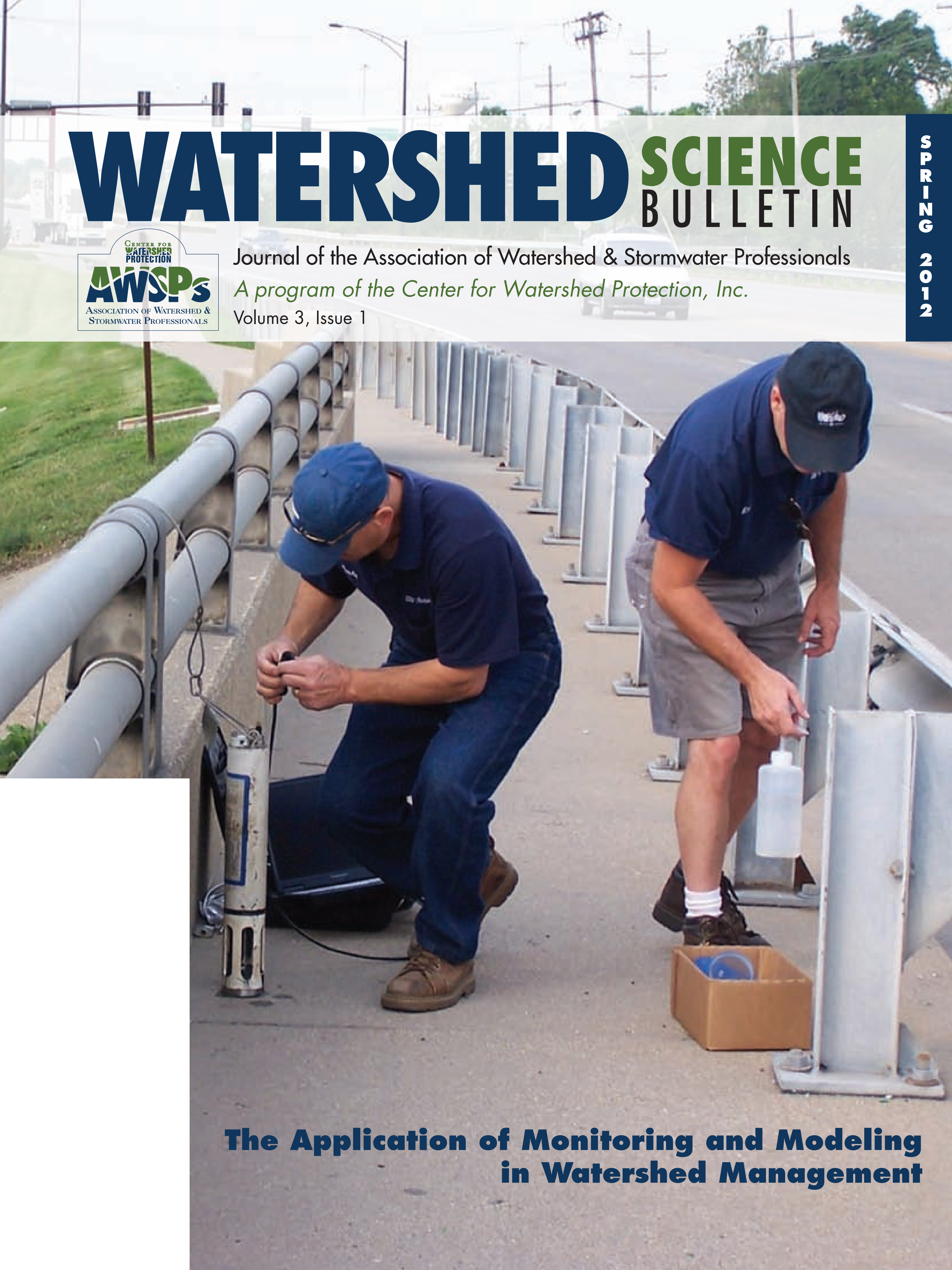
WATERSHED SCIENCE BULLETIN

SPRING 2012

Center for Watershed Protection
AWSPs
Association of Watershed & Stormwater Professionals

Journal of the Association of Watershed & Stormwater Professionals
A program of the Center for Watershed Protection, Inc.
Volume 3, Issue 1



The Application of Monitoring and Modeling in Watershed Management

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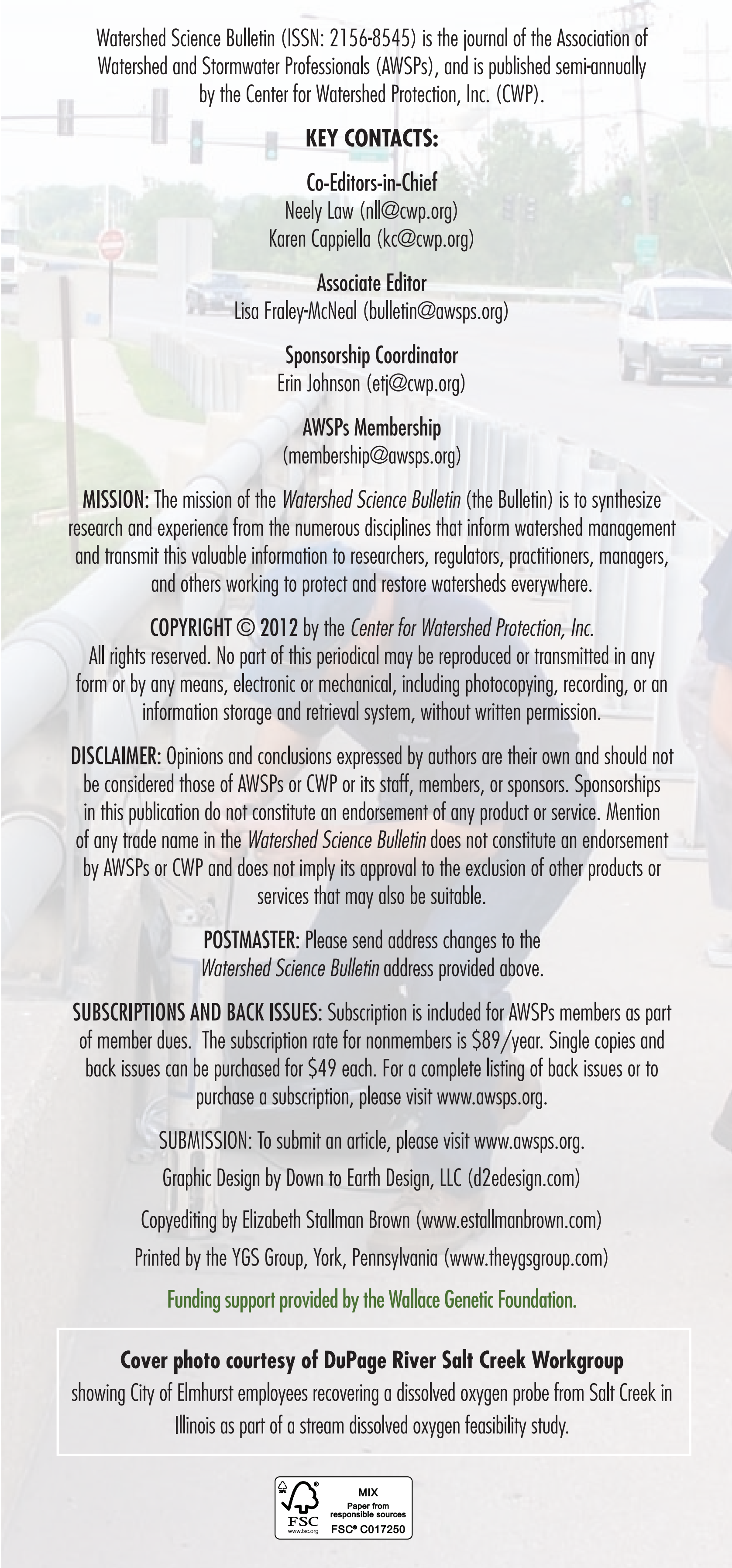

Watershed Science Bulletin (ISSN: 2156-8545) is the journal of the Association of Watershed and Stormwater Professionals (AWSPs), and is published semi-annually by the Center for Watershed Protection, Inc. (CWP).

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SUBMISSION: To submit an article, please visit www.awsps.org.

Graphic Design by Down to Earth Design, LLC (d2edesign.com)

Copyediting by Elizabeth Stallman Brown (www.estallmanbrown.com)

Printed by the YGS Group, York, Pennsylvania (www.theygsgroup.com)

Funding support provided by the Wallace Genetic Foundation.

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Locally Derived Water Balance Method To Evaluate Realistic Outcomes for Runoff Reduction in St. Louis, Missouri

Introduction

The Metropolitan St. Louis Sewer District (MSD) is the coordinating authority of a 61-permittee Phase II municipal separate storm sewer system (MS4) permit. MSD is carefully following the development of new national postconstruction stormwater regulations, which focus on maintaining or restoring the runoff component of the undeveloped (i.e., natural) water balance. If the Energy Independence and Security Act (EISA) Section 438 technical guidance is the "writing on the wall" for a national rule, then development projects would be required to implement postconstruction controls that capture and retain on-site (i.e., no discharge) the 95th percentile daily rainfall depth (3.8 cm in St. Louis).

Figure 1. Example of naturally vegetated Missouri prairie and sinkhole pond.

Stormwater professionals may question whether a rule like this would be appropriate nationwide. MSD developed a water balance model to evaluate the potential runoff reduction that may be achieved in local watersheds in response to the targeted EISA rule. The predevelopment water balance in the St. Louis region has not previously been studied for this purpose. This vignette presents a "simple" approach to developing an annual estimate of runoff, and one that may be a useful tool for other stormwater managers whose watersheds' predevelopment hydrology has not been assessed.

Methods

The water balance is the balance between the input of water from precipitation and the output of water by runoff, evapotranspiration, storage, and infiltration. Numerically, the runoff component of the water balance is expressed as $R = P - ET - N - \Delta S$, where R is runoff, P is precipitation, ET is evapotranspiration, N is infiltration or recharge, and ΔS is the change in storage (in soil).

The one-dimensional Thornthwaite method is used to estimate components of the water balance on a daily time-step. MSD used a modified version of this method, as described below.

Climate, Evapotranspiration, and Vegetation

MSD obtained 21 years of daily weather data from the National Weather Service[1] for Lambert St. Louis Airport for the period January 1989 to December 2009. We calculated daily potential evapotranspiration rates according to the American Society of Civil Engineers (ASCE) standardized reference evapotranspiration equation, thus replacing the Thornthwaite evapotranspiration rates with the ASCE rates. We then multiplied daily reference evapotranspiration rates by the landscape coefficient for a grass prairie (0.5), a reasonable approximation of an undeveloped, naturally vegetated condition in Metropolitan St. Louis and much of Missouri (see Figure 1). This prairie landscape coefficient is consistent with the US Geological Survey (USGS) rain garden report, *Evaluation of Turf-Grass and Prairie-Vegetated Rain Gardens in Clay and Sand Soil, Madison, Wisconsin, Water Years 2004–2008*, which estimates the landscape coefficient for a prairie-planted rain garden area to range from 0.2 to 0.7.

Infiltration (Recharge)

The near-surface geology of much of St. Louis City and County consists of urbanized (e.g., cut, filled, and reworked) clayey silt soil over limestone bedrock. The thickness of urbanized fill over bedrock varies greatly. MSD used results for Southwest Missouri from the USGS report, *Groundwater-Flow Model and Effects of Projected Groundwater Use in the Ozark Plateaus Aquifer System in the Vicinity of Greene County, Missouri—1907–2030*, to estimate groundwater recharge as only limited research and modeling of groundwater has been conducted for Metropolitan St. Louis. The surficial geologic conditions (clay or silt soil over limestone bedrock) in Southwest Missouri and St. Louis are similar in many ways.

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[1] National Oceanic and Atmospheric Administration's National Weather Service, "NHDS Access of Historical Data," http://amazon.nws.noaa.gov/hdsb/data/archived/index.html.

The USGS groundwater report estimated recharge to be an average of 2.5% of annual precipitation. Thus, only a limited amount of precipitation can result in deep infiltration.

Soil Storage

The maximum available water storage is the product of the soil's porosity (saturation) and the thickness of the root zone. When the maximum available water storage is exceeded, runoff occurs (if the precipitation is not frozen). The minimum available water storage is the product of the wilting point and the thickness of the root zone. The values MSD used in calculations were representative of silt loam. The root zone thickness used for the prairie condition was 1.5 m; this is consistent with observations reported in the USGS rain garden report.

Model Limitations

This modified Thornthwaite water model has a number of limitations. First, the model does not account for rainfall intensity; thus, where the intensity of the storm exceeds the infiltration rate of the soil, runoff is underestimated. Second, the model assumes that runoff occurs on the same day as precipitation. This assumption is supported by recent work by Debusk and colleagues, who showed that, in an undeveloped watershed with clayey soils, nearly all precipitation (even interflow) is discharged within 18 hours after runoff begins. Third, this model assumes that all snowmelt runoff occurs on the first day on which the air temperature is above freezing. This assumption makes little difference for annual or seasonal water balance comparisons because snow melts during a time of year when soil is typically saturated and evapotranspiration rates are low. Finally, because the model is one-dimensional, calculations do not differentiate between runoff as interflow or overland flow.

Results and Discussion

Tables 1 and 2 summarize the results. The total average annual precipitation was ~100 cm; of this, 42% resulted in runoff, primarily between January and July.

Table 1. Summary of water balance conditions.

Component	Annual Quantity (cm)	Percentage of Annual Precipitation
Evapotranspiration	55	55
Deep Infiltration	2.5	2.5
Runoff	42	42

Table 2. Summary of runoff (discharge) conditions.

Time Period	Annual Avg. Runoff (cm)	Runoff as % of Annual Precipitation	Runoff as % of Quarterly Precipitation
Total	42	42	
January–March	12	12	60
April–June	16	16	50
July–September	5	5	19
October–December	9	9	40

Forthcoming nationwide stormwater regulations may mandate that runoff from a developed site should amount to only 5% of annual rainfall. However, this study shows that runoff accounts for a much greater percentage of annual rainfall (42%) and is a natural process in undeveloped, naturally vegetated conditions in St. Louis, Missouri.

By illustrating that runoff (discharge) is a major component of the water balance in undeveloped, natural conditions, this analysis suggests a shortcoming to a nationwide retention rule applied to local watersheds. During summer, rainfall is absorbed into the soil and then removed through evaporation and transpiration. Because evapotranspiration rates are highest during summer months, much of the soil's water-holding capacity is available to absorb precipitation through early fall. However, after rainfall occurs in late fall, soil becomes saturated. Snow that accumulates over already saturated soil results in mid-winter snowmelt runoff. Rainfall in late winter and early spring, even small events, results in runoff. In this model, about 67% of the annual runoff occurred from precipitation events with rainfall depths less than the 95th percentile daily rainfall. Requiring retention of all storms less than the 95th percentile daily rainfall is not a surrogate for water balance restoration.

Conclusions

Attempts to mimic the runoff conditions of an undeveloped, naturally vegetated site can be affected by many factors, especially the available water storage capacity of the site's soil. Available water capacity is affected by weather, geology, soil type, vegetation, and evapotranspiration.

A clear definition of postconstruction best management practice performance goals is needed. However, requiring retention of all storms up to the 95th percentile daily rainfall is difficult to justify in St. Louis—and in much of Missouri—and is potentially counterproductive to the improvement of water quality. Instead, a balanced performance goal composed of some infiltration and some attenuated discharge would better approximate a natural condition.

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This vignette was prepared by Jay Hoskins, PE, Metropolitan St. Louis Sewer District.