938	1/100 acre	4.00	Corn in rotation	31.59	17.22
1931–1938	1/100 acre	4.00	Oats in rotation	31.59	1.07
1931–1938	1/100 acre	4.00	Continuous Bermuda	31.59	0.03

The preceding data indicate that soil losses under different plant covers increase with increase in open growth of the crops. At the Tyler Station it was found that a 3-year crop rotation of cotton, corn, and Kobe Lespedeza, with a winter cover crop of small grain each year, reduced soil losses about 80 per cent compared to areas of continuous cotton over the 5-year period 1931-1935. A large part of this saving has been attributed to the Lespedeza and winter cover crops.

Strip Cropping.—The results obtained from strip cropping in the different experimental areas have been variable. There is unanimity in concluding that they are beneficial in retarding run-off and erosion. However, some experiments have indicated the need of terracing to support the practice. In general, it may be estimated that a strip of semi-permanent cover equal to better than one-third of the area cultivated and supported by the over-all type of crop planted will produce benefits equal to one-third those estimated for an over-all permanent cover crop treatment.

Application of Experimental Results to Watersheds.—The application of the results obtained at the experimental areas to actual watershed conditions of the different reservoir drainage areas is made difficult by our unfamiliarity with the actual behavior of soil movement over watersheds of considerable size. The silt deposition in a reservoir may differ widely from the total soil loss in that drainage area. The conditions of erosion and deposition in stream channels and on lower slopes and flood plains as a result of flood currents must be measured before any comparison of the total soil loss and of the soil deposited in a reservoir can be made. It is felt that the experimental data concerning the effectiveness of the different erosion control practices in controlling erosion are directly applicable to those reservoirs with small drainage areas which obtain directly so-called bedload as well as soil which is carried in suspension in the run-off water. But no erosion control program so far has entirely controlled any watershed of any appreciable size on which erosion data are available. About the only two ways in which such data could be obtained would be (1) by comparing bedload movement and material in suspension in run-off water from watersheds having complete erosion control treatments and watersheds not having such treatment, or (2) by comparing soil movement data for a few years before any treatment and after erosion control had been applied for a number of years. These would have to be watersheds of considerable size, because results obtained on relatively small watersheds would not give accurate evidence of what would be happening in the large reservoirs located on the principal tributaries such as West Fork or Elm Fork. Ultimately, the type of information now being collected at the Brushy Creek Watershed may serve the purpose, but the securing of useful data of this character will require the passage of a considerable period of time. In the determinations made in this report, little more than a rough relationship of erosion control practices to sedimentation rates can thus be expected for watersheds more than a few square miles in area. Even for these watersheds it would be necessary to have a comprehensive picture of the watersheds before computations can be made of the probable effect of erosion control measures on silting rates. It would be necessary to have (1) a complete soil inventory made by mapping the watersheds, (2) to determine the cause of erosional conditions, (3) to develop a sound land-use program based upon 1 and 2 and a consideration of economic factors, and (4) to plan supporting conservation practices designed to supplement the land-use program, such as (a) the various methods of using vegetation to control erosion, contour strip cropping and buffer strip, grassed waterways, etc.,

(b) the mechanical practices such as terraces, diversion ditches, contour furrows, etc., and (c) cultivation practices such as contour tillage and basin listing.

Kaufman City Lake Watershed

A complete inventory and a land-use plan was made for only one watershed, that of the Kaufman City Lake. The watershed area is 1,064 acres, including lake area 107 acres, roads 16 acres, and farmsteads 17 acres. The soil types are Wilson clay loam 46 per cent, Wilson clay 43 per cent, Crockett clay loam 11 per cent, and Crockett fine sandy loam less than one per cent. Accelerated erosion has affected practically all of the land in the watershed. About two-thirds of this area has been affected by slight erosion (less than 25 per cent of the original top soil removed) and one-third by moderate erosion (25 to 75 per cent of top soil removed). Occasional gullies are found on practically all the moderately eroded fields and on about one-fifth of the fields which have been slightly eroded. Most of this erosion has taken place since extensive cultivation began about 40 years ago. About one-third of the watershed would soon be rendered unproductive if the past rate of erosion were allowed to continue unchecked.

After questioning a number of the inhabitants in the community concerning the length of time the area has been in cultivation, it was found that the consensus of opinions established forty years as the period over which extensive cultivation has been carried on. These same inhabitants who had been living in, adjoining, or near the area from thirty to forty-eight years reported that at the beginning of cultivation cotton was grown on approximately 75 per cent of the cultivated area, oats on 15 to 20 per cent, and corn, with a limited acreage of wheat, on the remainder. This division of acreage soon changed to 80 per cent for cotton, with oats and corn equally divided on the remainder. This cropping acreage continued until the advent of the A. A. A. program of the Federal Government which has reduced the cotton acreage to approximately 39 per cent. Feed crops (corn, oats, grain sorghum, etc.) are now grown on 32 per cent and cowpeas, sudan, clovers, vetches, and other soil improving crops on 29 per cent of the total cultivated acreage.

In the past very little attention has been given to rotation in the cropping system, cover crops were not used, the rows were often listed up and down the slopes, and the practice of burning cotton stalks of the preceding crop was commonly practiced.

The present average yield of cotton on the soil still in cultivation was reported to be about one-third bale per acre in contrast to one-half to three-fifths when the land was first put into cultivation. Oats yields have dropped from an average of 45 to 60 bushels to 25 to 30 bushels; and corn yields have fallen from an average of 40 to 45 bushels to 18 to 20, with the corn in late years usually being put on the deeper, more pro-

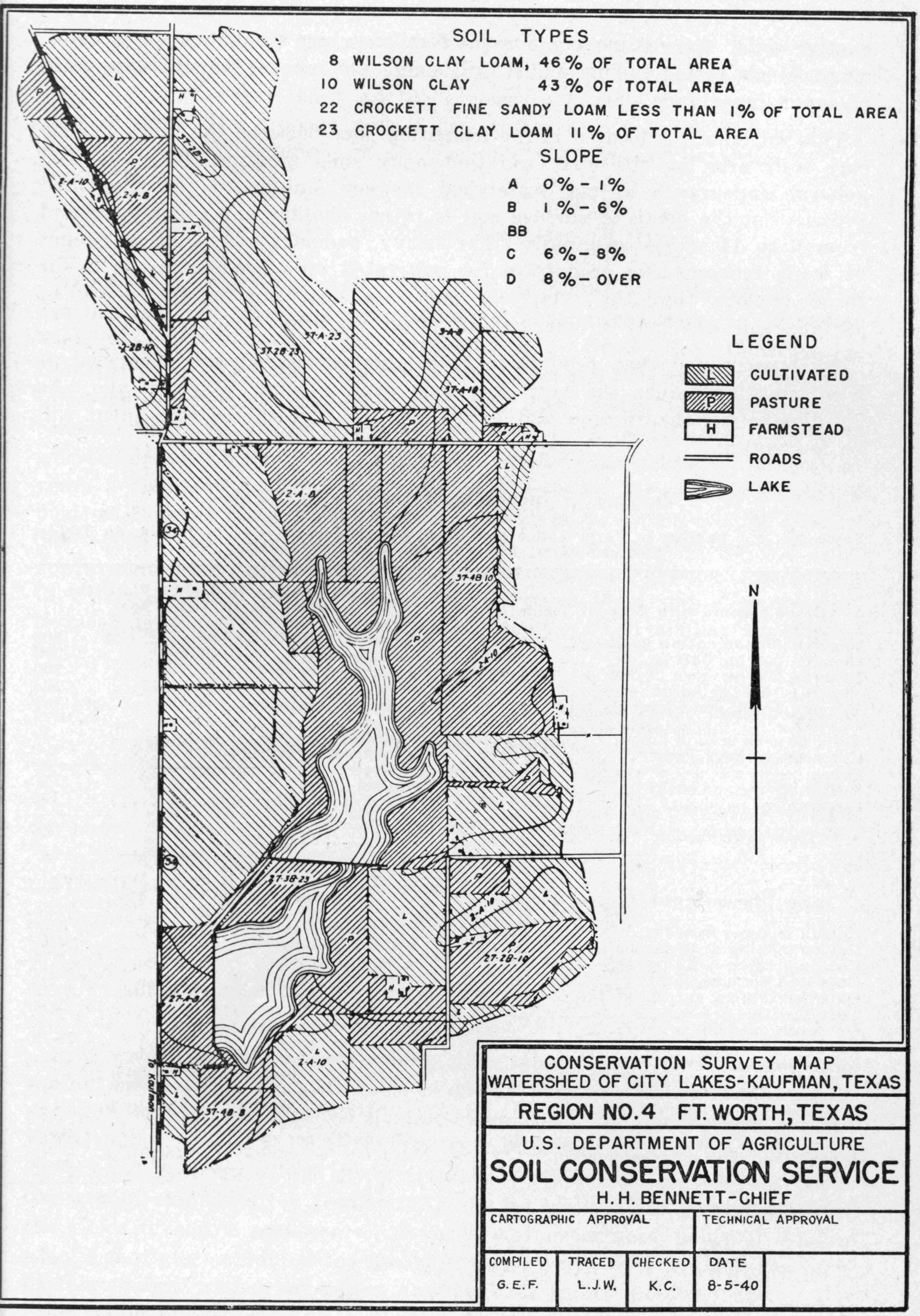

Fig. 2. Conservation survey map, watershed of city lakes, Kaufman, Texas

ductive soils. As yet, no commercial fertilizers are used, but the keeping of livestock is increasing which will make the use of barnyard manure of some importance.[1]

This watershed is located in the transition zone between the Black Prairie clay soils area on the west and the sandy soils area on the east. The general appearance of the watershed is very similar to the Blackland Prairie, but the depth of surface soil is rather shallow and probably varied from 6 to 11 inches originally. The heavy, compact, clay subsoil cannot be made economically productive for cultivated crop production. It is for these reasons that the relatively moderate reduction in the depth of surface soil has had so marked an effect on crop yields.

It is estimated that production from this watershed has decreased at least one-third since the land was first broken some 40 years ago. As an illustration the income and expenses for a typical 80-acre farm will be presented:

Decline in Income and Decline in Yields

Table No. 4. Decline in Farm Labor and Management Income Due to Decline in Yields, 80 Acre Farm, Kaufman City Lake Watershed

Gross Income with Present Yields		Gross Income if Yields Were the Same as 40 Years Ago	
20 acres, 8 bales cotton @ $50	$ 400	20 acres, 12 bales @ $50	$ 600
15 acres, 450 bu. oats @ 30¢	135	15 acres, 900 bu. oats @ 30¢	270
10 acres, 200 bu. corn @ 50¢	100	10 acres, 400 bu. corn @ 50¢	200
5 acres, 10 T. gr. sorgh. @ $7	70	5 acres, 17.5 T. gr. sorgh. @ $7	123
15 acres, truck and forage used in home	50	15 acres, truck, etc., for home use	75
Value of pork used in home	50	Value of pork used in home	50
Chickens, turkeys, eggs	150	Chickens, turkeys, eggs	150
Calves	40	Calves	40
Butter (home and cash)	50	Butter	50
Government payments	130	Government payments	130
A. Gross farm income	$ 1,175		$ 1,688

Farm Expenses with Present Yields		Farm Expenses if Yields Were the Same as 40 Years Ago	
Cotton seed per acre 40¢	$ 8.00	Cotton seed per acre 40¢	$ 8.00
Cotton picking @ $7 per bale	56.00	Cotton picking @ $7 per bale	84.00
Cotton ginning @ $7 per bale	56.00	Cotton ginning @ $7 per bale	84.00
Oats seed per acre @ $1	15.00	Oats seed per acre @ $1	15.00
Oats thrashing & cutting @ 10¢	45.00	Oats thrashing & cutting @ 10¢	90.00
Corn seed 50¢ per acre	5.00	Corn seed 50¢ per acre	5.00
Gr. sorgh. seed 25¢ per acre	1.25	Gr. sorgh. seed 25¢ per acre	1.25
Feed for chickens	75.00	Feed for chickens	75.00
Miscellaneous: Such as replacements, repairs, blacksmithing, depreciation, cash expense for workstock and for hogs and cows, etc.	155.00	Miscellaneous: Such as replacements, repairs, blacksmithing, depreciation, cash expense for workstock and for hogs and cows, etc.	155.00
Taxes 50¢ per acre	40.00	Taxes 50¢ per acre	40.00
Interest on capital investment of $3,700 at 5%	185.00	Interest on capital investment of $3,700 at 5%	185.00
B. Total expenses	$ 641.00		$ 742.00
C. Labor and Management income (A—B)	534.00		946.00

[1]On the average, there are 5 head of cattle and 3 workstock per farm.

If the foregoing $5 per acre decline in the annual farm labor income were applied to the entire watershed, the total annual decline in the productivity of this watershed would be close to $4,800. This is the cost of past damage. The problem now is how to increase crop yields and carrying capacity of pastures, or at least prevent further depletion of soil productivity.

The Effects of Control Measures on Yields

Data concerning the probable effects of conservation measures on yields are limited. No accurate measurements have been made in Kaufman Watershed. However, in the Blackland Elm Creek Soil Conservation Demonstration Area the Operations and Research divisions of the Soil Conservation Service have been studying the effects of terracing and contour tillage on yields. The yields from 50 to 75 small farm field plots were recorded for four consecutive years, 1936-1939, inclusive. After four years a summary of the records revealed that, on the average, terraced fields of Houston Black Clay yielded 43 pounds more cotton and 3.9 bushels more corn than unterraced fields having this same type of soil and approximately the same average slope and degree of erosion. On Austin Clay it was found that for cotton this increased yield was even greater, terraced land producing 91 pounds more cotton than similar unterraced fields.

Table No. 5. Four Years Results from Crop Yield Measurements on Terraced and Unterraced Fields on Two Major Soil Types in the Elm Creek Watershed, Temple, Texas, (1936-1939)

	Cotton Average yield in pounds per acre	Corn Average yields in bushels per acre
Houston Black Clay		
Terraced	249	31.4
Unterraced	206	27.5
Austin Clay		
Terraced	290	31.0
Unterraced	199	27.3

Apparently, cotton was benefited more than corn by terracing and contour tillage. This is, undoubtedly, due to the fact that cotton, since it does not mature for several months after corn, and since it is a tap-rooted plant, it is able to utilize the extra amount of moisture stored in the ground by terraces and contour tillage at that time of the year when the lack of rainfall often results in decreased yields. The spread between the yields of cotton obtained on terraced and unterraced fields of Austin Clay is partially accounted for by the foregoing and by the quick response of this shallow and drier soil to any increase in its moisture during the drier summer months.

Figuring 10 cents per pound for cotton lint, and 50 cents per bushel of corn, the terraced Houston Clay acre produced $24.90 worth of cotton and $15.70 worth of corn per year over the four-year period 1936-1939; whereas, the unterraced acre produced $20.60 worth of cotton and $13.75 worth of corn per year. Figuring the increased cost of picking the extra 43 pounds of cotton at 1.5 cents per pound (assuming the extra seed will pay for the extra cost of ginning) and the extra cost of harvesting 3.9 bushels of corn at 5 cents per bushel results in a total net difference of $3.65 in favor of the terraced acre for cotton and $1.75 for corn, not including the cost of terraces and their maintenance. For Austin Clay the differences in favor of the terraced acre are $7.73 for cotton and $1.66 for corn. A somewhat greater difference has been found between yields of terraced and unterraced fields on the sandy soil area at the Tyler Station.

Table No. 6. Crop Yields on Terraced versus Unterraced Acres in Field L, Tyler, Texas (1931-1937)

Year	Crop	Terraced yield in bushels Per Acre	Area yield in pound seed cotton Per Acre	Unterraced yield in bushels Per Acre	Area yield in pound seed cotton Per Acre
1931	corn	20.0	....	17.6	....
1932	cotton	....	705	....	379
1933	corn	14.9	....	7.6	....
1934	cotton	....	555	....	238
1935	corn	30.5	....	20.5	....
1936	cotton	....	315	....	313
1937	corn	12.8	....	9.7	....
Total	....	78.2	1,575	55.4	930

In the foregoing case the average annual per acre difference in favor of terraced cotton and corn is about $5.00. At the end of the 7-year period the unterraced area with a rather steep slope had become badly gullied and had reached a stage ready for abandonment; whereas, the terraced area, having otherwise the same cropping treatment, was found in a satisfactory farming condition.

Carrying Capacity of Pastures

The effectiveness of permanent grass cover to check erosion has already been shown, but no accurate data are available to show the effect of pasture seeding and sodding on the carrying capacity. After questioning a number of farmers in the Kaufman area who have cooperated with the Kaufman C. C. C. Camp in pasture improvements, it was found that now 4 to 6 acres are sufficient to carry a cow for 8 months, whereas 8-12 acres were required before such treatment. This means an increase in the gross income of about $1.25 or $1.50 per acre per year, i. e., from $1.50 to $2.50-$3.00.

The Effect of Erosion on Land Value

In addition to the decline in crop yields, the capital value of the land itself has been declining because of soil erosion.

Table No. 7. Estimated Value of Land in Kaufman City Lake Watershed, Texas[1]

Erosion Class Slope and Soil Type	Acreage	Present Fair Market Value		Present Fair Market Value with Estimated Virgin Soil Profile	
		Per Acre	Total	Per Acre	Total
(1)	(2)	(3)	(4)	(5)	(6)
2-A-8	80	$ 35.00	$2,800.00	$ 60.00	$ 4,800.00
2-A-8	177	30.00	5,310.00	60.00	10,620.00
2-A-8	46	25.00	1,150.00	40.00	1,840.00
2-A-8	84	15.00[2]	1,260.00	35.00	2,940.00
2-A-10	58	40.00	2,320.00	60.00	3,480.00
2-A-10	58	25.00	1,450.00	35.00	2,030.00
2-2B-10	9	40.00	360.00	60.00	540.00
3-A-8	15	15.00	225.00	35.00	525.00
27-2B-10	100	15.00	1,500.00	35.00	3,500.00
27-3B-23	12	15.00[2]	180.00	35.00	420.00
37-A-10	25	30.00	750.00	45.00	1,125.00
37-A-10	32	15.00[2]	480.00	35.00	1,120.00
37-A-23	65	30.00	1,950.00	45.00	2,925.00
37-2B-8	5	15.00	75.00	35.00	175.00
37-2B-23	25	15.00	375.00	35.00	875.00
37-3B-22	5	15.00	75.00	35.00	175.00
37-4B-8	27	20.00	540.00	30.00	810.00
37-4B-10	13	30.00	390.00	45.00	585.00
37-4B-10	60	15.00	900.00	35.00	2,100.00
37-4B-10	45	15.00[2]	675.00	35.00	1,575.00
Total or average	941	$ 24.00	$22,765.00	$ 45.00	$ 42,160.00

[1]Total Watershed area is 1,064 acres, including lake area 107 acres, roads 16 acres, and farmsteads 17 acres. The lake and road areas are not included in the above table.

[2]This land around lake area is subject to frequent flooding, and its actual present value is estimated at $10 per acre. Its present value would have been $15 per acre, as stated above, were there no lake and no frequent flooding.

Soil Types:
- 8—Wilson Clay Loam
- 10—Wilson Clay
- 22—Crockett Fine Sandy Loam
- 23—Crockett Clay Loam

The foregoing land appraisal of the Kaufman Watershed was made by the appraisal and option section of the regional land acquisition division of the Soil Conservation Service and by a land appraiser of a local bank. The first column gives the erosion class, slope, and soil types assigned in the original conservation survey by Camp S.C.S.-34 T.

The second column gives the acreage, as determined by the appraiser, of the erosion class having the same present fair market value.

The third column gives the present fair market value determined by the appraiser after a physical inspection of the area, a search of the County records for recent land sales in the area, and after investigating sales of similar lands in the community. The present fair market value is the amount expressed in terms of money that a ready, willing, and reasonably cautious purchaser who did not have to buy would be justified in paying to a ready and willing seller, who did not have to sell, at the date of inspection. This value takes into consideration only the soils and not the improvements (buildings, fencing, wells, farm ponds, and engineering improvements of the Soil Conservation Service). Too, this value reflects the easy accessibility of this area, facilitated by a good surfaced State highway running full length along its west side, and comparatively good graded dirt roads reaching the more inland parts; the close proximity to the town of Kaufman (south end of the watershed joins the townsite), a county seat town having a population of 2,475; and the location between two competitive markets, Kaufman and Terrell, Texas, a town of 9,100 population. These two towns are only twelve (12) miles apart, and are connected by the State highway running along the west side. The city of Dallas, having a population of over 260,000, is only thirty-two (32) miles distant and connected by paved roads.

The fourth column gives the present market value as estimated by the appraisers if the virgin soils were intact, with all other conditions exactly the same as of the date of inspection (which conditions include the favorable accessibility and proximity of Kaufman). The appraisers based their estimates of the original soil profiles on profiles determined to be unchanged and of the same soils in the surrounding territory, and on their experiences with the same soils over several of the north Texas counties.

This fourth column, as may be expected, does not show as wide a fluctuation in values, within the column, as it does the third column—the estimated topography of the different soils in their virgin state being the determining factor in the evaluation. The third column shows a wider difference of values, within the column, not only because of topographical variations, but also, because of the modification caused by man since its cultivation and use as pasture for domestic animals.

Productivity of the soil is one of the most important factors influencing the value of agricultural land. The estimate of the past capital loss due to erosion has been based primarily upon the value of the soil under present conditions as compared with what it would have been if there were no erosion. Similarly, a future estimate of capital loss due to erosion may be based upon the value of soil if it were maintained under present conditions as compared with what it would be if soil deterioration were allowed to continue unchecked. Of course, there will always be some erosion in an agricultural watershed like the Kaufman area, and the control measures will have the effect of reducing rather than eliminating erosional losses. Thus, assuming that the past average decline in the value of land of $485 (Total value 40 years ago $42,160 less the present total value of $22,765 = $19,395; $19,395 ÷ 40 years = $485 loss per year) or $0.52 per acre per year would continue in the future if no control measures would be adopted, the control program recommended by the Soil Conservation Service would not eliminate all of this loss. On the basis of the effectiveness of the various measures it seems a conservative estimate to state that if the following work which has been recommended by the Operations Specialist of the Soil Conservation Service were adopted, the present land values would increase, on the average, at least as much as the cost of the control program, and the past $0.52 annual per acre decline in the value of the land would be reduced to about $0.20 per acre per year.

The Cost of Conservation Practices and Their Effect on Income

The following program of work has been planned and recommended in this watershed:

1.	Cultivated land retired to pasture	90 acres
2.	Cultivated land retired to meadow	16 acres
3.	Terraces to construct	34 miles
4.	Fences to construct	2,200 rods
5.	Fences to remove	950 rods
6.	Land to be sodded	100 acres
7.	Overseeding of pasture	150 acres
8.	Linear feet of terrace outlet sod	24,000 feet
	(1) Terrace outlet sod, 18″ centers	28 acres
9.	Linear feet of outlet channel	2,000 feet
	(1) Channel excavation	1,600 cu. yd.
	(2) Channel sodding	4,200 sq. yd.
10.	Strip crop seeding	30 acres
11.	Strip crop lines	5 miles
12.	Terrace lines	37 miles
13.	Meadow seeding	8 acres

About 60 per cent of the total area has already been placed under agreement, and about the same amount of the preceding work has been completed. The total cost of the program has been estimated at $5,000 or an average of $5.30 per acre.[1] The cost has been distributed about equally between the land owners and the C. C. C. Camp of the Soil Conservation Service. Practically all of the cost of actual terracing has been borne by the farmers while the more substantial contributions by the C. C. C. Camp have been for pasture and meadow sodding and seeding, channel sodding, fence construction and removal, and for running the strip crop and terrace lines.

After the completion of the foregoing conservation program, the present estimated average annual gross farm income of $14.70 per acre is expected to increase about one-tenth ($1.55 per acre) almost immediately, and probably more after a few years, as compared to the continuous decline in the past. The gross annual productivity of the entire watershed of 925 acres (excluding lake area, farmsteads, and roads) is, therefore, expected to increase by about $1,435, i. e., to increase from $13,600 to $15,035.

On the other hand, the future annual maintenance cost of the conservation practices—as well as the annual cost of picking the increased yields of cotton, harvesting of the larger amount of corn, etc.—would be expected to increase, on the average, about $1.00 per acre per year or by $925 for the entire watershed, thus leaving a net farm gain of about $510. In addition to this net annual gain in farm income, the past annual

[1]Per unit costs: Terrace construction $40 per mile, terrace lines $8.90 per mile, strip crop lines $5.00 per mile, strip crop seeding $2.30 per acre, pasture seeding $2.85 per acre, pasture sodding $5.10 per acre, fence removal $0.091 per rod, fence construction $0.68 per rod, meadow seeding $4.75 per acre, channel sodding $0.10 per sq. yd.

decline in the value of land $485 (as was pointed out previously) would be reduced by something like $300. The total annual evaluated farm benefits of the conservation program have thus been estimated at $810.

Assuming that the farmers had financed the entire program[1] and had to borrow the entire cost and had contracted to pay 6 per cent interest annually, and assuming, further, that the various erosion control devices had an average life of 25 years,[2] the average annual cost would be only $391, as compared to the average annual benefit of $810. The ratio of annual farm net benefits to total annual cost would thus be better than 2 to 1 ($810 to $391). Therefore, the farm benefits alone (city benefits were computed at $425 annually) will be more than sufficient to justify the entire conservation program. The latter has been worked out almost entirely on the basis of agricultural interests of the watershed. Few provisions have been made to specifically protect the lake.

The total acreage in this watershed was:

	Before C. C. C. Camp	In 1939
Cultivated (acres)	551	420
Pasture (acres)	369	493
In meadow (acres)	4	12
Farmsteads and roads (acres)	33	32
Lake area (acres)	107	107

The cultivated land was:

	Before C. C. C. Camp	In 1939
Cotton (acres)	310	162
Corn (acres)	70	60
Grain sorghum and Sudan (acres)	55	65
Small grains, chiefly oats (acres)	100	80
Idle land (acres)	16	0
Soil improving crop	0	53

Summary of the Effects of Control Measures on Silting of Kaufman Lake

The reports of the several soil and water conservation experiments have been reviewed, as have also several other data and personal observations pertinent to evaluation of the anticipated benefits to erosion control to be derived from the various treatments. It has been estimated that the various proposed watershed treatments, if applied to about 90 per cent of the watershed, would reduce the silt inflow into the lake (considering the two lakes as a unit) to about 50 per cent of what it would be if no

[1]Actually they contribute only about one-half the total cost, but it is unlikely that the Government would finance the program in other watersheds.

[2]Actually they would probably last forever, with proper maintenance.

control measures were employed,[1] i. e., to about 3.32 acre-feet annually as compared to 6.63 acre-feet without control measures. As a result, the useful life of this reservoir would be extended from 37 years with the present rate of siltation to 74 years with the erosion control measures. From 1903 to 1939 about 2.76 acre-feet of sediment per square mile of watershed have accumulated annually in the old reservoir. Approximately 4.36 acre-feet of sediment per square mile of drainage area are deposited annually in the new lake. These data indicate that the erosion rate has been greatly accelerated during the past three decades, concurrent with increased intensive agricultural use of the watershed. Considering the similarity of topography, soils, land use, and other characteristics of the two watersheds, it seems probable that without erosion control measures the present rate of silt deposition in the new lake would apply to the watersheds of both lakes in the future. A comparison of the sedimentation damage to Kaufman City Lake without and with erosion control measures and the expected benefit follows.

VALUE OF BENEFITS DERIVED THROUGH RETARDING SEDIMENTATION OF RESERVOIRS

By the discussion in the foregoing chapter it has been shown that substantial benefits accrue to the land value and productivity of a drainage area as well as to a reservoir downstream as a result of a properly planned erosion control program. Except for the Kaufman Watershed sufficiently detailed erosion surveys and land-use plans have not yet been made on the reservoir drainage areas in the Trinity Basin upon which to base satisfactory estimates of the silt-reduction effect of control measures. This information is very fragmentary at present, because of the absence of adequate systematic effort to get it and because the securing of useful data requires the passage of a considerable period of time even after such systematic effort is started. On the basis of data collected in 1938-1940, estimates of the effect of the control measures in reducing sedimentation rates in various reservoirs in the Trinity Basin have been made by the Trinity River Flood Control Survey group. These estimates, however, were based upon Erosion Experiment Station studies on small plots and should be considered applicable only in a general way to drainage areas of more than a few square miles.

Kaufman City Reservoir

The estimates which appear in the preceding chapter show that the predicted average annual silt deposition in the reservoir of 6.65 acre-feet without control measures would be reduced to about 3.32 acre-feet with the watershed control program and that the remaining useful life of this reservoir would be extended from 37 years with no control program to

[1]After making allowance for what may be expected under actual watershed conditions, i. e., considering the imperfections to be expected in the permanent and temporary cover conditions, cultivation practices, terrace upkeep, etc.

74 years with the erosion control measures.[1] The siltation damage to Kaufman City Lake with erosion control measures would be computed as follows:

1. At 3.5 per cent, the present or discounted value of the deferred cost of $34,440 to replace the reservoir at the end of its useful life, 74 years hence =

$$\$34{,}440\ (1.035)^{-74} = \$34{,}440\ (0.0784177) = \$2{,}701$$

At 3.5 per cent, the equivalent annual cost of replacement during the 74-year period =

$$\$2{,}701 \frac{1}{A_{74} \text{ at } .035} = \$2{,}701\ (0.0379782) = \$103$$

2. The increased annual expense, due to increase in cost of water purification during the 44 years, 1970-2014, (the method is the same as explained previously under "Sedimentation Damage to Relatively Small Municipal Reservoirs") is $425. The amount in 2014 of the increase in cost of water treatment =

$$\$425\ S_{44} \text{ at } .035 = \$425\ (\$101.2383313) = \$43{,}026$$

The present value of this increase in cost =

$$\$43{,}026\ (1.035)^{-74} = \$43{,}026\ (0.0784177) = \$3{,}374$$

The *equivalent* annual expense of increase in cost for the 74-year period=

$$\$3{,}374 \frac{1}{A_{74} \text{ at } .035} = \$3{,}374\ (0.0379782) = \$128$$

Summary:

Annual cost of reservoir replacement......................	= $103
Annual expense of increase in cost of water purification.....	= 128
Total annual damage due to silting of the reservoir.....	= $231

Annual Benefit of Control Measures:

Annual damage without control measures...	= $656
Annual damage with control measures	= 231
Annual benefit of control measures.....	= $425

The foregoing *method* of computing sedimentation damages and benefits of control measures is applicable to all the small water supply reservoirs; namely, Farmersville, Terrell, Kemp, Mabank, Corsicana, Dawson, Kerens, Wortham, Palestine, and Wills Point.

Although obtaining the same answer, a different method of computing the annual benefit of sedimentation control and of the justifiable annual expenditure or contribution by the City toward the watershed control program would be on the basis of so-called Capitalized Cost. The Capital-

[1]For siltation damage without control measures see Table No. 1 and "Sedimentation Damage to Relatively Small Municipal Reservoirs."

ized Cost method will be explained here because of the different cost of operation and annual utility loss series and capacity replacement series without and with control measures for the different reservoirs, which some readers may find difficult to compare and interpret by the *equivalent annual cost method.*

Comparison of Annual Siltation Damage Without and With Erosion Control Measures and Determination of the Justifiable Annual Expenditure for Control Measures at Kaufman on the Basis of Capitalized Cost

I. Without control measure the amount in 1977 of the annual 22-year increase in cost of water treatment =

(1) $425 S_{22} at .035 = $425 ($32.3289022) = $13,740

The compound amount of $1 for 37 years at 3.5% = $3.5710254
The interest on $1 for 37 years at 3.5% .... = $2.5710254
The interest on $X for 37 years at 3.5% .... = $13,740

$$\$X = \frac{\$13{,}740}{\$2.5710254} = \$5{,}344$$

which is the capitalized cost of annual increased expense of water treatment.

(2) Capitalized cost of replacement of lost capacity each 37 years =

$$\$34{,}440 \frac{1}{(1.035)^{37} - 1} = \$13{,}400$$[1]

(3) Therefore:

Capitalized cost of increased cost of water purification	= $ 5,344
Capitalized cost of capacity replacements............	= 13,400
Total capitalized cost of siltation without control measures..................................	= $18,744

II. Likewise, the amount in 2014 of the annual 44-year increased cost of water purification with control measures =

(1) $425 S_{44} at .035 = $425 ($101.2383313) = $43,026

The compound amount of $1 for 74 years at 3.5% = $12.7522226
The interest on $1 for 74 years at 3.5% .... = $11.7522226
The interest on $Y for 74 years at 3.5% .... = $43,026

$$\$Y = \frac{\$43{,}026}{11.7522226} = \$3{,}661,$$

which is the capitalized cost of annual increased cost of water treatment.

(2) Capitalized cost of replacement of lost capacity each 74 years =

$$\$34{,}440 \frac{1}{(1.035)^{74} - 1} = \$2{,}931$$

[1]The same answer may be obtained: $34,440 (0.0136132) = $469; $469 ÷ .035 = $13,400. The factor 0.0136132 is the annuity whose accumulation at 3.5% compound interest for 37-year period is $1.

(3) Therefore:

Capitalized cost of increased operating expenses........ =$3,661
Capitalized cost of capacity replacements .... = 2,931

Total capitalized cost of siltation with control measures .... =$6,592

III. Summary:

$18,744 = capitalized cost of increased operating expenses and storage replacements without control measures.
6,592 = capitalized cost of increased operating expenses and storage replacements with control measures.

$12,152 = total capitalized cost of control measures.

3.5% on $12,152 = $425, which is the justifiable annual expenditure for control measures indefinitely.

In order to calculate capitalized cost, it was necessary to make the assumption that capital expenditure series and increased operating expense series for Kaufman City Lake estimated for 37 years without control measures will repeat themselves in succeeding 37-year periods. Likewise, the capital expenditure series and increased operating expense series estimated for 74 years with control measures will repeat themselves in succeeding 74-year periods (control measures prolong the life of the reservoir from 37 to 74 years). Also, the assumption was made that storage capacities are renewed at regular intervals at the same price as the cost of first replacement. It should be recognized that no careful estimator really contemplates that future renewals will be exact duplications of present capacities or that they will take place at the cost of first replacement. Yet, the writers have been unable to make a specific forecast of changes, and they were forced to assume a continuance of the conditions prevailing during first replacement of the reservoir.

Calculations of Value of Reduced Sedimentation

Eagle Mountain Reservoir: It has been pointed out that the silt-reduction effect of control measures are greatest where the watersheds are small and the lakes obtain directly so-called bedload as well as sediment which is carried in suspension in the run-off water. At Kaufman the effectiveness was estimated at 50 per cent, which is probably the maximum degree of control that is economically justified. For reservoirs which have watersheds of more than a few square miles, the control measures should not be expected to reduct silt flow by more than about 40 per cent. In one watershed, that of the Eagle Mountain Lake, the usual upland erosion control measures are not expected to reduce the silt inflow more than 31 per cent. This condition is due to the fact that the channels are already clogged with sediment and there are large amounts of past erosional debris which have been deposited on most of the valley bottoms in this watershed. Here, the sandy, rolling uplands have been riddled by gullies and severely devastated by sheet erosion.

Because of the uncertainty concerning the relationship of control practices to sedimentation rates the following computations of erosion control benefits should be viewed as but rough approximations. Thus, assuming the past average annual silt inflow of 1,013 acre-feet into this lake could be reduced about 31 per cent, the computations of the benefits of control measures would be as follows:

I. (a) Life of reservoir without control measures is 140 years.
   (b) Life of reservoir with control measures is 203 years.
   (c) The decline in the value of annual reservoir services without control measures is estimated to start after 10 years from 1940.
   (d) The decline in the value of annual reservoir services without control measures is estimated to start after 15 years from 1940.
   (e) Annual loss of reservoir services and annual cost of reservoir replacement without control measures....... =$8,928[1]
   (f) Annual loss of reservoir services and annual cost of reservoir replacement with control measures.......... = 5,159[2]
   (g) Annual benefit of control measures.............. =$3,769

II. The step-to-step computations of the annual loss of reservoir services and of the annual cost of reservoir replacement *with* control measures are essentially the same as explained under sedimentation damages *without* control measures (see "Sedimentation Damage to Eagle Mountain Reservoir"), i. e.,

Let $R = Value of services rendered annually at the beginning. Then, the amount at the end of 203 years of all the services rendered equals $\$R\ S_{203}$ at .025 less the amount at the end of 203 years of the losses in revenue or services due to silting.

This is

$$\$R\ S_{203} \text{ at } .025 - \frac{R}{188}[S_1 \text{ at } .025 + \text{——} S_{188} \text{ at } .025]$$

Now, the amount at the end of 203 years of all the services rendered =

$$\$R\ (\$5{,}972\text{[3]}) - \frac{\$R}{188}(\$161{,}029\text{[4]}) =$$

$$\$R\ (\$5{,}972) - \$R\ (857\text{[5]}) = \$5{,}115\ R$$

[1]See "Sedimentation Damage to Eagle Mountain Reservoir."
[2]See the following computations.
[3]The amount of $1 per annum at 2.5% compound interest for 203 years.
[4]The sum of the amounts of $1 per annum at 2.5% compound interest for 188 years.
[5]The sum of the compound amount factors of $161,029 ÷ 188 years = $857.

$$\$5,115\ R = \$111,216,556^{1} + \$69,504,000^{2} + \$3,257,329^{3} = \$183,977,885$$
$$R = \$35,969^{4}$$

Having determined the value of R, we can compute the amount at the end of 203 years of the losses in reservoir services due to silting.

This is

$$\frac{R}{188}\left[S_1 \text{ at } .025 + \text{———} S_{188} \text{ at } .025\right]^{5} =$$

$$\frac{R}{188}(\$161,029) =$$

$$\frac{\$35,969}{188}(\$161,029) = \$30,808,068$$

The present value of this loss is

$$\frac{\$R}{188}\left[S_1 \text{ at } .025 + \text{———} S_{188} \text{ at } .025\right](1.025)^{-203\,6}$$

$$\$30,808,068\ (1.025)^{-203} = \$30,808,068\ (0.0066536^{7}) = \$204,985$$

The *equivalent* annual loss of reservoir services during the 203-year period is

$$\$204,985\ \frac{1}{A_{203} \text{ at } .025} = \$204,985\ (0.0251675^{8}) = \$5,159$$

Annual Benefit of Control Measures:

Annual damage without control measures	=	\$ 8,928[9]
Annual damage with control measures	=	5,159
Annual benefit of control measures	=	\$ 3,769[10]

All Reservoirs: A summary of the estimated beneficial effects of upland erosion control measures, if applied to all the reservoir watersheds in the Trinity Basin, is presented in the following table. The method of calculating the effectiveness of control measure in reducing sedimentation of reservoirs is essentially the same as that explained previously under "Kaufman City Reservoir." However, these estimates are based upon reconnaissance erosion and land use surveys by the Soil Conservation

[1]Original cost of \$744,937 × \$0.025 = \$18,623; \$18,623 × \$5,972 = \$111,216,556.
[2]Annual cost of operation and maintenance of \$12,000 × \$5,792.
[3]Replacement cost of lost capacity.
[4]\$183,977,885 ÷ \$5,115 R

[5]This may be written $\frac{R}{188}\sum_{n=1}^{188} S_n$

[6]This may be written $\left[\frac{R}{188}\sum_{n=1}^{188} S_n\right](1.025)^{-203}$

[7]The present value of \$1 at 2.5%, for 203 years.
[8]Annuity whose present value at 2.5% compound interest is \$1, for 203 years.
[9]See "Sedimentation Damage to Eagle Mountain Reservoir."
[10]The same answer would be obtained by using the Capitalized Cost Method.

Table No. 8. Appraised Value of Benefits Derived Through Retarding Sedimentation of Reservoirs, Trinity River Basin, Texas

Name of Reservoir	Annual Silt Inflow		Remaining Life of Reservoir[1]		Annual Siltation Damage		Annual Benefit of Control Measures[4]
	Without Control Measures	With Control Measures	Without Control Measures	With Control Measures	Without Control Measures	With Control Measures[2]	
	(1) Ac.-ft.	(2) Ac.-ft.	(3) Years	(4) Years	(5) Dollars	(6) Dollars	(7) Dollars
Bridgeport	817.6	560.0	242	353	2,669	1,180	1,489
Eagle Mountain	1,012.8	699.0	140	203	8,928	5,159	3,769
Lake Worth	47.2	32.6	Indef.[3]	Indef.[3]	14,402	7,771	6,631
Lake Dallas	1,301.5	754.0	64	111	29,009	13,236	15,773
White Rock	156.1	81.0	Indef.[3]	Indef.[3]	64,496	35,979	28,517
Bachman	20.9	12.5	Indef.[3]	Indef.[3]	6,700	2,446	4,254
Mt. Creek	684.0	321.0	31	67	30,406	6,419	23,986
Weatherford	4.7	2.2	30	64	1,315	296	1,019
Farmersville	5.0	3.0	55	92	268	79	189
Terrell	41.4	24.0	24	42	2,863	1,142	1,721
Kaufman	6.6	3.3	37	74	656	231	425
Kemp	5.9	3.3	24	43	457	174	283
Mabank	1.8	1.0	68	123	100	51	49
Corsicana	39.0	23.0	94	160	966	559	407
Dawson	13.0	7.8	27	45	767	343	424
Kerens	9.5	5.7	52	86	573	179	394
Wortham	1.1	0.6	107	197	85	25	60
Palestine	1.1	0.6	100	183	139	47	92
Wills Point	5.1	2.7	21	39	533	240	293
Totals	....	....	....	....	165,332	75,556	89,776

[1]Column 11, Table No. 1 ÷ Columns 1 or 2, Table No. 8.

[2]The step-to-step computations are essentially the same as explained in detail under "Sedimentation Damage to Bridgeport—Wills Point Reservoirs" and in this chapter under Kaufman and under Eagle Mountain Reservoirs.

[3]See Table No. 1 and text under "Sedimentation Damage to Lake Worth, White Rock, and Bachman Reservoirs."

[4]For interest rates see text under "The Rate of Interest."

Service and the Trinity flood control survey personnel, rather than upon detailed soil conservation and reorganized land use surveys of entire watersheds. The latter type of data are available only for the Kaufman and the White Rock[1] reservoir watersheds. Therefore, although based upon the best available data, these estimates are of necessity but rough approximations.

The assumption has been made that the recommended changes in land use and application of soil conservation measures could be applied to approximately two-thirds of the total land area in each of the watersheds[2] and that the silt reduction effect of the control program starts immediately. Actually, however, there would be a short period of development during which time the control program would have a somewhat smaller, but indeterminate, effect on silting rates.

SUMMARY AND CONCLUSIONS

In the preceding pages the economic nature and scope of the problem of reservoir sedimentation has been briefly outlined, and the relative cost of conservation of agricultural lands with consequent protection of developed storage against depletion by silting has been discussed. The estimated costs and the evaluated relative farm and town benefits of a comprehensive upland erosion control program in one reservoir watershed, that of the Kaufman City Lake, have been reported in detail. Additional estimates of sedimentation damage and of the expected erosion control benefits to 18 reservoirs have been computed and presented with explanatory discussions of each.

In the Kaufman watershed the annual farm benefits of the recommended conservation program were computed at $810 and those of the city at $425. The total initial cost, after making allowance for increased annual cost of maintaining the conservation practices of the program, was estimated at $5,000 ($5.30 per acre). The conservation practices, property maintained ($1.00 per acre per year was allowed for this purpose) might be expected to be serviceable indefinitely, but conservatively amortizing the cost over a 25-year period would require an average yearly expenditure of only $391, interest being at 6 per cent per annum, as compared to the average annual benefit of $810. In other words, if the farm interests alone had to finance the program and had to borrow the entire cost, the ratio of annual farm net benefits to total annual cost would be better than 2 to 1 ($810 to $391). Expressed in another way, the $810 annual farm benefit, at 6 per cent interest, would amortize the $5,000 cost in about 8 years. At the end of this period and thereafter $810 per annum or $0.88 per acre would be available as a net profit. (The annual combined farm and town benefit of $1,235 would amortize the $5,000 in about 5 years.) Obviously, this relatively comprehensive conservation program is

[1]See Richard M. Marshall and Carl B. Brown, Erosion and Related Land Use Conditions on the Watershed of White Rock Reservoir, Washington, D. C., 1939.

[2]In the Kaufman area this was figured at 90 per cent.

probably by far the most profitable investment the average farmer may hope to make. Yet, considerable financial inducements have been necessary in order to establish the program. Much of this reluctance on the part of the farmers is due undoubtedly to his failure to appreciate the full effects of wasteful agriculture. In some instances the conservativeness of farmers in holding to traditional or commonly established farming practices may hinder rapid progress in the light of present day knowledge of good agriculture. As to how many of the reservoir watersheds the Kaufman ratio of annual evaluated benefits to estimated cost of the program would be applicable was not determined. No doubt, over some parts of the more severely eroded watersheds, with less productive soils, such a relatively complete program may not be possible from the standpoint of land conservation alone. But when the attendant decreased movement of upland soil particles, with consequent decreased sediment load and corresponding benefits to the reservoir interests, are considered, a far more general adoption of remedial measures may be expected to follow.

In the past there has been little or no town-farm cooperation in the development of erosion control in reservoir watersheds. This is due largely to the difficulty of dealing with individual land owners or operators and to a lack of definite information concerning the effectiveness of partial control measures in controlling erosion. With the advent of the conservation districts program in Texas a cooperative public and private conservation program should prove feasible, inasmuch as the bulk of the conservation measures needed to control the silting of reservoirs are essentially identical with the measures needed for agricultural soil and water conservation purposes.

The total annual siltation damage to all the reservoirs in the Trinity River Basin without upland erosion control was found to be approximately $165,000 per year. On the present worth basis this amounts to a total of about $5,000,000. Financially speaking, this represents the present aggregate lump sum sedimentation damage. It is the same as the aggregate $165,000 damage annually. Under existing conditions over one-half the total annual damage or about $90,000 can be viewed as preventable if recommended erosion control practices should be applied to approximately two-thirds of the total land area in each of the reservoir watersheds. The downstream reservoir interests should find it to their advantage to secure even a higher percentage of land treatment and to cooperate in securing the ultimate best use of soil resources. A much more effective control program should be feasible in many of the watersheds if the combined downstream reservoir and upland farm and ranch interests adversely affected by the accelerated rate of erosion are included in a consideration of the costs and benefits.