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Variation in infiltration with landscape position: Implications for forest productivity and surface water quality

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Abstract

Variation of infiltration rates with landscape position influences the amount, distribution, and routing of overland flow. Knowledge of runoff patterns gives land managers the opportunity to affect changes that optimize water use efficiency and reduce the risk of water quality impacts. The objective of this study was to assess the effect of landscape position and associated soil properties on infiltration in a small (147 ha) forest/pasture watershed in the Ozark Highlands. Three previously reported studies measured infiltration rates using double ring, sprinkling, single ring, and tension infiltrometers on soils at varying landscape positions. Although large variation in infiltration rates was observed among measurement techniques, upland and side slope soils (Nixa and Clarksville) had consistently lower infiltration rates compared to the soil in the valley bottom (Razort). A conceptual understanding of watershed runoff is developed from these data that includes infiltration excess runoff from the Nixa and Clarksville soils and saturation excess runoff on the Razort soil. Management of the soil water regime based on this understanding would focus on increasing infiltration in upland soils and maintaining the Razort soil areas in forest. Forest productivity would be enhanced by increasing plant-available water in upland soils and decreasing flooding on the Razort soil. Surface water quality would be improved by reducing the transport of potential water contaminants from animal manure applied to upland pastures.

Keywords: Infiltration; Landscape position; Soil properties

1. Introduction

Characterization of the spatial relationships of surface runoff generation has been an active area of research for several decades (Betson and Marius, 1969; Dunne and Black, 1970; Anderson and Burt, 1978; Bernier, 1985). Locations within watersheds with differing infiltration characteristics have been referred to as variable-source areas, partial area contributions, or hydrologically-active areas, all of which refer to the nonuniform occurrence of surface runoff in response to precipitation. Often, the distinction is made between areas where runoff is generated when precipitation occurs at a rate greater than the soil's infiltration rate

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(infiltration excess runoff) and areas where runoff occurs because the soil is saturated to the surface (saturation excess runoff). Spatial variation of surface soil hydraulic properties therefore influences the amount and distribution of infiltration and the routing of overland flow following precipitation events.

Nonuniform infiltration within a watershed leads to differences in plant-available water stored in the root zone and influences the partitioning between evaporation from the soil and plant transpiration (Luxmoore and Sharma, 1980; Luxmoore, 1983; Kachanoski and De Jong, 1988; Grayson et al., 1997). In addition to fiber production, forested watersheds provide several important ecosystem functions including the production of clean water suitable for municipal, industrial, and agricultural uses. Water moving through the root zone or across the soil surface also transports sediment, nutrients, pesticides, and pathogens that may be delivered in quantities that impair ground or surface waters. Understanding the spatial variation of infiltration within watersheds is therefore critical to developing and implementing management practices that optimize plant-available water and minimize nonpoint source pollution (Or and Hanks, 1992; Gburek and Sharpley, 1998; Walter et al., 2000).

There has been a dramatic expansion of poultry and livestock production into nontraditional animal-producing regions of the U.S., in particular, the Mid-South and Southeast. Many of the new production facilities are located in areas with soils that were never cultivated or cultivation ceased due to excessive erosion and/or low productivity. A large percentage of land in these areas is now a mosaic of pasture and forest, which is managed for livestock grazing and pulp or timber production. Manure generated by the animal feeding operations is typically disposed by land-application, primarily to pasture (McLeod and Hegg, 1984; King et al., 1990; Liu et al., 1997) and to a much lesser extent, forest land (Minkara et al., 1995; Samuelson et al., 1999; Sauer et al., 2000).

The Savoy Experimental Watershed (SEW) is a field research site for the study of water quality impacts from land application of animal manure in landscapes typical of the Mid-South U.S. The SEW is located in Northwestern Arkansas and is comprised of six small watersheds within and surrounding the 1250 ha Savoy Substation of the University of Arkansas. Intensive hydrologic investigations in the SEW have focused on Basin 1, a 147 ha watershed with an ephemeral channel that discharges onto the Illinois River floodplain. A distinctive characteristic of Basin 1 hydrology is that there is often no surface discharge at the outlet following intense storm events. This occurs even though discharge from adjacent springs increases significantly and debris trails (leaves and branches) on the forested side slopes indicate that surface runoff had occurred within the watershed.

Three previously published studies have addressed various features and scales of interaction between the surface hydrology and surface soil properties of Basin 1 (Table 1). The first study involved measurements of soil physical, chemical and hydraulic properties along transects located in soil map units between the riparian forest adjacent to the Illinois River and the ridge top on the north side of Basin 1 (Sauer et al., 1998). The second study utilized simulated rainfall on pairs of 1 m × 2 m runoff plots at varying slopes and aspects, on pasture and forest sites within Basin 1 to determine nutrient runoff from applied poultry litter (Sauer et al., 2000). The third study used ring and tension infiltrometers to measure saturated and unsaturated hydraulic properties of soils in varying landscape positions on three transects across Basin 1 (Sauer and Logsdon, 2002).

Taken independently, none of the three studies provided a comprehensible representation of infiltration patterns in the watershed or of any consistent relationship between infiltration rate and soil properties. As animal production and human population both continue to increase rapidly in Northwestern

Table 1
Summary of infiltration data collected on soils of Basin 1

Infiltrometer type	Soils	No. of measurements	Area of measurement	Measurement site distribution	Reference
Double ring	Rg, CaC, and NaC	60	0.07 m^2	Transects within soil map units	Sauer et al. (1998)
Sprinkling	ClG and NaC	32	2 m^2	Paired plots	Sauer et al. (2000)
Single ring	Rg, ClG, and NaC	42	44.2 cm^2	Transects across main channel	Sauer and Logsdon (2002)