Appendix 3-D

Wetland Hydrology - The Water Budget

Contents

3.D.1 Introduction

The water budget is the main hydrological procedure used to evaluate wetland designs. This procedure is primarily for wetlands formed by impounding water. Alternate design approaches are briefly discussed in Section 7.D.5. For the general policy of wetland design, see Chapter 2, Legal Policies and Procedures. The water budget is basically a routing procedure that sums the water inputs into a wetland area, the outflows, and the storage. All of these values are given in terms of water depth in the wetlands. Because of the sensitivity of vegetation to water depth, the desired computational accuracy should be to 1 in. However, the hydrology will probably not be known or predicted to this level of accuracy. In order to be assured of the success of the wetland project, the designer should strive to provide an excess supply of water. However, the sensitive nature of vegetation to water depth requires that adequate control of the water level must be built into the project so that flooding of the growth area will not kill the new plants in the wetlands. Sufficient spillway capacity should be provided to pass the excess water without exceeding the requirements for the proposed vegetation.

3.D.2 Data Requirements

A fairly substantial amount of data is needed for the water budget design. First is a detailed topographic survey of the wetland site. This may be done by aerial mapping procedures supplemented with ground surveys. The survey should be accurate enough to develop a contour map with contour intervals of about 1 to 2 ft. The topographic survey of the site should be in sufficient detail to allow the designer to accurately establish appropriate grades and slopes to support wetland hydrology and vegetation. Standard USGS topographic mapping may be accurate enough to determine certain hydrological features such as drainage area and slope.

All the data necessary to develop a synthetic hydrograph for the watershed should be determined. The example problem presented in this discussion uses the Natural Resource Conservation Service, NRCS, (formerly the Soil Conservation Service) method. The data required for this method includes drainage area, land use, soil types, curve numbers, and time of concentration. If there are any plans to change the land use in the watershed, the details of the proposed changes need to be determined and incorporated into the wetland design. Precipitation data requirements are very extensive. Rain gages located in the region around the wetland site need to be identified and their data examined. The entire record of these gages should be studied to determine the wettest year of record, the driest year of record and the average year of record that would be representative of the wetland site. For each of these years, obtain the daily rainfall records. If the water supply is to come from a stream that has a USGS gage, the complete hydrograph or the complete daily average discharge record for the entire length of record for the gage should be examined. Complete hydrographs for the wettest and driest years of record and an average year should be obtained. If the wetland is constructed on the edge of a lake or reservoir, daily lake levels that correspond to the wettest, driest, and an average year should be obtained if the data is available. If the lake levels are not available, this data should be synthesized by utilizing rainfall records, reservoir operating procedures, and routing procedures.

Caution is suggested in using entire period-of-record of rainfall and stream gages in urbanized areas or any area that has had large land use changes. Urbanization can change rainfall patterns and amounts (rain shadows, etc.) and generally change the stage-discharge relationship particularly affecting the peak discharge and timing of rising and falling limbs of the flood hydrograph.

The success of the wetlands is also a function of the geology of the area. A sufficient amount of geological data should be obtained for wetland development. The services of an experienced geologist or hydrogeologist may be necessary for this part of the design process. Soil hydraulic conductivities or permeabilities of the different strata under the wetlands need to be modeled. In some cases, soil borings may be necessary to better define the local geology. A sufficient number of piezometric test wells need to be placed to define the hydroperiod of the water table throughout the wetlands area. It is desirable that wells be in place for at least two years. If the wells are not monitored during a dry cycle, the time period should be longer or appropriate adjustments should be made to the levels.

3.D.3 The Water Budget Equation

The water budget equation is a form of the basic routing equation.

$$I - O = dS/dt \qquad \textbf{(3.D.1)}$$

Where:

I = Inflow per unit time
O = Outflow per unit time
dS/dt = The change in storage per unit time

Expressed in another way that can relate to the depth of water in the wetlands, the equation becomes:

$$dV = dt(I - O) \qquad \textbf{(3.D.2)}$$

and

$$dD = dV/A \qquad \textbf{(3.D.3)}$$

where:

V = The volume of water in the wetland
A = The surface area of the water
D = The depth of the water
t = Time

The following factors combine to express the water budget equation.

Inflows:
1. Direct precipitation
2. Surface inflows
3. Subsurface inflows

Outflows:
1. Surface outflows
2. Subsurface outflows
3. Evapotranspiration

Expressed in equation form this becomes:

$$P + SWI + GWI = ET + SWO + GWO + dV/dt \qquad \textbf{(3.D.4)}$$

Where:

P = Precipitation
SWI = Surface water inflow
GWI = Groundwater inflow
ET = Evapotranspiration
SWO = Surface water outflow
GWO = Groundwater outflow
dV/dt = Change in storage

All terms except time are in units of depth of water in the wetlands.

In some cases the turnover rate of the water may be a factor. Then:

$$T = I/V \qquad \textbf{(3.D.5)}$$

Where I is the quantity of water over a time period (cubic feet per day) and T is the time period. Residence time, R, becomes:

$$R = 1/T = V/I \qquad \textbf{(3.D.6)}$$

3.D.3.1 Precipitation

Precipitation is recorded at weather stations, which are usually located some distance from project sites. Many factors affect the accuracy of the weather station data and the transposing of data from these distant recording sites to the study area. These are rain shadows, changes in elevation, lake effects, complex topography, and human activities including urbanization, deforestation, and any large land use changes. When any of these factors are present, it may be necessary to obtain data close to the site. If extrapolation is necessary, a sound basis for extrapolation should be used. Rainfall extrapolation procedures are generally found in any good hydrology textbook.

The rainfall amount is a direct input into the wetland. However, part of the rain that falls will be intercepted by vegetation over the wetland. Good estimates for interception are generally not available except for forestlands. Studies of forest hydrology may be helpful. The percentage of rainfall that is intercepted varies from 8 to 35 percent (Mitsch and Gosselink). The median value for deciduous forest is 13 and 28 percent for coniferous forest.

In the application of the water budget equation, precipitation (P) is usually combined with the surface water inflow term (SWI).

3.D.3.2 Surface Water

Surface water inflows can come from several sources, including direct runoff from the watershed in the form of sheet flow, shallow channel flow, stream flow, and overflow from a lake. The important thing is to accurately determine the runoff. The hydrologic methods discussed in this chapter can be used to determine runoff. Since we are concerned with maintaining a desired water surface elevation in the basin, flow volume and its temporal distribution are the primary hydrologic variables that are to be determined. Measurements should be made to calibrate runoff models. When stream flow is a factor, a computer model such as HEC-RAS can be used to calculate water levels and velocities. Other methods for determining water levels and velocities include direct measurements and FEMA data. Surface water inflows (SWI) in the application of the water budget equation are expressed as the volume in cubic feet (cf) of flow during the calculation time step. The usual time step (dt) is one month. Some may consider this time step too long. With computer technology and sufficient data to support the effort the time step may need to be shortened to achieve greater accuracy.

Any impoundment structure should be checked to see if it can safely pass greater magnitude floods such as the 1 percent chance flood. Standard pond routing procedures should be utilized. For this purpose, surface water outflow from the wetlands should be calculated, utilizing the weir equation or contracted channel flow procedures. For the latter, the computer program listed above can be utilized. In the water budget application, it is assumed that all water that exceeds the level of the weir during a time step will flow out over the weir. Then, SWO for a time step is equal to all the volume that exceeds the volume of the basin at weir level.

3.D.3.3 Groundwater

Depending upon the hydrogeology of a wetland mitigation site, groundwater input may be significant to the hydrologic budget of a wetland, e.g., many glacial-landscape sites, sloped wetlands, and many dry-climate sites. On the other hand, if groundwater output on a potential wetland site is greater than the potential water input, then maintaining a wetland on the site can be difficult if not impossible. Unfortunately, groundwater data is relatively more difficult and time-consuming to collect than surface water data. These data should be collected by an experienced professional and are outside the scope of this appendix. The interested reader may learn more about groundwater flow in Freeze and Cherry (1979).

To determine groundwater flow into the wetland site, the water levels in unconfined or confined aquifers need to be determined, which is usually done be installing monitoring wells. A monitoring well is constructed with a well screen and casing. To properly set and seal well screens, the site hydrogeology must be understood and the type of aquifers present (confined, unconfined or leaky) must be known. The water level in a unconfined aquifer is referred to as the water table, while piezometric surface is used to describe the water level in a confined or leaky aquifer. Using the water levels in the well, the water table and /or piezometric surface at the wetland site can be determined. Three wells in a single aquifer are needed to determine the general direction of groundwater flow in that aquifer. Also water level data should be collected over time because the direction of groundwater flow may vary over time. To determine the rate of groundwater flow, the hydraulic conductivity of the geologic materials and the hydraulic gradient must be determined. The hydraulic gradient is determined using the water level data and is usually expressed in terms of horizontal and vertical gradient. The volumetric flow rate is defined by Darcy's Law:

$$q = KA(dh/dt) \qquad (3.D.7)$$

where:

q = the discharge
K = the hydraulic conductivity or permeability
A = the cross-sectional area perpendicular to flow
dh/dt = the hydraulic gradient

The basic data for defining groundwater flow are the direction and rate. Readers should understand that both the rate and direction and rate of groundwater flow into and out of the wetland varies seasonally.

The effect that significant cutting or filling of earth areas near the proposed wetland mitigation site might have on the groundwater table elevation must also be considered. For example, if a highway cut lower than the groundwater table is proposed up gradient of the mitigation site, it could drawdown the water table levels at the mitigation site.

3.D.3.4 Evapotranspiration

Evapotranspiration includes both the surface evaporation of water and transpiration through plants. In wetlands, the evaporation from the water surface is usually affected by cover. Evaporation rarely adequately estimates total losses. Pan evaporation rates (evaporation from a shallow pan) are used to determine the ratio of total precipitation to total evaporation (P/E) for any specific region. Factors affecting evapotranspiration are exposed water surface area, solar radiation, temperature of the air and the water, wind speed, and relative humidity. Plants can control transpiration rates to some degree by closing leaf stomata. In dry areas, plants can activate water conservation measures when they experience dry conditions.

In wetlands, the vegetation reduces the evaporation rates. In marshlands, the exposed water surface area is reduced by the plants. Wind velocities at the water surface are reduced by the shielding effects of vegetation. At the water surface microclimates exist, as a result of the shielding effects of vegetation. These microclimates have higher humidity than the surrounding air. All of these effects reduce evaporation. Studies have shown that evapotranspiration rates vary from 30 to 90 percent of the rates from nearby open water.

The evaporation component can be reasonably estimated; but the transpiration component depends on knowledge of how much water the plants release through transpiration. The rates have been estimated to be from 0.53 to 5.40 times evaporation alone. In a pond, vegetation may reduce evaporation rates to about three-fourths of pan evaporation. Dry land transpiration may enhance evaporation beyond pan evaporation rates. In wetlands where supply overwhelms evapotranspiration, the need for evapotranspiration estimates is reduced. Calculated values may overestimate actual evapotranspiration rates. Evapotranspiration data may be available from state climatological centers.

There are several methods available to predict evapotranspiration. They vary in difficulty of application and accuracy. Either physical methods or climatologically based methods can be used to compute evapotranspiration. Physical methods require information about solar radiation and detailed information on transpiration specifically for the types of plants in the wetland. The Penman-Monteith equation utilizes the energy balance equation to compute evapotranspiration. Due to the complexity of this procedure it is not included in this manual. If you wish to apply it, references 9 through 14 are recommended. Climatologically based methods rely on temperature reports and require straightforward computations. These are readily used for wetland design. Modified climatologic methods are also straightforward. The Blaney-Criddle method has been developed for Utah and may be used for many areas of the country (Christiansen, J.E.). The Thornthwaite-Mather method is another recommended method (Pierce). The Thornthwaite equation is:

$$PET = 16\left(\frac{10T_a}{I}\right)^a \qquad \textbf{(3.D.8)}$$

where:

PET = Potential evapotranspiration in mm/mo
T_a = mean monthly air temperature (ºC)
$a = 0.49 + 0.0179I - 0.0000771I^2 + 0.000000675I^3$ **(3.D.9)**

Where the monthly heat index, I, is computed over a 12-month interval by the following equation:

$$I = \sum_{i=1}^{12}\left(\frac{T_a}{5}\right)^{1.5} \qquad \textbf{(3.D.10)}$$

The formula is for a standard month of 30 days of daylight and must be adjusted to latitude and month according to the table given by Dunne and Leopold. (Table 7.D.1). The PET is adjusted by multiplying the calculated PET by the correction factor in the table. In the water budget process evapotranspiration (ET) is equal to PET in units of in/mo.

Table 3.D.1 Correction Factors for Monthly Sunshine Duration

[From Dunne and Leopold (1978)]

Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
50 N	0.71	0.84	0.98	1.14	1.28	1.36	1.33	1.21	1.06	0.90	0.76	0.68
40 N	0.80	0.89	0.99	1.10	1.20	1.25	1.23	1.15	1.04	0.93	0.83	0.78
30 N	0.87	0.93	1.00	1.07	1.14	1.17	1.16	1.11	1.03	0.96	0.89	0.85

3.D.4 Alternate Design Analysis Procedures

Alternate wetland restoration design procedures are utilized, which do not rely on flooding of the wetlands but on saturation of the soil through elevation of the groundwater table. Several structural methods are available to accomplish this. One method is to construct a series of channels and/or ponds throughout the wetland area. These channels and ponds can be filled by some water source. The hydrologic analysis for this type of design will consist of two parts: analysis of water supply and analysis of groundwater flow. If the water supply is from a stream that has a gage, the gage data should be analyzed to determine the discharges for the wettest and driest years of record and an average year. For ungaged streams, this analysis will have to be done by computing hydrographs to predict the expected water supply. The second part of the analysis, analyzing the groundwater flow, confirms that the water table will be raised to the appropriate levels during the required time in the growing season. This type of analysis is outside the scope of this manual and should be performed by a qualified groundwater specialist. There is at least one computer program available to do this type of analysis: DRAINMOD developed by R. W. Scaggs of North Carolina State University. If the soils are highly permeable, the groundwater analysis may not be required. However, groundwater-monitoring wells should be utilized to assure that the required groundwater levels are achieved and maintained.

3.D.5 Water Budget Computation Procedures

The procedures given here utilize the NRCS curve number approach to determine runoff and the Thornthwaite evapotranspiration procedures. Other runoff and evapotranspiration methods may be more appropriate in particular areas.

STEP 1 - Obtain Basic Data for Site

- Soils data including soil types and soil permeabilities.

- Topographic survey data for site.
- Watershed data including NRCS soil type (A, B, C, or D), land use, present and future urbanization, historic rainfall data, daily rainfall data for wettest, driest, and average year, historic mean monthly temperatures.

STEP 2 - Calculate Runoff from Watershed

All calculations are done on a monthly basis.

a. Map the NRCS soil types. Determine the extent of each soil type in watershed in acres.
b. Map the land uses for the watershed.
c. Overlay the land use map over the soil type map. This will divide the watershed into sub-areas based on land use and soil type.
d. Determine NRCS curve numbers (CN) for each sub-area.
e. Determine weighted curve number for watershed using the equation:

$$CN_{weighted} = \frac{\sum_{i=1}^{n} CN_i \; A_i}{\sum_{i=1}^{n} A_i} \qquad \textbf{(3.D.11)}$$

where:

CN_i = NRCS curve number for sub-area i
A_i = Area of sub-area i
n = Number of sub-areas

f. Determine the wettest year, the driest year and an average year from the rainfall data.
g. Determine the minimum amount of precipitation that will cause runoff. This is done graphically by finding the point where the runoff curve number line intersects the horizontal axis or by setting the rainfall-runoff equation equal to zero and solving for P.

$$SRO = (P - 0.2S)^2/(P + 0.8S) \qquad \textbf{(3.D.12)}$$

$$0.0 = (P - 0.2S)^2 / (P + 0.8S)$$

$$(P - 0.2S)^2 = 0.0$$

$$P = 0.2S, \text{ (inches)} \qquad \textbf{(3.D.13)}$$

Where:

$$S = [(1000.0 / CN) - 10.0], \text{ (inches)} \qquad \textbf{(3.D.14)}$$

Therefore:

$$P = (200/CN) - 2, \text{ (inches)} \qquad \textbf{(3.D.15)}$$

h. Calculate surface runoff depth, SRO, for all precipitation events large enough to produce runoff. This can be done by solving equation 7.D.12.

i. Calculate the runoff volume for the watershed by multiplying the runoff depth, SRO, by the drainage area in acres.

   Volume = SRO × A

j. Convert the runoff volume to depth over the wetlands.

STEP 3 - Calculate Potential Evapotranspiration (PET)

Use evapotranspiration data from the State Climatologist or other climatological agency. If data is questionable or not available, use the Thornthwaite Equations (equations 7.D.8, 7.D.9, and 7.D.10) to calculate PET. Adjust the PET for latitude and month using values from Table 7.D.1.

STEP 4 - Determine Groundwater Influences

a. Determine groundwater outflow (infiltration). The rate is equal to the hydraulic conductivity of the soil, K in units of ft/month.

b. Determine groundwater inflow. A conservative estimate will be to assume that this is zero.

STEP 5 - Tabulate Results

a. Express all inflows and outflows as depth over wetland site (usually to a reference datum). Divide volumes by site area to get depth. Precipitation and infiltration are usually already expressed as depth.

b. Determine storage, S, in terms of depth over wetland area including any storage from previous month.

$$S = \Sigma \text{ Inputs} - \Sigma \text{ Outputs} + S(\text{Previous}) \qquad \textbf{(3.D.16)}$$

c. If the depth is greater than the height of the control structure, usually a weir, the depth will equal the height of the control structure. If it is less than the bottom of the wetlands, it is equal to the bottom of the wetlands.

d. Plot the results by month to determine the drawdown regimes.

3.D.6 Example Wetland Water Budget Problem

A wetland mitigation site is proposed for construction just upstream of a tributary to Black Creek. The location of the site is at approximately 45 degrees latitude. An adjustable control structure will be built at the upstream end of the culvert under the road. It will be set to establish a design water depth in the wetland equal to 3.28 feet. The wetland will occupy the creek bed and floodplain of the creek. The soils in the proposed wetlands are highly impervious, so there will be no direct groundwater inflow into the wetlands. The stream is spring fed. Therefore, it has a moderate base flow. To define this base flow a stream gage was set up for two years at the site and a minimum flow of 0.07 cfs was determined. After the location studies were made, the following data was assembled.

Step 1 – Data for Wetland Site on tributary to Black Creek

- The permeability of the soil for the wetlands was determined to be K= 3.1×10^{-6} in./sec. or 0.679 ft./mo.
- A topographic map outlining the drainage area (Figure 7.D.1),
- Monthly rainfall for years 1948-1996 (Table 7.D.2),
- Daily rainfall for 1954 (Table 7.D.3), identified as the dry year,
- Daily rainfall for 1964 (Table 7.D.4), identified as the wet year,
- Daily rainfall for 1968 (Table 7.D.5), identified as an average year, and
- Monthly average temperatures for these same years (Table 7.D.6).

The planned wetlands will have a gradually sloping bottom, which will have a depth to volume relationship as shown in the graph in Figure 7.D.2.

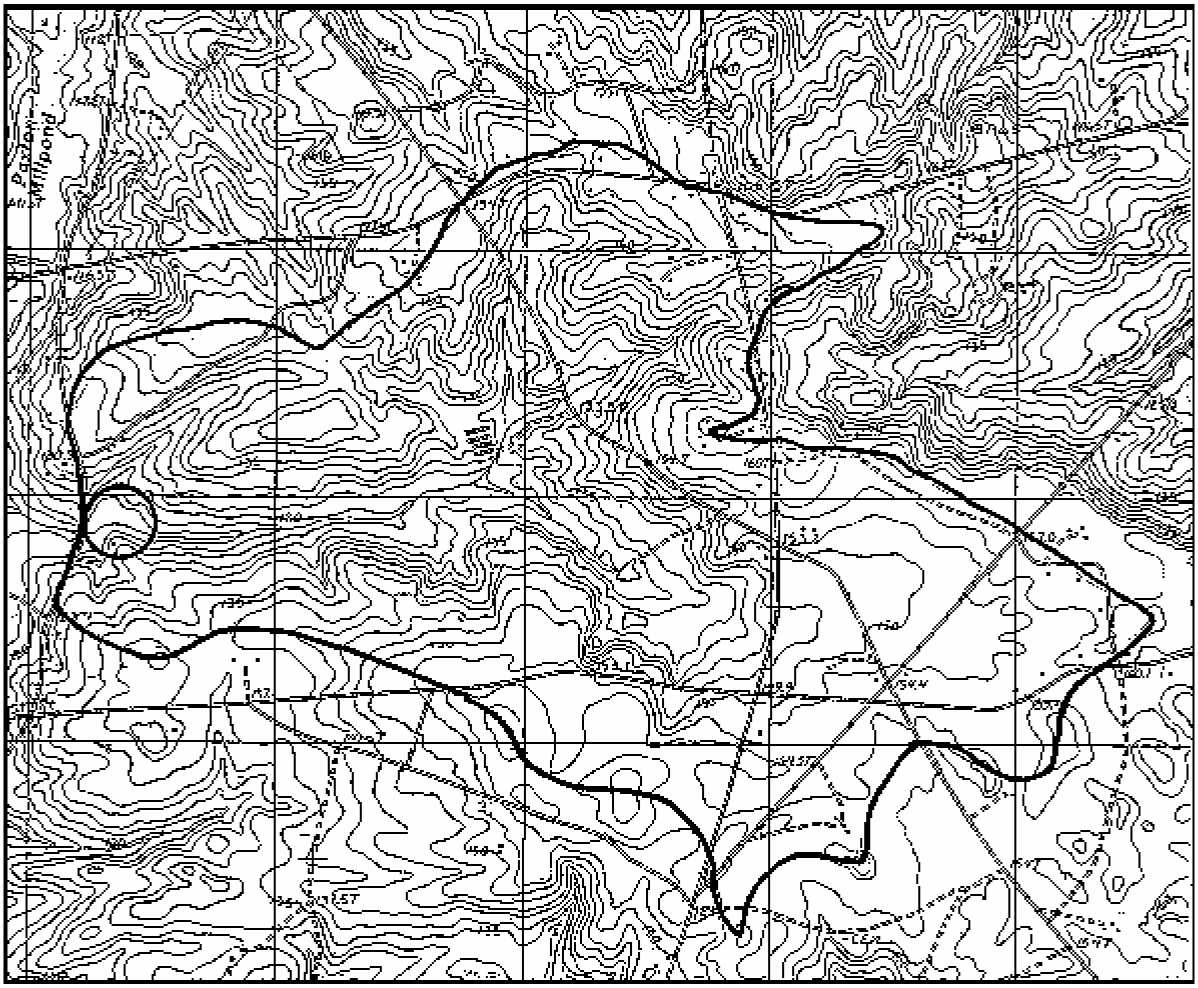


Figure 3.D.1 Topographic Map of Watershed for Example Problem (Dark Line Indicates Drainage Area Boundary)

Table 3.D.2 Total Precipitation (inch)

From Year 1948 to 1996

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
1948	0	0	0	0	0	0	1.67	1.78	4.69	2.25	4.41	2.48	17.29
1949	0.62	4.11	0.81	3.55	1.51	1.09	3.45	10.75	1.69	1.53	0.65	1.04	30.82
1950	1.78	0.72	2.68	0.88	2.87	2.29	7.60	3.04	4.16	0.86	1.09	2.27	30.24
1951	0.97	0.91	3.12	3.14	0.19	3.08	5.26	0.82	3.03	0.43	1.49	2.42	24.85
1952	2.23	2.78	4.51	2.00	2.23	1.57	0.75	77.28	1.71	0.45	1.02	2.34	98.87
1953	1.28	3.57	2.38	2.20	2.25	4.16	2.74	4.39	5.65	0.21	0.82	4.78	34.43
1954	1.23	1.46	1.57	1.35	1.42	0.96	1.44	3.81	1.13	0.79	1.24	1.25	17.63
1955	3.16	1.40	1.29	2.58	1.93	0.81	1.90	3.08	0.89	1.64	1.37	0.21	20.26
1956	1.11	3.51	2.57	3.42	1.24	1.09	2.37	1.14	5.11	1.18	0.43	1.57	24.74
1957	1.60	0.84	2.96	1.45	4.32	1.20	0.74	2.65	4.34	1.16	4.64	1.57	27.46
1958	2.63	2.49	2.88	3.79	2.44	2.32	5.60	1.24	0.49	1.71	0.37	2.48	28.46
1959	1.89	3.21	4.04	1.70	3.73	1.72	8.95	2.91	4.59	7.79	0.43	1.56	42.53
1960	4.60	3.58	3.97	2.52	0.95	1.53	3.08	3.55	2.54	1.10	0.44	1.53	29.39
1961	1.89	5.59	3.70	3.55	1.64	1.26	3.67	8.76	0.94	0.53	0.65	2.07	34.25
1962	4.18	3.11	2.83	2.07	1.49	3.08	1.72	2.00	1.84	0.57	2.92	1.46	27.27
1963	3.46	2.54	2.11	2.69	1.85	3.12	1.60	1.23	2.56	0.00	2.70	3.25	27.12
1964	4.08	3.43	3.97	2.32	1.69	1.91	6.63	6.42	4.46	6.63	0.88	2.95	45.38
1965	0.92	3.43	4.95	2.57	0.94	5.28	2.79	6.05	3.86	1.51	1.14	0.41	33.84
1966	4.65	2.92	1.44	2.31	3.95	2.36	1.85	2.07	1.30	1.59	0.68	2.13	27.25
1967	1.80	2.81	1.98	2.40	5.70	2.69	4.68	7.21	1.53	0.40	2.39	1.67	35.26
1968	3.83	0.73	1.24	2.91	2.69	3.48	5.98	0.71	1.55	2.78	3.36	2.10	31.34
1969	1.70	1.95	3.32	2.94	2.11	3.03	2.78	1.89	2.04	0.75	0.77	2.90	26.19
1970	2.11	1.66	5.42	0.59	2.90	1.32	3.05	4.59	2.40	5.27	0.92	2.93	33.16
1971	2.93	3.37	6.14	2.78	1.75	4.80	7.15	6.89	3.24	2.22	1.51	1.87	44.64
1972	4.91	2.31	2.44	0.75	4.13	3.93	6.00	1.85	1.62	0.74	3.62	3.47	35.75
1973	3.38	3.70	7.02	2.88	2.60	9.53	2.05	4.46	2.88	0.46	0.26	4.29	43.52
1974	3.97	2.89	1.52	1.91	2.19	2.90	2.83	3.99	2.86	0.01	2.88	2.97	30.92
1975	2.74	4.14	3.48	2.96	5.07	1.84	6.38	2.04	2.14	0.57	1.44	3.24	36.03
1976	2.31	0.56	3.37	0.52	2.98	7.53	4.22	0.66	3.70	3.36	3.30	4.86	37.36
1977	2.70	0.79	4.08	0.59	0.57	1.42	0.37	6.89	0.97	3.10	1.35	2.38	25.21
1978	5.96	0.82	2.25	2.76	1.99	3.05	1.35	2.87	2.63	0.51	1.92	1.17	27.28
1979	3.34	5.22	2.27	4.41	4.17	3.53	4.69	2.61	5.06	1.13	2.51	0.97	39.91
1980	3.04	1.21	6.89	1.30	2.90	1.46	0.80	2.12	4.67	1.02	1.11	0.86	27.38
1981	0.54	2.63	1.45	1.20	2.18	3.40	3.49	2.99	0.25	1.22	0.95	5.50	25.81
1982	2.41	2.83	1.06	4.15	1.88	2.72	6.43	3.79	2.14	0.95	1.69	2.40	32.43
1983	2.36	3.46	4.73	3.66	0.45	1.84	0.47	2.16	2.09	1.43	2.34	4.24	29.23
1984	2.57	3.14	3.57	2.42	2.76	4.17	5.60	2.08	0.43	0.66	0.50	1.13	29.03
1985	2.11	4.60	0.36	0.83	2.02	2.55	4.81	3.64	0.05	5.44	3.85	0.57	30.82
1986	0.68	0.94	2.07	0.23	0.73	0.57	0.81	6.15	0.36	3.89	4.03	1.62	22.06
1987	5.38	3.47	3.46	0.26	0.72	4.18	2.54	6.96	3.39	0.64	2.93	1.00	34.94
1988	2.64	1.30	1.28	1.94	1.34	1.07	2.09	7.60	4.85	2.37	1.02	0.48	27.98

Table 3.D.2 Total Precipitation (inch) (continued)

From Year 1948 to 1996

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
1989	1.22	2.13	3.15	2.75	2.86	3.86	6.06	2.05	3.32	1.45	1.19	3.40	33.44
1990	1.57	1.65	1.47	0.81	2.60	0.82	3.31	4.19	1.70	7.53	1.31	1.06	28.02
1991	3.53	1.20	4.88	3.02	4.48	2.29	11.27	5.00	1.58	0.35	0.94	1.69	40.23
1992	2.02	2.68	2.18	2.04	1.24	4.10	1.38	6.19	2.96	2.72	2.59	2.10	32.20
1993	4.82	2.12	3.87	1.05	1.92	0.48	1.30	1.51	2.51	2.76	1.25	1.54	25.13
1994	2.68	2.61	2.89	0.19	1.28	7.15	2.38	3.42	2.11	3.05	1.98	3.75	33.50
1995	2.89	4.31	1.09	0.63	1.09	6.89	5.06	4.31	3.55	2.32	1.86	1.41	35.43
1996	1.87	0.75	4.20	1.53	1.73	0.86	0	0	0	0	0	0	10.94
Avg	2.58	2.48	2.96	2.05	2.20	2.78	3.53	5.18	2.52	1.86	1.70	2.15	31.98

Table 3.D.3 Year 1954 (Dry Year) Precipitation (inch)

Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0	0	0.04	0.01	0.13	0.19	0	0.02	0	0	0	0
2	0	0	0	0	0	0.01	0.07	0.28	0	0	0	0
3	0	0	0.04	0	0.15	0.46	0	1.59	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0.20	0
5	0	0	0	0	0	0	0	0	0	0	0.08	0.51
6	0	0	0	0	0	0	0	0	0	0	0	0.06
7	0	0	0	0	0	0	0.05	0	0	0	0	0
8	0	0	0	0.03	0.02	0	0	0	0	0.01	0	0
9	0	0	0	0.29	0	0	0.02	0.53	0	0.08	0	0.08
10	0.08	0	0	0.01	0	0.03	0	0	0	0.55	0	0
11	0.29	0	0	0	0	0.17	0	0	0.17	0	0	0
12	0	0	0	0	0	0	0	0	0.18	0	0	0
13	0	0	0.29	0	0.81	0	0.17	0	0	0	0	0.49
14	0.02	0	0.05	0.22	0.13	0	0	0	0	0	0.03	0.01
15	0.01	0	0	0.51	0	0	0.68	0	0	0	0.01	0
16	0.42	0.20	0	0.03	0	0	0.38	0	0.77	0	0.12	0
17	0	0	0	0.02	0	0.08	0	0.13	0	0	0.01	0
18	0	0	0	0	0	0.01	0	0	0	0	0.30	0.01
19	0	0	0.35	0	0	0	0	0	0	0	0	0.08
20	0	0.10	0	0	0.03	0	0	0	0	0	0.13	0
21	0.04	0.04	0	0	0	0	0	0	0	0	0	0
22	0.37	0	0	0.23	0	0	0.02	0.04	0	0	0	0
23	0	0	0.08	0	0	0	0	0.26	0	0	0.16	0
24	0	0.19	0.07	0	0	0	0	0	0	0	0.01	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0.08	0	0	0	0.03	0	0	0	0	0
27	0	0	0.19	0	0	0	0	0.01	0	0	0.01	0
28	0	0.92	0.04	0	0.08	0	0	0.93	0	0.13	0.18	0
29	0	0	0.04	0	0.07	0	0	0	0	0.03	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0.28	0	0	0	0.01	0	0	0	0	0.01
SUM	1.22	1.45	1.56	1.34	1.41	0.95	1.43	3.78	1.12	0.79	1.23	1.24
YEAR TOTAL		**17.52**										

Table 3.D.4 Year 1964 (Wet Year) Precipitation (inch)

Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.04	0	0	0	0	0.17	0	0	0	0.03	0	0
2	0	0	0.77	0	1.31	0.02	0.72	0	0	0.09	0	0
3	0	0	0	0.03	0.33	0	0	0	0	0.10	0	0.23
4	0	0	0.03	0	0	0	0.37	0	0	0.81	0	0.26
5	0	0.47	0.10	0	0	0	0	0	0	1.64	0	0.03
6	0.17	0.01	0	1.14	0	0.29	0	0	0	0	0	0
7	0.03	0.12	0	0.01	0	0.31	0	0	0	0	0	0
8	0.35	0.10	0	0.33	0	0	0	0	0	0	0	0
9	0.88	0	0	0	0	0	0	1.59	0	0	0	0
10	0	0.01	0.04	0	0	0	0.04	0.90	0	0	0	0
11	0.03	0.08	0	0	0	0	0.01	0.19	0	0	0	0
12	0.88	0	0	0	0	0	0.04	0	1.81	0	0	0.11
13	0.01	0.29	0	0.06	0	0.17	0.26	0	0.26	0	0	0
14	0	0.04	0.40	0	0	0	0.02	0	0	0.01	0	0
15	0	0.49	0.88	0	0	0	0	0.05	0	2.62	0	0
16	0.12	0.01	0	0	0	0	0.10	0.19	0	1.29	0	0
17	0.28	0	0	0	0	0	0.53	0.04	0	0	0	0.06
18	0	0.93	0	0	0	0.06	0.67	0	0	0	0	0.01
19	0	0	0.13	0	0	0	1.09	0	0	0.02	0	0
20	0.48	0	0.13	0	0	0	0.58	0	0	0.01	0.52	0.17
21	0	0	0.02	0	0	0.03	0.97	0	0	0	0	0
22	0	0	0	0	0	0.33	0.58	0	0	0	0	0
23	0	0	0	0	0	0.04	0.02	0	0	0	0	0
24	0.35	0	0.02	0.01	0	0.15	0.11	0	0	0	0.22	0
25	0.31	0.35	1.09	0.08	0	0.31	0	0	0	0	0.13	0.22
26	0	0	0.33	0	0	0.03	0	0	0	0	0	1.83
27	0	0.30	0	0.64	0	0	0.04	0	0.03	0	0	0
28	0	0.23	0	0	0.04	0	0.01	0.16	0.06	0	0	0.01
29	0	0	0	0	0	0	0	2.69	0	0	0	0
30	0	0	0	0	0	0	0.45	0.39	2.28	0	0	0
31	0.12	0	0	0	0	0	0	0.17	0	0	0	0
SUM	4.06	3.41	3.94	2.30	1.68	1.90	6.60	6.38	4.44	6.62	0.87	2.93
YEAR TOTAL		**45.14**										

Table 3.D.5 Year 1968 (Average Year) Precipitation (inch)

Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.31	0	0	0	0	0	0	0	0.08	0	0	0.35
2	0.05	0.13	0	0	0.06	0.14	0	0	0	0	0	0.03
3	0.06	0	0	0.29	0	0	1.38	0	0	0	0	0.36
4	0.17	0	0	0	0.06	0	0.93	0	0	0	0	0.07
5	0	0	0	0.36	0.02	0	0.63	0.01	1.08	0.61	0	0
6	0.18	0	0	0	0	0	0	0	0	0.06	0	0
7	0.02	0	0	0	0	0.80	0	0	0	0.10	0	0
8	0	0	0	0	0	0.28	0	0	0	0	0.76	0
9	0.10	0	0	0.41	0	0.98	0.97	0	0.08	0	0.04	0
10	1.79	0	0.42	0.05	0	0.03	0.53	0	0	0	0.96	0
11	0.01	0	0.16	0	0.08	0	0.18	0.15	0	0	0.06	0
12	0.47	0	0.17	0	0.05	0.75	0.33	0.04	0	0	0	0
13	0.13	0	0	0	1.33	0	0	0.06	0	0	0	0
14	0	0	0	0	0.29	0	0	0	0	0	0	0.11
15	0	0	0	0.11	0	0	0	0	0	0.07	0.08	0
16	0	0	0.22	0	0.17	0	0	0	0	0.18	0	0
17	0	0	0.01	0	0.12	0.10	0	0	0	0.08	0.16	0
18	0	0	0	0	0.13	0.03	0.67	0	0	1.66	0	0
19	0	0	0	0	0	0	0.31	0.12	0	0	0	0
20	0	0	0	0	0	0	0	0.02	0	0	0	0
21	0	0.03	0	0	0	0	0	0	0	0	0	0
22	0	0.03	0.02	0	0	0	0	0	0	0	0	0.32
23	0	0	0.10	0.08	0	0.11	0	0	0	0	0	0.19
24	0.51	0.01	0	0.22	0	0.26	0	0.05	0	0	0	0
25	0.01	0	0	0	0.03	0	0	0.11	0	1.27	0	0
26	0	0	0	0	0.28	0	0	0	0.30	0	0	0
27	0	0	0	0.03	0	0	0	0	0	0	0	0
28	0	0.01	0	0.14	0	0	0	0	0	0	0	0.33
29	0	0.51	0	1.20	0.06	0	0	0	0	0	0	0
30	0	0	0.13	0	0	0	0.02	0	0	0	0	0
31	0	0	0.01	0	0	0	0	0.14	0	0	0	0.31
SUM	3.80	0.73	1.23	2.89	2.67	3.46	5.94	0.71	1.54	4.03	2.06	2.09
YEAR TOTAL		**31.15**										

Table 3.D.6 Mean Daily Temperature (ºF)

Year 1954 (Dry Year)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
18.3	27.1	26.2	39.8	46.7	59.7	65.9	66.0	57.6	49.4	39.7	27.5

Year 1964 (Wet Year)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22.4	22.9	29.9	42.5	56.4	60.6	68.7	64.1	57.8	47.7	39.9	23.1

Year 1968 (Average Year)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
18.4	13.7	32.1	44.2	47.9	59	65.6	64.6	62	52.2	36.1	24.2

STORAGE VOLUME

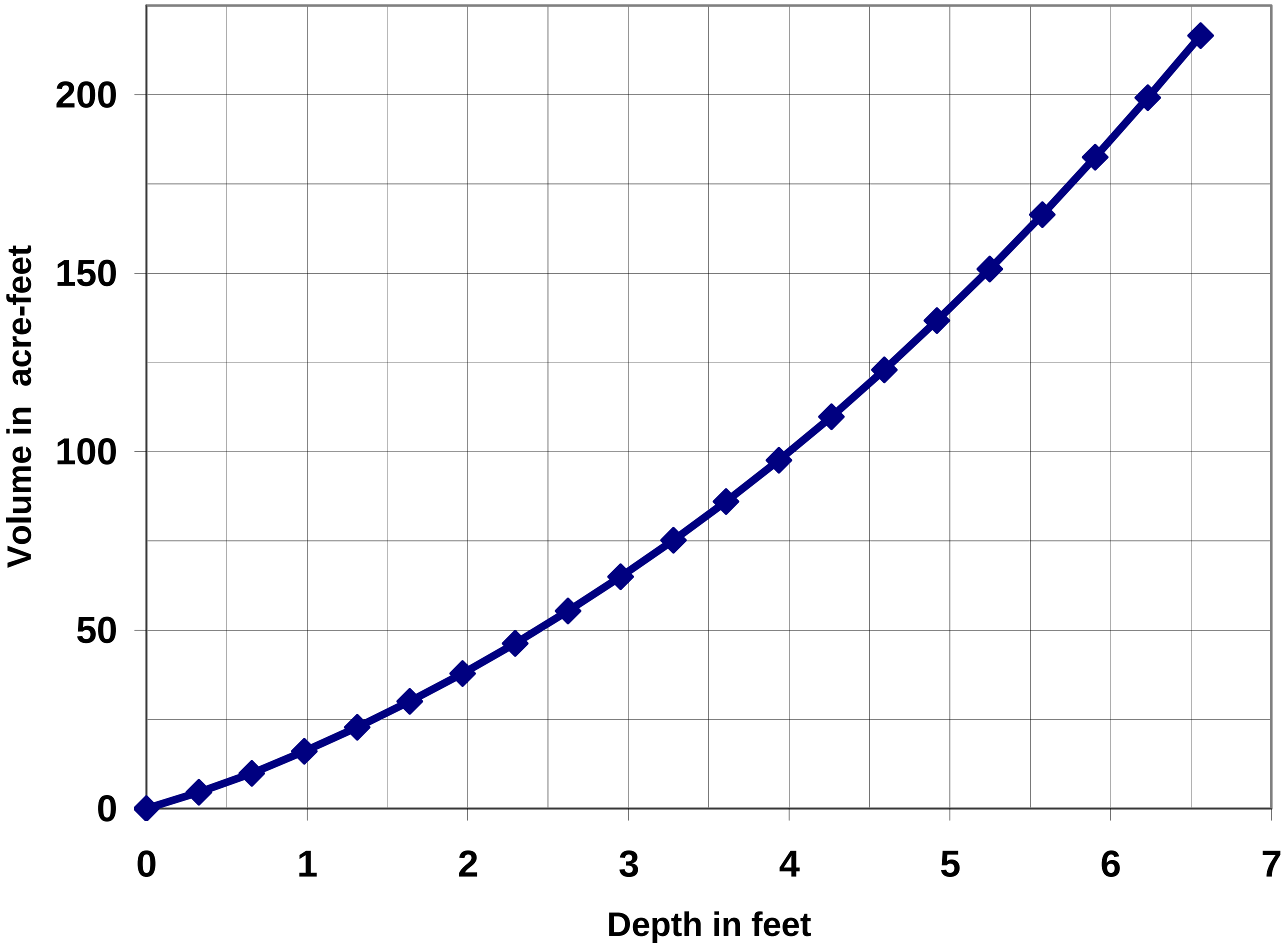


Figure 3.D.2

Step 2 - Utilizing the topographic map, soils map, aerial photography, and field observations the drainage area was delineated and land use determined. The weighted curve number for the drainage area was then determined utilizing equation 7-E-11. These results are summarized below.

Table 3.D.7

Determine Weighted Curve Number					
Soil Type	**Land Use**	**Hydrologic Condition**	**Area (acres)**	**CN**	**CN X A**
A	Woods	Poor	299	45	13,455
B	Woods	Good	346	55	19,030
B	Row Crops	Good	173	78	13,494
C	Woods	Poor	316	77	24,332
C	Meadow	-	255	71	18,105
D	Woods	Fair	329	79	25,991
Totals			1,717		114,407

$$CN_{weighted} = \frac{\sum_{i=1}^{n} CN_i \quad A_i}{\sum_{i=1}^{n} A_i} \qquad \textbf{(3.D.11)}$$

CN = 114,407/1,717 = 66.6

Find the minimum precipitation that will cause runoff.

S = (1000.0 / CN) - 10.0 (**3.D.14**)
S = (1000.0/66.6) - 10.0 = 5.0 in.

P = 0.2S (**3.D.13**)
P = 0.2 (5.0 in.) = 1.0 in.

Starting with the average precipitation year, 1968 solve for runoff using equation 3.D.12 and rainfall over threshold of 1 inch.

Table 3.D.8 Runoff Computation for Average Year

Runoff Computation for 1968 (Average Year)				
1	**2**	**3**	**4**	**5**
Month	**Daily Precipitation, P, that Produces Runoff (in.)**	**SRO (in.)**	**Volume (acre-ft.)**	**Total Runoff Volume per Month (acre-ft.)**
January	1.79	0.11	15.4	15.4
February	-	-	-	-
March	-	-	-	-
April	1.2	0.01	1.1	1.1
May	1.33	0.02	2.9	2.9
June	-	-	-	-
July	1.38	0.03	3.8	3.8
August	-	-	-	-
September	1.08	0.00	0.2	0.2
October	1.66	0.08	11.0	
	1.27	0.01	2.0	13.0
November	-	-	-	-
December	-	-	-	-

Where:

- Column 2 is each rainfall event that will produce runoff.
- Column 3 is the computed surface runoff in inches based on equation 3.D.12, where P is equal to the daily precipitation and S is computed from equation 7.D.14:

$$SRO = (P - 0.2S)^2/(P + 0.8S)$$

- Column 4 is the volume of rainfall in acre-ft. over the entire watershed.
- Column 5 is the total runoff volume for each month in acre-ft.

Step 3 - Calculate potential evapotranspiration (PET) utilizing Thornthwaite procedure (equations 3.D.8, 3.D.9, and 3.D.10). The Thornthwaite procedure is conventionally done in metric then converted to English units once complete.

Table 3.D.9

Potential Evapotranspiration for 1968						
1	**2**	**3**	**4**	**5**	**6**	**7**
Month	**Mean Temp (^oC) T_a**	**$(T_a/5)^{1.5}$**	**PET (mm/mo)**	**Correction Factor**	**PET (mm/mo)**	**PET (in./mo)**
January	-7.6	0	0	0.76	0	0
February	-10.2	0	0	0.87	0	0
March	0.1	0.00	0.2	0.99	0.2	0.01
April	6.8	1.58	33.3	1.12	37.2	1.47
May	8.8	2.35	43.6	1.24	54.0	2.13
June	15.0	5.20	74.8	1.31	97.6	3.84
July	18.8	7.31	94.3	1.28	120.7	4.75
August	18.1	6.89	90.6	1.18	106.9	4.21
September	16.7	6.09	83.3	1.05	87.4	3.44
October	11.2	3.36	55.6	0.92	50.9	2.00
November	2.3	0.31	10.9	0.80	8.7	0.34
December	-4.3	0	0	0.73	0	0
	I =	33.08				
	a =	1.02				

Where:

- Column 2 is the mean monthly temperature, T_a, converted to ºC.
- Column 3 is the intermediate computation $(T_a/5)^{1.5}$ for computing the monthly heat index, *I*, where *I* is computed by equation 7.D.10
- Column 4 is *PET* computed by equation 3.D.8, and "*a*" is computed by equation 3.D.9.

$$a = 0.49 + 0.0179I - 0.0000771I^2 + 0.000000675I^3$$

$$a = 0.49 + 0.0179(33.08) - 0.0000771(33.08)^2 + 0.000000675(33.08)^3$$

$$PET = 16\left(10\,T_a / I\right)^a$$

$$PET\ (April) = 16 \times ((10 \times 6.8)/33.08)^{1.02} = 33.3\ mm/mo$$

- Column 5 is the correction factor for latitude interpolated between 40° and 50°.
- Column 6 is PET modified by the correction factor.

$$PET\ (April) = 33.3 \times 1.12 = 37.2\ mm/mo = 1.47\ in./mo$$

- Column 7 is PET converted to inches/month.

Step 4 - Groundwater inflow and outflow were summarized in Step 1.

Step 5 - Compute water budget. In this example the inflow is computed in terms of volume then converted to depth in the wetlands based on the depth-volume graph. Computations in this example start with the pond empty. If we knew the level from the previous month, it should be the starting point.

Table 3.D.10

Water Budget Computation for 1968								
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Month	**Runoff Volume (acre-ft.)**	**Base Flow (acre-ft.)**	**Total Volume (acre-ft.)**	**Depth (ft.)**	**PET (ft.)**	**Ground-water Outflow (ft.)**	**Depth (ft.)**	**Total Storage Volume (acre-ft.)**
January	15.4	4.2	19.6	1.17	0	0.68	0.49	7.4
February	0	4.2	11.6	0.74	0	0.68	0.06	1.3
March	0	4.2	5.5	0.36	0	0.68	0	0
April	1.1	4.2	5.3	0.38	0.12	0.68	0	0
May	2.9	4.2	7.1	0.46	0.18	0.68	0	0
June	0	4.2	4.2	0.27	0.32	0.68	0	0
July	3.8	4.2	8.0	0.52	0.39	0.68	0	0
August	0	4.2	4.2	0.27	0.35	0.68	0	0
September	0.2	4.2	4.4	0.28	0.27	0.68	0	0
October	13	4.2	17.2	1.05	0.17	0.68	0.20	3.1
November	0	4.2	7.3	0.48	0.03	0.68	0	0
December	0	4.2	4.2	0.27	0	0.68	0	0

Where:

- Column 2 is the runoff computed in Table 3.D.8.
- Column 3 is the base flow converted to acre-ft. per month.

$$\text{Base Flow} = (0.07\ cf/sec)(3600\ sec/hr)(24\ hr/day)(365\ day/yr)(yr/12mo)(acre/43560sf) = 4.2\ acre\text{-}ft/mo$$

- Column 4 is the total volume, which is equal to the volume remaining from the previous month plus the runoff and the base flow for the current month.

February: V = 7.4 acre-ft. + 0 acre-ft. + 4.2 acre-ft. = 11.6 acre-feet

- Column 5 is the depth for that volume based on the depth volume relationship in Figure 3.D.2.
- Column 6 is the PET from Table 3.D.9.
- Column 7 is the groundwater flow or permeability expressed as depth in ft. per month.
-

$$K = (3.1\times10^{-6}\ in./sec)(1/12\ ft./in.)(3,600\ sec./hr.)(24\ hr./day)(365\ day/yr)(1/12\ yr/mo) = 0.68\ ft./mo$$

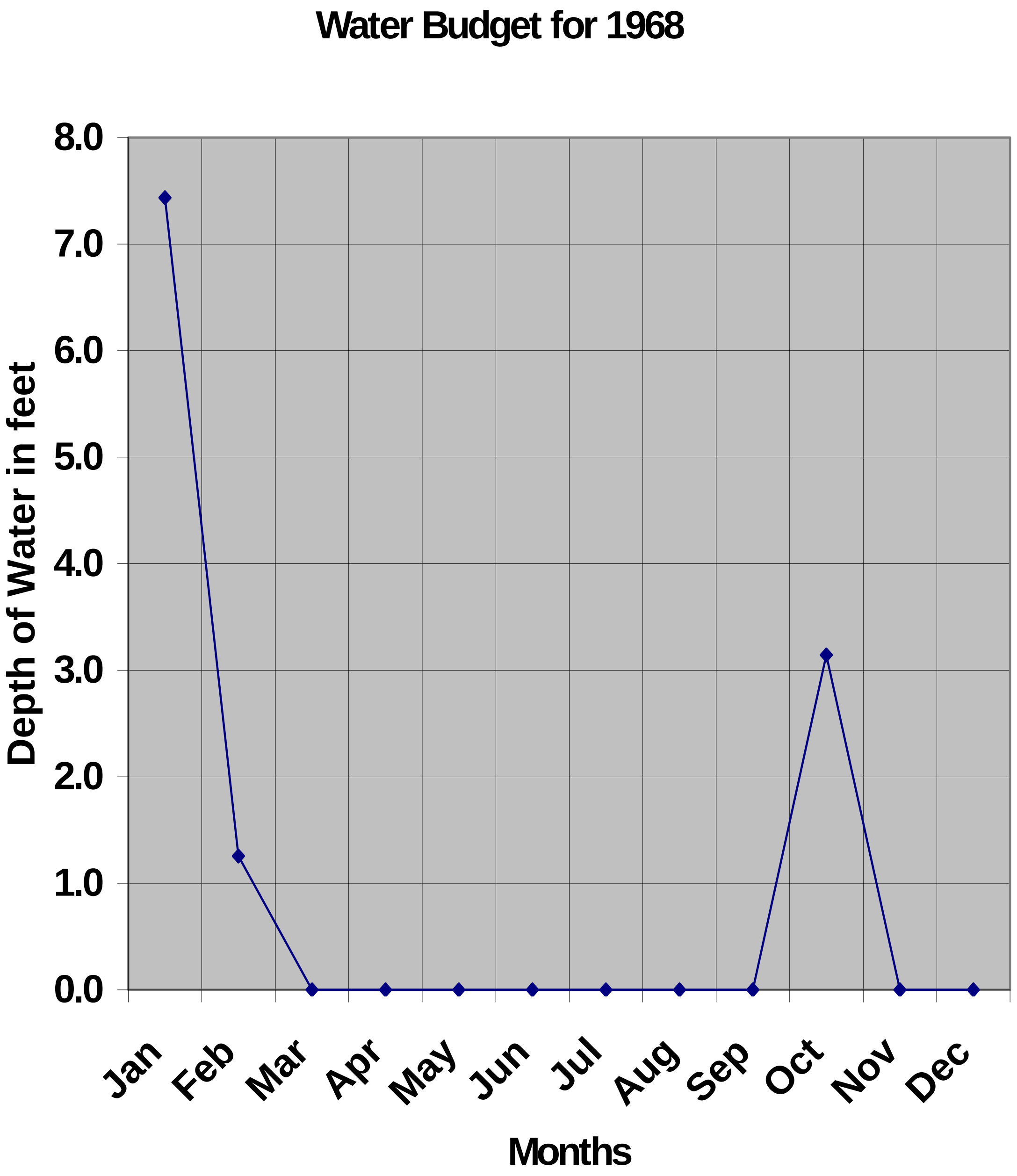
- Column 8 is the total depth of water remaining in the wetland basin at the end of the month computed as column 8 = column 5 - (column 6 + column 7) or inputs - outputs.

February Depth = 0.74 ft. – (0 ft. + 0.68 ft.) = 0.06 feet

When this volume is computed as negative, it is assumed to be equal to 0.0 ft. depth. When it is greater than 3.28 ft., it is assumed that the flow will pass over the wetland weir and the depth will be 3.28 ft.

- Column 9 is the volume of water remaining at the end of the month corresponding to the depth in column 8 (shown in figure 3.D.2).
- Plot water budget for 1968.

Figure 3.D.3 Water Budget for 1968 (Average Year)



Repeat the process for the wettest year and the driest year. Compute the runoff for the year 1964, remembering that the minimum daily precipitation for runoff to occur is one inch.

This example included base flow to show how it should be handled. In most cases, the accuracy associated with base flow determination will probably not be sufficient to include it in the computations. Therefore, a more conservative estimate of water budget would be computed by assuming no base flow. If hourly rainfall is available, it would be more accurate to compute the water budget based on a rainfall event rather than assuming the daily rainfall record represents the rainfall event.

When the water budgets are computed, the results should be given to the wetland specialist. The wetland specialist will determine if there is sufficient water and sufficient draw down at the appropriate times of the year to support the proposed vegetation in the wetland. Because of the uncertainties in the analysis and the variability of climatic conditions, the weir must be adjustable so that the water level can be raised or lowered at the appropriate times of the year to meet the requirements of the vegetation.

3.D.7 References

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