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Determining the Effects of Farm Ponds on Runoff From Small Watersheds

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Determining the Effect of Farm Ponds on Runoff from Small Watersheds

F. R. Crow and W. O. Ree*

Farm ponds on agricultural watersheds have various implications for different individuals or groups. To the rancher, a full pond may mean the difference between success and failure of his livestock enterprise. To the sportsman, it means a good fishing spot. To the city government concerned about water for home and industry, farm ponds may be looked upon as wasteful impoundments of runoff water that might otherwise have helped to fill the city reservoir.

The research hydrologist searching for the ideal experimental watershed is concerned with the farm pond. Generally he would seek a watershed free of ponds since ponds may affect the rates and amounts of runoff. However, because of the great number of farm ponds in the Southwest, it is often impossible to find a watershed that does not contain one or more farm ponds. In this event, it is necessary to resort to a water budget or similar procedure to account for runoff water retained by the ponds.

This publication reports one method of adjusting runoff data for watersheds having ponds and discusses some of the effects of farm ponds on the runoff from watersheds near Stillwater.

Background Information

Farm Ponds on the Stillwater Watersheds

The hydrology research project was initiated in July, 1951, and has been continuous since that time. The watersheds are privately owned, native grasslands typical of large areas of the reddish prairies of Kansas, Oklahoma, and Texas. Detailed descriptions of the watersheds are published elsewhere (1, 2).

Typical of grazing lands of the Southwest, two of the watersheds in this project contain farm ponds for livestock water. Figure 1 shows the smaller watershed, W-3, which has a drainage area of 92 acres and contains one pond. Watershed W-4, Figure 2, has a 206-acre drainage area and three ponds. Characteristics of the four ponds are shown in Table I.

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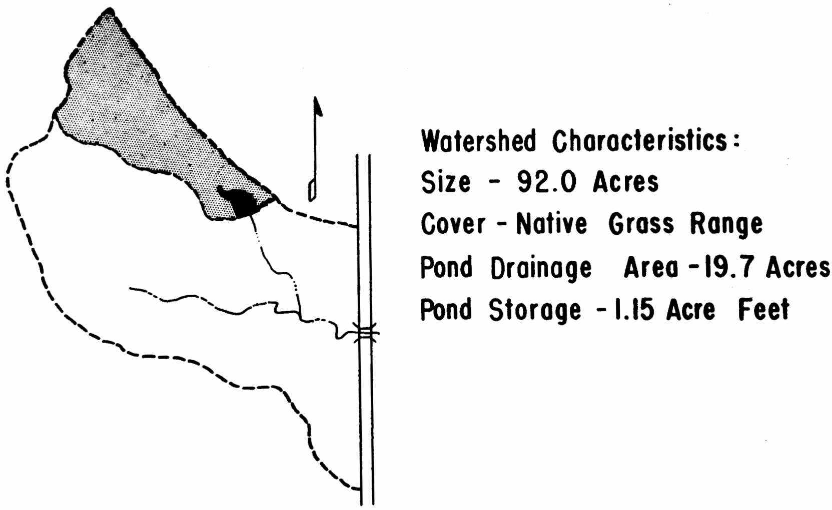

Figure 1. Single pond watershed (W-3), near Stillwater, Oklahoma.

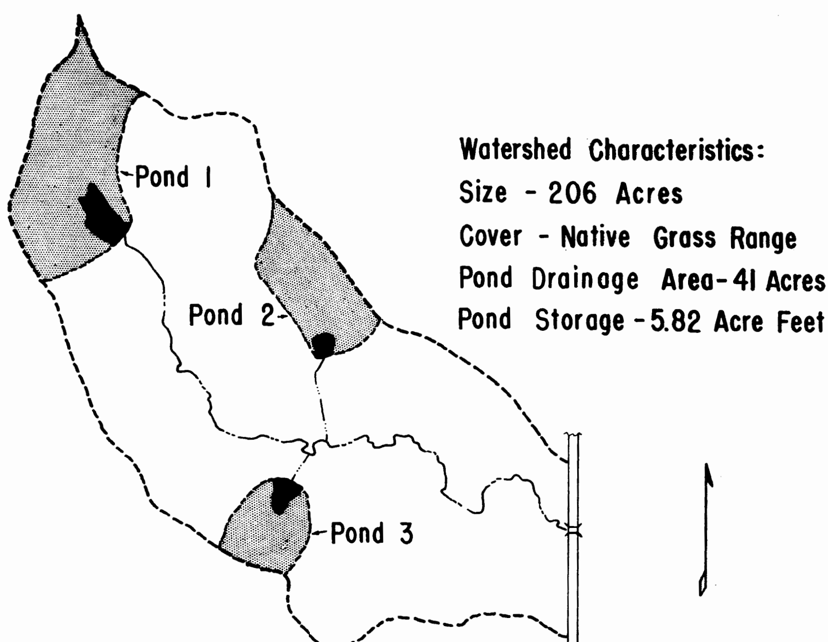

Figure 2. Multiple pond watershed (W-4), near Stillwater, Oklahoma.

TABLE I—POND CHARACTERISTICS, WATERSHEDS W-3 AND W-4

Watershed	Pond No.	Drainage Area (Acres)	Pond Storage (Acre-feet)	Capacity (Runoff Inches)	Watershed Capacity Ratio
W-3	1	19.7	1.15	0.70	17.1
W-4	1	22.9	3.91	2.05	5.9
W-4	2	11.4	0.38	0.40	28.5
W-4	3[1]	6.7	1.53	2.75	4.4

[1]Pond 3 was not constructed until January, 1955.

Factors Influencing the Effect of Ponds on Watershed Yields

Many interrelated factors govern the total effect of farm ponds on the water yield of small watersheds. Among these are the total drainage area; the number of ponds; the individual and combined drainage areas of the ponds; the geometry of the ponds as it affects their relationships of depth, surface area, and storage capacity; and the ratio of pond drainage area to storage capacity.

For watersheds having ephemeral flow the water level in any given pond is ever changing, and with it the remaining available storage also varies. The demands of usage, seepage and evaporation lower the water level, while direct rainfall and runoff raise the water level.

The extent to which any given pond will affect watershed runoff depends on (1) the available storage capacity of the pond at the beginning of the storm, and (2) the amount of direct rainfall and runoff. At the outset of a storm there are three possible conditions that may exist relative to the pond water level:

Condition I Pond level is low. Available storage capacity exceeds direct rainfall and rainfall runoff. Pond will not fill during storm. Watershed area is reduced by the amount of the pond drainage area and remains constant throughout runoff period.

Condition II Pond is partially full. Available storage capacity is less than direct rainfall and runoff. Pond will fill before the end of storm runoff. Watershed area changes during runoff period.

Condition III Pond is full at beginning of storm. All storm runoff flows through spillway and contributes to total watershed runoff.

The initial pond water level is a very important consideration. Therefore, if possible, in accounting for their effects on runoff all ponds on the watersheds should be instrumented with stage recorders. If this is impracticable, as was the case for the Stillwater watersheds, an analytical procedure may be used to estimate the pond level, with an occasional staff gage reading to serve as a check.

Procedures for Estimating Runoff Retained by Ponds

The following symbols will be used in the discussion that follows:

P = Direct rainfall

Q_m = Runoff volume measured at the watershed gaging station

Q_p = Runoff volume retained by pond

Q_a = Runoff volume adjusted to include runoff volume retained by pond

A_t = Drainage area of gaged watershed, including pond drainage area

A_p = Drainage area of pond

L = Pond water level

S = Available storage capacity at any given pond level (Acre inches per acre of pond watershed)

The Problem

The basic problem is to estimate the amount of runoff retained by each pond on the watershed. At the outset of the problem the following data are readily available:

1. The amount of rainfall

2. The volume of runoff (Q_m) measured at the gaging station (This volume is calculated and expressed in inches of depth over the entire watershed assuming all ponds overflowing, though they may be only partially full.)

3. The water level in the pond at the beginning of the storm (This elevation may be obtained by stage recorder or by accounting for evaporation, seepage, and usage since the last storm.)

The following data must be determined:

1. The exact drainage area contributing to the gaging station at any

time during the storm; that is, whether the ponds are overflowing or are retaining runoff.

2. The water level in the pond during and after the storm.

3. The adjusted runoff volume (Q_a).

Procedure — Single Pond Watersheds

The procedure followed on the Stillwater watersheds can best be illustrated by an actual example, using watershed W-3 as the model. The depth-storage curve for the single pond on this watershed is shown in Figure 3.

The following assumptions are made:

1. That rainfall and runoff occur uniformly over the entire watershed. For watersheds no larger than W-3 and W-4 this appears to be a reasonable assumption, especially since they have the same type of cover. However, for larger watersheds this assumption may not be valid.

2. That usage, seepage and evaporation can be estimated with satisfactory accuracy, using applicable published data. Usage is considered to be negligible. Seepage is believed to be negligible because of the high clay content of the soils on which the ponds are constructed. Monthly

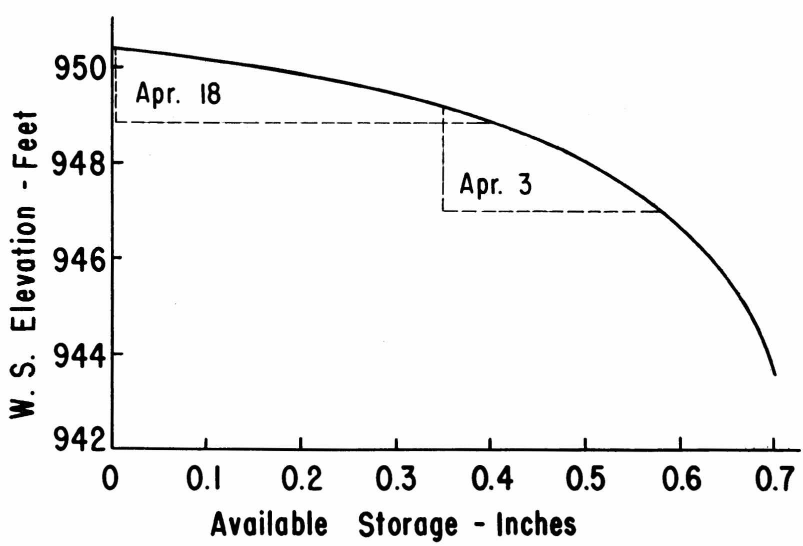

Figure 3. Available pond storage curve, Pond 1, Watershed W-3.

evaporation is assumed to be the same as reported at Lake Hefner near Oklahoma City as reported by the U.S. Geological Survey (3).

Condition I. The storm of April 3, 1957, illustrates the procedure for Condition I. Figure 4 shows the pond to be at a low level before the storm and remaining partially empty after the storm. For this storm the following quantities are known:

Rainfall	(P)	=	0.93 inches (0.08 feet)
Runoff	(Q_m)	=	0.175 inches
Pond Level	(L_o)	=	947.00 feet

1. Apply rainfall correction, assuming pond level rise is equal to the rainfall depth.

$$L = 947.00 + 0.08 = 947.08$$

2. Determine available storage capacity (S_1) when $L = 947.08$

$S_1 = 0.57$ inches (from Figure 3)

3. Determine whether pond can fill during storm

$Q_m = 0.175$

$Q_m < 0.57$ Therefore Condition I applies; pond cannot fill.

4. Calculate adjusted runoff (Q_a).

Pond drainage area cannot contribute to downstream gaging station. Therefore drainage area $= A_t - A_p = 92 - 20 = 72$

$$\text{Adjusted runoff } Q_a = Q_m \left[\frac{A_t}{A_t - A_p} \right]$$

$$= 0.175 \left[\frac{92}{72} \right] = 0.223 \text{ inches}$$

(Note: At this point check Step 3 to see if Q_a exceeds S)

5. Determine available storage capacity after storm (S_2)

$S_2 = S_1 - Q_a = 0.570 - 0.223 = 0.347$ inches

6. Determine pond level after storm (L_2) when $S = 0.347$

$L = 949.05$ (From Figure 3)

Condition II. The condition of the pond in which it will fill prior to the end of the storm runoff (Condition II) is illustrated in the storm of April 18, 1957, which has been described in detail (4).

The following data apply:

Rainfall	(P)	=	4.34 inches (0.36 ft.)

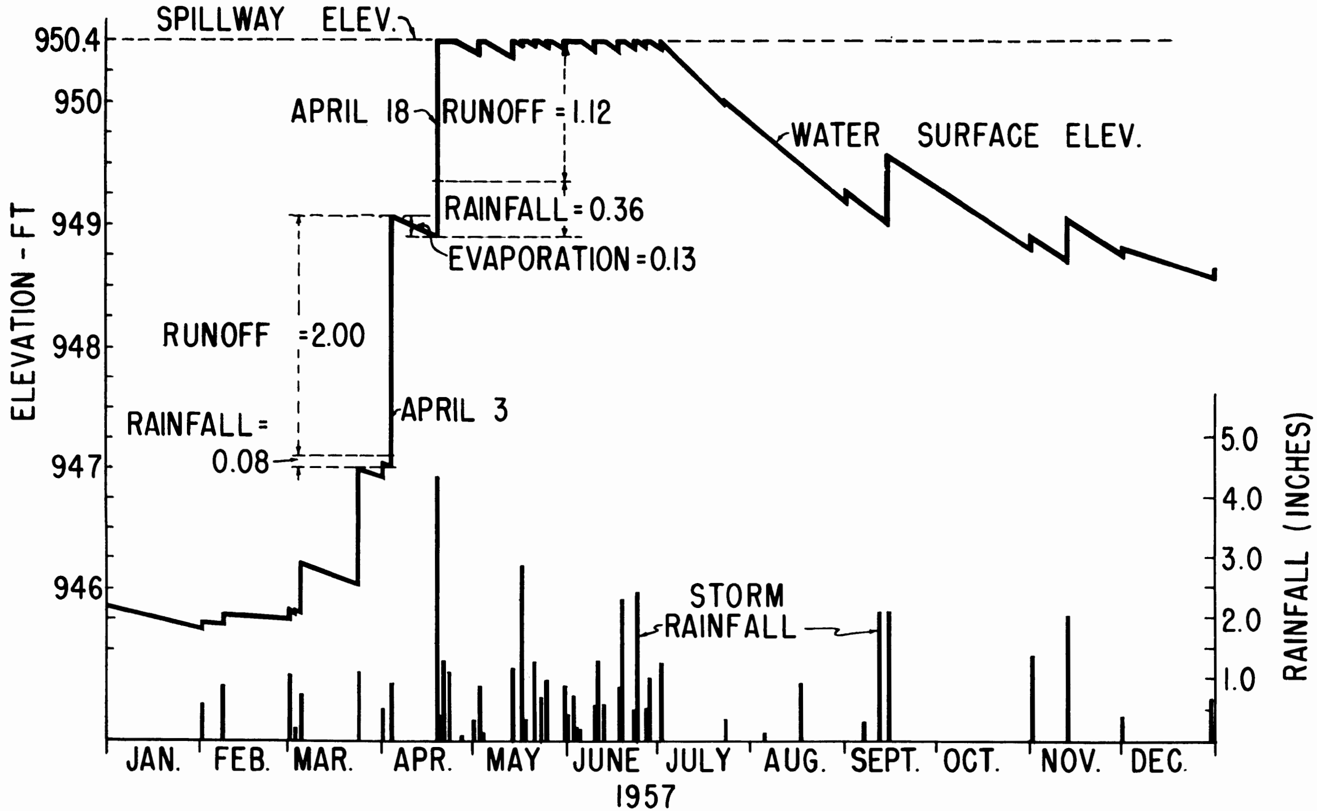

Figure 4. Pond elevations and storm rainfall, Watershed W-3.

Runoff $(Q_m) = 2.718$ inches
Pond Level $(L_o) = 948.92$

1. Pond level (L_1) after rainfall correction
   $L_1 = 948.92 + 0.36 = 949.28$

2. Available storage capacity (S_1) when $L = 949.28$
   $S_1 = 0.314$

3. Will pond fill during storm?
   $Q_m > S_1 \qquad 2.718 > 0.314$

   Therefore Condition II applies; pond will fill.

4. Calculate adjusted runoff (Q_a).
   Pond drainage area contributes to gaging station during latter part of storm. The adjusting coefficient $\frac{A_t}{A_t - A_p}$ then applies only to that part of Q_m required to fill the pond. By algebraic manipulation it can be shown that a more convenient form of the adjustment equation $Q_a = Q_m + S\left(\frac{A_p}{A_t}\right)$ can be derived from the adjusting coefficient.

$$Q_a = Q_m + S\left(\frac{A_p}{A_t}\right)$$

$$Q_a = 2.718 + 0.314\left(\frac{19.7}{92}\right) = 2.785$$

Procedure — Multiple Pond Watersheds

Watershed W-4 will be used to illustrate the procedure for adjusting for pond retention on multiple pond watersheds. This watershed has a total drainage area of 206 acres, with three ponds having a total drainage area of 41 acres.

As the number of ponds on a watershed increases, the problem of determining their combined effect becomes increasingly complex. Some ponds may be partially full and retaining runoff; others may be full and therefore having no effect. The number of combinations (C) of ponds either retaining runoff or not retaining runoff is: $C = 2^N$, where N is the number of ponds. Thus, for a three pond watershed there are eight different combinations. For each combination there is a different coefficient, depending on the actual drainage area contributing to the runoff that must be applied to determine the adjusted runoff (Q_a).

The different combinations of ponds and the adjusting coefficient $\frac{A_t}{A_t - A_p}$ are shown in Table II. Electronic computer analysis can be readily used to determine the relationships involved in this table.

TABLE II—COMBINATIONS OF PONDS RETAINING RUNOFF

Combination	Is Pond Retaining Runoff?			Adjusting Coefficient
	Pond 1	Pond 2	Pond 3	
1	Yes	Yes	Yes	1.248
2	Yes	Yes	No	1.200
3	Yes	No	No	1.125
4	No	No	No	1.000
5	No	No	Yes	1.034
6	No	Yes	Yes	1.096
7	No	Yes	No	1.059
8	Yes	No	Yes	1.168

Results and Discussion

The amount of runoff retained by the ponds on watershed W-4 relative to the total watershed runoff is shown in the double mass plotting in Figure 5. Of particular interest is the manner in which this plotting is alternately horizontal and sloping. The horizontal lines indicate periods of extremely heavy or frequent runoff when the ponds were having no effect on the total watershed runoff because the direct rainfall was sufficient to keep the ponds at spillway level. Periods of normal or less than normal runoff appear as sloping lines, indicating that part of the runoff was being retained by the ponds. Four distinct drought periods are evident on the graph.

The data for watershed W-4 were arranged into four groups according to amounts of monthly runoff. As expected, the greatest retention occurred during periods of low monthly runoff. The three ponds, with drainage areas covering 20% of the watershed area retained only 8.19% of the total runoff. This is due to the depth-volume relationships, which are individual characteristics of each pond. Ponds with steep sides and considerable depth lose less of their contents through evaporation and therefore require less runoff to refill them.

TABLE III—WATERSHED RUNOFF AND RETENTION BY PONDS — WATERSHED W-4

Monthly Runoff Amount (Inches)	Months (No.)	Watershed Runoff (Inches)	Retained by Ponds (Inches)	Percent Retained
0 - 1	130[1]	15.555	1.274	8.19
1 - 3	14	23.471	.574	2.45
3 - 5	3	10.909	.317	2.91
5 - 7	3	19.286	.308	1.60

[1]Not consecutive months.

The relatively small effect of farm ponds on the water yield of watershed W-4 during periods of high runoff is also shown in Table III. Retention was less than 3 percent for each of the three runoff categories greater than one inch per month. During the 20 months when runoff was greater than one inch, the average retention by ponds was only 2.23 percent of the total runoff.

As shown in Figure 5, the average reduction in total watershed runoff due to retention by ponds was 3.57 percent. This relatively small

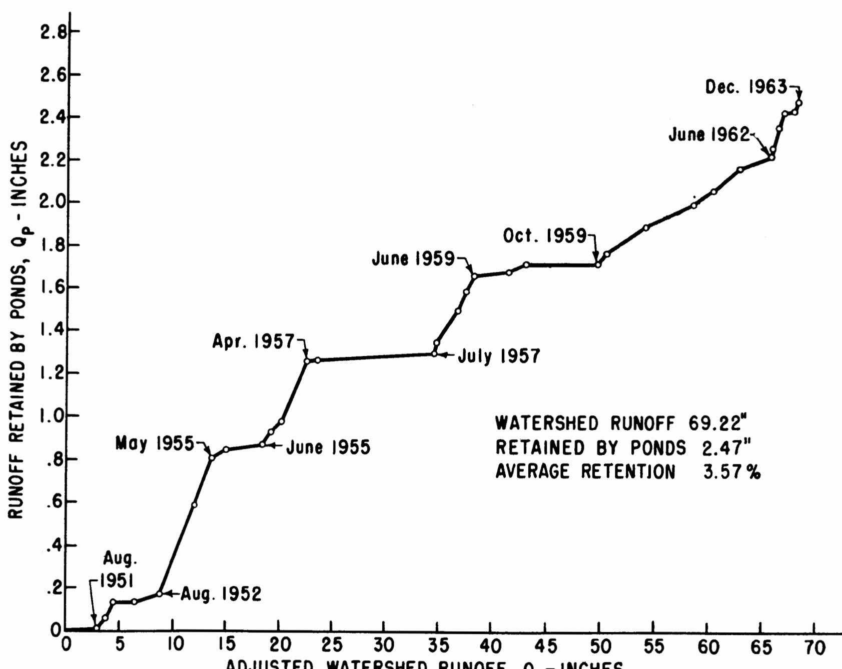

Figure 5. Double mass curve showing runoff retained by ponds compared with total runoff from Watershed W-4.

percentage indicates that the ponds had little effect on the total water yield of the watershed.

Summary and Conclusions

Many interrelated factors determine the total effect of farm ponds on small watersheds. Among these are the total area, the number of ponds, the individual and combined drainage areas of the ponds, the geometry of the ponds, and the ratio of pond drainage area to storage capacity.

The extent to which any given pond will affect watershed runoff depends on (1) the available storage capacity of the pond at the beginning of the storm, and (2) the amount of direct rainfall and runoff. The initial pond water level is an important consideration. If it is impracticable to measure all pond levels with stage recorders, an analytical procedure may be used for estimating the levels, with an occasional gage reading to serve as a check.

Procedures were developed for estimating runoff retained (1) by a single pond on a watershed and (2) by multiple ponds on a given watershed. On the multiple pond watershed, the average reduction in total watershed runoff due to retention by ponds was 3.57 percent. During the 130 months when runoff was less than one inch per month, the average runoff retention was 8.19 percent. During the remaining 20 months, the average runoff retention by ponds was 2.23 percent.

Although the pond drainage areas occupy 20 percent of the watershed (W-4), the runoff retained by the ponds was much less than that amount, even in extended dry periods.

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Oklahoma's Wealth In Agriculture

Agriculture is Oklahoma's number one industry. It has more capital invested and employs more people than any other industry in the state. Farms and ranches alone represent a capital investment of four billion dollars—three billion in land and buildings, one-half billion in machinery and one-half billion in livestock.

Farm income currently amounts to more than $700,000,000 annually. The value added by manufacture of farm products adds another $130,000,000 annually.

Some 175,000 Oklahomans manage and operate its nearly 100,000 farms and ranches. Another 14,000 workers are required to keep farmers supplied with production items. Approximately 300,000 full-time employees are engaged by the firms that market and process Oklahoma farm products.

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