Pond Construction
Farm Ponds
Reservoirs

Storage Pond Design

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Recorded data from two experimental reservoirs and a study of factors relevant to water storage reveal important design information for irrigation water storage ponds

FARM reservoirs properly designed and constructed can furnish a reliable and economical supply of water for supplemental irrigation in many soil areas where adequate supplies from streams or shallow wells are not available or economically feasible. For upland areas like much of north Missouri they are the only practical source of water supply.

There are three principal factors to be evaluated in the design of farm reservoirs for an irrigation water supply. The first of the three is *(a)* the irrigation-water requirement. As for any system this includes determination of consumptive use, available moisture capacity of the soil root zone, probable soil-moisture deficits at the beginning of the season, and application efficiency. The other two factors are (*b*) evaporation and seepage losses from the reservoir and *(c)* drainage area size and probable water yield during drought cycles. With those three factors evaluated the design engineer can determine whether a one or two-year water supply reservoir is the more practical and the storage volume required.

Irrigation Water Requirement

Consumptive Use. The three generally accepted methods for determining consumptive use are Blaney-Criddle, Thornthwaite, and Penman. Solution by one of these or from experimental measurements establishes the amount of water to be provided from a combination of soil-moisture reserves, rainfall and irrigation. Experimental work in the east and midwest is supplying direct data on consumptive use for the humid region. During the drought of 1954 at the Midwest Claypan Experiment Farm near McCredie in central Missouri irrigated corn used 22 in from planting time in early May to September 1. This was at an average rate of 0.185 in per day for the 120-day period. Average daily use reached 0.37 in during midJuly. With soybeans it averaged 0.239 in per day for the same period and reached 0.51 in during midJuly.

Available Moisture Capacity. A knowledge of the available moisture capacity of a soil is necessary for determining what part of the total water requirement can be supplied from soil-moisture reserves. With a large amount of available moisture storage in the soil the storage-reservoir volume may be less. Soils such as the claypans which have an available capacity of over 8 in in the upper 4 ft will not need a surface storage reservoir as large as that required for sandy soils. Soil-moisture capacity data, as available, is generally published in irrigation guides. (1) * Recently emphasis has been placed on securing additional data of this type.

Probable Soil-Moisture Deficits. A high available soil-moisture capacity is of little value from the standpoint of reducing the size of a surface-storage reservoir if this capacity is only partially filled by rainfall between crop seasons. Deficits may be computed from climatological and water-use data. Most midwest soils have an annual moisture cycle characterized by depletion during the summer by growing crops, followed by recharge during the fall and winter. When fall and winter precipitation is appreciably below the soil-moisture capacity, planting time deficits may be expected. It is probable that not more than 50 percent of the available moisture capacity of the root zone on the higher capacity soils should be used for reduction of reservoir storage volume. A more positive figure may be secured by probability analysis of computed deficits.

Application Efficiency. This factor has been evaluated from numerous tests in the irrigation section of the country. Somerhalter (9) has reported an average measured efficiency of 84.1 percent for sprinkler and 72.4 percent for furrow (loss from end of furrow included). In general, losses during irrigation have been considered to range from 15 to 30 percent. Seventy-five or 80 percent appears to be a satisfactory application-efficiency value for design purpose for the humid region.

Evaporation and Seepage Losses

Reservoirs improperly designed and poorly constructed have large losses from evaporation and seepage. These losses may result in storage efficiencies (volume available for pumping during the irrigation season divided by total storage volume) of less than 50 percent. Rohwer (7) reports that evaporation from a copper-lined pond 85 ft in diameter averaged 70 percent of that from a standard Weather Bureau pan. He also reported a similar ratio between lake and pan evaporation.

Evaporation and seepage have been measured, beginning in 1951, from a 16-acre and a 1-acre reservoir at McCredie, Mo. The results show that evaporation from the reservoirs averaged 73 and 78 percent, respectively, of that from the Weather Bureau pan. The pan, however, was located at Columbia, 25 miles west of the reservoirs.

Losses by months from the McCredie reservoirs are plotted against the Weather Bureau pan data in Figs. 1 and 2. A linear relationship, as expressed by the following equation, was assumed:

$$E_r = S + b\ E_p$$

in which E_r = monthly reservoir loss in inches

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*Numbers in parentheses refer to the appended references.

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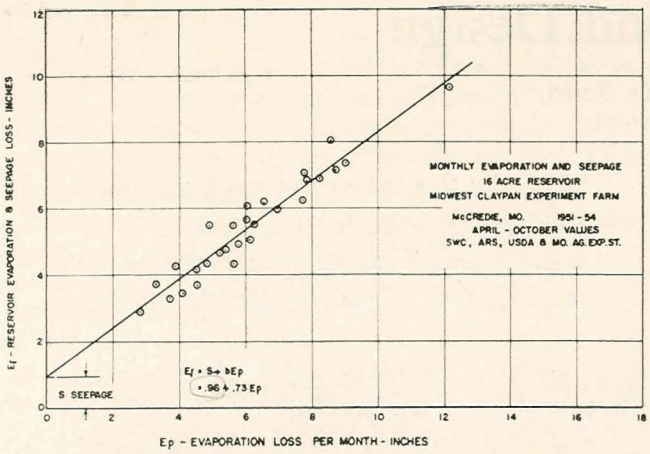
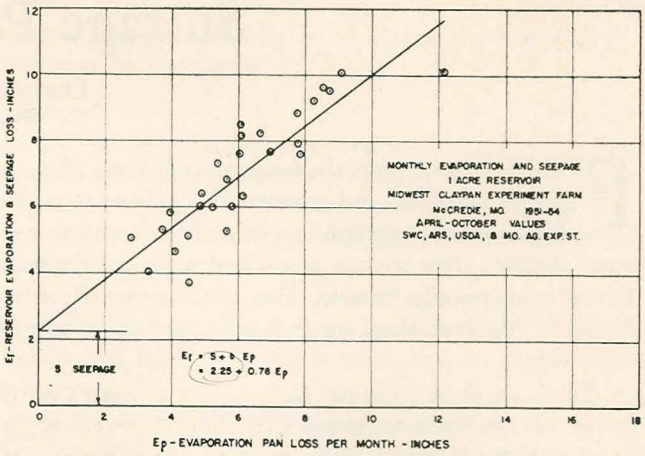




Evaporation and seepage losses from reservoirs on the Midwest Claypan Experiment Farm, McCredie, Mo., in relation to evaporation from U.S. Weather Bureau pans • Fig. 1 *(Left)* Data from a 16-acre, clay-blanketed reservoir • Fig. 2 *(Right)* Data from a 1-acre reservoir

E_p = monthly Weather Bureau pan loss in inches

S = average monthly seepage loss in inches

b = a constant expressing the ratio of reservoir to pan evaporation loss.

S and b were evaluated by the method of least squares.

Approved construction methods for control of seepage were followed in construction of the 16-acre reservoir. This included a clay blanket over the face of the dam and other pervious soil areas in the bottom of the reservoir. The corrugated metal spillway tube of the 1-acre reservoir allows leakage through rivet holes when the water level is within 6 to 8 in of being full. This increases the seepage rate for certain months and may account for the greater scatter about the relationship line than for the 16-acre reservoir. While a core trench was installed during construction of the dam for the 1-acre reservoir no special compaction was used other than by the bulldozer used in the construction process. The 1-in-per-month seepage rate for the 16-acre reservoir is probably near a normal amount for well-constructed reservoirs. That of the small reservoir is on the excess side.

Evaporation data from Weather Bureau pans are available for most sections of the country. Evaporation may be computed also by equations such as Rohwer's (7), equation 10. Most Weather Bureau pans are operated only 7 months of the year. Losses during the remainder of the year however, are usually small. For the 16-acre reservoir at McCredie total losses averaged 2.14 in per month for the 5-month period November to March. By use of the reservoir loss equation, pan evaporation for this period was calculated to average 1.62 in per month or 26 percent of the average measured pan loss during the other 7 months of the year.

Watershed Yield

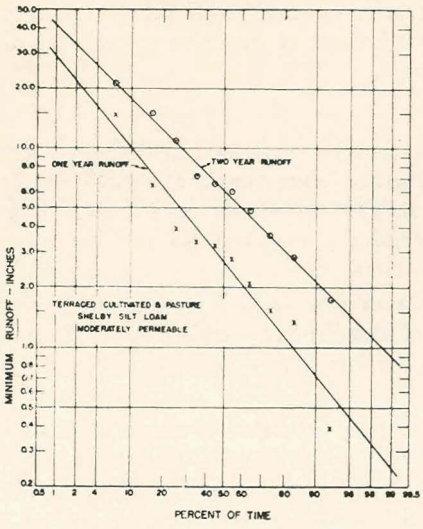
Generally farm ponds have been constructed with small drainage areas to minimize the spillway problem and to insure sanitary and silt-free water. Seldom has the ratio of drainage to pond area exceeded 5 to 1. For irrigation water-supply reservoirs, much larger drainage areas are required to insure supplies of water during drought cycles. Runoff records upon which probable yield amounts can be based are limited both in extent and in duration. For Missouri, records are available for two soil types, both record periods including a drought cycle.

Runoff records were secured on the Shelby silt loam area of northwest Missouri during the 10-year period 1932-41. The soil is of glacial origin and is classified as moderately permeable. The runoff amounts from a well-managed bluegrass pasture watershed and from a terrace area in cultivated crops, both approximately 5 acres in size, were averaged to simulate the runoff from a mixed-cover watershed. The acreages of pasture and cultivated crops average about equal on farms in this soil area.

The single storm runoff amounts were totaled for each water year (July 1 to June 30) and plotted on logarithmic probability paper. Plotting points were from a table presented by Beard (2). A linear relationship on log probability paper was assumed. A trend line was fitted to the data by the method of least squares. Logarithms of runoff amounts and plus or minus horizontal linear measurements from the 50 percent line to each of the percent of time plotting points, were used for the two ordinates. Fig. 3 shows the data for the Shelby soil. Runoff amounts for two consecutive water years were also computed and plotted on the figure. The plottings for both the single and the 2-year runoff amounts show a definite linear relationship. The minimum single-year runoff during the 10-year period was 0.39 in. It occurred during the year ending June 30, 1938. According to the trend line an amount this low could be expected to occur once in 25 years.

Runoff records from a 154-acre mixed-cover watershed in the Mexico silt loam area of central Missouri were secured during the 13-year period 1941-54. The soil is a claypan classified as slowly permeable. The runoff amounts were plotted as described for Shelby soil data and presented in Fig. 4. Runoff from the Mexico soil watershed does not fit a linear relationship as satisfactorily as that from the Shelby area. The extremely low runoff of 0.21 in for the water year ending June 30, 1954, steepened the trend line such that the line does not appear to represent the true trend of the data. The trend line does indicate, however, that an amount this small could be expected once in 1000 years.

Minimum 1 and 2-year amounts of runoff that may be expected during different time periods were read from the



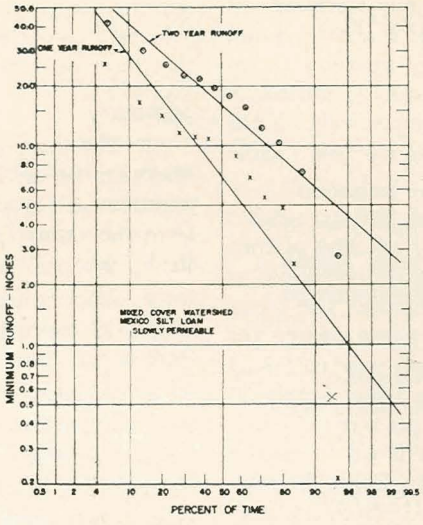


Fig. 3 *(Left)* Water-year runoff for one and two consecutive years from a moderately permeable area for the 10-year period, 1932-41 • Fig. 4 *(Right)* Water-year runoff for one and two consecutive years from a slowly permeable area for the 13-year period, 1941-54

curves of Figs. 3 and 4 and tabulated in Table 1. These values may be used in determining size of watersheds on similar soil and climatic areas required to fill irrigation water supply reservoirs during drought cycles. Since both records were secured during a period of limited length containing a drought cycle the tabulated values may be considered conservative for design purposes.

TABLE 1. MINIMUM WATER YEAR AMOUNTS OF RUNOFF TO BE EXPECTED DURING DIFFERENT TIME PERIODS FOR SOILS OF TWO PERMEABILITY CLASSES

Return Period	Moderately permeable Shelby silt loam		Slowly permeable Mexico silt loam	
	1 year	2 years	1 year	2 years
Years	Inches	Inches	Inches	Inches
10	0.71	2.15	1.64	6.10
25	0.43	1.46	0.97	4.30
50	0.32	1.14	0.69	3.43
100	0.24	0.91	0.51	2.80

Selecting Size of Reservoir

Recommendations for size of reservoirs are stated generally in terms of acre-feet storage per acre to be irrigated. Several of the general recommendations are as follows:

Larson (5)	1.00 acre-feet per acre.
Ruby (8)	1.50 acre-feet per acre.
Beasley (3)	1.25 to 1.75 acre-feet per acre.
University of Illinois (4)	1.50 to 2.00 acre-feet per acre.

The latter two vary the size depending upon the irrigation requirement for different soils. For a specific case, refinement can be made depending upon evaporation, seepage, surface area, and whether the design is based on holding a 1 or 2-year supply. Table 1 shows that minimum runoff for 2-year periods are at least three times that of the 1-year amounts. Evaporation and seepage losses will be higher for a 2-year supply because of the larger average surface area during the first year. With a 1-year supply reservoir the volume need be large enough to hold only the irrigation requirement plus evaporation and seepage during the irrigation season. But for a 2-year supply the volume must be two times the single-year supply plus the increased loss during the first irrigation season because of the larger area and plus the between season losses.

If an irrigation requirement of 400 acre-inches is assumed for the period July through September, a total storage volume of 555 acre-inches will be required, if it is to be stored in a reservoir with the storage-depth relationship of the 16-acre McCredie reservoir. Evaporation and seepage minus rainfall during the 3-month period was assumed to be 14.4 in. This was the 3-month average net loss for the 16-acre McCredie reservoir during 1953 and 1954. Without the direct measurement it could have been estimated by the reservoir loss equation and Weather Bureau pan data. For this reservoir a water depth of 10.0 ft and a surface area of 10 acres would be required to hold the 555 acre-inches. But with only this amount of storage the reservoir would be empty at the end of the irrigation season. For the supply to be replenished before the next season, runoff would have to equal the 555 acre-inch storage plus an additional 55 acre-inches for the net loss during the 9-month period, October to June. For 24 out of 25 years this would require a claypan soil drainage area of 630 acres. But for two consecutive drought years like 1953-54 there would have been no water for irrigating during 1954.

A reservoir similar to the one in the previous illustration, but with the dam of sufficient height to hold a 2-year supply, would require a storage volume of 1240-acre-inches. The depth of water would be 14.5 ft and the surface area 15.75 acres, the same as the McCredie reservoir. A claypan drainage area of about 290 acres would be required to supply 1240 acre-inches of runoff during a 2-year period with the minimum amount of runoff to be expected 96 percent of the time. The reason a smaller drainage area is required for a 2-year supply reservoir than for a 1-year supply reservoir, is the fact that 4.4 times as much runoff can be expected during two consecutive years than during a single year for a 25-year return period and a drainage area of claypan soil. This is shown in Table 1.

A breakdown of the losses by periods for the 1 and 2-year supply reservoirs are shown in Table 2. Depth-area and depth-volume curves for the 16-acre McCredie reservoir were used in making these determinations. The monthly rainfall and reservoir losses that were used in the analysis are shown in Table 3.

TABLE 2. EVAPORATION AND SEEPAGE LOSSES AND CORRESPONDING RESERVOIR DEPTHS BY PERIODS FOR 1 AND 2-YEAR SUPPLY RESERVOIRS, WITH STAGE-VOLUME RELATIONSHIP OF THE 16-ACRE RESERVOIR AT McCREDIE

Supply period	Irrigation Depth, ft	Irrigation Vol., ac-in	Net Loss† During irrigation Season Depth, ft	Net Loss† During irrigation Season Vol., ac-in	Net Loss† Between seasons Depth, ft	Net Loss† Between seasons Vol., ac-in	Total Depth, ft	Total Vol. ac-in
One year	8.8	400	1.2	155	—	—	10	555
Two years								
1st year	2.5	400	1.2	190	—	—	3.7	590
2nd year	8.8	400	1.2	155	0.8	95	10.8	650
Total	11.3	800	2.4	345	0.8	95	14.5	1240

†Evaporation plus seepage minus rainfall. Irrigation season assumed to be July 1 to September 30.

The storage capacity of the 1-year supply reservoir was increased nearly 40 percent to provide for evaporation and seepage losses but with the 2-year supply reservoir an increase of 55 percent was required. The storage efficiencies of the reservoirs are 72 and 65 percent, respectively. If the reservoir side slopes had been steeper the net loss (Table 2) storage volume would have been less.

The annual irrigation requirement of 400 acre-inches assumed in the illustration is sufficient for 16 acres of corn and 16 acres of pasture during severe drought conditions as experienced during 1953 and 1954 at McCredie. The 1-year storage volume is equivalent to 1.45 acre-feet storage per acre to be irrigated and the 2-year supply reservoir 3.23 acre-feet per acre to be irrigated. For the 1-year supply 20 acres of drainage area would be required per acre to be irrigated, but for the 2-year-supply reservoir it would require only 9 acres. With soil such as the Shelby, larger drainage areas per irrigated acre would be required. Both the storage volume and the drainage area per irrigated acre would be less with a reservoir with steeper side slopes.

TABLE 3. EVAPORATION AND SEEPAGE BY MONTHS FROM THE 16-ACRE RESERVOIR AT McCREDIE AND MONTHLY RAINFALL AMOUNTS FOR THE DROUGHT YEARS OF 1953 AND 1954

	1953		1954	
Month	E+S	Rainfall	E+S	Rainfall
January	1.19	1.42	0.92	0.71
February	2.09	1.01	1.64	0.72
March	2.60	3.60	2.81	1.99
April	3.70	2.95	4.33	3.58
May	5.55	3.74	2.02	3.62
June	7.34	3.50	6.23	2.45
July	7.17	1.96	9.61	0.20
August	7.06	2.14	5.94	5.33
September	6.91	2.38	6.09	1.93
October	3.46	2.72	3.72	4.72
November	3.02	0.60	2.00	1.04
December	2.75	0.71	1.13	1.52
Total	52.84	26.73‡	49.44	27.81‡

‡Normal annual rainfall 39.01 in.

Reservoirs with steeper side slopes and increased depth are more efficient in storing water because of the smaller area for evaporation and seepage. To illustrate this point, reservoir stage-volume curves were prepared for round reservoirs with side slopes of 5, 10 and 20 percent, all with a bottom area of two acres. Increasing the side slopes from 5 to 20 percent reduced the storage volume required to hold the losses by half. The results are shown in Table 4. This is an important point to consider in reservoir design. However, it is recognized that steep side slopes are impractical for the larger reservoirs on areas with gently rolling to moderate land slopes because of excessive amounts of soil that must be excavated.

TABLE 4. EFFECT OF RESERVOIR SIDE SLOPE ON STORAGE VOLUME REQUIRED TO HOLD EVAPORATION AND SEEPAGE LOSSES

	Reservoir side slope (2-acre bottom)		
Item	5 percent	10 percent	20 percent
1-year supply			
Loss volume	100 ac-in	80 ac-in	50 ac-in
Loss as percent of use*	25 percent	20 percent	12½ percent
Storage efficiency	80 percent	83 percent	89 percent
Total depth	8.5 ft	10.9 ft	13.6 ft
2-year supply			
Loss volume	360 ac-in	240 ac-in	170 ac-in
Loss as percent of use*	45 percent	30 percent	21 percent
Storage efficiency	69 percent	77 percent	82 percent
Total depth	13.5 ft	17.6 ft	22.1 ft

*Use volume 400 acre-inches per season.

Summary

1 The three factors to be evaluated in design of farm reservoirs for an irrigation water supply are: *(a)* irrigation requirement per year, *(b)* evaporation and seepage losses from the reservoir, and *(c)* drainage-area size and watershed yield.

2 Evaporation losses from a 16-acre reservoir has averaged 73 percent of that from a standard U. S. Weather Bureau pan during the last 4 years, and 78 percent from a 1-acre pond.

3 Seepage from a clay-blanketed reservoir 16 acres in size has averaged 1 in per month, and 2¼ in per month from the 1-acre pond without the blanket.

4 Evaporation and seepage losses for the 16-acre reservoir, minus rainfall during the drought years of 1953-54, totaled 24 in per year of which one-half was seepage.

5 The amount of runoff to be expected from a slowly-permeable claypan-soil watershed 24 out of 25 years is 1 in or more but for two consecutive years the amount is 4.3 in or more.

6 The amount of runoff from a watershed with moderately permeable soil was less than half that from a watershed with the slowly permeable soil.

7 A reservoir with capacity for a 2-year supply is needed to insure an adequate supply during drought cycles.

8 For a 1-year supply reservoir 20 acres of claypan-drainage area are needed per acre to be irrigated to insure a supply 24 out of 25 years, but only 9 acres for a 2-year-supply reservoir.

9 Storage volume per acre to be irrigated should be 1½ acre-feet per acre for a 1-year supply reservoir and 3¼ acre-feet for a 2-year supply reservoir on midwest claypan soils.

10 Reservoir storage volume required to hold the quantity of water that will be lost through evaporation and seepage may be reduced by 50 percent by steepening the average side slopes from 5 to 20 percent.

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