



3.1.8 Water Balance Calculations

Water balance calculations can help to determine if a drainage area is large enough or has the right characteristics to support a permanent pool of water during average or extreme conditions. When in doubt, a water balance calculation may be advisable for retention pond and wetland design.

The details of a rigorous water balance are beyond the scope of this manual. However, a simplified procedure is described herein that will provide an estimate of pool viability and point to the need for more rigorous analysis. Water balance can also be used to help establish planting zones in a wetland design.

3.1.8.1 Basic Equations

Water balance is defined as the change in volume of the permanent pool resulting from the total inflow minus the total outflow (actual or potential). Equation 3-24 presents this calculation.

Equation 3-24
$$\Delta V = \sum I - \sum O$$

where:

- Δ = delta or "change in"
- V = pond volume (ac-ft)
- Σ = "the sum of"
- I = Inflows (ac-ft)
- O = Outflows (ac-ft)

The inflows consist of rainfall, runoff and baseflow into the pond. The outflows consist of infiltration, evaporation, evapotranspiration, and surface overflow out of the pond or wetland. Equation 3-24 can be expanded to reflect these factors, as shown in Equation 3-25. Key variables in Equation 3-25 are discussed in detail below the equation.

Equation 3-25
$$\Delta V = PA + R_o + B_f - IA - EA - EtA - Of$$

where:

- P = precipitation (ft)
- A = area of pond (ac)
- R_o = runoff (ac-ft)
- B_f = baseflow (ac-ft)
- I = infiltration (ft)
- E = evaporation (ft)
- Et = evapotranspiration (ft)
- Of = overflow (ac-ft)

Rainfall (P) – Monthly rainfall values can be obtained from the National Weather Service climatology at <http://www.srh.noaa.gov/mrx/climat.htm>. Monthly values are commonly used for calculations of values over a season. Rainfall is then the direct amount that falls on the pond surface for the period in question. When multiplied by the pond surface area (in acres) it becomes acre-feet of volume. Table 3-17 presents average monthly rainfall values for Knoxville based on a 30-year period of record.

Table 3-17. Average Rainfall Values in Inches for Knoxville, Tennessee

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P (feet)	4.57	4.01	5.17	3.99	4.68	4.04	4.71	2.89	3.04	2.65	3.98	4.49
Annual Precipitation 48.2												



Source: www.ncdc.noaa.gov/oa/climate/online/ccd/nrmppcp.txt

Runoff (R_o) – Runoff is equivalent to the rainfall for the period times the “efficiency” of the watershed, which is equal to the ratio of runoff to rainfall (Q/P). In lieu of gage information, Q/P can be estimated one of several ways. The best method would be to perform long-term simulation modeling using rainfall records and a watershed model.

Equation 3-21 gives a ratio of runoff to rainfall volume for a particular storm. If it can be assumed that the average storm that produces runoff has a similar ratio, then the R_v value can serve as the ratio of rainfall to runoff. Not all storms produce runoff in an urban setting. Typical initial losses (often called “initial abstractions”) are normally taken between 0.1 and 0.2 inches. When compared to the rainfall records in Knox County, this is equivalent to about a 10% runoff volume loss. Thus, in a water balance calculation, a factor of 0.9 should be applied to the calculated R_v value to account for storms that produce no runoff. Equation 3-26 reflects this approach. Total runoff volume is then simply the product of runoff depth (Q) times the drainage area to the pond.

Equation 3-26 $Q = 0.9PR_v$

where:

- Q = runoff volume (in)
- P = precipitation (in)
- R_v = volumetric runoff coefficient [Equation 3-22]

Baseflow (B_f) – Most stormwater ponds and wetlands have little, if any, baseflow, as they are rarely placed across perennial streams. If so placed, baseflow must be estimated from observation or through theoretical estimates. Methods of estimation and baseflow separation can be found in most hydrology textbooks.

Infiltration (I) – Infiltration is a very complex subject and cannot be covered in detail here. The amount of infiltration depends on soils, water table depth, rock layers, surface disturbance, the presence or absence of a liner in the pond, and other factors. The infiltration rate is governed by the Darcy equation, shown in Equation 3-27.

Equation 3-27 $I = Ak_h G_h$

where:

- I = infiltration (ac-ft/day)
- A = cross sectional area through which the water infiltrates (ac)
- k_h = saturated hydraulic conductivity or infiltration rate (ft/day)
- G_h = hydraulic gradient = pressure head/distance

G_h can be set equal to 1.0 for pond bottoms and 0.5 for pond sides steeper than about 4:1. Infiltration rate can be established through testing, though not always accurately. Table 3-18 can be used for initial estimation of the saturated hydraulic conductivity.

Table 3-18. Saturated Hydraulic Conductivity

(Source: Ferguson and Debo, 1990)

Material	Hydraulic Conductivity	
	in/hr	ft/day
ASTM Crushed Stone No. 3	50,000	100,000
ASTM Crushed Stone No. 4	40,000	80,000
ASTM Crushed Stone No. 5	25,000	50,000
ASTM Crushed Stone No. 6	15,000	30,000
Sand	8.27	16.54
Loamy sand	2.41	4.82



Material	Hydraulic Conductivity	
	in/hr	ft/day
Sandy loam	1.02	2.04
Loam	0.52	1.04
Silt loam	0.27	0.54
Sandy clay loam	0.17	0.34
Clay loam	0.09	0.18
Silty clay loam	0.06	0.12
Sandy clay	0.05	0.10
Silty clay	0.04	0.08
Clay	0.02	0.04

Evaporation (E) – Evaporation is from an open lake water surface. Evaporation rates are dependent on differences in vapor pressure, which, in turn, depend on temperature, wind, atmospheric pressure, water purity, and shape and depth of the pond. It is estimated or measured in a number of ways, which can be found in most hydrology textbooks. Pan evaporation methods are also used, though there are no longer pan evaporation sites active in Knox County. Formerly pan evaporation methods were utilized at the Knoxville Experiment Station.

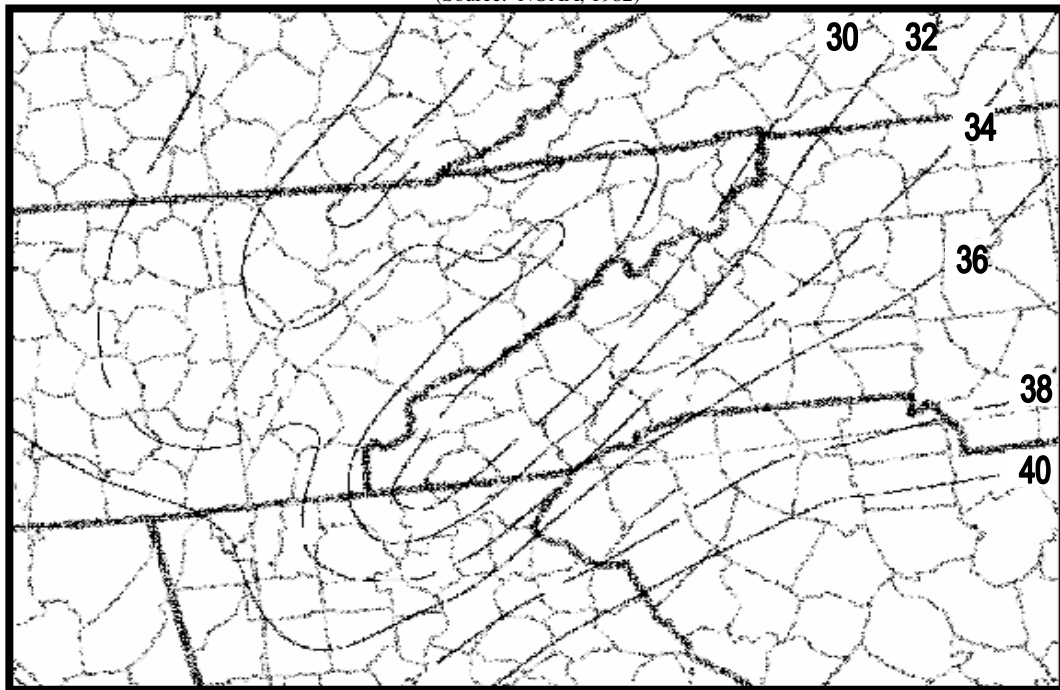
Table 3-19 presents pan evaporation rate distributions for a typical 12-month period based on pan evaporation information from one station in Knox County. Figure 3-8 depicts a map of annual free water surface (FWS) evaporation averages for Tennessee based on a National Oceanic and Atmospheric Administration (NOAA) assessment done in 1982. FWS evaporation differs from lake evaporation for larger and deeper lakes, but can be used as an estimate of it for the type of structural stormwater ponds and wetlands being designed in Knox County. Total annual values can be estimated from this map and distributed in accordance with the percentages presented in Table 3-19.

Table 3-19. Pan Evaporation Rates - Monthly Distribution

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2.9%	3.8%	7.2%	10.6%	13.1%	13.1%	13.2%	12.4%	9.8%	6.7%	4.1%	3.1%

Figure 3-8. Average Annual Free Water Surface Evaporation (in inches)

(Source: NOAA, 1982)





Evapotranspiration (E_t). Evapotranspiration consists of the combination of evaporation and transpiration by plants. The estimation of E_t for crops is well documented and has become standard practice. However, the estimating methods for wetlands are not documented, nor are there consistent studies to assist the designer in estimating the wetland plant demand on water volumes. Literature values for various places in the United States vary around the free water surface lake evaporation values. Estimating E_t only becomes important when wetlands are being designed and emergent vegetation covers a significant portion of the pond surface. In these cases conservative estimates of lake evaporation should be compared to crop-based E_t estimates and a decision made. Crop-based E_t estimates can be obtained from typical hydrology textbooks or from the web sites mentioned above. A value of zero shall be assumed for E_t unless the wetland design dictates otherwise.

Overflow (O_t). Overflow is considered as excess runoff, and in water balance design is either not considered since the concern is for average precipitation values, or is considered lost for all volumes above the maximum pond storage. Obviously, for long-term simulations of rainfall-runoff, large storms would play an important part in pond design.

Example 3-8. Water Balance Calculation for Pond

Knox Farms, a 26-acre site in Knox County, is being developed along with an estimated 0.5-acre surface area pond. There is no baseflow. The desired pond volume to the overflow point is 2 acre-feet. Will the site be able to support the pond volume? From the basic site data we find that the site is 75% impervious with sandy clay loam soil.

Step 1: From Equation 3-22, $R_v = 0.015 + 0.0092(75) = 0.71$. With the correction factor of 0.9 the watershed efficiency is 0.64.

The annual lake evaporation from Figure 3-8 is about 32.5 inches.

For a sandy clay loam the infiltration rate is $I = 0.34$ ft/day (Table 3-18).

From a grading plan, it is known that 10% of the total pond area is sloped greater than 4:1.

Monthly rainfall for Knox County was found from the Web site provided above.

Step 2: The table below shows summary calculations for this site for each month of the year.

	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Days per Month	31	28	31	30	31	30	31	31	30	31	30	31
2	Precip. (in)	4.57	4.01	5.17	3.99	4.68	4.04	4.71	2.89	3.04	2.65	3.98	4.49
3	Evap. Dist. (%)	2.9	3.8	7.2	10.6	13.1	13.1	13.2	12.4	9.8	6.7	4.1	3.1
4	R_0 (ac-ft)	6.33	5.56	7.16	5.53	6.49	5.60	6.53	4.01	4.21	3.68	5.52	6.23
5	P (ac-ft)	0.19	0.17	0.22	0.17	0.20	0.17	0.20	0.12	0.13	0.11	0.17	0.19
6	E (ac-ft)	0.06	0.08	0.14	0.22	0.26	0.26	0.26	0.25	0.20	0.13	0.08	0.06
7	I (ac-ft)	5.01	4.52	5.01	4.85	5.01	4.85	5.01	5.01	4.85	5.01	4.85	5.01
8	Bal. (ac-ft)	1.45	1.13	2.23	0.63	1.42	0.66	1.46	-1.13	-0.71	-1.35	0.76	1.35
9	Run. Bal. (ac-ft)	1.45	2.00	2.00	2.00	2.00	2.00	2.00	0.87	0.16	0	0.76	2.00

Explanation of Table:



1. Days per month
2. Monthly precipitation from web site is shown in Table 3-17.
3. Distribution of evaporation by month from Table 3-19.
4. Watershed efficiency of 0.64 times the rainfall and converted to acre-feet (from Equation 3-26).
5. Precipitation volume directly into pond equals precipitation depth times pond surface area divided by 12 to convert to acre-feet.
6. Evaporation equals monthly percent of 48 inches from line 3 converted to acre-feet.
7. Infiltration equals infiltration rate times 90% of the surface area plus infiltration rate times 0.5 (Banks greater than 4:1) times 10% of the pond area converted to acre-feet.
8. Balance is Lines (4 + 5) minus lines (6 + 7).
9. Running Balance is accumulated total from line 9 keeping in mind that all volume above 2 acre-feet overflows and is lost in the trial design.

It can be seen that for this example the pond has potential to go dry in late fall. This can be remedied in a number of ways including compacting the pond bottom, placing a liner of clay or geosynthetics, and changing the pond geometry to decrease the surface area.