Memorandum

To: MIDS Work Group
From: Barr Engineering Company
Subject: Regional Hydrologic Metrics – Curve Numbers (Item 6, Work Order 1)
Date: December 14, 2010
Project: 23/62 1050 MIDS

Standard engineering practice during design of stormwater systems usually employs Curve Number methodology. Curve Number methodology is often required by municipal stormwater ordinance due to its wide and historic acceptance as an appropriate rural and urban hydrologic method. Curve Numbers are determined according to the ground cover and soil type, and are used to approximate the varying infiltration, interception and storage capacities of different land covers. A high Curve Number (such as 98 for impervious pavement) indicates low infiltration/abstraction and high runoff, while a lower Curve Number (such as 30 for certain wooded areas) indicates high infiltration/abstraction and low runoff. The Minnesota Stormwater Manual defines Curve Number as "an index combining hydrologic soil group, land use factors, treatment, and hydrologic condition. Used in a method developed by the SCS to determine the approximate amount of runoff from a rainfall event in a particular area." (MPCA 2005).

History of Curve Number Method

Curve Number methodology as it is now used was developed beginning in the 1950s and updated in the decades since. It is an event-based empirical model developed by the Natural Resources Conservation Service (NRCS) (formerly SCS) based on outflow data collected from relatively uniform agricultural landscapes at a watershed-wide scale, using larger precipitation events and larger flood flows. It was originally developed to estimate stream flow based on calendar day storm/rainfall data. Curve Number methodology forms the theoretical basis for NRCS (formerly SCS) TR-20 and TR-55, where various regions of the nation are assigned varying intensities of design storms and varying recurrence event precipitation totals.

The method was originally developed to calculate the anticipated runoff volume from a watershed and was later adapted to estimate runoff discharge rate. The typical application is to apply a constant, dimensionless Curve Number to calculate runoff volume from rainfall volume. An assumed typical hydrograph (flow as a function of time) and calculated time-of-concentration (the time of flow from the farthest point on the watershed to the outlet) are used to calculate runoff rates. Curve Numbers generally vary from 30 to 98; the higher the Curve Number, the greater the volume of runoff is generated. Table 1 lists Curve Numbers for common Minnesota land covers (NRCS 1986).

Table 1. Curve Numbers for Selected Land Covers[1]

Land Cover	Hydrologic Condition	Curve Numbers for Hydrologic Soil Groups			
		A	B	C	D
Predevelopment[2]					
Woods	Good	30[3]	55	70	77
Prairies, no grazing	Good	30	58	71	78
Developed					
Impervious Surfaces	NA	98	98	98	98
Turfgrass, cover < 50%	Poor	68	79	86	89
Turfgrass, cover < 50 to 75%	Fair	49	69	79	84
Turfgrass, cover > 75%	Good	39	61	74	80
Agricultural					
Fallow, bare soil	NA	77	86	91	94
Fallow, crop residue	Good	74	83	88	90
Row crops, straight row	Good	67	78	85	89
Small grain, straight row	Good	63	75	83	87
Pasture, grazing	Good	39	61	74	80

[1]These Curve Numbers supplied by TR-55 are for Antecedent Runoff Condition II (ARC II).

[2]The Curve Numbers listed for Predevelopment are considered appropriate for native soil and vegetation conditions.

[3]TR-55 specifies a Curve Number for Woods "A" Soils as 30 for runoff calculations, while acknowledging that the actual Curve Number for this condition is lower (unspecified). Minnesota Stormwater Manual lists a presettlement Curve Number of 20 (Table 8.3).

Application of Curve Number Method

The Curve Number for each soil type and land cover dictates the expected maximum storage of the soil, S, where S is in inches.

$$S = \frac{1000}{CN} - 10$$

Abstractions, I_a, (interception, depression storage and evaporation) are generally considered to be 20% of the soil storage.

$$I_a = 0.2 * S$$

Runoff volume is then calculated using the following equation:

$$Q = \frac{(P - I_a)^2}{(P + 0.8 * S)}$$

The runoff calculated in the above equation is then applied to a rainfall frequency distribution to determine the runoff hydrograph. The NRCS method dictates a Type II 24-hour frequency distribution for Minnesota, however, the runoff volume generated can be applied to other storm durations and intensities. Curve Number methodology is even used in conjunction with continuous rainfall data to determine runoff on an annual basis, but as will be discussed later, the applicability of the Curve Number method for small storms is suspect.

Curve Number Method Advantages

The primary reason that Curve Number methodology is popular today is the ease of use (Lamont 2008). It is used in TR-20 and various software models for hydrology estimates, including water quality models (such as P8) to attempt to estimate pollutant loadings and sediment yield, and flood hydrology models (such as HydroCAD). Curve Number methodology is frequently used to estimate peak runoff flow, runoff volume and runoff hydrographs for precipitation events of all sizes. Only limited site data, such as location, soil type, land use and slope are required to complete calculations. The method is believed to be relatively accurate for larger scale planning efforts, such as regional flood storage ponds and other flood control facility sizing.

Other common hydrologic methods, including Green-Ampt and Horton Infiltration methods, do not share the advantage of ease of use, and thus are not used as often as Curve Number methodology in stormwater regulation or by developers in sizing storm sewer systems and rate and volume control stormwater best management practices (BMPs).

Curve Number Method Deficiencies

Despite its advantages and widespread acceptance, the Curve Number method presents certain disadvantages for some modeling and estimating applications. In general, these deficiencies are the result

of the nature of the method's empirical development in large non-urbanized watersheds, in contrast to the differing conditions encountered in urbanized areas. Put simply, the Curve Number method was not originally developed for the urbanized land uses where the method is now most-frequently employed.

Developed for Agricultural, Not Urban Watersheds

Classification of variable urban soils under specific Curve Numbers remains in question. The Curve Number method was developed on uniform agricultural watersheds and later adapted for urban watersheds (Peters 2010). The model performs well on rural landscapes, but was not developed to consider the complexity of a small urban site with many different land covers and BMPs (Reese 2006).

Abstractions

The Curve Number method poorly estimates initial abstraction/losses, as the method was developed focusing on the long-term conditions for daily rainfall. Initial abstraction is calculated as a function of the Curve Number, as 0.2**S*. This does not often account for variation and complexity of smaller, flatter sites and soils within stormwater BMPs. Recent research has suggested that a value of 0.05 or 0.1 may be more appropriate than 0.2 (Reese 2006, Lamont 2008, Eli 2010) and most modeling packages allow the user to adjust this value; however, changing the abstraction value from the standard 0.2 requires the creation of new Curve Numbers for all land cover types and antecedent runoff conditions (Lamont 2008).

The most common application of the method uses a constant Curve Number and antecedent runoff condition (ARC) for an entire precipitation event, although some modeling packages allow the Curve Number to vary with time and ARC. The possible inaccuracy concerning the lack of early-event variation of Curve Number (initial losses, infiltration, etc.) and the inability of the method to account for varying antecedent moisture content are deficiencies of the method (especially for small precipitation and first flush water-quality scale events).

Small Precipitation Events and Continuous Modeling

Curve Number methodology has difficulty accurately determining runoff for small precipitation events (less than 3"), and especially for events less than ½ inch (Peters 2010). In the Twin Cities, storms less than ½ inch account for 65% of all precipitation events greater than 0.1 inches (MPCA 2005 – Appendix B). The method is believed to be more accurate for larger precipitation events.

The method was not originally developed to model snowmelt or continuous rainfall/runoff simulations, nor was it developed to describe the hydrologic communication between rainfall, soil, soil moisture, subsurface flow and stream flow, therefore has severe limitations in being used for these purposes.

Even though it is sometimes used as such, it was not developed to be used for non-point source water quality modeling calculations, such as variable infiltration rates, making a distinction between

disconnected impervious surfaces and pervious surfaces, etc. Modelers have observed inaccurate prediction of runoff volume for small precipitation events, and corresponding inaccurate estimation of pollutant/sediment delivery using this method. Inaccuracy is heightened when only a portion of the real watershed is actually contributing runoff.

Composite Curve Number Deficiencies

A composite Curve Number is the areal-weighted average Curve Number of multiple areas with different Curve Numbers, aggregated into a single area with a single curve number. A distributed method differs from a composite Curve Number in that it separates pervious and impervious areas, calculating their runoff independently to avoid undesired approximations that occur in composite Curve Number calculations. Results differ if a composite Curve Number is used in the calculations or if a distributed approach is used.

Peters calculated that for a theoretical 20-acre, 30% impervious site, and a 1.3-inch rainfall event, using the composite Curve Number approach generated only 30% of the runoff volume that a distributed Curve Number approach would generate (0.17 acre-feet versus 0.55 acre-feet). The distributed Curve Number method is generally more accurate because each land cover type is considered, enhancing the resolution of the analysis (Peters 2010). Employing the composite Curve Number method can lead to inadequate sizing of water quality and rate control stormwater BMPs.

Composite and distributed Curve Number methods generate more similar results for larger storms (5-year, 100-year, etc.); however, when evaluating small storms, composite Curve Numbers for Commercial, Industrial, and varying impervious densities Residential Sites are not recommended for use even though they are listed by the NRCS, in various models, and in Table 8.4 of the Minnesota Stormwater Manual.

References

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