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EVAPORATION PAN RECORDS NEEDED FOR SMALL RESERVOIR INFLOW CALCULATIONS *

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ABSTRACT

Small floodwater-retarding or storage reservoirs provide an economical means for measuring watershed runoff. Flood flow rates and amounts can be determined from spillway discharge calibration and reservoir stage records. Seepage and evaporation losses from and precipitation on a reservoir are of little significance in flood peak calculations; however, they are of major importance in calculating water yield. This is especially true during prolonged runoff periods. Data from a 6.48-hectare reservoir and its 61.9-hectare watershed at McCredie, Missouri, are presented to illustrate the use of evaporation pan data in connection with raingage and reservoir stage records for the purpose of determining total watershed runoff.

The method is unique in that it involves (1) establishing a relationship between pan evaporation and reservoir losses during periods of no runoff and little or no rainfall, (2) using the relationship to derive values of reservoir losses from evaporation and seepage during periods of runoff, and (3) combining estimated reservoir loss with spillway discharge and/or change in storage volume to obtain total runoff from the watershed into the reservoir.

Runoff computed by this proposed method shows the April to October runoff for 21 years (1944-1964) was 12.8% more than previously computed using only spillway discharge and change in storage. This increase was most notable during periods of high soil moisture, when runoff continues for long periods.

RÉSUMÉ

De petits réservoirs de retard ou des réservoirs de barrage donnent un moyen économique de mesurer le ruisselement du bassin versant. Les taux de débit de crue et le total de la crue peuvent être déterminés par l'étalonnage des déversoirs et les relevés des niveaux des réservoirs. Les pertes par infiltration et par évaporation du réservoir, et la précipitation sur le réservoir sont de peu d'importance pour le calcul du débit maximum de crue; cependant, elles sont de plus grandes importances pour calculer le rendement d'eau. C'est vrai surtout pendant les périodes de ruissellement prolongé. Les données d'un réservoir de 6,4 hectares et son bassin versant de 61,9 hectares à McCredie, Missouri, sont présentées pour illustrer le traitement des données du bac d'évaporation avec le pluviomètre et avec les relevés des niveaux dans le réservoir dans le but de déterminer le ruissellement total du bassin versant.

La manière est unique en ce qu'elle implique (1) établir un rapport entre le bac d'évaporation et les pertes du réservoir pendant des périodes sans ruissellement, et peu ou pas de pluie, (2) se servir de ce rapport pour tirer les valeurs des pertes du réservoir par évaporation et par infiltration pendant des périodes de ruissellement, et (3) combiner les pertes estimées pour un réservoir avec déversement et/ou le changement dans le cubage du réservoir afin d'obtenir le ruissellement total du bassin versant dans les réservoir.

Le ruissellement calculé avec cette nouvelle méthode montre que le ruissellement d'avril à octobre pour 21 années (1944-1964) était 12.6% plus élevé que ce qu'on avait calculé auparavant en employant seulement le déversement et le changement du cubage du réservoir. Cet accroissement était le plus notable pendant des périodes de haute humidité du sol, quand le ruissellement continue pour de longues périodes.

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Introduction

Gathering reliable runoff data from small watersheds is usually expensive. An economical small watershed runoff station is often made feasible by adding a stilling well and water stage recorder to a small floodwater-retarding or storage reservoir. Records of reservoir stage, spillway discharge, and precipitation are not sufficient to accurately determine watershed runoff volumes; evaporation and seepage losses must be accounted for. Though these losses are generally not significant in peak flow computations, they are important in water balance studies. The investigation reported here shows how the addition of evaporation pan data increased the accuracy of determining total runoff from a small watershed.

Runoff into a reservoir will last for a few hours or several days, depending on the soil type and moisture condition of the watershed at the time of the storm. It is incorrect to conclude that runoff has stopped when the spillway discharge equals the rate of depletion of reservoir storage or when there is no outflow and the reservoir stage becomes constant. When evaporation and seepage losses are greater than inflow and the reservoir elevation is below spillway level, the stage may be falling even though inflow continues. A near-constant stage may mean low evaporation and seepage loss with no inflow or outflow, or an inflow which is just about equal to these losses and outflow.

This paper presents a method in which reservoir losses from evaporation and seepage during runoff periods are included in the runoff calculations. The steps used in this method are: (1) Establish a relationship between pan evaporation and reservoir loss for each month using periods with little or no rainfall and no inflow or outflow; (2) Use this relationship to derive values of reservoir losses from evaporation and seepage during runoff periods; (3) Combine the estimated reservoir losses with spillway discharge and/or change in storage to obtain the total inflow from the watershed for the period.

Use of this method for one April-October season added 29 mm of watershed runoff, or 21% to the runoff as compiled in accordance with instructions outlined in USDA Agricultural Handbook No. 224[3]. This earlier method accounted only for changes in reservoir storage and rainfall on the reservoir surface. In these earlier calculations, inflow to the reservoir was considered to be zero when the rate of decrease in reservoir volume was just equal to the spillway discharge. At stages below spillway elevation when the stage became constant, watershed runoff was considered to be zero. However, inflow may still have continued under both these conditions—being offset by evaporation and seepage losses. Interflow has been shown to exist on parts of this watershed[4]; therefore, neglecting it, as done in previous calculations, would introduce sizeable errors in total runoff.

Description of watershed

The McCredie, Missouri, watershed is about 1.61 km long and 0.40 km wide, with a drainage area of 61.9 hectare exclusive of the reservoir area. The reservoir has a surface area of 6.48 hectare at spillway elevation. The soils in the watershed are of loessial origin over glacial till with an impeding stratum at depths of 200-500 mm. One-third of the watershed has slopes less than 2%, more than one-half has between 2 and 5% slopes, and only one-tenth has slopes greater than 5%. Figure 1 is a map of

[3]Holtan, H. N., Minshall, N. E., and Harrold, L. L. *Agricultural Handbook No. 224—Field Manual for Research in Agricultural Hydrology*, Washington, D. C., June, 1962.

[4]Minshall, N. E., and Jamison, V. C., "Interflow in Claypan Soils." *Am. Geophysisal Union, Water Resources Research*, Vol. 1, No. 3, pp. 381-390; 1965.

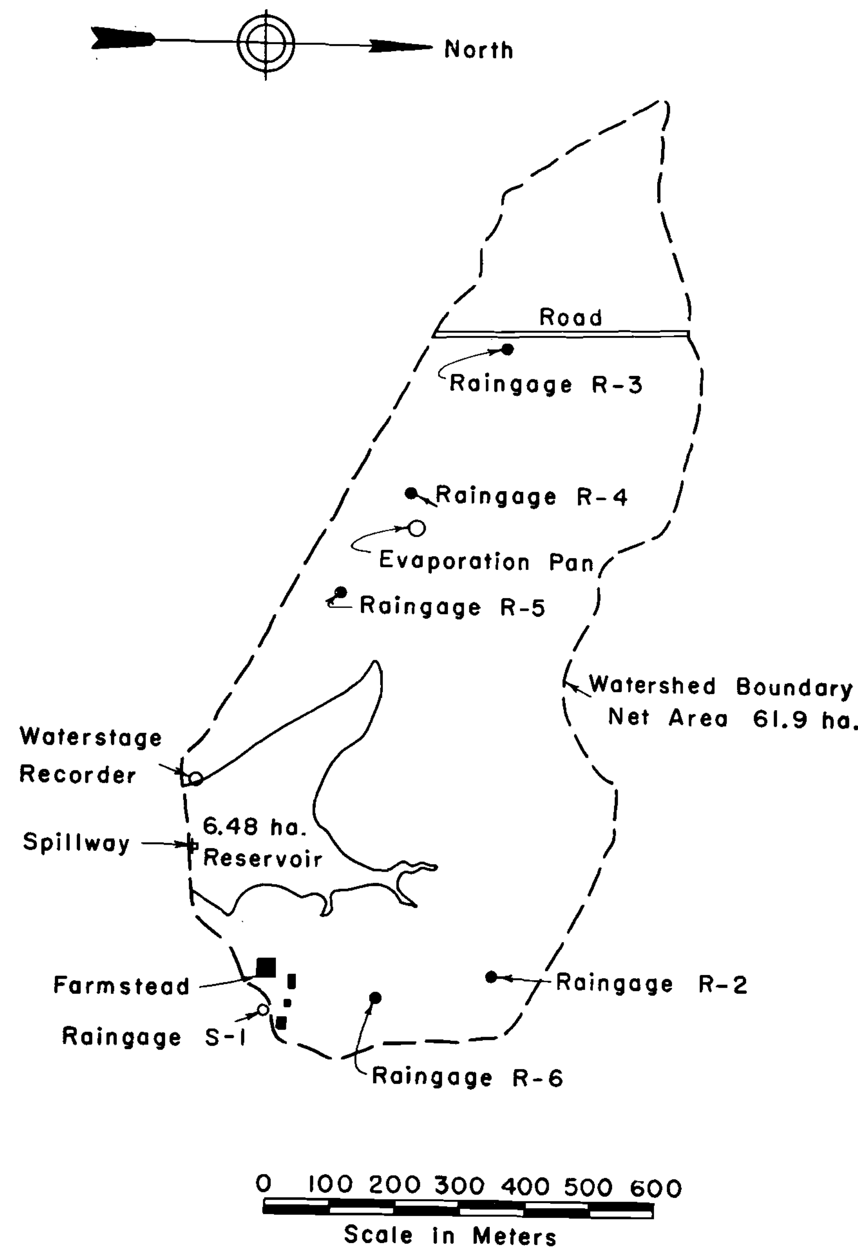

Fig. 1—Map of McCredie Watershed Showing Instrumentation.

the watershed showing the location of the raingages, water stage recorder, spillway, evaporation station, and outline of the reservoir. To hold seepage losses to a minimum, a clay blanket was placed over the entire upstream face of the dam at the time of construction. This method was also used on other areas in the reservoir that the soil texture indicated to be pervious.

Basic data

Continuous records of precipitation and runoff have been collected on the McCredie watershed since April 1941.

Precipitation was originally measured with five recording and one standard raingage. All stations except R-2 andR-4 were discontinued prior to 1956. Precipitation on the reservoir for the period 1944-1955 was taken as the average of gages S-1 and R-5. Records from raingage R-4 were used in subsequent years, since it was the nearest to the evaporation station.

Discharge from the reservoir is measured through a 76.2 × 76.2-cm reinforced concrete drop inlet having a total fall of about 5.5 m and a maximum capacity of 2.83 m^3/sec. A full-scale model of this inlet and a one-fourth-scale model of the entire structure were calibrated in a laboratory [5]. Records of stage in the reservoir have been obtained with a water stage recorder having a stage ratio of 2.54 cm of chart equal to 3.05 cm of stage for 1944-1952 and 1954-1958 and 6.10 cm of stage for 1953 and 1959-1964.

Evaporation pan records have been collected at the McCredie station since 1956. This station uses a standard U.S. Weather Bureau pan with stilling well and hook gage which is read twice weekly to the nearest millimeter from April 1 to November 1. Daily evaporation pan data for the period 1944-1955 were obtained at the University of Missouri Horticultural Experiment Station located about 48 km west of the reservoir. To make subsequent analyses comparable for the two periods, data for 1944-1955 were also grouped by 3-day intervals.

Relation between pan evaporation and reservoir loss

The relation between pan evaporation and reservoir loss was not constant throughout the year. This may be due to the lag in water temperature in the reservoir as compared to that in the evaporation pan. This relationship, as determined for each month, was based on data for only those periods when it was certain that neither surface runoff nor interflow was present.

To illustrate the method, table 1 shows evaporation pan and reservoir loss data for July 1956 and 1961. These data were selected because they provide a good range of conditions. The pan evaporation for each period was computed by adding the precipitation to the difference in hook gage readings. The reservoir stage was read to the nearest 0.001 m from the recorder charts at the times when evaporation pan readings were taken. The difference in stage represents the reservoir losses or gains due to inflow, outflow, evaporation or seepage. When water was withdrawn from this reservoir for irrigation and other uses, the net storage change was obtained by adding the change in reservoir stage and precipitation and deducting withdrawals (table 1).

Negative reservoir loss values (table 1) resulted from an increase in storage due to runoff. Also, periods of comparatively low reservoir losses, such as July 16-19, 1956,

[5] University of Minnesota, St. Anthony Falls Hydraulic Laboratory, *Technical Paper*, No. 19, Series B. "Hydraulics of Closed Conduit Spillways," by Fred W. Blaisdell.

Table 1. PRECIPITATION, PAN EVAPORATION, RESERVOIR EVAPORATION AND SEEPAGE LOSSES, AND ESTIMATED WITHDRAWALS FOR THE MC CREDIE, MISSOURI, RESERVOIR FOR JULY 1956 AND 1961

Date	Time of Observation	Precipitation	Evaporation Pan: Hook Gage Reading	Evaporation Pan: Difference	Evaporation Pan: Evaporation	Reservoir: Stage 1/	Reservoir: Loss	Withdrawals	Reservoir Loss, Net storage Change S + P - I
		(P)			(E_p)		(S)	(I)	
		mm.	m.	m.	mm.	m.	mm.	mm.	mm.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1956									
6-29	1037		0.783 2/			5.071			
7- 2	1345	0	.760	.023	23	5.045	26	3e	23
7- 2	1345		.783			5.045			
7- 3	1500	57	.829	-.046	11	5.092	-47	15e	-5
7- 3	1500		.783			5.092			
7- 4	1045	47	.819	-.036	11	5.288	-196	0	-149
7- 4	1045		.783			5.288			
7- 6	1137	0	.775	.008	8	5.280	8	0	8
7- 6	1137		.783			5.280			
7- 9	1015	21	.779	.004	25	5.314	-34	0	-13
7- 9	1015		.783			5.314			
7-13	0910	26	.783	.000	26	5.321	-7	0	19
7-13	0910		.783			5.321			
7-16	1753	56	.814	-.031	25	5.614	-293	0	-237
7-16	1753		.783			5.614			
7-19	1555	14	.782	.001	15	5.624	-10	0	5
7-19	1555		.783			5.624			
7-23	1753	9	.771	.012	21	5.613	11	0	20
7-23	1753		.783			5.613			
7-27	0826	0	.760	.023	23	5.596	17	0	17
7-27	0826		.783			5.596			
7-30	0820	3	.767	.016	19	5.581	15	1e	17

1/ Spillway at 6.09 m.

2/ Water was added to or removed from the evaporation pan to give the same initial reading for each period.

e = estimated

Table 1. (Cont.)

Date	Time of Obser-vation	Precipi-tation (P) mm.	Evaporation Pan: Hook Gage Read-ing m.	Evaporation Pan: Differ-ence m.	Evaporation Pan: Evapo-ration (E_p) mm.	Reservoir: Stage 1/ m.	Reservoir: Loss (S) mm.	With-drawals (I) mm.	Reservoir Loss, Net storage Change S + P - I mm.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1961									
6-30	0835		.762			5.968			
7- 3	1815	113	.838	-.076	37	6.111	-143	0	-30
7- 3	1815		.762			6.111			
7- 7	1125	15	.752	.010	25	6.102	9	0	24
7- 7	1125		.762			6.102			
7-10	0825	0	.741	.021	21	6.084	18	0	18
7-10	0825		.762			6.084			
7-14	0830	7	.744	.018	25	6.070	14	0	21
7-14	0830		.762			6.070			
7-17	0830	0	.747	.015	15	6.056	14	0	14
7-17	0830		.762			6.056			
7-21	1455	28	.765	-.003	25	6.066	-10	0	18
7-21	1455		.762			6.066			
7-24	0848	55	.803	-.041	14	6.130	-64	0	-9
7-24	0848		.762			6.130			
7-28	1015	9	.750	.012	21	6.102	28	0	37
7-28	1015		.762			6.102			
7-31	0830	0	.740	.022	22	6.085	17	0	17

show evidence of inflow to the reservoir. Only those periods having no inflow into or outflow from the reservoir were considered usable in establishing a relation between pan evaporation and reservoir loss. All such July periods for the 9 years (1956-1964), when the pan was located at the reservoir, were analyzed as one group. The records for 1944-1955, with the evaporation pan located at the University of Missouri Horticultural Experiment Station (48 km to the west), were analyzed separately.

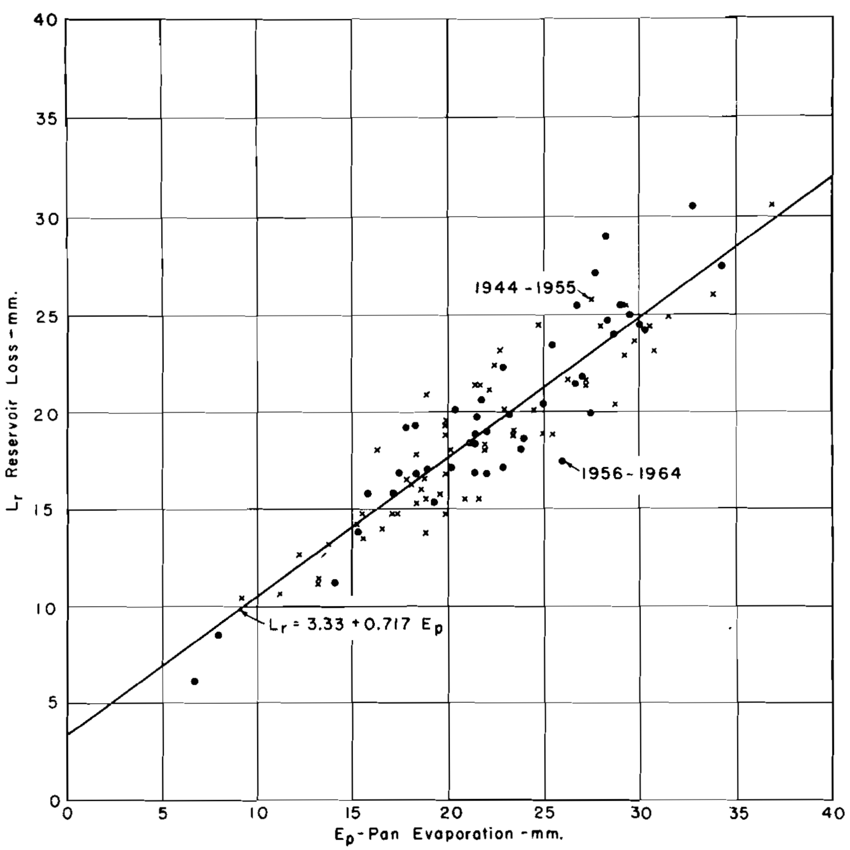

Fig. 2—Relation Between Pan Evaporation and Reservoir Loss for 3 to 4 Day July Periods.

The data for all usable 3 to 4 day July periods for the entire 21 years are plotted in figure 2. The line of best fit for July, computed by the method of least squares, shows that: $L_r = 3.33 + .717\ E_p$ where: L_r is the reservoir evaporation and seepage loss, and E_p is pan evaporation. As shown by Smith [6], the slope of this line (.717) represents the ratio of reservoir to pan evaporation and the y intercept (3.33) represents reservoir seepage.

[6] Smith, D. D., *Agricultural Engineering*, Vol. 36, No. 11, pp. 743-746, November 1955.

Use of a variable time interval may raise a question as to the accuracy of the method. Examination of figure 2 shows about the same scatter of points for each period even though the 1944-1955 data are all for 3-day intervals, while for the 1956-1964 data the interval varied between 3 and 4 days. Seepage is approximately 1 mm per day, but the variation of points from the computed line is ± 4 mm. The scatter of points in figure 2 may be due to instrument lag when the stage changes direction, seepage into the banks of the reservoir following a rise in stage, or wave action from high winds splashing water over the spillway.

The relation between pan evaporation and reservoir loss varied from month to month. Calculated values for each month (April through October) for the two separate periods (1944-1955 and 1956-1964) show good agreement with the entire 21-year record. This indicates that, when evaporation pan records in the immediate vicinity are not available, evaporation records at some distance from the reservoir can be used. The investigation shows that, except for April and May, these relations might very well be represented by a single equation. The maximum departure of June through October equations from the mean, within the usual range of pan evaporation values (10 to 36 mm in a 3 to 4 day period), was only 1 mm.

Reservoir losses for all usable periods were expanded to monthly losses by the ratio of monthly pan evaporation to pan evaporation for the usable period. This method of expanding reservoir loss data to monthly values is probably in error to the extent that it appears to relate evaporation (a variable) to seepage (a constant). However, except for April and October, the seepage loss is less than 20 percent of the total reservoir loss. Furthermore, since about two thirds of the actual records are usable, this apparent error is reduced to approximately 7 percent. The least squares equations were then determined for each month. Exept for April and October, these equations gave the y intercept or monthly seepage loss of 25 mm. This record of seepage loss was further verified during long winter periods both with and without ice cover. These seepage losses also agree with earlier findings by Smith [6]. The slope of these lines or ratio of reservoir to pan evaporation increased gradually from .65 in May to .77 in September. Smith found an average ratio of .73 for April-October.

Computation of watershed runoff volumes

Data for the periods shown in table 1 are used to illustrate the improved runoff computation method using evaporation pan data. During periods with no inflow, the observed reservoir loss and that determined by the pan to reservoir relation (fig. 2) show close agreement. These periods were omitted from the runoff computations.

Runoff computed by the proposed new method can be expressed as an equation:

$$R = \frac{L_r + I - S - P}{A_d / A_r} + O$$

where:

R is the total runoff in millimeters from the watershed.

L_r is the estimated reservoir loss based on pan evaporation and the relation established in fig. 2. It is shown in column 6 of table 2.

I is withdrawals for irrigation and other uses from column 10 of table 1.

S is the actual loss in stage in the reservoir in column 9, table 1. A negative value represents increase in stage.

P is the precipitation shown in column 3, tables 1 and 2.

The above are depths on the reservoir in millimeters.

A_d is the average net watershed area in hectares, exclusive of the reservoir area.

A_r is the average surface area of the reservoir in hectares.

O is the outflow through the spillway in millimeters from the watershed.

Table 2. COMPUTED RUNOFF INTO MC CREDIE, MISSOURI, RESERVOIR FOR JULY 1956 AND 1961 INCLUDING ALLOWANCE FOR ESTIMATED EVAPORATION AND SEEPAGE LOSSES

Period from	to	Precipitation (P)	Pan Evaporation (E_p)	Reservoir Loss: Actual (S+P-I)	Reservoir Loss: Estimated from graph 1/ (L_r)	Reservoir Loss: Difference L_r minus (S+P-I)	Mean Reservoir Stage 2/	Ratio: 3/ (A_d/A_r)	Runoff to or from Storage	Outflow through Spillway (O)	Total Runoff for Period (R)
		mm.	mm.	mm.	mm.	mm.	m.		mm.	mm.	mm.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1956											
7- 2-1345	7- 3-1500	57	11	-5	11	16	5.069	14.25	1	0	1
7- 3-1500	7- 4-1045	47	11	-149	12	161	5.182	13.70	12	0	12
7- 6-1137	7- 9-1015	21	25	-13	21	34	5.297	13.20	3	0	3
7- 9-1015	7-13-0910	26	26	19	22	3	5.316	13.10	0	0	0
7-13-0910	7-16-1753	56	25	-237	22	259	5.465	12.40	21	0	21
7-16-1753	7-19-1555	14	15	5	15	10	5.621	11.75	1	0	1
1961											
6-30-0835	7- 3-1815	113	37	-30	29	59	6.142	9.55	6	21	27
7- 3-1815	7- 7-1125	15	25	24	22	-2	6.105	9.70	0	2	2
7-21-1455	7-24-0848	55	14	-9	14	23	6.126	9.60	2	9	11
7-24-0848	7-28-1015	9	21	37	18	-19	6.114	9.70	-2	6	4
7-28-1015	7-31-0830	0	22	17	19	2	6.096	9.75	0	0	0

1/ Figure

2/ Taken from water stage recorder chart (not mean of values of column 7 of table 1).

3/ Ratio of drainage area (A_d) to reservoir area (A_r).

Sample computations are shown in table 2. In this table columns 1-5 were taken directly from table 1. Column 6 is the estimated normal reservoir loss from seepage and evaporation based on actual pan evaporation and the relation established in fig. 2. Column 7 is column 6 minus column 5 and represents the net change in reservoir stage in millimeters due to surface runoff from the watershed or outflow through the spillway. A minus value in this column represents a decrease in reservoir volume through spillway discharge. This change is expressed as millimeters on the surface of the reservoir and must be converted to millimeters over the drainage area. Fig. 3 shows the ratio of the drainage area to reservoir area required for this conversion. The mean reservoir stage shown in column 8 was taken from the water stage recorder chart and applied to fig. 3 to obtain the ratio of drainage area to reservoir area shown in column 9. To determine the millimeters runoff depth from the watershed going in to or out of storage (column 10), the values in column 7 were divided by those of column 9. A negative value in column 10 indicates discharge over the spillway due to reduction in storage.

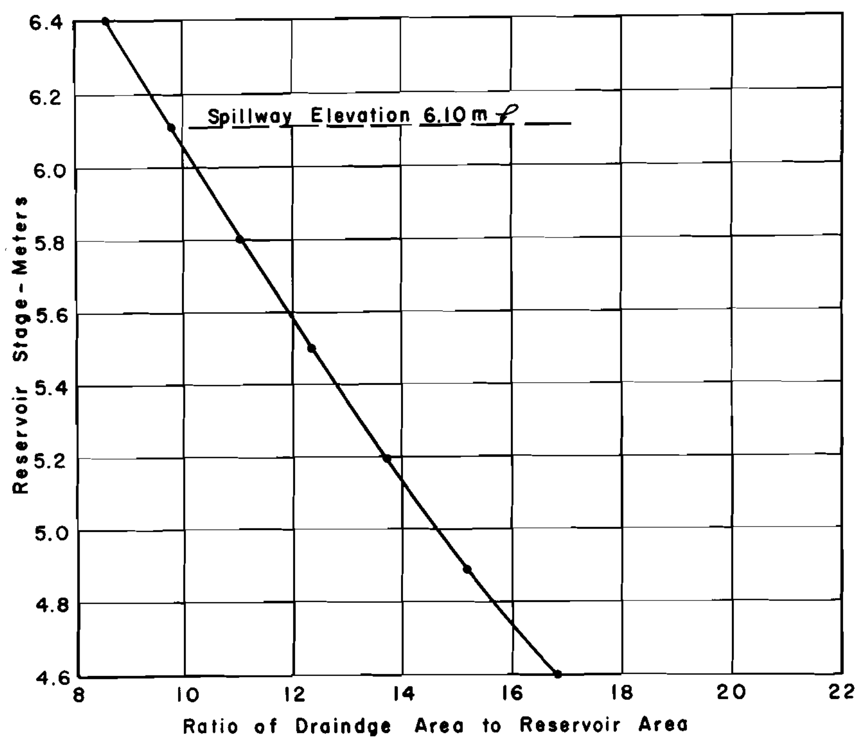

Fig. 3—Relation of Drainage Area to Reservoir Area for Various Stages.

Data to obtain the spillway outflow in column 11 were taken from reservoir water stage recorder charts. This information was placed on punch cards and a computer program gave instantaneous rates, m^3/sec and millimeters per hour, and accumulated amounts in millimeters. The runoff from the drainage area shown in column 12 is the sum of columns 10 and 11.

The scatter of points in fig. 2 might result in the conclusion that the proposed method is no more accurate than the present one. However, the drainage area is about 10 times the reservoir area; therefore, a departure of 2 mm from the computed relation will result in a difference of only 0.2 mm in the calculated watershed runoff.

Comparison of results

Table 3 shows the montly total runoff by the present and proposed methods for the months of April through October for the years 1957, 1958, 1959, and 1961, and the 21-year totals (1944-1964). This shows that the present method underestimated the total runoff for these months by more than 200 mm or 12.8%. The relationof April through October runoff by the two methods is shown in fig. 4. The proposed method always produces runoff equal to or greater than computed by the present

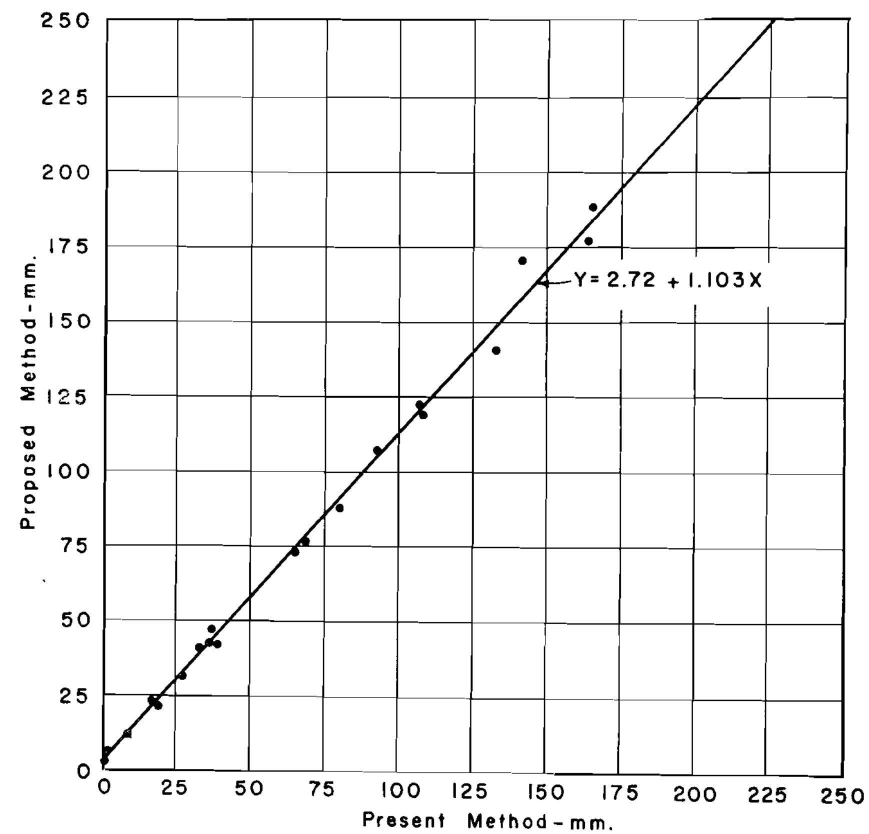

Fig. 4—Relation Between Present and Proposed Computed April-October Runoffs for the McCredie, Mo., Watershed.

Table 3. COMPARISON OF MONTHLY RUNOFF MC CREDIE, MISSOURI, WATERSHED PRESENT METHOD = SPILLWAY DISCHARGE + STORAGE CHANGE - PRECIPITATION (AGRIC. HANDBOOK NO. 224). PROPOSED METHOD INCLUDES ESTIMATED EVAPORATION AND SEEPAGE LOSSES

Year	1957		1958		1959		1961		Totals 1944-64		Difference 1944-64
Month	Pres.	Prop.	Pres.	Prop.	Pres.	Prop.	Pres.	Prop.	Pres.	Prop.	
	mm. (1)	mm. (2)	mm. (3)	mm. (4)	mm. (5)	mm. (6)	mm. (7)	mm. (8)	mm. (9)	mm. (10)	mm. (11)
April	57	62	11	13	7	8	48	53	447	495	48
May	6	9	11	15	15	20	70	76	277	327	50
June	43	46	19	25	0	0	0	1	258	294	36
July	0	5	87	99	0	1	36	44	225	269	44
August	0	0	12	17	0	0	0	0	45	54	9
September	0	0	0	0	1	2	11	14	229	247	18
October	1	1	2	2	46	46	0	1	224	238	14
Totals	107	123	142	171	69	77	165	189	1705	1924	219
Difference		+16		+29		+8		+24		+219	

method. This is because the present method does not account for prolonged inflow which is partially offset by evaporation and seepage losses. The difference in the two methods appears to be greatest during storms with high antecedent moisture when flow into the reservoir is likely to continue for several days. These conditions are common during the early spring.

The greatest difference in runoff for an individual storm, 3.3 mm, occurred as a result of 108 mm of precipitation on June 29, 1957. As shown in table 3, the most difference for one month was July 1958, when the proposed method showed 12 mm or 14% more than the present method. Another month with notable variation was July 1961. All of these periods were preceded by above-normal precipitation, which resulted in long recessions.

In periods of low antecedent moisture, only minor differences in runoff amounts were noted between the two methods. This is well illustrated by the runoff for the months of September and October 1959. The difference in runoff between the two methods amounted to slightly more than 1 mm out of a total of 48 mm. The entire runoff for these two months resulted from more than 250 mm of precipitation between September 23 and October 10. Prior to this period, the total precipitation since June 1 was only 145 mm or 38% of normal. All runoff for April 1959 was from a storm of 38 mm after a period of three weeks with little precipitation. October data (table 3) also show little difference in runoff between the present and proposed methods. This generally reflects a dry soil condition during the late fall months.

Conclusions

1. Evaporation pan data in conjunction with reservoir stages and recording raingage records were necessary to provide more accurate estimates of total runoff than those obtained with method outlined in USDA Agricultural Handbook No. 224.
2. Runoff computed by the proposed new method shows the April to October total for 1944-1964 was 12.8% more than that obtained by the present method.
3. A relation has been established between pan evaporation and reservoir loss.
4. Pan evaporation at the reservoir and another location 48 km from the reservoir show about the same relation to reservoir loss.
5. The proposed method needs better instrumentation and data recording than presently used on most watershed reservoir installations.