TEXAS

# ENGINEERING TECHNICAL NOTE

Subject : HYDROLOGY

No. : 210-18-TX3

Reference : PROCEDURE FOR MAKING A RESERVOIR OPERATION STUDY

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SOIL CONSERVATION SERVICE
U.S. DEPARTMENT OF AGRICULTURE

TEXAS ENGINEERING TECHNICAL NOTE

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HYDROLOGY

# PROCEDURE FOR MAKING A RESERVOIR OPERATION STUDY

## INTRODUCTION

This Technical Note provides information relative to the source of data for making a reservoir operation study and a manual procedure for making the study.

A computer program (RESOP) is available at the Fort Collins Computer Center. The Reservoir Operation Study program is similar to any program dealing with budgets or flood routing. The inflow minus the outflow equals the storage remaining in the reservoir. Spillage, evaporation, and seepage are considered in the operation routine. Reservoir Operation Study Input Data Forms 1 and 2 provide a format to record input data. Footnotes on the back side of Form 1 provide instructions. This technical note gives sources of input data.

## GENERAL

The interest of local organizations to include conservation storage in reservoirs being planned in watershed programs, makes it necessary that Soil Conservation Service technicians have a procedure to follow in developing reservoir operation studies. Reservoir operation studies for fish and wildlife or irrigation purpose can be the responsibility of the Soil Conservation Service technicians. Studies for municipal water supplies will be developed by a consultant responsible to the municipality concerned, but should be reviewed by Service technicians.

A reservoir operation study should extend from a period of sufficient runoff to fill the reservoir through a critical drought period. The volume of storage and the plan of withdrawal will cause the critical period to vary; thus, it is necessary that the operation study extend over a sufficient period of time to ensure that demands can be met. The period 1947 to 1957 has been determined to be a historical drought in Texas and may be sufficient; however, the period 1941 to 1957 will reveal the ability of the reservoir to fill before the critical period and for reservoirs with a high storage-runoff ratio, the longer period should be used.

## PRECIPITATION

Monthly amounts of precipitation for a gage nearest to the site should be tabulated. The U.S. Weather Bureau Climatography Publications contain this information.

## INFLOW

Monthly inflow to the reservoir site should be determined from, or checked with stream gage records where they are available. Historical gage records are available in USGS Water Supply Papers. The Texas Department of Water Resources Report 244 contains a compilation of surface water records in Texas through December 1975 and is a convenient source of historical gage records.

Historical gaged runoff includes both surface runoff and spring flow, and is related to changing developments that have occurred during the period of record. These developments include diversions, return flows, changed land use and land treatment condition, and other factors affecting runoff. In planning for future water use, the future condition of development of the watershed should be used.

Runoff for a site location may be determined from the historical gage records, adjusted for future conditions of development, by a drainage area relationship, by a drainage area - precipitation ratio, or by a drainage area - precipitation - runoff condition ratio. For river basins in the State of Texas, the Bureau of Reclamation prepared for the U.S. Study Commission - Texas, monthly future condition runoff by subwatersheds for the period 1941-1957. These are considered conservative estimates of future condition runoff, but are in a readily usable form and may be used where applicable.

The SCS technicians usually will be involved in reservoir sites which have drainage areas smaller than those with gage records and, in some instances, on streams which are not related to gaged records. In these areas, monthly runoff can be determined from a rainfall-runoff analysis using storm rainfall on the site drainage basin and the future condition hydrologic soil-cover complex curve number developed for the site.

The ARS in Temple, Texas, has developed a computer program that uses the average runoff curve number and daily rainfall to compute the monthly runoff from a watershed. This is a soil moisture budgeting program and can be made available.

Figure 1 can be used to estimate monthly rainfall based on the runoff curve number and monthly rainfall. If this approach is used, however, the computed average annual runoff should be checked with gaged runoff from other areas of approximately the same size and located in similar climatic zones.

Monthly runoff should be tabulated in inches and in acre-feet as inflow to the site.

## EFFECTIVE PRECIPITATION

Effective precipitation is that portion of precipitation that does not result in runoff, and is obtained by subtracting the inches of runoff from inches of precipitation.

## GROSS LAKE SURFACE EVAPORATION

Gross lake surface evaporation is the total evaporation loss from a unit area of lake surface, and may be obtained by applying the appropriate coefficient to pan evaporation.

Considerable data are available on rates of evaporation as measured by various types of pans. The three general types of pans currently in use are:

| Name | Size (Inches) Diameter | Depth | Remarks |
|---|---|---|---|
| Young (screened) | 24 | 36 | Sunken in ground |
| Bureau of Plant Industry (BPI) | 72 | 24 | Sunken in ground |
| Weather Bureau Class A | 48 | 10 | On low wood platform |

Use of the data from the various types of evaporation pans requires that it be correlated to a unit base. Previous studies indicate that BPI pan data, when multiplied by 1.24, will approximate Weather Bureau Class A pan data. Young screened pan data will need to be multiplied by 1.28 to approximate Weather Bureau Class A pan data.

The coefficient which will be applied to Weather Bureau Class A pan data to obtain gross lake surface evaporation should be taken from Figure 2. For most studies made by the Soil Conservation Service, the annual average Class A pan coefficient may be applied to convert pan evaporation to gross lake surface evaporation. Greater refinement is possible by using a monthly coefficient which may be computed from the following table.

Table - 1*, Monthly Coefficients

| Month | Coefficient Percent of Annual |
|---|---|
| January | 98.6 |
| February | 85.7 |
| March | 82.1 |
| April | 82.1 |
| May | 87.1 |
| June | 93.7 |
| July | 101.4 |
| August | 107.9 |
| September | 112.9 |
| October | 116.6 |
| November | 117.9 |
| December | 114.3 |

* Based on Geological Survey Circular 229, Water Loss Investigations, Volume 1 - Lake Hefner Studies, Technical Report.

Texas Water Development Board Report 64 has monthly Gross Lake Surface Evaporation tabulated for the period 1940-1965, by quadrangles, covering the State of Texas. These were based on a 78 percent annual Weather Bureau Class A pan coefficient. A ratio of the appropriate coefficient, taken from Figure 2, to 78 percent multiplied by the values contained in Report 64 will result in an adjustment due to the effects of solar radiation, wind, dew point, and air temperature.

## NET LAKE SURFACE EVAPORATION

This is the actual evaporation loss which would occur from a unit area of lake surface, and is obtained by subtracting effective precipitation from gross lake surface evaporation. Net lake surface evaporation will be computed in inches, but the corresponding values in feet should be tabulated to facilitate the reservoir operation study.

## SEEPAGE LOSSES

Reservoirs providing conservation storage generally should not be considered when it appears that seepage losses will be significant. If the water holding ability of the site is questionable, the assistance of the State Geologist should be requested.

## DEMAND ON RESERVOIR

The demand on the reservoir generally varies from month to month. Some industrial demands may be constant, but municipal uses will reach peak demand in the summer months. Irrigation demand will occur during the crop-growing season and will vary inversely with effective precipitation Municipal and industrial demands will be determined by the consultant responsibile to the local organization concerned. Reservoir demands for irrigation use, however, may be the responsibility of Soil Conservation Service technicians, and should consider the crop(s') water requirement, the portion of this need that will be supplied by precipitation and the efficiency of the irrigation operation. A brief description of a procedure of developing irrigation demands on a reservoir is given below.

1 Effective Precipitation

Effective precipitation is that portion of rainfall that is not lost to runoff or deep percolation and is available for consumptive use of crops. Soils in the area planned for irrigation usually are not similar to those in the reservoir drainage area. Thus effective precipitation as computed above is not applicable to irrigation. The effective precipitation on irrigated land can be estimated by applying the following percentages to the total monthly precipitation:

| | |
|---|---|
| 1st inch | - 100% effective |
| 2nd inch | - 95% effective |
| 3rd inch | - 90% effective |
| 4th inch | - 80% effective |
| 5th inch | - 60% effective |
| 6th inch | - 40% effective |
| Over 6 inches | - 20% effective |

2. Consumptive Use

Consumptive use is the depth of water, in inches, removed from a vegetated area by evaporation of moisture from soil surface, by evaporation of intercepted water from plant surfaces, by development of plant tissues, and by transpiration from vegetal growths. There are several recognized formulae or procedures used for determining consumptive use. The Blaney-Criddle method is probably the most widely used, and is based on an empirically determined relation of the monthly consumptive use of a specific crop to certain climatological factors. Some of the better-known methods are those discussed in "Methods of Computing Consumptive Use of Water" by Wayne D. Criddle, Paper 1507, Volume 84, IR-1, Journal of the Irrigation Drainage Division, Proceedings of the American Society of Civil Engineers, January 1958.

The Texas Board of Water Engineers' Bulletin 6019, "Consumptive Use of Water by Major Crops in Texas," gives a procedure for estimating consumptive use in which the physiologic characteristics of the plant are related to air temperature, dew point temperature, wind movement, and solar radiation. The bulletin has monthly consumptive use values tabulated for major crops grown in each of 24 areas of major production covering the State of Texas. These values may be taken directly from the bulletin.

3. Calculation of Net Consumptive Use

Net monthly values for consumptive use of irrigation water for each crop are obtained by subtracting effective precipitation from the consumptive use. The percentage of each crop to be irrigated should be determined and the weighted net monthly consumptive use determined. These should be expressed in feet per acre to facilitate operation studies for varied amounts of irrigation.

4. Consideration of Losses

Farm waste, deep percolation, and canal and lateral losses should be provided for in the reservoir. Committee Print No. 12 of the Select Committee on National Water Resources of the U.S. Senate gives the following irrigation efficiencies:

| Item | 1954 | 1980 | 2000 |
|---|---|---|---|
| Farm Efficiency | 50.0% | 59.2% | 68.4% |
| Canal Efficiency | 60.6% | 64.7% | 70.5% |
| Overall Efficiency | 30.3% | 38.3% | 48.2% |

Forty-five percent overall efficiency is commonly used for project type irrigation and 55 percent is used for nonproject type. In the event that detailed information on irrigation efficiencies is available for individual areas, such data should be used in lieu of the values set forth above.

5. Calculation of Diversion Requirement

Monthly diversion requirements for the critical period may be calculated by dividing the net value of consumptive use of irrigation water by overall efficiency. The requirement rates thus determined are then applied to the acreage planned for irrigation and the demand on the reservoir is determined. Other reservoir releases such as those required by prior water rights should be added to the diversion requirements to obtain total demand on the reservoir.

## RESERVOIR AREA-CAPACITY CURVE

An area-capacity curve should be developed for the reservoir. Though sedimentation in the reservoir will actually reduce its surface area, there are likely to be losses due to evapotranspiration in the area occupied by the sediment. By assuming all sediment in the bottom of the reservoir, the original area above the sediment pool will be maintained. This permits omission of estimates of sediment allocations and provides an allowance for evapotranspiration from the reservoir fringe area. Figure 3 is an example of a reservoir area-capacity curve.

## RESERVOIR OPERATION STUDIES

Table 2 gives an example of the operation study. In the example, the conservation pool was assumed full at the end of the month prior to the study, and net evaporation loss for each month is based on the surface area at the end of the prior month. It is evident that more precise values could be obtained from use of the average surface area during the month, but to do so will require trial and error computations and will not give significantly better results.

A discussion of Table 2, by columns, follows. Months are listed for long enough periods to ensure demands can be met.

Col. 1 - Monthly precipitation in inches is listed for a location at or near the site.

Col. 2 - Monthly inflow, in inches, to the reservoir site is listed. If gaged runoff is used, this is calculated from Column 3.

Col. 3 - Monthly inflow in acre-feet may come from gage records If a rainfall-runoff analysis is made, the column is computed from Column 2.

Col. 4 - Effective precipitation is obtained by subtracting Column 2 from Column 1.

Col. 5 - Gross evaporation is computed by adjusting pan evaporation to lake surface evaporation or is computed by use of climatic data.

Col. 6 - Net evaporation in inches results from subtracting Column 4 from Column 5.

Col. 7 - Net evaporation in feet is Colunn 6 divided by 12

Col. 8 - Net evaporation in acre-feet is the product of Column 12 for the previous month and Column 7 for the current month.

Col. 9 - Seepage losses where significant, should be tabulated in feet per acre and then multiplied by the surface area (Column 12) for the previous month to determine the reservoir loss to seepage.

Col. 10 - Demand in acre-feet should include all withdrawals or releases from the reservoir.

Col. 11 - Storage at the end of the month is obtained by adding inflow to the storage at the end of the previous month and subtracting net evaporation, seepage, and demand.

[Col. 11 - (previous month) + Col. 3 - Col. 8 - Col. 9 - Col. 10]

Col. 12 - Read from area capacity curve, Figure 3.

Col. 13 - Spillway discharge will be any storage at the end of the month that is in excess of the reservoir capacity.

# Table 2

## Reservoir Operation Study

## Drainage Area 20 Sq. Mi.

| Year and Month | Precipitation | Inflow | | Effective Precipitation | Gross Evaporation | Net Evaporation | | | Seepage | Demand | Storage End of Month | Surface area, End of Month | Spillway Discharge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inches | Inches | Ac.-Ft. | Inches 1 - 2 | Inches | Inches 5 - 4 | Ft. | Ac.-Ft. | Ac.-Ft. | Ac.-Ft. 1/ | Ac.-Ft. | Acres | Ac.-Ft. |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1947 | | | | | | | | | | | 9000 | 740 | |
| Oct. | 0.05 | .02 | 24 | .03 | 6.25 | 6.22 | .52 | 385 | 0 | 0 | 8639 | 715 | |
| Nov. | 1.44 | .02 | 23 | 1.42 | 3.58 | 2.16 | .18 | 129 | 0 | 0 | 8533 | 710 | |
| Dec. | 2.32 | .03 | 30 | 2.29 | 2.08 | -0.21 | -.02 | - 14 | 0 | 0 | 8577 | 712 | |
| 1948 | | | | | | | | | | | | | |
| Jan. | 1.18 | .04 | 38 | 1.14 | 1.78 | 0.64 | .05 | 35 | 0 | 0 | 8580 | 712 | |
| Feb. | 2.74 | .04 | 41 | 2.70 | 1.28 | -1.42 | -.12 | - 85 | 0 | 0 | 8706 | 722 | |
| Mar. | 0.67 | .03 | 33 | .64 | 3.22 | 2.58 | .22 | 159 | 0 | 0 | 8580 | 712 | |
| Apr. | 1.41 | .03 | 27 | 1.38 | 4.90 | 3.52 | .29 | 206 | 0 | 284 | 8117 | 676 | |
| May | 3.47 | .25 | 264 | 3.22 | 5.54 | 2.32 | .19 | 128 | 0 | 341 | 7912 | 660 | |
| June | 1.26 | .04 | 46 | 1.22 | 7.60 | 6.38 | .53 | 350 | 0 | 509 | 7099 | 600 | |
| July | 1.41 | .02 | 20 | 1.39 | 7.75 | 6.36 | .53 | 318 | 0 | 484 | 6317 | 540 | |
| Aug. | 2.37 | .01 | 10 | 2.36 | 9.34 | 6.98 | .58 | 313 | 0 | 462 | 5552 | 482 | |
| Sept. | 2.33 | .00 | 5 | 2.33 | 6.70 | 4.37 | .36 | 173 | 0 | 416 | 4968 | 438 | |
| Oct. | 2.65 | .02 | 22 | 2.63 | 5.85 | 3.22 | .27 | 118 | 0 | 0 | 4872 | 430 | |
| Nov. | 1.13 | .01 | 9 | 1.12 | 4.22 | 3.10 | .26 | 112 | 0 | 0 | 4769 | 422 | |
| Dec. | 0.03 | .01 | 11 | 0.02 | 3.15 | 3.13 | .26 | 110 | 0 | 0 | 4670 | 416 | |
| 1949 | | | | | | | | | | | | | |
| Jan. | 4.18 | .04 | 46 | 4.14 | 1.64 | -2.50 | -.20 | - 83 | 0 | 0 | 4799 | 425 | |
| Feb. | 3.72 | 0.60 | 644 | 3.12 | 1.51 | -1.61 | -.13 | - 55 | 0 | 0 | 5598 | 485 | |
| Mar. | 2.02 | 0.03 | 36 | 1.99 | 2.90 | 0.91 | .08 | 39 | 0 | 0 | 5595 | 485 | |
| Apr. | 9.38 | 1.98 | 2117 | 7.40 | 3.00 | -4.40 | -.37 | -179 | 0 | 0 | 7891 | 660 | |

1/ Includes all requirements on the reservoir to provide for prior water rights.

Table 2

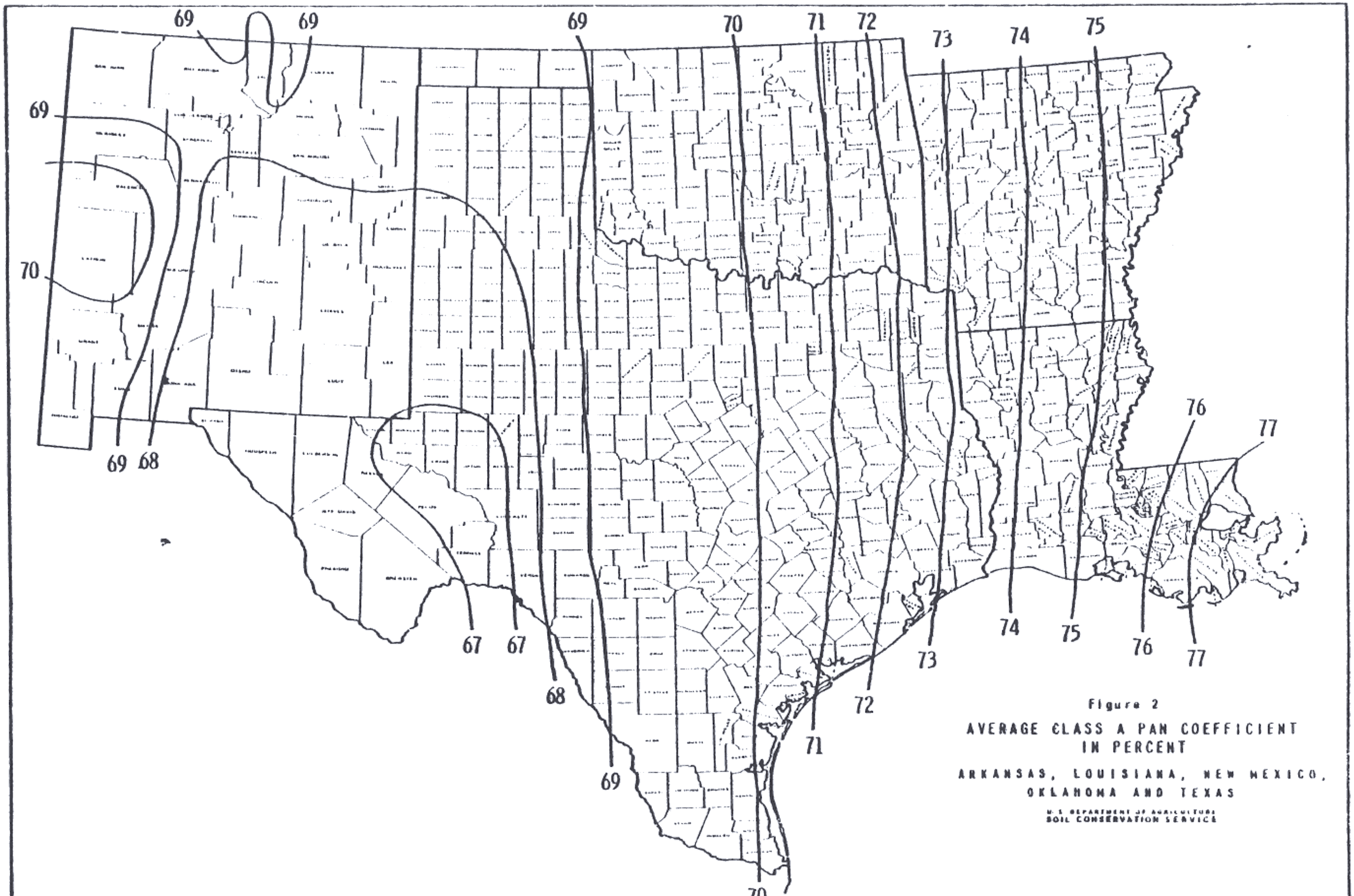



Figure 2

AVERAGE CLASS A PAN COEFFICIENT
IN PERCENT

ARKANSAS, LOUISIANA, NEW MEXICO,
OKLAHOMA AND TEXAS

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

From U.S. Weather Bureau Technical Paper No. 37

J-67 4-N-16544

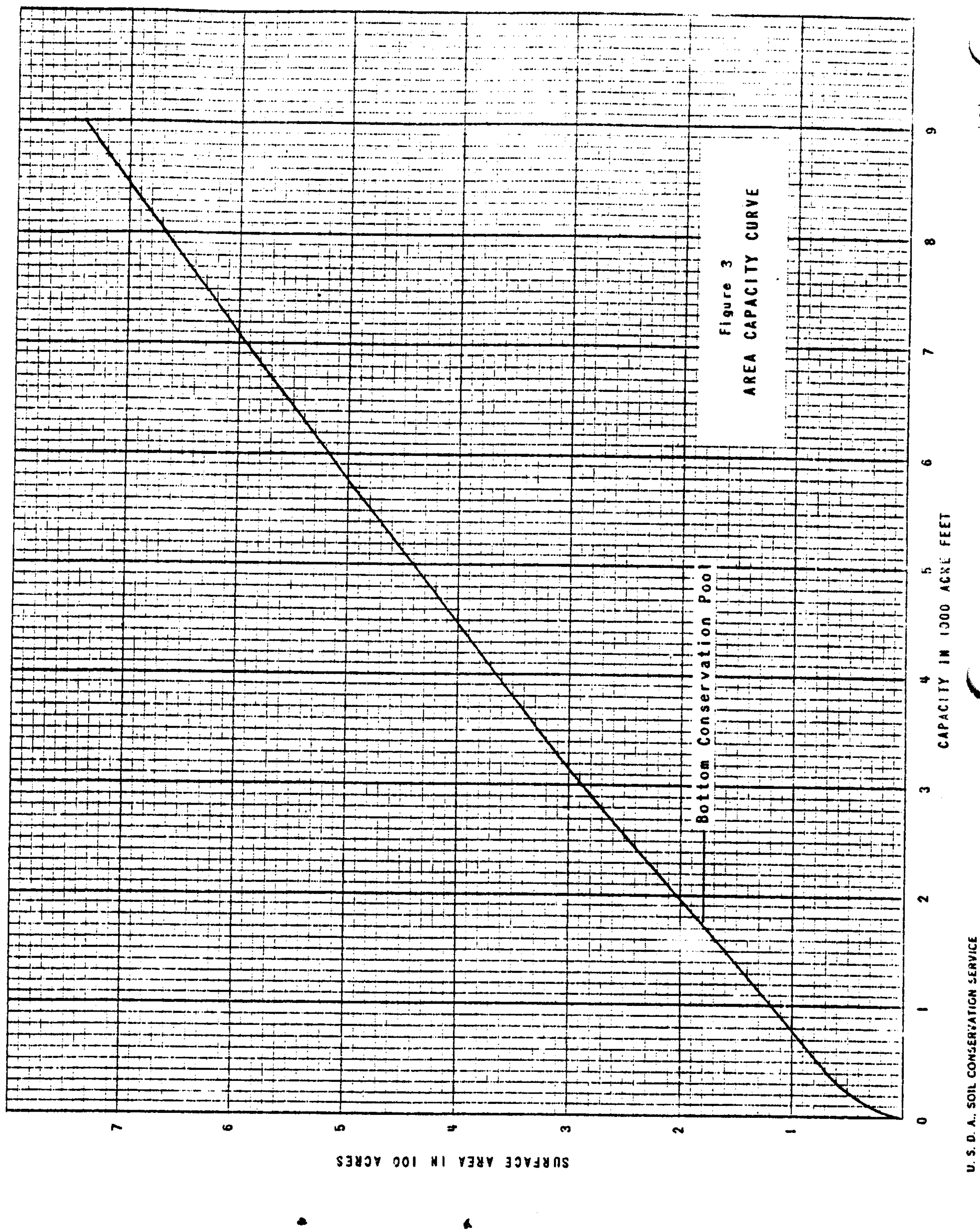
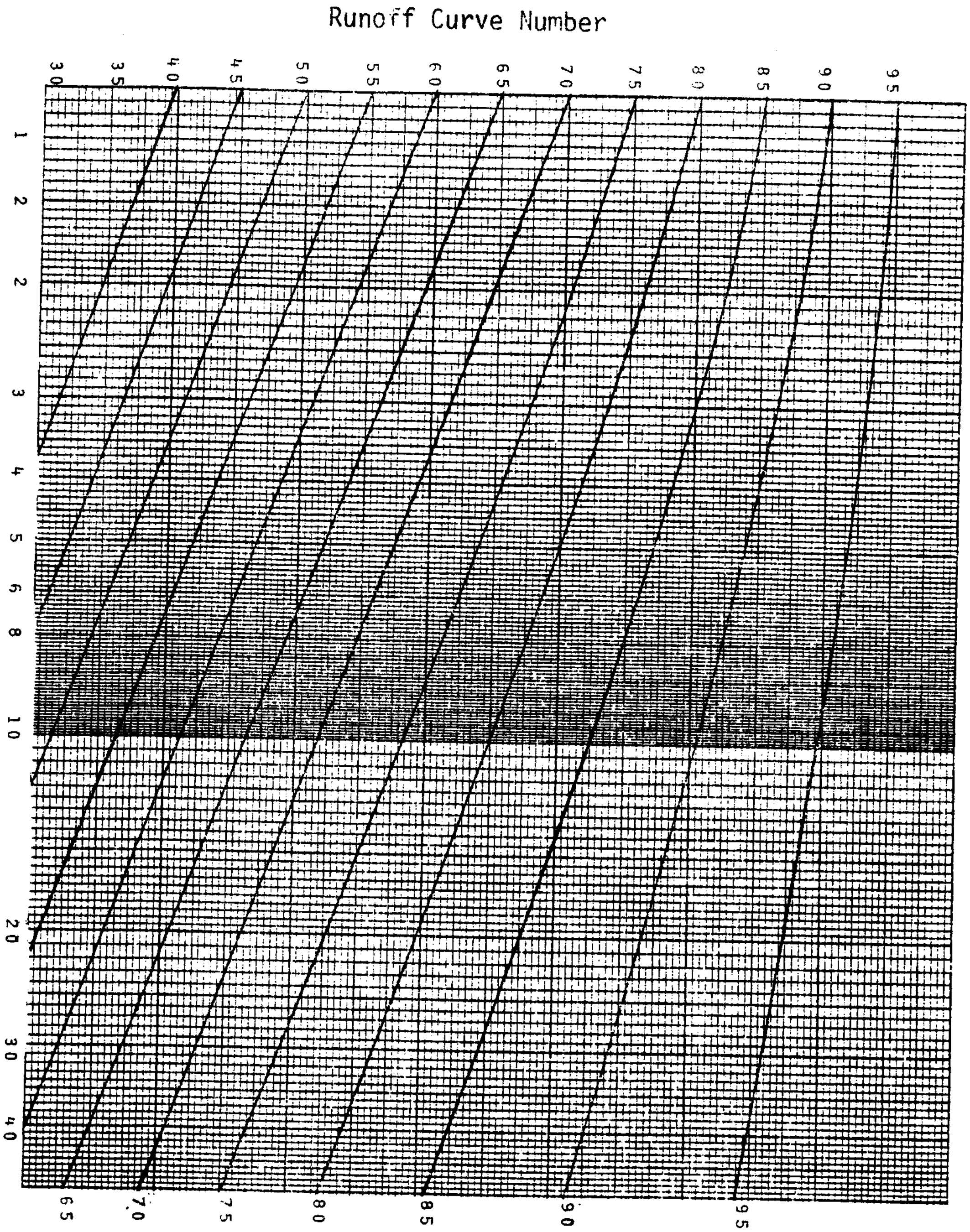



Figure 3
AREA CAPACITY CURVE




Days

Runoff Curve Number - Duration Adjustment

Figure 1

RESERVOIR OPERATION STUDY

Input Data Form 1

PROGRAM RESERVOIR OPERATIONS STUDY ______ PROGRAMMER ______ DATE ______ PAGE ___ OF ___ PAGES

| LABEL | OPERATION | OPERAND | | SP COMMENTS | | |
|---|---|---|---|---|---|---|
| TITLE | | | | | | |
| TITLE | | | | | | |
| | ACRE-FEET | ACRES | ACRE-FEET | ACRES | ACRE-FEET | ACRES |
| AREA-CAP | | | | | | |
| AREA-CAP | | | | | | |
| AREA-CAP | | | | | | |
| AREA-CAP | | | | | | |
| | UPPER LIMIT-AF | STARTING CAP-AF | LOWER LIMIT-AF | DRAINAGE AREA, SM | | |
| LIMITS | | | | | | |
| | EVAP. COEFF. 1/ | 1ST YEAR OF RECORD | CODE 2/ | % DEMAND 5/ | | |
| GENERAL | | | | | | |
| | AVG DEPTH, FT. | RATE, FT./MO. | AVG. DEPTH, FT. | RATE, FT./MO. | AVG. DEPTH, FT. | RATE, FT./MO. |
| SEEPAGE 4/ | | | | | | |
| SEEPAGE | | | | | | |
| SEEPAGE | | | | | | |
| SEEPAGE | | | | | | |
| | % CAPACITY | % DEMAND | % CAPACITY | % DEMAND | % CAPACITY | % DEMAND |
| MAXIMIZE 5/ | | | | | | |
| MAXIMIZE | | | | | | |
| MAXIMIZE | | | | | | |
| MAXIMIZE | | | | | | |
| | COEFF. FACTOR JAN./JULY | COEFF. FACTOR FEB./AUG. | COEFF. FACTOR MARCH/SEPT. | COEFF. FACTOR APRIL/OCT. | COEFF. FACTOR MAY/NOVEMBER | COEFF. FACTOR JUNE/DECEMBER |
| FACTOR 6/ | | | | | | |
| FACTOR | | | | | | |
| | CONTROL WORD | CONTROL WORD | CONTROL WORD | CONTROL WORD | CONTROL WORD | CONTROL WORD |
| CHANGE 7/ | | | | | | |

Printed in U.S.A.

Evaporation Coefficient (Percent).--The annual class A pan evaporation coefficient, in percent, taken from U. S. Weather Bureau Bulletin No. 37, Plate 3, is entered in this space. The computer multiplies this annual coefficient by a monthly distribution factor to obtain a monthly pan evaporation coefficient. The computer then multiplies these monthly coefficients by the appropriate monthly class A pan evaporation to obtain the monthly gross lake evaporation.

If Texas Bulletin 6006 is used for evaporation, enter the annual coefficient as 6XX.X where XX.X is the correct annual class A pan evaporation coefficient. The computer will then set up a ratio of this coefficient to the value 78.0. The computer will multiply this ratio by the evaporation given in Bulletin 6006 to obtain the monthly gross lake evaporation.
If lake evaporation is given, the coefficient must be 100.0
The net lake evaporation in acre-feet will be the figure printed under Evaporation on the output listing.

Code.--Insert a "0" when no other sites above or below this site are being considered.
Insert a "1" when spillage from this site is to be saved as inflow to a lower site.
Insert a "2" when spillage from an above site is to be added as inflow to this site.
Insert a "3" when both "1" and "2" apply.
Insert a "4" when 2 or more sites are above a lower site and their outflow is to be added as inflow to the lower site.

% Demand - 0 indicates a normal run; 1 indicates that the lowest capacity will be checked against th lower limit and the demand modified until the maximum demand is reached. A 2 performs the same func as a "1" except all printing is suppressed until the maximum demand is found. Mutually exclusive w "MAXIMIZE" (see footnote 5).

Average depth is equal to: Acre feet/Acres.
The seepage rate may be constant or it may vary be average depth (feet) and rate (acre ft. per month), but at least two average depths and rates must be given even though the rate stays constant. The first average depth given must be for the upper limit. If the rate is constant the second average depth woul be zero and the rate would be the same as for the upper limit.

MAXIMIZE is used to control demands upon the reservoir based upon capacity. As net capacity is change demand is modified to ensure no encroachment into the reserved pool capacity. MAXIMIZE is mutually ex clusive with % Demand (See footnote 3).

FACTOR allows modifying the pre-stored coefficients used to determine lake evaporation. Data for a 12 months must be entered.

CHANGE allows selected information to be modified. Enter the Control Word of the Card to change. A information on that card must be re-entered. Multiple change cards may be entered.

# RESERVOIR OPERATION STUDY
(Water Budget)
Input Data Form 2

WATERSHED ______ Year ______ Page ___ of ___

| CONTROL WORDS | | JAN. / JULY | FEB. / AUG. | MARCH / SEPT. | APRIL / OCT. | MAY / NOV. | JUNE / DEC. | CARD IDENT. |
|---|---|---|---|---|---|---|---|---|
| RAINFALL | | | | | | | | |
| RAINFALL | | | | | | | | |
| RUNOFF | | | | | | | | |
| RUNOFF | | | | | | | | |
| EVAP. | | | | | | | | |
| EVAP. | * | | | | | | | |
| DEMAND | | | | | | | | |
| DEMAND | | | | | | | | |

1 2 3 4 5 6 7 8 9 10 [illegible]

Year ______

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| RAINFALL | | | | | | | | |
| RAINFALL | | | | | | | | |
| RUNOFF | | | | | | | | |
| RUNOFF | | | | | | | | |
| EVAP. | | | | | | | | |
| EVAP. | | | | | | | | |
| DEMAND | | | | | | | | |
| DEMAND | | | | | | | | |
| END DATA | | | | | | | | |
| END JC | | | | | | | | |