WATERSHED SCIENCE BULLETIN

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Association of Watershed & Stormwater Professionals

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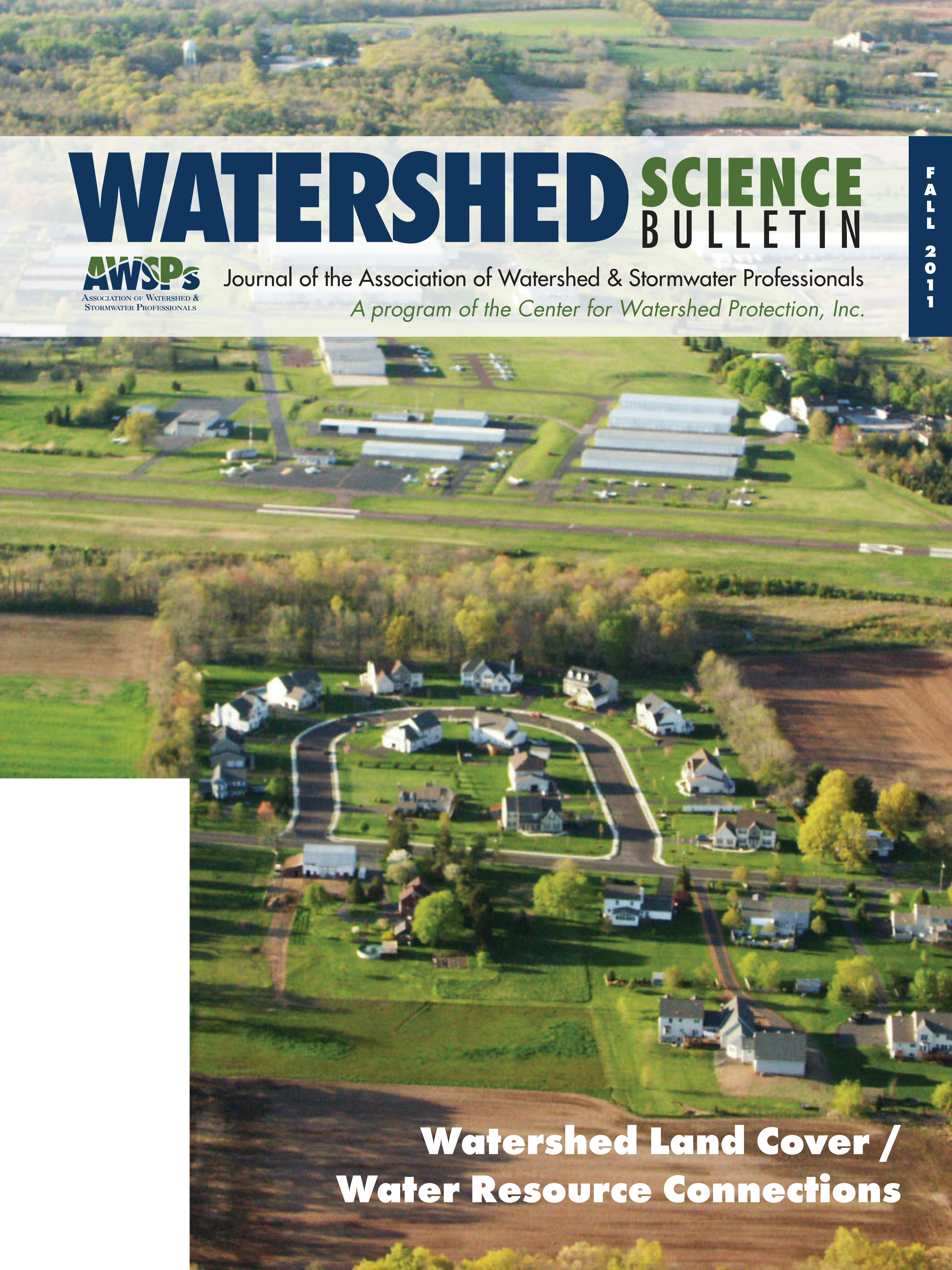

Watershed Land Cover / Water Resource Connections

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This bird's-eye view of Bucks County, Pennsylvania, taken from a hot air balloon, shows the variety of land cover types on this rural and suburban landscape. Trees, turf, pavement, cropland, and even bare soil are present in this fast-developing suburb of Philadelphia.

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The Curve Number Method in Watershed Management and Watershed Health

Observation and science have demonstrated for many years that land cover and land use impact the runoff generated from a watershed. However, not until 1954 was there a method by which to assess the impacts and inform watershed management practices. The US Department of Agriculture (USDA) Soil Conservation Service (SCS, now the Natural Resources Conservation Service [NRCS]) initiated PL 566, the Small Watershed and Flood Control Act of 1954, which supported upland management and engineering structures for small (<101,171 ha [<250,000-acre]) watersheds. Aimed at upstream flood control and concurrent agricultural conservation, the planning, design, and administration of this act required the routine estimation of runoff depth for a variety of land, soil, and climate conditions. With no suitable existing methods available, SCS developed the curve number (CN) method to meet this agency need. The agency's ability to accomplish this task was limited by available data and by the pencil-and-paper-and-slide-rule techniques of the time.

Today, the CN method continues to be widely used and has been incorporated into simulation models—most notably TR-55—and applied to urban hydrology and stormwater management. The success of this method has enabled watershed and stormwater practitioners to better understand the impacts of development on watershed health and reduce them as needed with best management practices or environmental site design practices. Although ideal and soil-based in concept, the CN method is imperfect in practice: more than 50 years of experience and subsequent comparisons with extensive rainfall–runoff data have generated a series of sobering findings, surprises, cautions, and numerous suggestions for professional users.

What is the CN Method?

The CN method is a simple, empirical equation that provides expected event runoff volume (depth) from event rainfall depth. It does not provide runoff rates and does not require data on rainfall duration or pattern—only depth. Central to its use is the CN coefficient, which is selected on the basis of soils, land cover, and land use. The runoff equation is $Q = (P - 0.2S)^2/(P + 0.8S)$, for $P > 0.2S$, and $Q = 0$ otherwise. And to solve for S, one applies the equation, $CN = 1{,}000/(10 + S)$, where P (rainfall) and Q (event runoff) and S are in depth units (inches in the English system), and CN is dimensionless. The parameter S is defined as the hypothetical maximum possible difference between P and Q, roughly understood as the potential water retention of the upland drainage area. The parameter $0.2S$ is the *initial abstraction* (*Ia*), or the rainfall required before the initiation of runoff. Land conditions—and the hydrologic response characteristics—are shown by the choice of the CN. Tables in the SCS' *National Engineering Handbook* provide CNs for a variety of land uses according to four different soil classifications. Naturally, land cover is a major issue, but only within the confines of a given soil type.

Experience and Findings

The CN method gave identity, hypotheses, and vocabulary to the processes and concepts of watershed-based runoff. The term *curve number* itself is used as a general description of hydrologic-based land condition and seems well suited as a general descriptor of watershed health. While intended only for internal USDA needs, the method that SCS developed so completely filled a waiting technical niche that it was accepted in much wider settings. Today, it is applied beyond its mere rain-fed agricultural origins and is used and modified internationally. Particularly after the publication of TR-55 in 1975, the CN method has found major application in urban hydrology, stormwater management design, and the analysis of developed watersheds, with natural extension to water quality planning and regulation. Despite its successful applications, watershed and stormwater practitioners must remember the limitations of the CN method to ensure that the integrity of the method and its application are upheld.

- Sensitivity analysis shows that the runoff calculations are more sensitive to the choice of CNs from published tables than to the rainfall depth used. Handbook CN tables are *estimates* given by the author(s) of the tables that are perhaps accepted by approving jurisdictions. However, very few such table entries have been verified by monitoring or other ground-truth data.

- CNs supplied in handbook tables are most reliable in urban situations and in some rain-fed agricultural situations—that is, in areas of high CNs. However, several published comparisons of CNs determined from local data with those from handbook tables show a lack of good universal concordance between the two.

- The best source of valid CNs is through the analysis of local rainfall–runoff data. Some guidance for this is provided in the sources below. Most such analyses show an unexpected secondary drift of CN with the event *P*, approaching a stable value at higher rainfalls. In general, the data show that small storms have runoff volumes consistent with high CNs.

- CNs for forested lands are especially suspect. The problems with these CNs result from misperceptions regarding the role of forests, combined with a set of runoff-controlling processes that differ from those for the agricultural lands and covers on which the method was founded. In particular, the factors controlling runoff in most forest conditions include the presence of multiple, continuous levels of cover, heavy vegetation and litter, absorbent soils with underlying layers, and significant roles for flowing channels as source areas. CN tables in use typically have token entries for "woods," but no entries for commercial forests or for silvicultural treatments analogous to agronomic practices.

- From a general hydrology standpoint, the CN equation is not universally valid. Although not common, distinct exceptions to the CN response pattern are not rare either, as some watersheds do not respond as predicted by the CN equation. Often, but not always, such watersheds are forested.

- Both real CNs and those shown in tables rely heavily on soil properties. NRCS provides authoritative classifications of soil series into hydrologic soil groups, but these classifications are disturbingly inconsistent, especially in the B and C groups.

- Most of the early original documentation and data have been lost, and this method received essentially no technical review in the professional or scientific literature. Its widespread acceptance in spite of the lack of review is based on the authority of NRCS.

- Researchers have found that $0.05S$ approximates the initial abstraction better than the original initial abstraction ratio of $Ia = 0.2S$. However, one should not apply this new value without changing the traditional CN tables, which are based on 0.2.

- The CN method is applied in three different modes: (1) As a runoff calculation for a rainstorm of the same return period (*not* for specific storms). This is its most successful application, and the one most appropriate to the existing CN tables. (2) As a runoff equation with variation attributed to prior moisture and other sources of variation, including error. (3) As a time-based process for infiltration in hydrograph models, or for soil moisture storage in daily time-step models. The CNs for these three different applications are not necessarily congruent: what works best for one application may not be best for another.

Potential for Greater Application

Despite the cautions listed above, the CN method is essentially the only tool of its kind that easily integrates soils, land cover, and practices to describe a watershed's hydrologic response. It is thus well grooved into engineering, design, and impact hydrology. However, the method seems to have a substantial unfulfilled potential for application in land management planning for hydrologic accountability in nonurban venues. Data analysis has shown that some long-established land uses presumed to be benign, such as grazing, have surprisingly strong impacts, even in humid zones. For example, several studies have found meadows (ungrazed) with CNs about 15 units lower than pastures (grazed).

Conclusion

If upland hydrologic responsibility for downstream impacts is an issue, the CN method may be an ideal off-the-shelf tool to appraise it. Hydrologic response is a key element of watershed health. In this respect, a "healthy watershed" would have the lowest possible CN. A lower CN means lower volumes of runoff from a given rainstorm and higher levels of infiltration, interception, evapotranspiration, and plant growth. These characteristics promote a storm runoff regime that creates less stress on downstream banks and channels while improving upland habitat and biological indicators of watershed health. For watershed planners, the CN method is a simple but powerful tool to flag and rate the health and stress at the channel, watershed, and subwatershed levels.

List of Sources

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Contributors

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Metropolitan Portland, Oregon, Urban Growth Boundary:

A Land Use Planning Tool Protecting Farms, Forests, and Natural Landscapes

In the early 1970s, Oregon Governor Tom McCall and a unique coalition of farmers and environmentalists convinced the Oregon State Legislature to adopt the nation's first set of land use planning laws to help protect the state's natural beauty from a rising tide of urban sprawl. The resulting state goals and guidelines require every city and county in Oregon to have a long-range plan addressing future growth that meets both local and statewide goals by using urban land wisely, protecting natural resources, and setting urban growth boundaries (UGBs).

A UGB separates urban land from rural land. It promotes the efficient use of land, public facilities, and urban services, such as roads, water and sanitary sewer systems, parks, and schools, inside the boundary. Land outside the UGB is served by a rural level of roadways, does not allow the development of sanitary sewer systems, and is zoned exclusively for farm and/or forest use or rural residences.

Metro, the regional government created by voters in 1979 for the Portland metropolitan area, is responsible for managing the Portland region's UGB, which contains portions of 3 counties, 25 cities, and more than 60 special service districts. The UGB line is more than 322 km long and includes an area of approximately 103,600 ha. State law requires Metro to have a 20-year supply of land for future residential development inside the boundary. Every 5 years, Metro must complete a 20-year forecast for population and employment growth; conduct a capacity review of the land inside the UGB; and, if necessary, expand the boundary to meet the requirement for a 20-year supply of land. As part of the capacity review, the cities and counties within the Metro UGB also have the opportunity to develop policies, provide incentives, and plan for more intense uses through increased densities or the development of mass transit projects, which can reduce the need to expand the UGB for additional housing.

Two challenges arose with this system as originally implemented. First, landowners near the UGB were under periodic threat of urban expansion with little certainty about where the next expansion would occur. Second, although the identification of areas to preserve was fairly clear-cut, City and regional leaders lacked a method for determining the ideal locations and conditions for urban growth. As a solution, Metro and the three surrounding counties, Clackamas, Multnomah, and Washington, have instituted a regional process for identifying lands suitable for future urban development and for the protection of valuable farms, commercial forests, and other environmentally important natural areas.

In 2007, the Oregon State Legislature passed Senate Bill 1011, 2007 Or. Laws chapter 723, which allows for the designation of lands outside the UGB as urban or rural "reserves," as a way to direct future development while protecting existing rural and/or ecologically significant lands. The legislation prescribes factors for placing land into either reserve category. Lands designated as urban reserves are areas deemed suitable for "city-building," to which future urban development outside the UGB will be directed. Lands recognized for their agricultural or environmental value are placed into a rural reserve and become completely off-limits