Environmental Hydrology Chapter 12 Equations:

Detention and Retention Ponds, Wetlands as Treatment Systems, Leachate Management in Landfills

Detention and Retention Ponds

Rational "C" Coefficient

Any of the runoff methods that are discussed in Chapter 5 can be used to determine the volume of runoff associated with the target precipitation event. However, the NRCS curve number method is the only true runoff volume/depth method that is presented. The rational "C" coefficient can be used as an indicator of the fraction of precipitation that will generate runoff. Many urban studies have related runoff to the amount of impervious area. Based on an analysis of data for more than 60 urban watersheds Urbonas et al, 1990 (as cited in ASCE, 1998) developed the following regression equation:

$$C = 0.858i^3 - 0.78i^2 + 0.774i + 0.04 \qquad (12.1)$$

where C is a runoff coefficient and i is fraction of the watershed that is impervious. A procedure that relates the detention volume to the runoff coefficient and the mean storm precipitation volume is presented by Guo and Urbones (1995) and ASCE (1998).

Schueler (1992) presents the following relationship between the runoff coefficient and impervious area:

$$C = 0.9i + 0.05 \qquad (12.2)$$

In Table 12.6 a summary is presented for different land uses of runoff coefficients derived from various methods including equations 12.1 and 12.2. For the NRCS curve number the runoff was calculated based on assuming Soil Type C, AMC III conditions and then calculating a runoff coefficient as the ratio of this runoff to the precipitation depth.

Wetlands as Treatment Systems

Detention Time

The detention time of water in a wetland can be calculated by the using the equations presented in Chapter 8. However, the optimal detention time in a wetland for most pollutants ranges from a few days to more than two weeks. Therefore, the theoretical detention time (sometimes called the hydraulic residence time), t_d is normally calculated as:

$$t_d = \frac{Vn}{q_d} \tag{12.3}$$

where V is the volume of the wetland (ft^3 or m^3), q_d is the daily inflow (ft^3 /d or m^3/d), and n is the porosity of the medium that water flow through for subsurface flow and is the ratio of water volume to the volume occupied by water and plants (0.85 for bulrushes, 0.95 for cattails, and 0.98 for reeds).

Hydraulic Loading Rate

The hydraulic loading rate, q_{hlr} is defined as:

$$q_{hlr} = \frac{q_d}{A} \tag{12.4}$$

where A is the wetland surface area (ft^2 or m^2). Mitsch and Gosselink report hydraulic loading rates that vary from less than 0.5 inches/day to more than 9 inches/day for wetlands that treat wastewater in Europe and North America. Fennessy and Mitsch (1989) recommend a hydraulic loading rate of about 2 inches/day for acid mine drainage and a minimum theoretical detention time of 24 hours.

The hydraulic loading rate can be related to changes in inflow and outflow chemical concentrations by the following first-order model:

$$\frac{C_o - C_b}{C_i - C_b} = \exp\left(\frac{-k_A}{q_{hlr}}\right) \tag{12.5}$$

where, C_i is the inflow concentration, C_o is the outflow concentration, C_b is the background concentration, and k_A is an areal removal rate constant. If equation 12.4 is substituted into equation 12.5 and the natural logarithm is taken of both sides of the equation the following equation is obtained:

$$A = -\frac{q_d}{k_A} \ln\left[\frac{C_o - C_b}{C_i - C_b}\right] \tag{12.6}$$

the units of q_d will depend on the units of the wetland area, A, and areal removal rate constant, k_A.

Like ponds, some of the flow will short-circuit through the pond and will have a residence/detention time that is much less than the theoretical time, while some of the flow will be fairly stagnant and might stay in the wetland two or three times longer than the theoretical time. To reduce short-circuiting the length-to-width ratio (called the aspect ratio) is made large. The NRCS recommend an overall aspect ratio of at least 3:1. However, they then divide the wetland ratio into cells with an aspect ratio of 10:1 which is consistent with the recommendations of Steiner and Freeman (1989).

An alternative approach to using areal rate constants is to use empirical equations that are constituent specific. For example Kadlec and Knight (1996) developed the following equation for nitrate nitrogen that is based on data from 553 wetlands but has an r-squared (r^2) value of only 0.35:

$$C_0 = 0.093 C_i^{0.474} q_{hlr}^{0.745} \qquad (12.7)$$

where C_o and C_i are in g/m^3 and q_{hlr} is in cm/day. Where possible avoid using empirical equations with r-squared values that are less than 0.7, and/or are based on only a few values, and/or either relate to a narrow range of values or the range of values is unknown.

It should be recalled that equation 12.7 assumes a first-in and first-out (plug flow) concept. An alternative approach is to assume there is complete mixing of the inflow with a portion of the water in the wetland and that the wetland acts like a series of continuous stir reactors.

Leachate Management in Landfills

Liners may be characterized using breakthrough time, this is the time taken for leachate to penetrate a liner. For a clay liner the breakthrough time (t) may be calculated from the following equation

$$t = d^2\alpha/K(d + h) \qquad (12.8)$$

d = thickness of the clay liner (ft)
α = effective porosity
K = coefficient of permeability (ft/yr)
h = hydraulic head (ft)

The coefficient of permeability and effective porosity are dependent on the type of clay used to construct the liner. This equation may be used to calculate the thickness of clay liner required if local or state regulations specify a minimum breakthrough time.