CURVE NUMBERS FOR GOLF COURSE WATERSHEDS

K. W. King, J. C. Balogh

ABSTRACT. *Storm event runoff is a critical component to the environmental and structural design related to hydrology. The curve number (CN) method is a robust and accepted method for determining excess rainfall. Measured CNs for golf course watersheds, and for that matter hydrologic data from golf course watersheds, are limited. Rainfall-runoff data from two golf courses, Morris Williams Municipal Golf Course (MWMGC) located in a semi-arid climate in Texas and Northland Country Club located in a cool-humid climate in Minnesota, were collected for a 5-year period. One hundred twenty-seven events on MWMGC and 86 events on NCC were used to determine CNs. The measured CNs, for normal antecedent moisture (AMC II) conditions were determined to be 63.4 at MWMGC and 78.2 at NCC. Each of the four methods used to calculate CN from the measured data produced CNs that were consistent for each site (standard deviation at MWMGC was 0.7, while standard deviation at NCC was 1.9). Hydrologic soil group, local climate that affects evapotranspiration (ET) and thus antecedent soil moisture, and site characteristics (specifically slope, drainage density, and connectivity) appear to have the most impact on the establishment of CNs for these two golf courses. The findings of this study indicate the importance of understanding local climate and site characteristics that influence hydrology when determining CNs. The CNs developed for these courses provide partial confirmation of CNs previously suggested for plot-scale turfgrass systems but more importantly highlight the significance of having localized measured data. The results from this study suggests that determination of CNs for golf course watersheds should not be based on traditional sources that rely solely on hydrologic soil classifications and land use or vegetative cover type.*

Keywords. *Design, Hydrology, Modeling, Runoff, Turfgrass, Urban.*

A primary focus of urban storm water management is environmental protection from the potential harmful effects of nutrient and pesticide transport (e.g., Hoffman et al., 2000; Meybeck, 1998), sedimentation (e.g., Arnold and Gibbons, 1996; Klein, 1979), and/or ecological alterations (e.g., Walsh et al., 2005; Paul and Meyer, 2001; Walsh, 2000). Of equal importance is storm event hydrology. Much of the recent literature associated with urban storm event hydrology has focused on the influence of impervious areas and drainage networks (e.g., Hatt et al., 2004; Lee and Heaney, 2003), specifically the short-circuiting they provide in transporting both water and pollutants to streams and water bodies. Much less information is available on the rainfall-runoff relationships from pervious and impervious surfaces prior to entrance into the drainage networks. Rainfall-runoff relationships on both pervious and impervious surfaces are critical to structural design and management/planning for storm water runoff. One method for predicting rainfall-runoff relationships from pervious surfaces is the curve number (CN) method (USDA-SCS, 1972). The CN method was originally designed for small ungauged agricultural watersheds. However, the application of the CN approach to pervious systems within the urban landscape is well documented and accepted (Rallison, 1980; USDA-SCS, 1986; Grove et al., 1998; Lim et al., 2006). Additionally, most hydrology reference and text books cite CNs for urban areas such as residential, industrial, commercial/business, and open spaces such as parks, golf courses, and lawns (Schwab et al., 1981; Chow et al., 1988; Rawls et al., 1993).

Curve number is a simple yet well tested approach used for determining rainfall-runoff relationships. CN is a single-parameter lumped model that predicts streamflow resulting from excess rainfall. CN was not designed to predict infiltration, although Hjelmfeldt (1980) showed that CN could be extended for infiltration estimates in certain cases. The CN model does not distinguish between the many pathways that water may enter the stream or surface water (i.e., overland flow resulting from infiltration excess also designated as Hortonian overland flow, saturation excess overland flow, groundwater flow, subsurface drainage). Selection of CN is generally accomplished using lookup tables and site-specific information based on soils, land use, vegetative cover, and antecedent moisture. Selection of CN is not dependent on topography, routing properties, or physical characteristics of the site.

Identification and utilization of curve numbers on homogeneous managed turf is not a new concept. Evans et al. (1998) and Moss et al. (1999) utilized tall fescue (*Festuca arundinacea* Schreb.) plots situated on a Maury silt loam (fine, mixed, mesic, Typic Paleudalf) soil in Lexington, Kentucky, to conduct runoff studies and pesticide transport. The soil was classified as a hydrologic group B soil. The plots were maintained on a 3% slope, and the fescue was mowed to a height of 100 to 150 mm. Evans et al. (1998) investigated the impact of irrigation on CN. Irrigated plots had a mean CN of 59, while CN on the non-irrigated plots was 45. Similarly, Moss et al. (1999) using simulated rainfall determined a

Submitted for review in October 2007 as manuscript number SW 7239; approved for publication by the Soil & Water of ASABE in April 2008.

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mean CN of 48.5. Ma et al. (1999) used one year of measured rainfall and runoff data from 'Tifway 419' bermudagrass plots (*Cynadon dactylon* (L) Pers × *C. transvaalensis* Burtt-Davy) in Griffin, Georgia, to identify an optimum CN for modeling purposes. The plots were constructed on a 5% slope on a Cecil sandy loam (thermic, Typic Hapludult). The soil was classified as hydrologic soil group C. The optimal curve number was determined to be 83.

Haith and Andre (2000) suggested adjusting curve numbers for pasture, range, and meadow to account for different turf scenarios (i.e., fairways, roughs, home lawns, greens). The adjustments were rationalized by drawing a similarity in the function of thatch to that of residue cover in conservation tillage. Based on previous research by Rawls et al. (1980), Haith and Andre (2000) recommended reducing the suggested CNs for pasture, range, and meadow by 10%. Application of this approach to 34 events from turfgrass plots resulted in a prediction efficiency of 0.76. Most of the improvement was noted with respect to the larger events.

Previous studies have focused entirely on small homogeneous turf areas and have not investigated the composite results from an entire golf course drainage area. As the number of golf courses continues to increase in the U.S. and abroad (National Golf Foundation, 2006), most likely so will urban development in and around the golf courses. The resulting development will lead to storm water management questions on or in the vicinity of golf courses. As design issues related to storm water management arise, availability of accurate CNs for design purposes will be critical. These CNs will need to be applicable for small heterogeneous watersheds, not homogeneous land/management units. The objective of this research was to use measured hydrology data from two small golf course catchments to initiate the identification of appropriate CNs for golf course land use and compare the calculated CNs with those recommended in CN tables (USDA-SCS, 1986).

Experimental Methods

Site Locations

Two golf courses with differing characteristics (table 1) were selected for this research: Morris Williams Municipal Golf Course (MWMGC) located in Austin, Texas, and Northland Country Club (NCC) located in Duluth, Minnesota. MWMGC is characterized by a series of grassed waterways, culverts, and casual water detention areas that cross the center of the course (fig. 1). The topography is such that the contributing area (29 ha) contains 10 greens (0.73 ha), 7 fairways (8.23 ha) and 7 tees (0.30 ha). The managed areas (greens, fairways, and tees) represent 32% of the total area. The contributing area also contains approximately 6.5 ha of reduced-managed rough, with the remainder comprised of unmanaged trees and shrubs. Soils at MWMGC (table 2) were formed in alluvium, clayey bedrock, and marl bedrock but have been subjected to considerable disturbance and redistribution as a result of local construction projects. The study area is dominated by two soil types: Travis (fine, mixed, thermic Ultic Paleustalfs) and Houston Black (fine, montmorillonitic, thermic Udic Haplusterts). Travis soils are located on the slopes, while the Houston Black clays are located in the valleys and areas surrounding the stream. The Houston Black clays have a high shrink/swell potential and a very slow permeability (less than 1.52 mm h^{-1}) when wet (USDA-SCS, 1974). However, preferential flow resulting from soil cracking contributes to high infiltration rates when the soil is dry (Arnold et al., 2005; Allen et al., 2005).

NCC has several subwatersheds or drainage areas with unnamed streams draining into Lake Superior. The study area is located along a stream on the northeastern part of the golf course (fig. 2). This area forms a discrete drainage area composed of six complete holes, three partial holes, and unmanaged areas of mixed northern hardwoods and bedrock outcroppings. The 21.8 ha drainage area is comprised of 8 greens (0.3 ha), 8.5 fairways (4.0 ha), 8 tees (0.5 ha), and 17 ha of unmanaged trees and grass. The managed turf area accounts for 21.7% of the measured drainage area. The drainage stream enters a small natural pond located at the inlet of the watershed. This stream then bisects the study area. NCC soils are characteristic of lacustrine clay deposits, moderately deep (3 to 6 m) over bedrock. The dominant soil on NCC is the Sanborg (fine, mixed, active, frigid, Oxyaquic Glossudalfs) - Badriver (fine, mixed, active, frigid Aeric Glossaqualfs) complex (table 2). Previous references to the soils located on NCC identified the soils as Cuttre, Ontonagon, and Bergland soils; however, more recent soil surveys have identified the soils as Sanborg-Badriver complex. All of these soils have very similar morphological, chemical, and physi–

Table 1. Site characteristics from two golf course watersheds, MWMGC and NCC.

		MWMGC (Austin, Texas)	NCC (Duluth, Minn.)
Grass		Tifdwarf 419 bermudagrass (*Cynadon dactylon* (L.) Pers × *C. transvaalensis* Burtt-Davy)	Creeping bentgrass (*Agrostis palustris* Huds. *A. stolonifera* L.)
Climate			
	Temperature	Avg. min (4°C); avg. max (35°C)	Avg. min (–9°C); avg. max (25°C)
	Precipitation	810 mm	980 mm
	Growing season	273 days	220 days
Management		Moderate	Moderate to intense
Area		29.0 ha	21.8 ha
	Greens	0.7 ha (10 greens)	0.3 ha (8 greens)
	Tees	0.3 ha (7 tees)	0.5 ha (8 tees)
	Fairways/roughs	8.2 ha (7 fairways)	4.0 ha (8.5 fairways)
	Open/grass areas	6.5 ha coastal bermudagrass (*C. dactylon* (L.) Pers	--
	Woodlands	13.24 ha scrub/live oak (*Quercus virginiana* (Mill.))	17 ha mixed northern hardwoods
Slopes		4% to 8%	3% to 25%
Elevation change		19 m	37 m

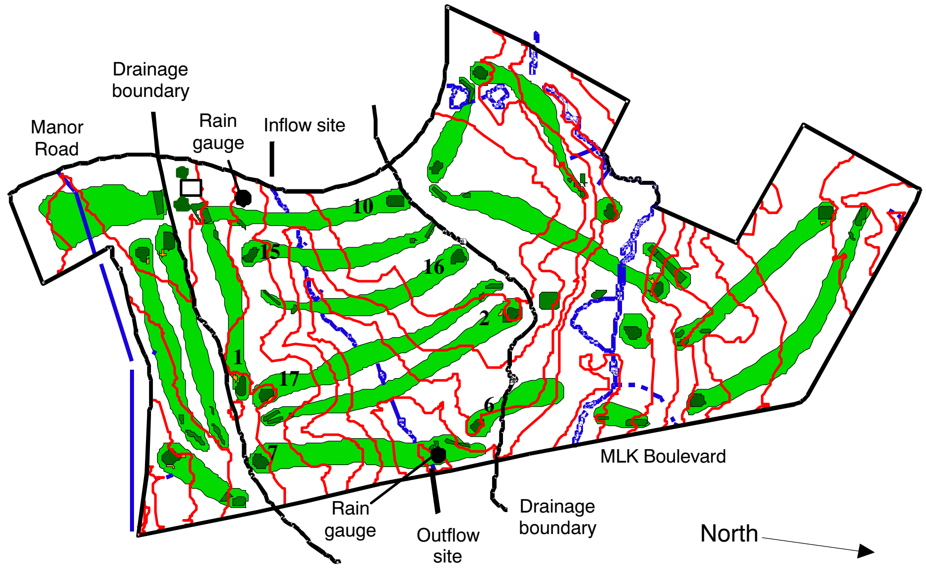

Figure 1. Layout of Morris Williams Municipal Golf Course (MWMGC). Area located between drainage boundaries, Manor Road, and MLK Boulevard was used in the study.

Table 2. Soil mapping units, extent of coverage, and NRCS hydrologic soil group classification for soils located in the study areas of MWMGC and NCC.

Soil Mapping Unit	Dominant Texture	NRCS Hydrologic Soil Group	Extent of Unit (ha)	% of Total Area
MWMGC (Austin, Texas)				
Houston Black + Urban, 1% to 3% slope	Gravelly clay	D	8.0	27.6
Travis + Urban, 1% to 8% slope	Gravelly loamy sand over sandy clay/sandy clay loam	C	21.0	72.4
NCC (Duluth Minnesota)				
Barto-Geylsolon-Rock outcrop complex, 0% to 18% slope	Gravelly sandy loam	D	1.7	8.0
Sanborg-Badriver complex, 3% to 18% slope	Clay	D	20.1	92.0

cal characteristics. The parent material is noncalcareous clayey lacustrine deposit over calcareous clays. Perched water table conditions on the site are common and are caused by the dense subsurface horizons and fine-textured soils.

Data Collection, Uncertainty, and Analysis

A subarea of each course was instrumented with Isco 730 bubble modules (MWMGC) or 4230 bubbler flowmeters (NCC). Precipitation and stream stage were collected on 15 min intervals (MWMGC) and 10 min intervals (NCC) for 5 years. At MWMGC, Isco 4150 area velocity sensors provided stream velocity. Stream velocity coupled with cross-sectional area permitted the development of stage discharge relationships for the inlet and outlet locations at MWMGC. Velocity and stage measurements at the inlet location were taken in parallel concrete road culverts 0.6 m and 1.2 m in diameter. Outlet measurements were collected in a concrete box culvert, 3 m wide by 1.5 m in height, that conveyed water under MLK Boulevard. At NCC, 0.9 m (3 ft) H-flumes were installed in the stream at the points where the stream entered the course and where the stream exited the course to provide control volumes and a pre-calibrated stage discharge relationship. Storm water runoff resulting from both golf courses was calculated as the difference in inflow and outflow volumes. The volume of discharge for each event was determined as the area under the hydrograph. The duration of the hydrograph was determined as the time difference between rainfall initiation and the time at which the discharge rate on the receding limb was within 5% of the discharge rate when rainfall began. This approach buffers the effect of baseflow on streamflow estimates following storm events. Contributions from groundwater influx to total storm water runoff volumes was assumed negligible because groundwater flow is primarily a component of baseflow, especially on these watersheds with fine-textured soils (Black, 1996). Precipitation was measured with Isco 674 tipping-bucket rain gauges. Rain gauges were positioned at the stream inlet and outlet locations at each course. Precipitation was recorded on the same time interval as stream stage.

Estimated error associated with discharge measurements may range from 2% to 35% depending on the type and stability of control volumes, accuracy and precision of measurement technologies, and frequency of equipment calibration (Harmel et al., 2006). In the case of MWMGC, the estimated error in the more significant discharge measurements was ±8.2% (±2% for area velocity measurements under ideal conditions and ±8% for non-changing flow control volume). Similarly, the estimated error for NCC was ±3% (±3% for pre-calibrated flow control structure with periodic current meter checks and ±0.35% for bubbler technology). These error estimates are based on work conducted by Harmel et al. (2006). In addition to error in the discharge measurements, error may also be introduced in the precipitation measurements. For high-intensity rainfall events (>100 mm h^{-1}), tipping-bucket rain gauges have been shown to lag measurements from standard gauges by as much as 10% (Nystuen, 1999), although Ciach (2003) reported biases less than 5%. None of the events used in this study exceeded the 100 mm

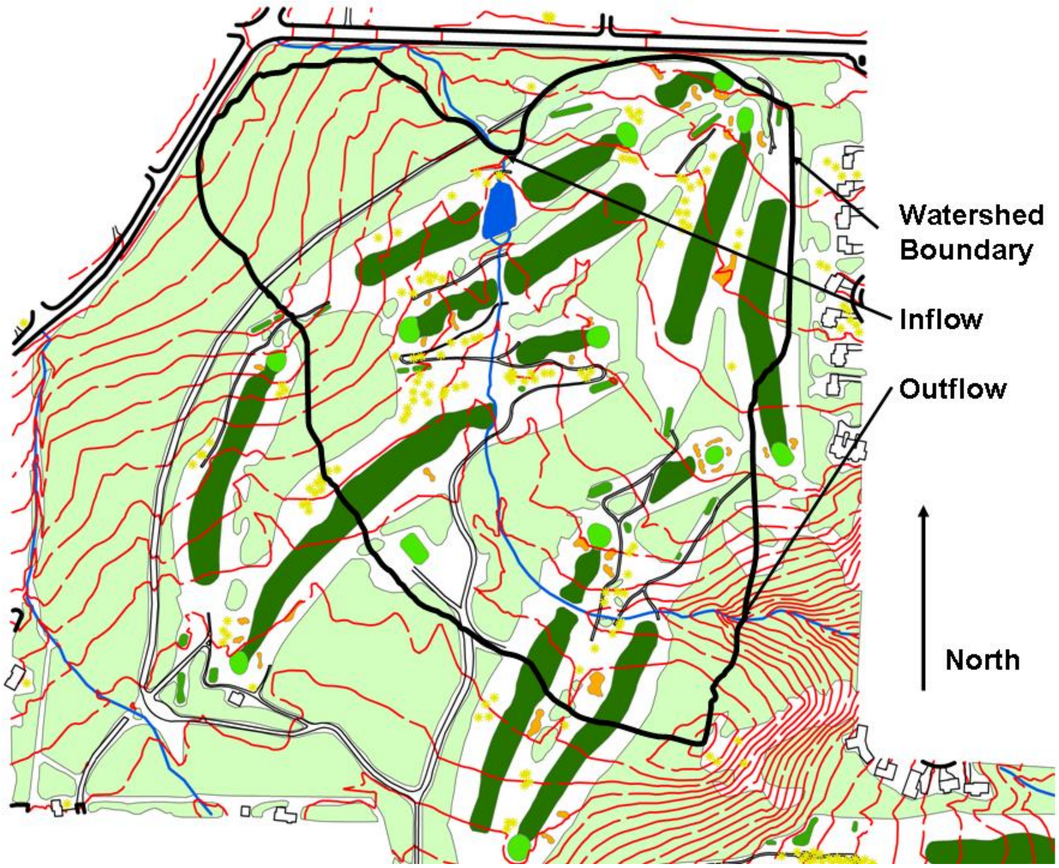

Figure 2. Layout of Northland Country Club. Sampling points were located at inlet and outlet of watershed.

h^{-1} intensity. However, it should be noted that the tipping-bucket rain gauge technology does introduce potential error. The level of uncertainty associated with the data used in this study is consistent with the low end of published and expected errors for field and watershed scale hydrology studies (Harmel et al., 2006), suggesting that the results obtained from the study are of high quality and reliable.

Differences in rainfall characteristics at each site were determined with the non-parametric Mann-Whitney rank sum test. All statistical analyses were conducted using SigmaStat 3.5 for Windows (Systat Software, 2006a) and a significance level of $P < 0.05$. Coefficients of determination (r^2) were determined with the linear least squares regression. Prediction efficiency (E), the description of distribution around the 1:1 line, was determined by the relationship outlined by Nash and Sutcliffe (1970). Curves were fitted with the curve fit option in SigmaPlot 10.0 for Windows (Systat Software, 2006b).

Methods for Curve Number Estimation

Four different methods were used to determine CN: asymptotic (Hawkins, 1993), $P/S > 0.46$ (Hawkins et al., 1985), least squares (Simanton et al., 1996), and maximum potential retention (Hjelmfelt, 1991). A primary misconception about CN development is that CN development is accomplished on a single event. In fact, CN development is based on multiple events at a specific location that is usually well defined by either soils, land use, and vegetation and/or a specific land use comprised of a combination of these parameters (i.e., golf courses in the specific case addressed here). Application of the CN occurs on an individual event basis, subject to adjustment for antecedent moisture conditions (AMC) that often follow a seasonal pattern (Feyereisen et al., 2008). CN is a representation of the central tendency; it is not constant but varies on an event basis (Hjelmfelt, 1991). CN is calculated independently of AMC, land use, vegetation, and soil type. Physical characteristics such as topography, slope, drainage density, depth to water table, or routing are not directly considered in the development of CN.

Asymptotic Method

The asymptotic approach (Hawkins, 1993) is conducted by first sorting all precipitation events in descending order from greatest to least followed by a similar sort for runoff amounts. Once sorted, each rainfall amount (P) is paired with each runoff amount (Q) in descending order, a process known as frequency matching. Frequency matching is assured because each of the ordered items has a like return period. Next, the retention parameter (S) and resulting curve number (CN) are calculated for each P:Q pair. Finally, the relationship between P (abscissa) and CN (ordinate) is determined. Three possible outcomes exist: complacent behavior, standard behavior, and violent behavior. Complacent behavior is defined by CNs that steadily decline with increasing precipitation, failing to approach a steady value. In cases where data exhibit this type of behavior, CNs cannot be identified using the asymptotic approach. Standard behavior is characterized by a similar CN decline with increasing precipitation; however, the CN values tend to remain constant with larger precipitation. Violent behavior is identified with increasing CNs with increasing precipitation before approaching a constant value with larger precipitation amounts. Once standard behavior has been determined, an equation of the form $y = y_0 + ae^{-bx}$ is fitted with the constraint that $y_0 + a = 100$. The asymptotic value and thus CN is defined by y_0.

P/S > 0.46 Method

The P/S > 0.46 approach (Hawkins et al., 1985) is based on probability theory and expands the ideas presented by Hjelmfelt (1982) and Smith and Montgomery (1979). Specifically, only runoff events where P/S > 0.46 should be used in determining the retention parameter (S) and thus the CN. A trial-and-error approach is used to determine those events that meet the P/S > 0.46 constraint. First, all events are sorted in descending order based on precipitation (P). The retention parameter (S) is calculated, and the P/S ratio is compared to the 0.46 threshold. If P/S is greater than 0.46, then the next largest event is added to the calculation. The mean retention parameter for all events used is calculated, and the process of comparing the next P/S ratio to 0.46 is undertaken. All events meeting the P/S constraint are used to determine a mean retention parameter and thus a CN.

Least Squares Method

The least squares method, as outlined by Simanton et al. (1996), is aimed at selecting a retention parameter (S) that minimizes the function $f(S) = \Sigma(Q_{ei} - Q_{oi})^2$, where Q_{ei} is the estimated runoff using an initial abstraction equivalent to 0.2 times the retention parameter (S), and Q_{oi} is the measured runoff. When using least squares, all measured data are used with no sorting. Once the function is minimized, the resulting retention parameter is used to calculate a curve number.

Maximum Potential Retention Method

The maximum potential retention approach (Hjelmfelt, 1991) is the classic approach to identify curve numbers. This approach utilizes the annual largest runoff producing events. The first step in this procedure is to identify the largest annual runoff events. These events will not necessarily coincide with the largest precipitation events. Second, the retention parameter for each event is calculated. Next, the mean of the retention parameters is determined and the curve number is calculated.

Results

Precipitation and discharge data at MWMGC were collected from 1 April 1998 to 30 March 2003. The same data were collected at NCC from 1 July 2002 to 30 June 2007. One hundred twenty-seven events at MWMGC and 86 events at NCC were identified for the present study. Here, an event was defined as any precipitation occurrence in which at least 6.35 mm of precipitation fell and in which there were no more than 6 h without recorded precipitation. A duration greater than 6 h between recorded precipitation was used to identify separate events. Significant differences ($P < 0.05$) in median rainfall intensity and median event duration were noted between MWMGC and NCC; however, no differences were apparent in median event rainfall depth (fig. 3). The median event size was 18.1 mm at NCC and 16.9 mm at MWMGC. The median 1 h intensity measured at MWMGC (10.4 mm h^{-1}) was significantly greater compared to NCC (7.4 mm h^{-1}). Conversely, the median duration of the events

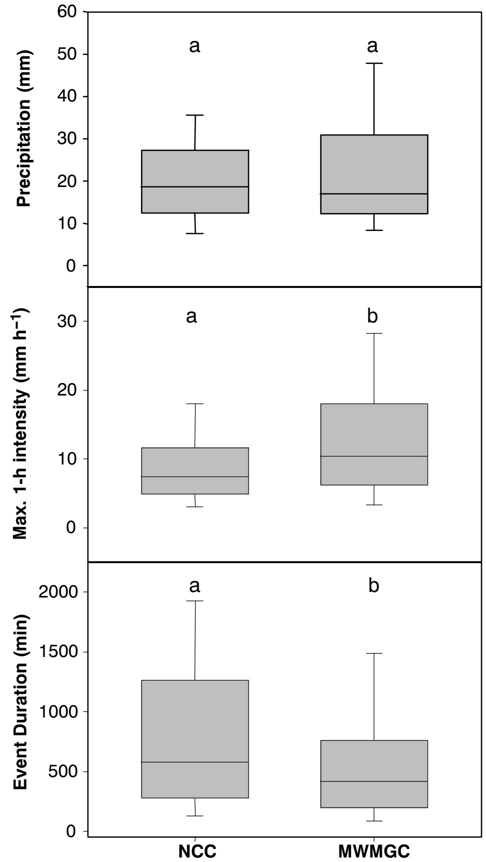

Figure 3. Box and whiskers plots of precipitation characteristics for measured storm events at NCC ($n = 86$) and MWMGC ($n = 127$). Boxes are bound by the 25th and 75th percentile values; the line in the box represents the median. Whiskers represent the 10th and 90th percentile measurements. For each plot, boxes noted with different letters indicate significant ($p < 0.05$) differences in median values using the Mann-Whitney nonparametric test.

Table 3. Calculated CNs for MWMGC and NCC using four different methods.

Location	Years of Record	Land Use	Area	Hydrologic Soil Group	CN	Method	Reference
MWMGC (Austin, Texas)	5	Golf Course	29 ha	C	63.0	Asymptotic	Hawkins, 1993
					63.1	P/S > 0.46	Hawkins et al., 1985
					63.0	Least squares	Simanton et al., 1996
					64.5	Maximum potential retention	Hjelmfelt, 1991
NCC (Duluth, Minn.)	5	Golf Course	21.8 ha	D	90.5	Asymptotic	Hawkins, 1993
					86.6	P/S > 0.46	Hawkins et al., 1985
					89.0	Least squares	Simanton et al., 1996
					90.7	Maximum potential retention	Hjelmfelt, 1991

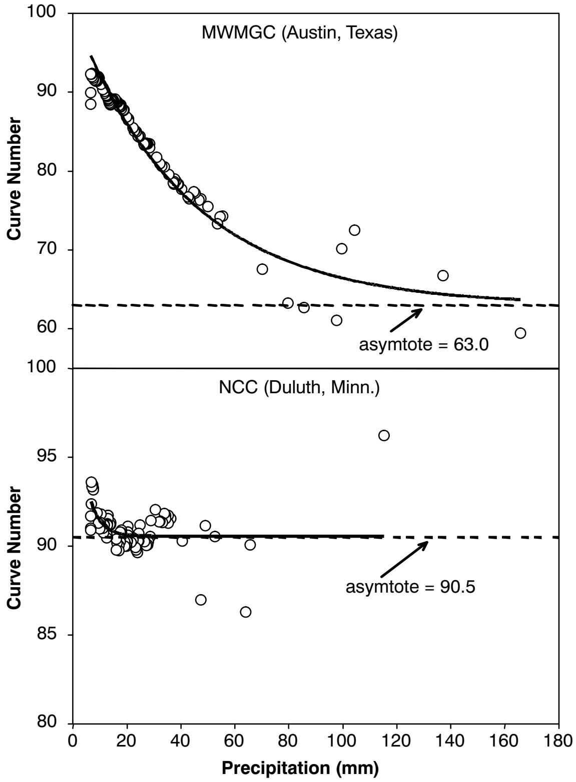

Figure 4. Determination of CN for MWMGC and NCC using the asymptotic method (Hawkins, 1993).

was greater at NCC compared to MWMGC, approximately 150 min greater. CNs were calculated for each course using measured rainfall-runoff and four different methods (table 3).

For MWMGC, the mean CN determined by the four methods was 63.4 with a standard deviation of 0.7. Likewise, the mean CN for NCC was 89.2 with a standard deviation of 1.9. CNs derived from the asymptotic method were 63.0 for MWMGC and 90.5 for NCC (fig. 4). Applying the P/S > 0.46 method to both sites resulted in CNs of 63.1 for MWMGC and 86.6 for NCC (table 4). Seven events were used in the P/S > 0.46 calculation for MWMGC, while 43 events were needed at NCC before the constraint was not met. Using the minimization of the least squares for all events at both locations resulted in CNs of 63.0 for MWMGC and 89.0 for NCC. When applied to the data from both sites, these CNs resulted in coefficients of determination of 0.53 for MWMGC and 0.61 for NCC (fig. 5). Similar findings were noted for prediction efficiency, 0.46 for MWMGC and 0.59 for NCC (fig. 5). Derivation by the maximum potential retention method produced CNs of 64.5 for MWMGC and 90.7 for NCC (table 5).

Discussion

For each course, the calculated curve numbers resulting from the four methods were surprisingly consistent. The consistency in measured CNs by the four methods at each location suggests considerable confidence in each CN. For comparison purposes, composite CNs for each course were also computed by applying the tables outlined in USDA-SCS (1986). Composite CNs were based on aerial weights deter-

Table 4. CN estimation for MWMGC and NCC as determined by the P/S > 0.46 method (Hawkins et al., 1985).

Date	Precip. (mm)	Runoff (mm)	S (mm)	P/S
MWMGC (Austin, Texas)				
17 Oct. 1998	165.8	32.7	270.4	0.613
14 Nov. 2001	137.2	56.5	115.9	0.710
29 Aug. 2001	104.4	18.8	180.3	0.553
1 July 2002	99.6	39.9	87.0	0.609
2 Nov. 2000	97.7	14.9	186.0	0.582
17 May 1999	85.6	52.5	38.0	0.585
19 Feb. 2003	79.5	10.9	160.2	0.536
5 Oct. 1998	70.1	3.0	216.1	**0.447**
		Average S = 148.3		
		CN = 25400 / (148.3 + 254) = 63.1		
NCC (Duluth, Minnesota)				
3 Oct. 2005	115.3	104.1	10.0	11.529
7 July 2002	65.5	1.6	229.1	0.548
21 Sept. 2006	64.0	6.4	148.7	0.495
22 Oct. 2004	52.6	16.5	59.5	0.470
9 May 2006	49.0	40.8	7.7	0.539
22 June 2002	47.2	7.6	87.3	0.523
4 June 2005	40.4	32.5	7.6	0.514
12 Sept. 2005	36.3	4.5	77.2	0.463
16 Aug. 2002	35.3	5.9	63.9	0.460
11 July 2004	35.3	10.1	43.5	0.481
7 July 2003	34.3	17.0	22.5	0.498
16 May 2004	34.3	15.2	26.4	0.525
30 May 2004	33.8	30.3	3.1	0.558
9 Sept. 2002	33.0	3.7	73.4	0.537
17 June 2006	32.5	7.7	46.6	0.538
29 June 2005	32.0	19.5	14.3	0.556
5 Sept. 2004	30.5	14.1	22.0	0.549
22 Apr. 2007	29.0	28.3	0.6	0.552
18 Sept. 2003	28.7	9.0	32.4	0.559
3 Oct. 2002	27.9	5.5	45.7	0.547
28 July 2004	27.7	3.8	55.9	0.540
18 June 2007	27.2	18.2	9.8	0.550
9 May 2003	26.4	16.7	10.9	0.553
12 Nov. 2005	26.4	14.9	13.9	0.570
18 May 2005	24.9	20.2	4.5	0.557
25 May 2005	24.4	12.2	15.7	0.560
31 July 2006	24.4	5.6	35.7	0.564
15 Sept. 2004	24.1	16.5	8.2	0.574
24 July 2002	23.9	0.7	80.0	0.551
28 Oct. 2003	23.4	4.6	38.0	0.542
19 Apr. 2005	23.1	5.1	34.9	0.539
11 Sept. 2003	22.1	3.1	43.8	0.515
18 May 2007	22.1	4.3	36.5	0.517
29 May 2006	21.6	6.8	24.3	0.512
12 Aug. 2002	20.3	1.2	56.8	0.477
22 June 2003	20.3	1.9	48.8	0.475
20 June 2005	20.3	6.7	22.1	0.481
13 June 2005	20.1	17.6	2.2	0.488
19 Sept. 2005	20.1	4.0	32.4	0.490
24 Sept. 2005	19.8	3.3	35.9	0.486
8 Aug. 2004	19.6	6.6	20.6	0.485
24 June 2003	19.3	8.9	14.0	0.486
1 Oct. 2004	19.3	6.3	21.0	0.492
29 July 2006	18.0	0.7	57.5	**0.455**
		Average S = 39.3		
		CN = 25400 / (39.3 + 254) = 86.6		

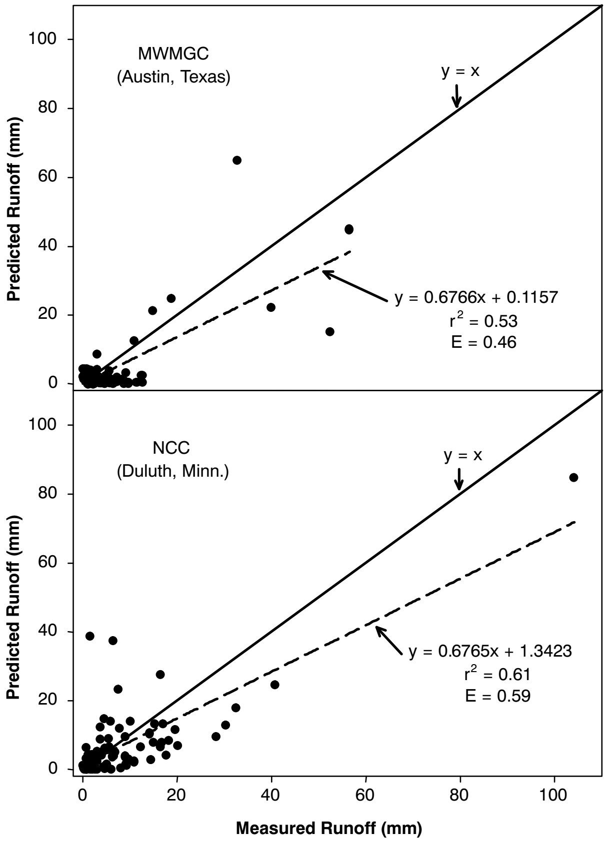

Figure 5. Results for each course from applying CN as determined by the least squares method (Simanton et al., 1996). CN = 63 for MWMGC and CN = 89 for NCC. Plotted are measured and predicted runoff volumes, coefficient of determination (r^2), and prediction efficiency (E) determined according to Nash and Sutcliffe (1970).

Table 5. CN estimation for MWMGC and NCC as determined by the maximum potential retention method (Hjelmfeldt, 1991).

Date	Precip. (mm)	Runoff (mm)	Retention, S (mm)
MWMGC (Austin, Texas)			
17 Oct. 1998	165.8	32.7	270.4
17 May 1999	85.6	52.5	38.0
2 Nov. 2000	97.7	14.9	186.0
14 Nov. 2001	137.2	56.5	115.9
1 July 2002	99.6	39.9	87.0
		Average S = 139.5	
		CN = 25400 / (139.5 + 254) = 64.5	
NCC (Duluth, Minnesota)			
22 June 2002	47.2	7.6	87.3
7 July 2003	34.3	17.0	22.5
30 May 2004	33.8	30.3	3.1
3 Oct. 2005	115.3	104.1	10.0
9 May 2006	49.0	40.8	7.7
		Average S = 26.1	
		CN = 25400 / (26.1+254) = 90.7	

mined by land use, soil characteristics, and vegetative cover. The composite CN for MWMGC was 74.1, while the composite CN for NCC was 77.1 (table 6). In the case of MWMGC, the composite CN was approximately 17% greater than the mean CN calculated by the four different methods. In contrast, the composite CN estimated from tabular values for NCC was 14% less than the mean calculated CN. A difference in CNs between courses was expected because of differences in soil composition and hydrologic soil groups between sites. Based on previous studies (Haith and Andre, 2000; Moss et al., 1999; Evans et al., 1998) where CNs on turfgrass had been determined, the expectation was that measured CNs for a particular hydrologic soil group would be less than those calculated from the CN tables, generally 10% to 25% less. The measured CN at MWMGC followed this trend; however, the measured CN at NCC was unexpectedly and considerably greater than the tabular CN. Local weather, land use management, topographic, and climatic differences were investigated to explain the unexpected large CN at NCC.

Characterization of the precipitation, particularly the amount, intensity, and duration of events, was investigated for both courses as a source of explanation for the relatively large CN measured at NCC (fig. 1). No significant difference ($p > 0.05$) in event size was measured between the two courses. The recorded maximum 1 h intensity of the events was significantly greater ($p < 0.05$) for MWMGC when compared to NCC. In general, short-duration, large-intensity events produce greater runoff; however, in this particular case, less runoff as suggested by smaller CNs was measured from the course with greater intensities and shorter durations.

Table 6. Calculations for determining composite CNs for MWMGC and NCC.

Land Use	Weighted area × CN[a] for each hydrologic soil group: A	B	C	D	Row Total
MWMGC (Austin, Texas)					
Greens	0.73/29 × 39 = 0.98	--	--	--	0.98
Tees	--	--	0.3/29 × 74 = 0.77	--	0.77
Fairways/roughs	--	--	6.7/29 × 74 = 17.85	1.23/29 × 80 = 3.40	21.25
Open grass area	--	--	2.13/29 × 71 = 5.22	4.37/29 × 78 = 11.74	16.96
Woodland	--	--	10.84/29 × 73.5[b] = 27.47	2.4/29 × 80 = 6.62	34.09
				Composite CN =	74.05
NCC (Duluth, Minn.)					
Greens	0.3/21.8 × 39 = 0.54	--	--	--	0.54
Tees	--	--	--	0.5/21.8 × 80 = 1.83	1.83
Fairways/roughs	--	--	--	4.0/21.8 × 80 = 14.68	14.68
Woodland	--	--	--	17.0/21.8 × 77 = 60.05	60.05
				Composite CN =	77.10

[a] CN was determined from USDA-SCS (1986) using land use description open spaces, lawns, parks, golf courses, cemeteries, etc., for greens, tees, and fairways; meadow classification for open grass areas; and wood or forest land for woodlands.
[b] Cover was determined to be between good and poor. CN was set to be average of the good and poor condition.

The inverse relationship in precipitation characteristics and CN suggests that factors other than local precipitation characteristics have a more significant impact on the CN.

Site characteristics and land use management were also evaluated to explain the large difference in measured CNs between the two courses. Managed turf on MWMGC accounts for approximately 32% of the total drainage area, while 22% of the NCC drainage area is managed turf. Turf management is relatively similar at both locations, with irrigation, density of turfgrass during the growing season, and depth of thatch being the exceptions. Irrigation is less while density of turfgrass and thatch depth is greater at NCC compared to MWMGC. Based on visual observations, the managed turf areas of NCC were generally wetter compared to MWMGC, although irrigation management did not explain the noted observational differences. Areal-weighted irrigation on MWMGC during the 5-year study period was 166 mm compared to an areal-weighted 48 mm at NCC during years 2003 and 2004. The greater irrigation at MWMGC was a result of a longer growing season and more evaporative demand. The minor differences in management do not help explain the large CN at NCC, suggesting that the greater CN may be a result of local site characteristics (e.g., perched water tables, greater slopes, evapotranspiration).

Kirby et al. (2005, 2002) suggested that runoff is a function of site characteristics or factors that can be characterized as either local (e.g., soils) or topographic (e.g., gradient). Local factors, other than soil composition, that are different between the courses are density of the wooded areas and soil compaction. On each course, the actual playing areas are severely compacted. Compacted soils have less evapotranspiration (ET) and thus greater runoff potential (O'Neil and Carrow, 1983). Compaction on the clayey Sanborg-Badriver soils of NCC would have a more pronounced impact compared to the Travis soils of MWMGC because of an already smaller volume of pore space. Aeration is used on a regular basis to combat compaction at both courses. In addition to aeration, the freeze/thaw cycles at NCC should further alleviate some of the compaction issues at that site. The Houston Black soils located on MWMGC have a high potential for shrinking and swelling. In the non-irrigated areas, substantial cracking occurs during dry periods, resulting in larger initial abstractions and reduced runoff potential or CN. Since compaction is an issue at both courses and is readily addressed, compaction does not appear to be an explanation for the large CN at NCC.

Forest density is also different at each course. A visual inspection of the forest density indicates that the density at NCC is much greater than at MWMGC. In general, a denser forest will produce less runoff, which is contrary to the findings of this study. Thus, forest density as a site characteristic does not help explain the differences in CNs.

The most notable topographic difference between the courses is slope or gradient. The slopes on NCC are much more pronounced than the slopes on MWMGC. Kirby et al. (2005) note that larger gradients produce greater runoff as a result of reduction in depressional storage, thinner soils, and increased drainage density. At NCC, depressional areas are widespread; however, drainage from the depressional areas is rapid due to installation of drop pipes and tiles that quickly convey the water to the stream. Subsurface drainage on MWMGC is present but not as systematic. The presence of perched water tables at NCC also leads to greater saturation excess flow and potentially more runoff. At NCC, the steeper slopes are more associated with thinner soils and outcrop areas where infiltration is minimal, suggesting that the larger measured CN is substantially influenced by slope, drainage density, and connectivity.

In addition to the local and topographic factors, climatic factors that affect antecedent soil moisture would also influence the CN, particularly evapotranspiration (ET). Estimated ET for central Texas is 750 to 900 mm year^{-1} compared to 450 to 600 mm year^{-1} for Minnesota (Hobbins et al., 2001). The estimated ET for central Texas is in the mid-range compared to the rest of the U.S., while the ET in Minnesota is on the lower end of the scale. The smaller ET in Minnesota will lead to increased antecedent moisture content (AMC), resulting in greater runoff. Thus, the CN calculated for NCC may actually correspond to AMC III (wet) conditions. Assuming the calculated CN is actually for AMC III conditions, a CN corresponding to normal AMC or AMC II conditions can be calculated using the relationships highlighted in USDA-SCS (1986). Applying this relationship to the NCC calculated CN of 89.2 yields a CN of 78.2, which is comparable to the composite CN of 77.1 estimated for the same location. This result suggests that the measured data actually represent an AMC III condition; therefore, the CN for normal AMC conditions would be 78.2.

Previous research on CNs for turfgrass plots suggests a 10% to 25% reduction in traditional or tabular CNs (Haith and Andre, 2000; Moss et al., 1999; Evans et al., 1998). Results from the current study both support and contradict the extension of the 10% to 25% reduction recommendation to watershed-scale golf courses. In support of that recommendation, data from MWMGC suggest an 18% reduction from the CN computed from traditional sources. In contrast, the CN calculated from suggested tabular values for NCC was approximately 14% less than the CN determined via the four methods previously outlined, implying that any additional reduction based on suggestions in the available literature would further compound the error in runoff predictions using the CN method. After correction to represent AMC II conditions, the CNs for NCC were comparable, indicating that applying the suggested reductions would still produce an erroneous CN that would cause underprediction of runoff. The current study demonstrates that in cool-humid climates where ET is reduced, the growing season is shorter, and topographic features facilitate runoff, a 10% to 25% reduction of CNs may not be appropriate. This study also demonstrates that under certain climatic conditions if a standard CN or a reduced CN is used, severe underestimation in discharge could occur. Thus, if the objective were to design a water control structure or estimate losses of sediment, nutrients, and/or pesticides, then the result would be an underestimation in design or environmental effects. When using the CN approach to predict streamflow for structural design on watershed areas containing significant amounts of managed turf, site-specific measurements of precipitation and discharge are needed to confidently determine the CN. When site-specific data are not available, caution should be exercised in relying heavily on the traditional CN values for turf areas. Similar cautions should also be followed when applying suggested reductions to published CN values. As shown here, the CN selections or suggested adjustments to the CNs may or may not be appropriate.

In addition to structural design, the implications of these findings also extend to modeling. Awareness of uncertainty between measured and suggested CNs should improve simulations for watersheds containing managed turf areas. However, recent criticism on the extension and use of the CN method in continuous-time hydrology and water quality models (Garen and Moore, 2005; Walter and Shaw, 2005) encourages the development and exploration of alternative rainfall runoff methods that incorporate variable source area theories (Ponce and Hawkins, 1996; Mitas and Mitasova, 1998). The criticism of the CN method is focused on continuous-time hydrology and water quality modeling, but it does not extend to using the method for design purposes, as is the focus of this article. The findings from this study, particularly those associated with NCC where topographic features, drainage density, and connectivity are integral to the measured streamflow, support investigation of and movement to more distributed methods for continuously predicting runoff.

Summary and Conclusion

Rainfall and discharge data from two golf courses located in different climatic regions of the U.S. were collected for 5 years. One course, Morris Williams Municipal Golf Course (MWMGC), was located in a semi-arid climate, and the other, Northland Country Club (NCC), was located in a cool-humid climate. One hundred twenty-seven events on MWMGC and 86 events on NCC were used to calculate curve numbers (CNs) for each course using four different methods.

Mean measured CNs from rainfall runoff data were 63.4 at MWMGC and 89.2 at NCC. The following points summarize the major findings from this study:

- The four methods used to develop CN values produced consistent results for each location in which they were applied.
- Compared to suggested curve numbers for the golf course land use, the results from this study were mixed. After adjustment for wet conditions (AMC III), the CN for NCC was comparable to the suggested tabular value; however, the measured CN for MWMGC was 18% less than the suggested CN derived from published tabular values.
- Reducing published curve numbers by 10% to 25%, as suggested by other studies completed at a plot scale, may or may not be justified on watershed-scale golf courses. On a broader scale, additional research is required to understand scaling issues associated with deriving CNs on plots and projecting those to a watershed.
- Improvements in the existing recommended CNs for golf courses are needed.
- There is no substitute for measured data.
- Topographic and local site characteristics that facilitate runoff such as soil type, slope, drainage density, connectivity, and evapotranspiration should be considered when deriving CNs and utilizing the CN method.
- CN is an appropriate method for structural design when golf courses need to be represented; however, because of the diversity of land uses and management on golf courses, alternative methods that consider variable source areas should be considered for detailed hydrology and water quality assessments.

CN is a valuable, simple approach to determine streamflow resulting from excess rainfall. Based on the findings from this study and when data are available, it is recommended that the CNs be determined with multiple methods, not only to ensure greater confidence but also to provide a check that application of a single method was not misunderstood. After CN establishment, comparison with published CNs, if possible, for similar soils and characteristics should be completed. Completing this last step will help identify the impact of localized physical or climatic characteristics. Before application, determination of the normality or frequency of these characteristics should be evaluated and appropriate adjustments made to the CN.

For those entities utilizing the CN method for structural design or environmental assessments in the vicinity of golf courses, especially in the proximity of the locations studied here, the results from this study have immediate impact. Namely, when selecting CNs, investigation of topographic and climatic characteristics should be considered in addition to soils, land use, vegetative cover, and antecedent moisture content. The results also highlight the need to take advantage of measured data when available. However, to draw any overarching conclusions on the use of tabular CNs for watershed-scale golf courses, additional long-term data from multiple geographic and climatic locations would be required.

Acknowledgements

We would like to extend our appreciation to Sara Beth Scadlock, Ivy Leland, Emily Burgess, Heather McMains, and Georgie Mitchell for routinely collecting the hydrology data at both MWMGC and NCC. We would also like to thank Natalie Struble for organizing and summarizing the data into specific storm events. Additionally, we would like to acknowledge the superintendent and staff at both MWMGC and NCC for permitting the installation of sampling equipment and frequent access to the course to collect data. We would also like to thank Roger Risley, Minnesota NRCS Soil Survey Project Leader, for his inspection and insightful discussion on hydrologic soil group classifications. Finally, we would like to acknowledge Dr. Jimmy Williams, Senior Research Scientist with the Texas Agricultural Experiment Station, for his thoughts and discussion regarding the manuscript.

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