United States Department of Agriculture
Soil Conservation Service
Engineering Division

Technical Release No. 19
Central Technical Unit

DETERMINATION OF STORAGE REQUIREMENTS TO MEET SUPPLY-DEMAND RELATIONSHIPS

Purpose and Scope

The purpose of this Technical Release is to demonstrate techniques and procedures for determining the storage of water for use at a later date.

The increasing demands for surface-water supplies for irrigation, recreation, municipal, industrial and urban developments have emphasized the need for more information and study on the storage of water.

The storage provided depends upon the interrelationship between supply, losses, demand and their respective distributions throughout the year as well as the economics based upon the cost of storage against the benefits from use. It is the intent of this release to provide examples using varying intensities of analyses to solve storage problems and consider some of the important factors.

Nomenclature and description of terms used in this release are as follows:

Supply	-	Inflow at proposed site of reservoir.
Losses	-	Reservoir seepage and net lake evaporation (lake evaporation minus precipitation).
Water use	-	The amount of water available at the reservoir site. Losses between the reservoir outlet and the point of actual beneficial use should be included as part of the water use.

The solution of the storage problem requires the consideration of the following factors:

Legal Aspects of Water Storage.
The state and local laws governing the storage and use of water transgress all other considerations and complicate the study of water storage. It is therefore essential to first determine specifically the conditions under which water can be stored and used. This will answer the questions of by whom, when, and to a degree, how much water can be stored for future use.

Supply.

Monthly and annual runoff amounts.--The monthly and annual runoff values must be determined for a period of time long enough to reflect the "long-time" variability of runoff. Mean monthly values should be computed and used to determine the monthly percentages of the mean annual runoff.

A frequency curve should be developed for the series of annual runoff.

Distribution of monthly values for any given percent chance annual yield is made according to the monthly percentages of the mean annual flow. This is not exactly true but furnishes reasonable estimates for short-cut procedures.

Mass-flow diagram.--The mass-flow diagram is extremely valuable in the study of storage requirements or the determination of the flow which could be assured with a given amount of storage. The watershed yield data should be corrected for the estimated evaporation and seepage losses before constructing the mass-flow diagram. The mass-flow curve is the integral of the hydrograph; the abscissa being in units of time and the ordinate at any point being the total volume of flow, less estimated losses, that passed that point since zero time. The time unit is days which may be accumulated by months and plotted versus the volume unit second-foot-day. The slope of the curve at any point indicates the rate of change of volume with respect to time and is thus a rate of flow. Since the units are second-foot days and days, the rate of flow becomes cubic feet per second (cfs). Many kinds of data can be studied by the mass-diagram technique, but proper conversion units are essential. (See NEH-4, Supplement 4, Table 5.2-1). The mass-flow diagram technique will not be discussed in detail but is readily available in most hydraulic texts. (Page 517, King's Handbook of Hydraulics, 3rd edition).

Watershed condition.--The drainage area above the reservoir site should be examined to determine important hydrologic characteristics such as soils, land use and climatic variability. Possible future changes in land use that may affect runoff should be considered. Other upstream changes that would influence future runoff, such as additional storage, irrigation, municipal, domestic and industrial uses should also be considered.

Frequency of supply criteria.--A frequency of total annual supply should be selected based on the intended use and the adverse results of supply shortages during some years. For irrigation, it is common Service practice to use the 80% probability as a minimum criteria. This criteria provides, on the average, a complete annual supply four years in five and would permit a shortage during

one year in five. There are some irrigated crops that may indicate the probability should be raised to 90 or 95% and others where a design probability of 70% or less will be adequate to provide an economical design. The hydrologist should be certain the water user has a complete understanding of the probability of supply criteria used.

Storage.

Storage, as used here, is net storage and does not include the amount required to provide for future sediment accumulation. Net storage does include use, reservoir evaporation and seepage. Estimates of sediment storage requirements will be furnished by the geologist.

Survey of reservoir site.--A survey of the reservoir site is made to determine elevation, surface area and capacity relationships. The required capacity must provide storage for sediment, use, losses and flood water. Specific site conditions, such as spillway location, may place limitations on the available storage.

Demand.

Potential annual demand.--An estimate of the potential annual demand consisting of use, reservoir evaporation and seepage will have to be made. The use value should reflect all losses associated with the transit of water from the reservoir to the point of use and the actual efficiency of use to show the demand at the reservoir. This information is normally provided by the irrigation engineer or other engineers concerned with the water use requirement. The potential annual demand value is then compared with the annual runoff values. The average annual runoff is the average maximum amount that could be supplied through "carry-over" storage. Reservoir evaporation and seepage losses would reduce this maximum amount. The average potential demand may be larger than the average annual runoff. In this case it is known that demand cannot be satisfied and lower amounts will have to be considered. The potential demand may be less than the minimum year of record. In this case the annual supply is adequate but the seasonal distribution of supply and demand are important items.

Distribution of demand during year.--This distribution will normally be furnished to the hydrologist by other engineers concerned with the intended use of the water supply. The monthly demand should be determined in units of percent of total annual demand. The actual monthly demand may be determined by the product of the monthly percent and the selected total annual demand. Determining the monthly demand in percent will facilitate the computations of actual monthly demand when several values of total annual demand are being considered. The demand

distribution should be compared with the average monthly runoff distribution. If the runoff distribution is predominantly during one period of the year the comparison will be of assistance in estimating storage required to provide a given supply. For example, in many areas a very high percent of the annual runoff occurs during the winter and spring seasons. If the water use is for irrigation during July, August and September, it will be necessary to store an amount nearly equal to total demand plus reservoir losses due to evaporation and seepage.

Reservoir losses.--All possible reservoir losses must be considered. The principal losses are generally evaporation and seepage. A geologist should be requested to furnish estimated rates of permeability and/or transmissability. The hydrologist will determine seepage losses using monthly values of surface area and the associated permeability and/or transmissability rates.

Evaporation losses may be estimated on a monthly basis if past evaporation and precipitation records are available. Evaporation, like many climatic elements, is a variable. The past record should be long enough to reflect the long-time variability of net evaporation.

Adequate evaporation data will not be available for many reservoir locations. Where this is the case, it is suggested that evaporation estimates should be made on an annual, seasonal or monthly basis using the Weather Bureau Publication, Technical Paper No. 37, Evaporation Maps for the United States, or ES-1016, NEH-4.

If average annual evaporation, precipitation and water surface area are used in estimating annual evaporation losses these estimates will be too low during the years of above normal net evaporation. The standard deviation of evaporation is available in Technical Paper No. 37. This value may be added to the average value to obtain an evaporation that represents conditions during the years of higher losses.

The average surface area may be determined from the storage-surface area relationship and the mean storage. If there is a definite change in storage during the seasons, the evaporation and seepage losses may be computed separately for the May-October period and the November-April period. Evaporation data on the two periods are obtained from Technical Paper No. 37. In this case, a different average surface area is used for each period.

Example

The construction of a storage reservoir on Council Creek near Stillwater, Oklahoma has been proposed. The purpose of the storage is to provide irrigation water during the summer months. The area to be irrigated is located downstream from the reservoir site.

Legal Aspects of Water Storage.
In the following example, water appropriation rights authorize the storage of the total runoff that occurs from October 1 through May 31 of any year. An amount equivalent to the runoff that occurs from June 1 to September 30 must be released from the reservoir as it occurs.

Supply.
The drainage area at the reservoir site is 31 square miles (19,840 acres). A recording stream gage is located immediately below the structure site. Records are available from April 1934 through 1958. Analysis of the slopes of mass runoff curves for surrounding stations indicates this period to be representative of the long-term average.

A non-recording precipitation gage with records from 1931 to 1958 is located at Stillwater, Oklahoma. Pan evaporation and wind records are available from 1948 through 1957 at Stillwater. A first order Weather Bureau Station record is available at Oklahoma City, Oklahoma where all the climatalogical factors are recorded that are necessary in the determination of evaporation from reservoirs. (Tables 9-1 and 9-5, Chapter 9, NEH-4).

Monthly and annual runoff amounts.--The monthly and annual runoff amounts for October through May for water years 1935 through 1958 were determined from the records. This period of time reflects the "long-time" variability of runoff.

Watershed condition.--Future changes in land use and climate should not be significant. Additional demands for use are not foreseen during life expectancy of the project.

Frequency of supply criteria.--A frequency curve was developed for runoff from October through May for water years 1935 through 1958. The 80% probability from this curve was used as the minimum supply. (Figure 1)

The distribution of the 80% supply was made according to the percentage distribution of the mean monthly values of October through May for the period of record, 1935 through 1958.

Storage.
A survey of the reservoir site provided information for the preparation of Elevation-Surface Area and Elevation-Storage curves.(Figure 2) The geologist estimated the sedimentation rate to be 0.2 ac.ft./sq.mi./yr. With a life expectancy of 50 years and a drainage area of 31 square miles, the required storage for the sediment pool is 310 acre-feet. The invert of the intake is set at elevation of the top of the sediment pool. The principal spillway crest is set at the indicated maximum required storage and the emergency spillway crest at elevation dictated by design criteria. Flood water is detained between the crest of the principal spillway and the emergency spillway crest.

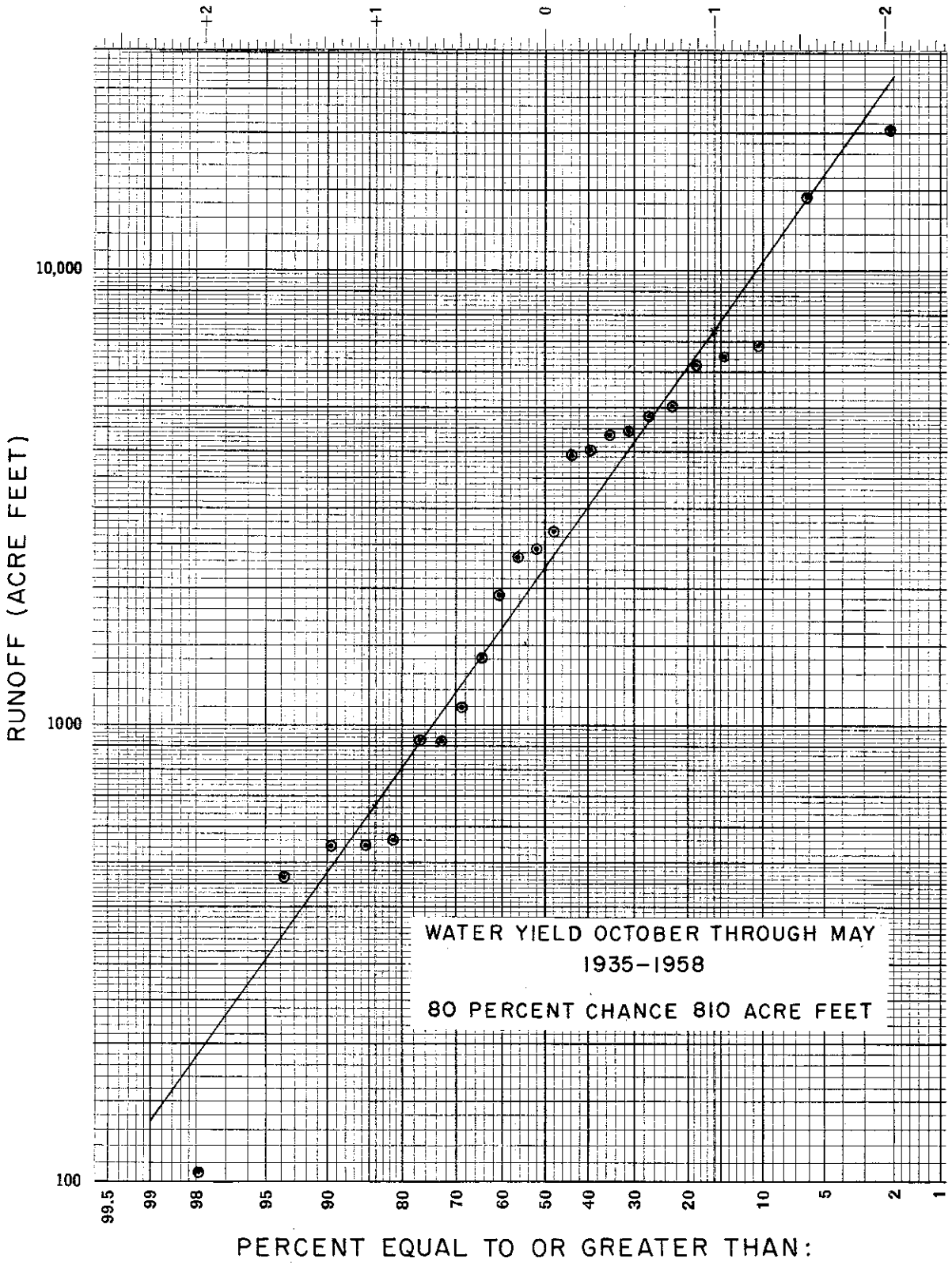

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Figure:- 1

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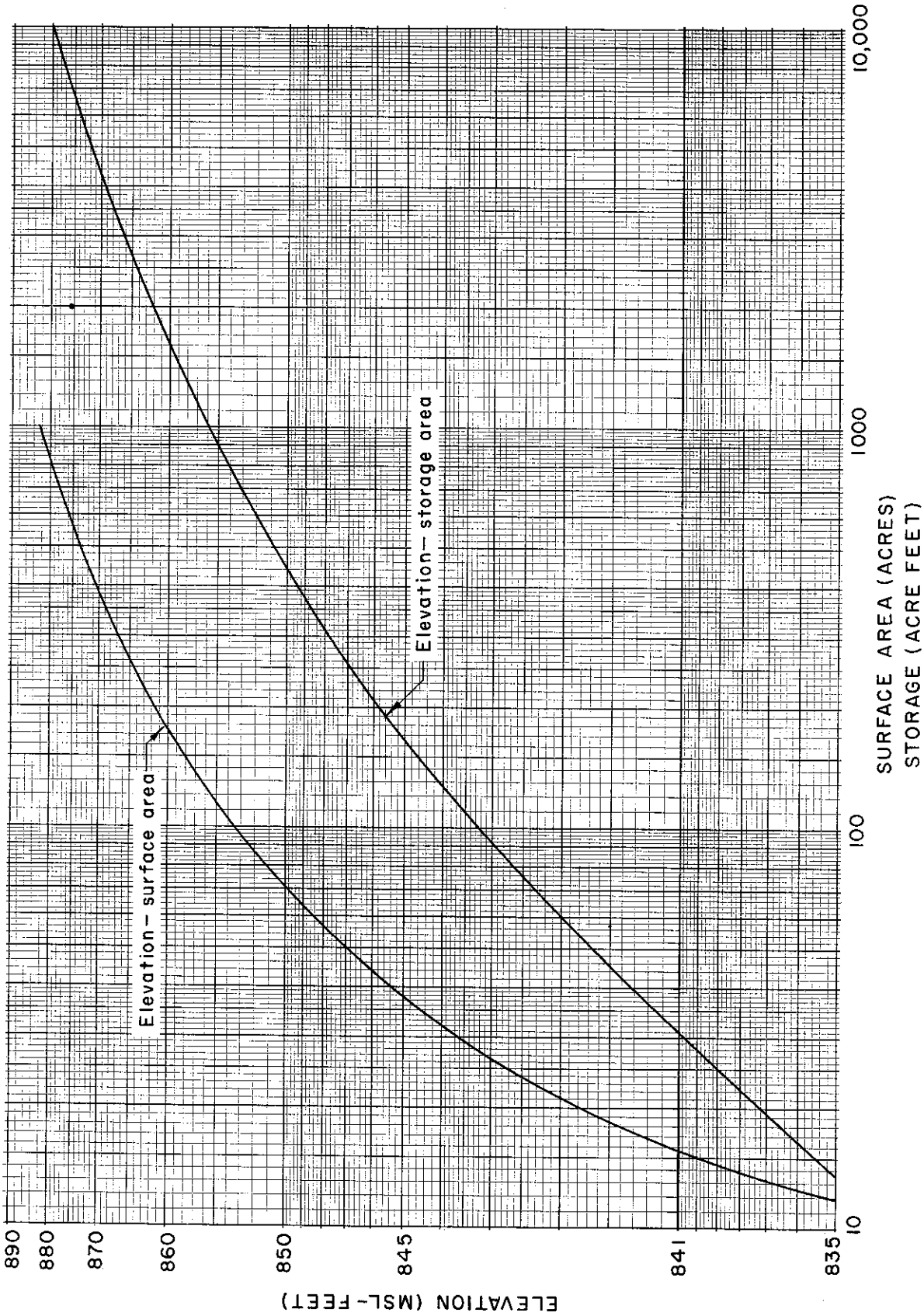

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Figure – 2

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Demand.
The estimate of the potential annual demand consisted of making estimates of the net lake evaporation and reservoir seepage losses plus the intended use by months. Net lake evaporation was computed by subtracting mean monthly precipitation at Stillwater from the mean monthly lake evaporation as taken from ES-1016, NEH-4. The mean monthly use requirements for the proposed project are shown in line 8 of Table 1.

Example of Water Storage Requirements.
A water budget equation can be written as follows: Watershed yield at point of storage plus precipitation on reservoir minus dead storage, required releases, evaporation, transpiration, and seepage equal the amount available for use. When any of these items are small they may be omitted for simplicity.

Approximation using annual values.--For approximations, it is possible to use annual values developed from regionalizations of specific data. This involves the use of isograms of annual runoff and evaporation. U. S. Geological Survey Circular 52, plate 1, presents the distribution of average annual runoff in the United States, however, these values need to be adjusted for areas under one hundred square miles. The Hydrologic Services Division of the U.S. Weather Bureau has released Technical Paper No. 37 which shows the distribution of average annual evaporation in the United States. With a map study of the proposed site and estimates of annual losses based upon the best knowledge available, a reasonable water budget can be determined by applying the water budget formula. This will be an approximate answer to the question of whether or not, on the average, the annual storage available for use will meet the estimated needs. In most cases, however, we are concerned with adequacy of the seasonal distribution. The use of average annual values will not adequately answer this question but it will indicate feasibility and whether we are justified in making a more detailed study.

Approximation using probability of annual supply and estimated losses.--The 80% probability of supply (810AF) was taken from the frequency curve in Figure 1 and distributed by months according to the accumulated mean monthly values in Table 1. The accumulated 80% supply for October through May is shown in Figure 3.

A trial-and-error procedure was used to estimate the demand consisting of net reservoir evaporation, seepage and use. An estimate of the accumulated mean monthly storage was made by subtracting the accumulated mean monthly use from the accumulated mean monthly 80% probability of supply (line 15, Table 1). With this estimated storage and its associated elevation, surface area and Figures 2 and 4 the reservoir evaporation and seepage were computed. The accumulated demand should be equal to or less than the supply or a new trial must be made after

Table 1. Council Creek near Stillwater, Oklahoma. Storage required to meet supply-demand relationship.

Line	Item	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Year
1	Mean monthly supply AF	493	179	134	107	144	494	926	1571	1248	620	508	439	
2	Accumulated mean monthly AF	493	672	806	913	1057	1551	2477	4048	No storage allowed				
3	Accumulated mean monthly %	12.2	16.6	19.9	22.6	26.1	38.3	61.2	100.0					
4	Acc. 80% probability AF	99	134	161	183	211	310	496	810	810	810	810	810	66.0
5	Lake evaporation (ES-1016) in.	6.3	3.5	2.0	1.5	1.9	3.1	4.7	5.5	7.8	10.2	10.7	8.8	
6	Precipitation, Stillwater, Okla. in.	2.85	2.01	1.35	1.14	1.27	2.16	3.53	4.83	4.08	2.98	3.05	3.62	32.87
7	Net lake evaporation ft.	0.287	.124	.054	.030	.052	.078	.098	.056	.310	.602	.638	.432	2.761
8	Mean monthly use AF								288	362	362	294	192	1498
9	Acc. mean monthly use AF								288	650	1012	1306	1498	
10	Acc. mean monthly use %								19.23	43.39	67.56	87.18	100.0	
11	Ave. mean monthly 80% prob. supply AF	50	116	148	172	197	260	403	653	810	810	810	810	
	Trial No. 1													
12	Use, AF								125	157	157	128	83	650
13	Acc. use AF								125	282	439	567	650	
14	Mean monthly use AF								62	204	360	503	608	
15	Line 11 - 14 (Est. storage) AF	50	116	148	172	197	260	403	591	606	450	307	202	
16	Elevation assoc. with 15 ft.	841.7	843.7	844.6	845.2	845.8	847.3	849.5	852.0	852.2	850.3	848.0	845.9	
17	Surface area assoc. with 16 Ac.	18	30	35	38	42	50	67	86	88	73	56	42	
18	Seepage AF	1	1	1	1	1	2	3	4	4	3	2	1	
19	Evaporation 7 x 17 AF	5	4	1	1	2	4	7	5	27	44	36	18	
20	Use AF	-	-	-	-	-	-	-	125	157	157	128	83	
21	Demand 18 + 19 + 20 AF	6	5	2	2	3	6	10	134	188	204	166	102	
22	Acc. Demand AF	6	11	13	15	18	24	34	168	356	560	726	828	
	Trial No. 2													
12	Use AF								121	152	152	124	81	630
13	Acc. use AF								121	273	425	549	630	
14	Mean monthly use, AF								60	197	349	487	590	
15	Line 11 - 14 (Est. storage) AF	50	116	148	172	197	260	403	593	613	461	323	202	
16	Elevation assoc. with 15 Ft.	841.7	843.7	844.6	845.2	845.8	847.3	849.5	852.0	852.3	850.4	848.1	846.3	
17	Surface area assoc. with 16 Ac.	18	30	35	38	42	50	67	86	89	74	57	45	
18	Seepage AF	1	1	1	1	1	2	3	4	4	3	2	1	
19	Evaporation 7 x 17 AF	5	4	1	1	2	4	7	5	28	45	36	19	
20	Use AF	-	-	-	-	-	-	-	121	152	152	124	81	630
21	Demand 18 + 19 + 20 AF	6	5	2	2	3	6	10	130	184	200	162	101	
22	Acc. Demand AF	6	11	13	15	18	24	34	164	348	548	710	811	
23	Required storage 4 - 22 AF	93	123	148	168	193	286	462	646	462	262	100	-1	

COUNCIL CREEK— NEAR STILLWATER, OKLAHOMA

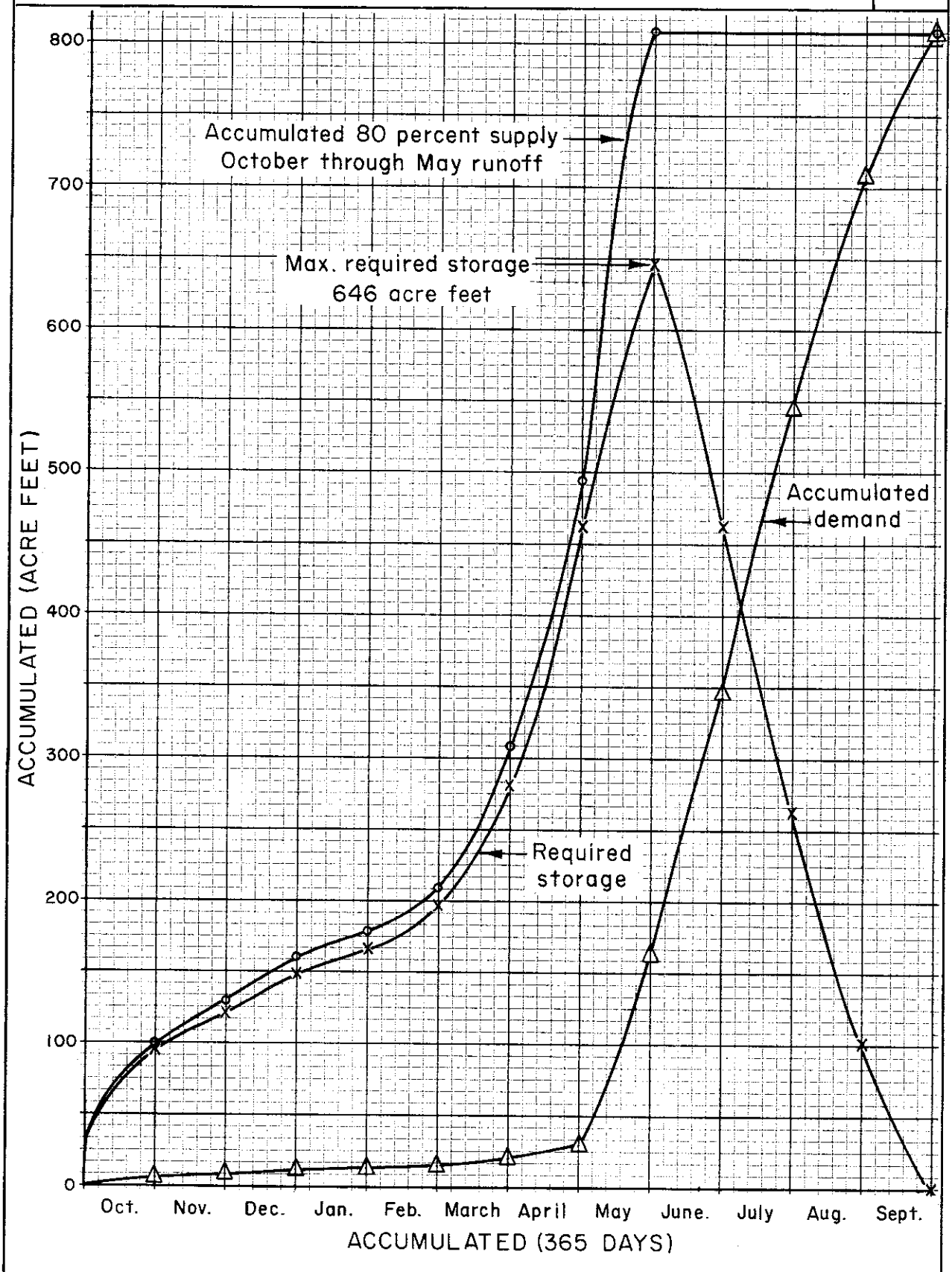

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Figure.— 3

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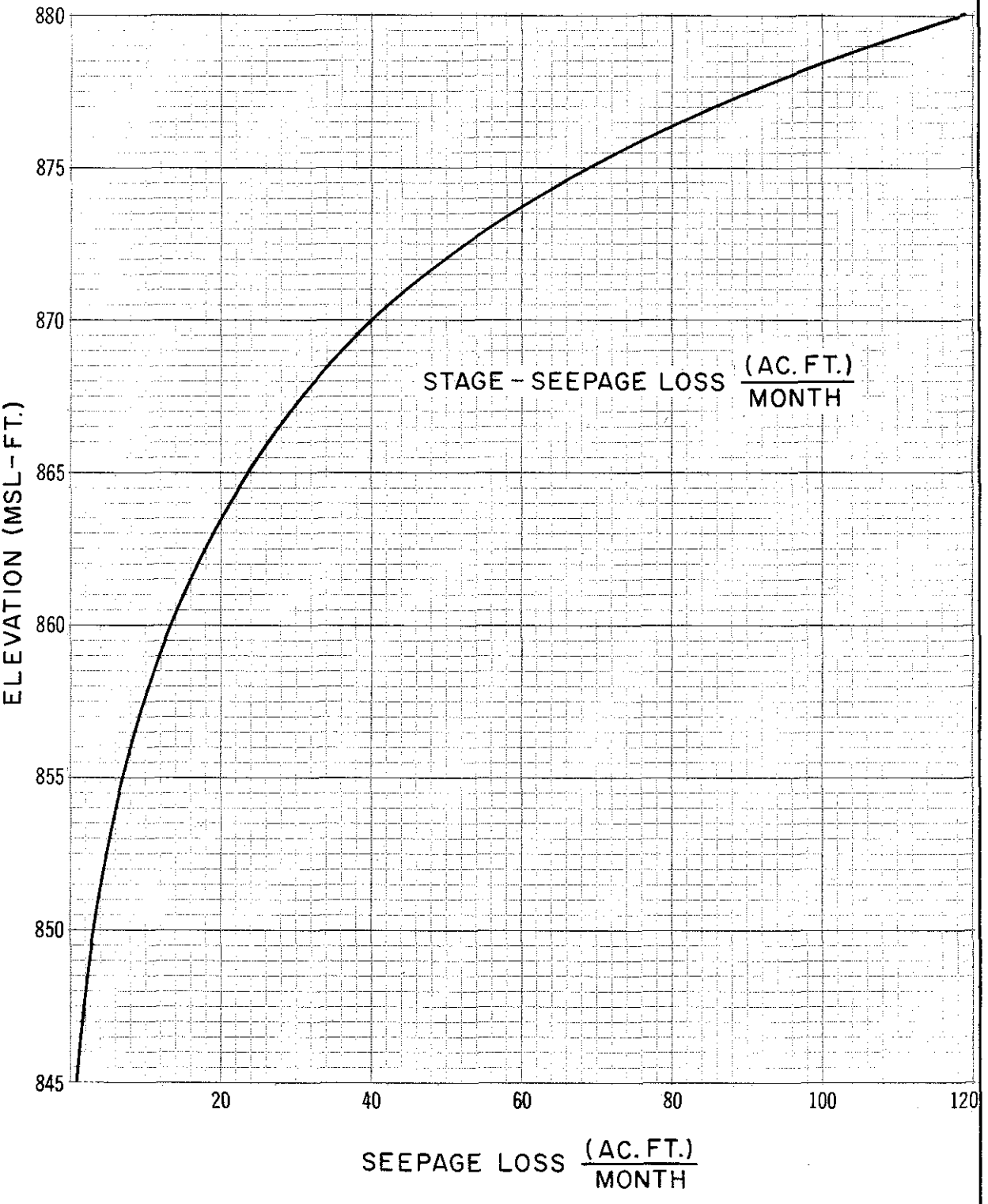

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Figure– 4

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decreasing the use. The example shown in Table 1 and Figure 3 illustrates how the use had to be reduced so the demand would not exceed the supply. The original proposal of use (1498 AC) exceeded the supply (810 AF) without considering losses, therefore, the use had to be reduced.

The results of using the 80% probability of annual supply and estimated losses were checked by the water budget analysis using observed data. During water-short years of 1950 and 1951 the required storage estimate of 646 acre-feet was sufficient to satisfy the indicated use but this was far below the proposed use of 1498 acre-feet.

Approximation using carry-over storage.--The original proposal was to provide 1498 acre-feet of use distributed by months as shown in line 8, Table 1. It has been shown the 80% probability of supply would not supply the proposed use but with carry-over storage, it might. A procedure for the estimation of required carry-over storage follows with the results shown in Figure 5.

1. Plot accumulated runoff for a critical low flow period.

2. Superimpose the accumulated use curve on the mass runoff diagram with time ordinates coinciding and the use line tangent to the mass curve at starting time. The use curve must intersect the mass runoff curve. The time period between the tangent and the intersection represents the time carry-over storage will be needed. The maximum ordinate value between the accumulated runoff and the accumulated use represents the maximum needed storage without consideration of storage needed to satisfy reservoir evaporation and seepage losses. This storage value is used as the mean storage value to determine mean surface elevation from which estimates can be made of the reservoir evaporation and seepage losses.

3. An accumulated demand curve is developed by summing the values of use, reservoir evaporation and seepage losses.

4. The accumulated demand curve is superimposed on the accumulated mass curve in a similar manner to the use curve. The maximum ordinate between the accumulated runoff curve and the accumulated demand curve is the required carry-over storage.

The results of this analysis were checked by the water budget approach and found to more than adequately provide the needed storage for water-short years 1949 through 1951.

Water budget analysis.--The water budget computation is a trial-and-error procedure. One must estimate the average monthly water budget from which the average monthly elevation can be obtained. This is then compared with

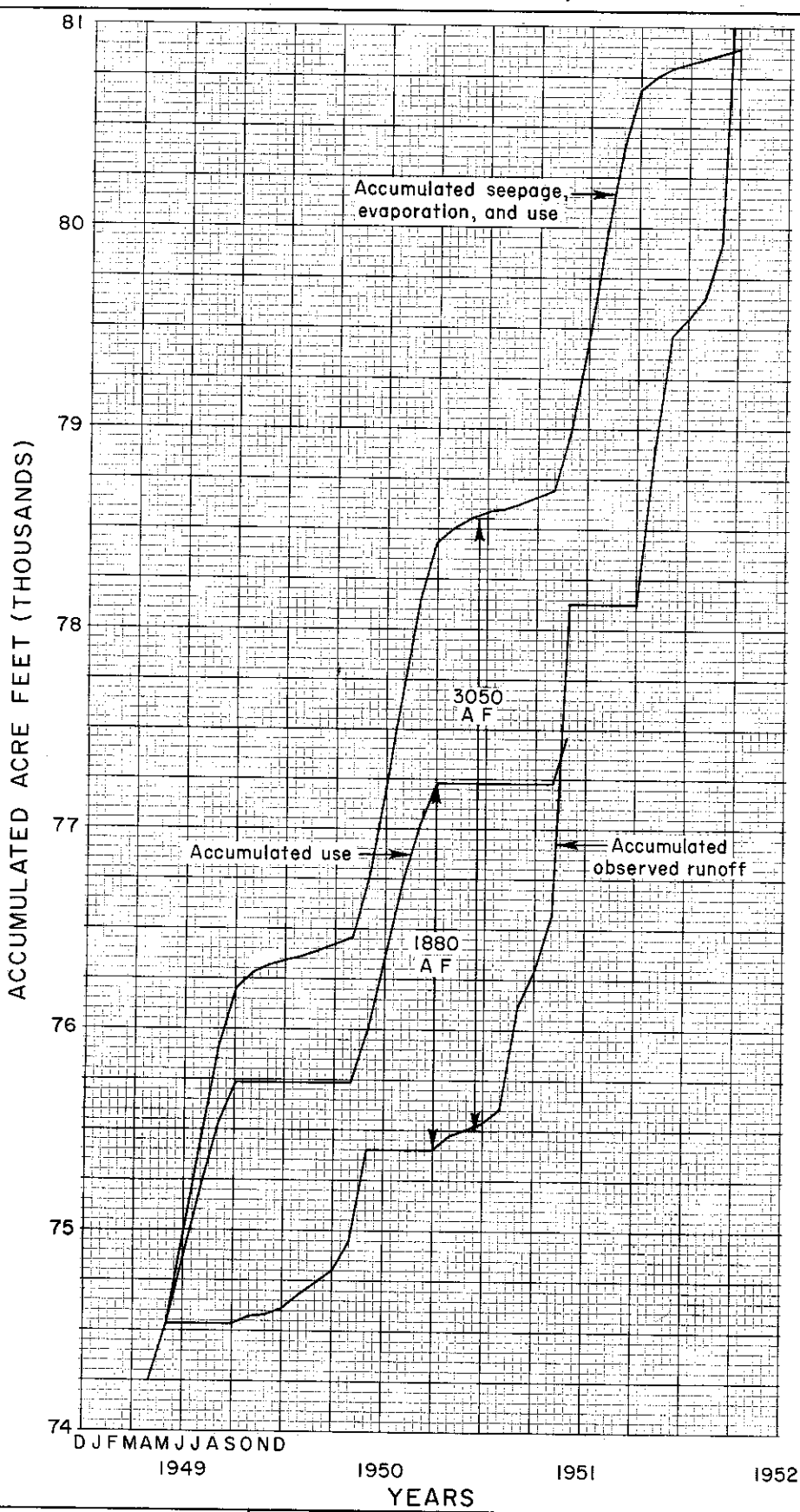

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Figure.–5

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the computed average monthly water surface elevation. This should be in agreement; if not, a new estimate of elevation should be made and the computed elevation recalculated.

The basic water budget equation can be written as follows:

$$U = S + I - E - E_s - Q_s - R$$

where

U = water available for use - acre feet

S = water storage above the intake elevation - acre feet

I = inflow - watershed yield - acre feet

E = evaporation - acre feet

E_s = seepage out of reservoir - acre feet

Q_s = spillway discharge - acre feet

R = required reservoir release - acre feet

The geologist provided a geologic cross-section through the reservoir site with log-borings indicating the type of materials present and their permeability rates. These rates were associated with stratum elevations and appear in Col. 5 of Table 2.

Table 2 for reservoir seepage losses was prepared as follows:

Col. 1 Elevation (ft.) Mean Sea Level datum

2 Surface Area (acres) (Figure 2)

3 Incremental surface area (acres). Difference in surface area associated with the elevation in question and the previous elevation.

4 Storage (ac.ft.). Total storage associated with elevation in question.

5 Seepage loss (cu.ft./sq.ft./day times number of days in month = (ft./mo.).

The assumptions for this example are as follows:

1. Seepage into the ground occurs in this particular reservoir site.

2. The laws of seepage apply.

Table 2. Reservoir Seepage Losses

① Elevation (ft.MSL)	② Surface Area (ac.)	③ Δ Surface Area (ac.)	④ Storage (ac.ft.)	⑤ Seepage Rate (ft./mo.)	⑥ Δ Seepage (ac.ft./mo.)	⑦ Σ Monthly Seepage (ac.ft.)
		43		0.03	1.29	
846	43		211			1.29
		13		.03	.39	
848	56		310			1.68
		14		.09	1.26	
850	70		436			2.94
		16		.09	1.44	
852	86		592			4.38
		18		.09	1.62	
854	104		782			6.00
		21		0.9	1.89	
856	125		1011			7.89
		23		.09	2.07	
858	148		1284			9.96
		25		.12	3.00	
860	173		1605			12.96
		30		.12	3.60	
862	203		1981			16.56
		37		.12	4.44	
864	240		2424			21.00
		40		.12	4.80	
866	280		2944			25.80
		45		.12	5.40	
868	325		3549			31.20
		55		.15	8.25	
870	380		4254			39.45
		60		.15	9.00	
872	440		5074			48.45
		70		.15	10.50	
874	510		6024			58.95
		85		.21	17.85	
876	595		7129			76.80
		95		.21	19.95	
878	690		8414			96.75
		110		.21	23.10	
880	800		9904			119.85

3. Hydraulic gradient developed is assumed to be one to one or one hundred percent.

4. Seepage loss equilibrium exists.

   It is expected that laboratory tests of undisturbed samples for the reservoir site and the borrow area will be available for making the estimate of seepage loss.

5. The site consists of uniform material.

Col. 6 Incremental seepage loss (ac.ft./mo.) 6 = 3 x 5

Example: Elevation 846

6 = (43) (.03) = 1.29 ac.ft./mo.

Col. 7 Summation seepage loss (ac.ft.)

This is the accumulation of incremental seepage losses.

Example: Elevation 848

7 = (13) (.03) + 1.29 = 1.68 ac.ft./mo.

Figure 4 is plotted from items 1 and 7 of Table 2.

Water budget computations were prepared as illustrated in Table 3. An explanation of the column headings and the method of computing the data in each column is discussed:

Col. 1 Year

2 Month

3 Runoff (ac.ft.) total watershed yield from recording stream gage record at site.

4 Estimated average water surface elevation for the month (ft.). An estimate is made of the water budget as follows:

Summation for month in question (Σ) 12 (previous month + 3 - 7 - 8 - 9 - 10 - 11 = 12 storage at end of current month (ac.ft.). Determine stage associated with the average of 12 (previous month) and 12 current month storage. This estimated stage 4 is then used for computing actual values.

5 Water surface area in reservoir (ac.) for stage in 4. (From stage-area curve for the reservoir).

Water Budget Analysis

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year	Month	Runoff AF	Est. Ave. Mo. Water Surface Elev. Ft.	Est. Ave. Water Surface Area Ac.	Evaporation Ft.	Evaporation AF	Seepage AF	Reservoir Release AF	Spillway Discharge AF	Demand AF	Storage at End of Mo. AF	Water Surface Elev. at End of Mo. Ft.	Computed Average Storage for Month AF	Elev. for Average Monthly Storage Ft.
		+				-	-	-	-	-				
	March										0			
1949	April	85	841.3	15	.459	7	0	0	0	0	78	842.9	39	841.3
	May	4470	859.9	173	.510	88	13	0	1397	0	3050	866.5	1564	859.9
	June	121	865.6	270	.680	184	24	121	0	274	2568	864.7	2809	865.6
	July	105	863.8	237	.721	171	20	105	0	238	2139	862.9	2354	863.8
	August	6	861.9	202	.685	138	17	6	0	242	1742	860.9	1940	861.9
	Sept.	289	860.5	182	.507	92	14	289	0	0	1636	860.2	1689	860.5
	Oct.	38	860.2	178	.309	55	13	0	0	0	1606	860.1	1621	860.2
	Nov.	13	860.0	175	.202	35	13	0	0	0	1571	859.9	1588	860.0
	Dec.	24	859.9	173	.151	26	13	0	0	0	1556	859.8	1563	859.9
	Sub.Total	5151				796	127	521	1397	754	1556	Check		
1950	January	72	860.0	175	.122	21	13	0	0	0	1594	860.0	1575	860.0
	Febr.	64	860.1	177	.166	29	13	0	0	0	1616	860.2	1605	860.1
	March	54	860.1	177	.371	66	13	0	0	0	1591	860.0	1604	860.1
	April	157	860.1	177	.606	107	13	0	0	0	1628	860.2	1610	860.1
	May	498	860.7	184	.531	98	14	0	0	184	1830	861.3	1729	860.7
	June	382	859.7	168	.641	108	13	382	0	413	1296	858.2	1513	859.7
	July	5020	858.0	148	.415	61	10	5020	0	0	1225	857.7	1260	858.0
	August	1170	857.1	137	.497	68	9	1170	0	107	1041	856.4	1133	857.1
	Sept.	104	855.8	123	.352	43	8	104	0	100	890	855.1	966	855.8
	Oct.	21	855.0	114	.386	44	7	0	0	0	860	854.8	875	855.0
	Nov.	35	854.8	113	.228	26	7	0	0	0	862	854.8	861	854.8
	Dec.	32	854.8	113	.140	16	7	0	0	0	871	854.9	866	854.8
	Sub. Total	7609				687	127	6676	0	804	871	Check		
1951	January	75	855.1	117	.170	20	7	0	0	0	919	855.3	895	855.1
	Febr.	514	857.2	139	.155	22	9	0	0	0	1402	858.9	1160	857.2
	March	167	859.2	163	.367	60	12	0	0	0	1497	859.5	1450	859.2
	April	277	860.0	175	.373	65	13	0	0	0	1696	860.6	1596	860.0
	May	1560	863.9	238	.421	100	21	0	72	13	3050	866.5	2372	863.9
	June	762	866.0	280	.512	143	26	762	0	100	2781	865.4	2916	866.0
	Sub. Total	3355				410	88	762	72	113	2781	Check		

Col. 6 Evaporation on average water surface area in reservoir (ft.).

Pan evaporation for station at Stillwater was fragmentary, necessitating correlation with first order station at Oklahoma City.

Steps used in arriving at lake evaporation at Stillwater, Oklahoma: From climatological factors at Oklahoma City, Oklahoma. Monthly pan and lake evaporations for Oklahoma City were computed using climatological factors with wind adjustments and Figures 9-2 and 9-3, Chapter 9, NEH-4. Procedure for making wind adjustments is given on page 9-18 with results shown in Table 9-5, Chapter 9, NEH-4.

A correlation equation was written between the "computed pan evaporation at Oklahoma City" and the "measured monthly pan evaporation at Stillwater, Oklahoma." (Tables 9-3 and 9-5, Chapter 9, NEH-4).

$$Y = 0.4 + 1.17\ X$$

where

X represents computed pan evaporation, using adjusted wind for Oklahoma City, Oklahoma,

Y represents measured monthly pan evaporation at Stillwater, Oklahoma.

The next assumption was that the pan-lake evaporation relationship at Oklahoma City would be a reasonable estimate of the pan-lake evaporation relationship at Stillwater, Oklahoma.

Monthly lake evaporation at Stillwater was computed by multiplying the computed monthly lake evaporation at Oklahoma City by the ratio of the observed monthly pan evaporation at Stillwater to the computed monthly pan evaporation at Oklahoma City.

$$E_{\ell s} = \frac{P_{os}}{P_{oc}} \quad E_{\ell o}$$

where

$E_{\ell s}$ represents the computed monthly lake evaporation at Stillwater.

P_{os} represents the observed monthly pan evaporation at Stillwater.

P_{oc} represents the computed monthly pan evaporation at Oklahoma City.

$E_{\ell o}$ represents the computed monthly lake evaporation at Oklahoma City.

Col. 7 Evaporation from average water surface area (ac.ft.)

7 = 5 x 6 (ac.ft.)

Col. (8) Total seepage using average monthly water surface elevation.

Example: November 1949

Estimated average monthly water surface elevation 860.0 (MSL). From stage-seepage loss curve (Figure 4) the total seepage equals 13.0 (ac.ft.)

(9) Reservoir release (ac.ft.) released to meet prior appropriations or maintain low flows. In this example all runoff that occurs from June 1 through September 30 must be passed through the reservoir without depletion.

(10) Spillway discharge computed for the month (ac.ft.) computed from mean stage over crest of spillway and hydraulics of the spillway.

(11) Gross water needed for month (ac.ft.). This information will be provided by the user or his agents.

(12) Storage at end of month (ac.ft.). Current month ((12) = summation of the previous month's storage at end of month (12) + (3) - (7) - (8) - (9) - (10) - (11).

(13) Water storage elevation at end of month (ft.) MSL from stage-storage curve with storage at end of month (12).

(14) Computed average storage for the month (ac.ft.). Computed as average of previous end of month storage and current end of month storage.

(15) Elevation for the average month storage (ft.) MSL stage (ft.) MSL associated with average monthly storage (ac.ft.)

The water budget analysis for the period March 1949 through June 1951 indicated that carry-over storage of 3050 acre feet provided for all the necessary requirements. In July of 1954 and 1956, 3050 acre feet of storage was not sufficient to provide for the demand. The determination whether the storage is adequate, inadequate or excessive is a judgment decision based upon this kind of analysis and the nature of the intended use. In this example, if the use were water supply, fire protection, or recreation, the storage might not be considered adequate. The storage could be considered adequate for irrigation, livestock water or orchard spray water where periods of low supply can be tolerated.

Water stored below the elevation of sediment pool cannot be used, however, if depletion has lowered the water level to the elevation of the sediment pool, evaporation and seepage will continue to deplete this storage and the storage would have to be replaced before water would be available for beneficial use.

USDA-SCS-HYATTSVILLE MD. 1967