Possible Tradeoffs from Urbanization on Groundwater Recharge and Water Quality

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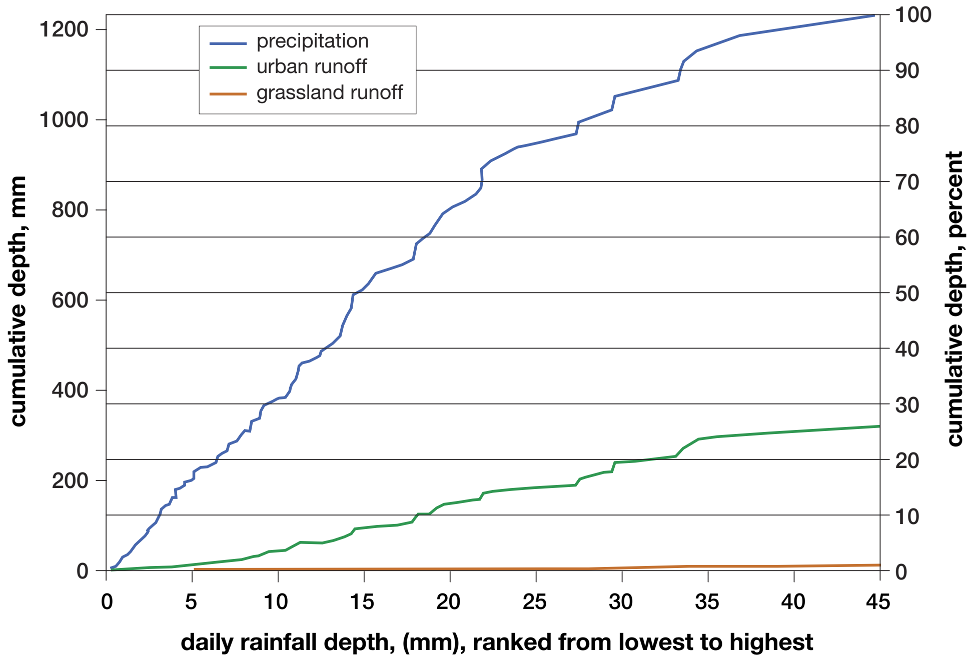
Stormwater floods the road and sidewalk during a July 2006 storm in Tucson.

Focused recharge of urban storm runoff is emerging as an important strategy to augment renewable groundwater supplies in the Southwest. Indeed, many communities in Arizona are already investigating and even implementing stormwater management approaches to enhance urban-runoff recharge. For example, Sierra Vista in southern Arizona is exploring the potential for enhanced runoff recharge to help offset groundwater consumption in order to attain sustainable water yields. Tucson, Arizona is aiming to offset a portion of its municipal water supply with focused recharge. Many cities in the Phoenix metropolitan area have already mandated retention basins or dry wells (see page 22), strategies that enhance recharge of storm runoff. Despite this trend in urban stormwater management, little information is available to water managers on the quantity and quality of this potential recharge water.

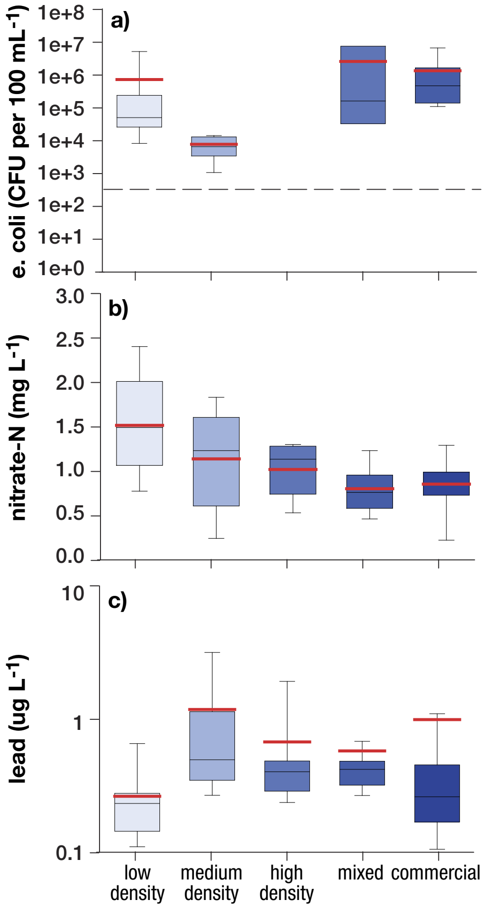
Under natural conditions, recharge in arid and semi-arid environments takes place almost entirely as mountain-front recharge and in ephemeral channels where runoff is concentrated (see sidebar, opposite page). As the area of impervious surfaces in urban areas increases, the quantity of urban runoff delivered to ephemeral waterways or retention basins likewise increases, subsequently enhancing recharge and potentially increasing renewable groundwater supplies. However, urbanization also increases the concentration and variety of pollutants and can diminish the potential for attenuation of pollutants during hydrologic transport, which may impact the quality of renewable recharge. Water management decisions must therefore take into account these water-quality issues and evaluate the tradeoffs between enhanced urban storm recharge and its potential impacts on water quality. Here we report findings from urban studies in southern Arizona that evaluated such tradeoffs.

Water Quantity Effects

Increases in runoff with urbanization have been widely documented (Arnold and Gibbons, 1996). However, few studies have focused on how urbanization, specifically the tract-housing style ubiquitous in the Southwest, has altered the characteristics of ephemeral flow in these environments. One detailed study conducted in Sierra Vista, Arizona by Kennedy (2007) showed that a 32-acre, residential-neighborhood watershed containing 62 large houses produced 30 times more runoff than an adjacent 80-acre grassland watershed (see



Ranked daily rainfall versus cumulative precipitation and runoff depth from a 32-acre residential neighborhood and an 80-acre grassland watershed in the Sierra Vista area from June 1, 2005 through Aug. 31, 2008. Runoff depth is calculated by dividing total volume of runoff by watershed area. Rainfall was measured on 185 days. These data illustrate, for example, that all daily rainfalls of 25 mm or less account for nearly 75 percent of all precipitation. Runoff on these days is about 58 percent of the total urban runoff, demonstrating the contribution of smaller storms.



Water quality across the urban land-use gradient in Tucson, Arizona with a) E. coli in colony-forming units (CFU) per 100 milliliter (ml); b) nitrate-N in milligrams/liter (mg/l); and c) lead in micrograms/liter (µg/l). The thin black line denotes the median concentration, the red line is the mean, and the bars denote the 95th percentile of observations. Black dashed line in E. coli chart indicates partial contact standard of 575 CFU/100 ml. The nitrate-N concentrations were well below the partial contact standard of 1,493 mg/l, and the lead concentrations were well below the ephemeral wash standard of 226 µg/l.

Photo: Dave Grieshop

chart, left). The increase in impervious surface area from rooftops, streets, and driveways was a primary cause of this difference, but a decrease in soil infiltration associated with site preparation also contributed to greater volumes of post-urbanization runoff. In the urban watershed, increases in runoff from small-magnitude (less than 20 millimeters) storm events were most significant and accounted for almost half of seasonal runoff. In contrast, these small storm events produced almost no runoff from the grassland watershed, where the 10 largest daily rainfall amounts, out of 185 observations, accounted for approximately 75 percent of all grassland runoff. These data suggest that in undeveloped watersheds, a large volume of rainfall is stored at the land surface and presumably lost to evapotranspiration (Walvoord and Scanlon, 2004). As development ensues, a larger proportion of rainfall, particularly from small events, produces runoff that reaches channels where it potentially can enhance recharge.

Consistent with Kennedy's findings, Gallo and others (in review) observed a runoff threshold response in urban watersheds of the Tucson Basin where a highly impervious watershed produced more runoff events (9 events) and higher water yields (less than 14 percent) than less impervious sites (6 events; less than 1 percent). This suggests that effective contributing area and differences in landscape complexity such as drainage density may significantly impact the quantity of urban runoff generated. Careful consideration of these attributes is critical for effective stormwater management.

Water Quality Effects

While imperviousness has a direct impact on the quantity of water produced, its impact on runoff quality is less well understood in arid and semi-arid regions. Gallo and others examined the quality of urban runoff from five watersheds in the Tucson Basin with varied urban land use and found that land-use metrics such as housing density and imperviousness did not correlate to urban runoff quality (see charts, above left).

Bacteria emerged as one of the largest water-quality threats measured in surface water, with fecal indicator bacteria, *Escherichia coli* (*E. coli*), exceeding the ephemeral wash partial-body-contact standards of 575 colony-forming units/100 milliliters at most of the study sites (upper chart). Fecal indicator bacteria were highest in catchments with a larger fraction of open space, parks, and agricultural use, suggesting that feces likely came from wildlife and domesticated animals as well as livestock. Viable populations of these bacteria were also extremely high in soils in ephemeral washes draining into the Rillito River, a major ephemeral channel in Tucson that has been identified

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Urbanization = More Recharge: Say What?

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It's true! There is now a convincing body of evidence that negligible or slightly negative recharge occurs in the interdrainage area of arid and semiarid basin floors (Walvoord and Scanlon, 2004). How does urbanization increase recharge? By increasing runoff and concentrating it in highly permeable washes. Basically, between desert vegetation that has evolved to efficiently extract water from the soil matrix, and geothermal gradients that force water vapor upward, a zone of very negative water potentials (-500 to less than -1,000 meters of water) is maintained at a depth of 5 to 16 feet in interdrainage areas. This zone presents a barrier that effectively isolates the hydrologically active soil from a nearly static deep vadose zone, and below that, groundwater. This isn't just a modeling result. Numerous inventories of chloride and tritium profiles in soil columns indicate this zone has been continuously maintained since desert vegetation was established 10,000 to 15,000 years ago in the Southwest.

So where does infiltrated water recharge to the aquifer? Primarily where runoff is concentrated; ephemeral channels and depressions where infiltration rates exceed the maximum root extraction rates. When urbanization occurs, rainfall that would have been transpired by desert plants in undisturbed landscapes runs off to channels and playas. But don't think this additional recharge solves growing water shortages in the Southwest: the increasing population that comes with urbanization consumes water much faster than augmented runoff increases recharge.

Reference

Walvoord, M.A., and B.R. Scanlon, 2004. Hydrologic processes in deep vadose zones in interdrainage arid environments, in J.F. Hogan, F.M. Phillips, and B.R. Scanlon, eds., Groundwater Recharge in a Desert Environment: The Southwestern United States, Amer. Geop. Union, Water Science and Applications Series, 9, 15-28.

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as an area of focused recharge. Viable populations were also high in the surface sediments of the channel itself. However, ongoing studies evaluating the fate of these bacteria in recharge areas show very low survival and transmission rates (J.E.T. McLain, personal communication). Future research identifying the sources and probability of pathogenic bacteria are needed to reduce threats to human health.

Other water-quality metrics such as nitrogen in the form of nitrate, and metals (including lead) in Gallo and others' study were generally well below the ephemeral wash standards (see middle and lower charts, page 19). Future research evaluating specific organic compounds is warranted to determine emerging nonpoint-source organic-contaminant threats to groundwater resources.

Findings from this study suggest that urbanization does not directly translate into lower runoff quality; factors such as the spatial arrangement of an urbanized area and nonpoint sources of solutes can have a large impact on runoff quality.

Can Modification Improve Quality?

Given the potential benefits of increased recharge from urban runoff versus its possible impacts on water quality, recent research has been directed at understanding how physical and chemical characteristics of urban ephemeral washes modify stream chemistry and whether urban environments could be modified to improve the quality of water delivered to areas of focused recharge. In this context, Lohse and others (in review) examined the physical and chemical characteristics of grass- and gravel-lined reaches in an urban ephemeral stream in Tucson and related these to storage and transport of different solutes. Significant differences in soil organic matter, pre-monsoon soil-water content, and stored anions were observed between the two types of channels. Both were sources of fecal indicator bacteria during runoff, but metals were more attenuated in grass-lined reaches, probably due to higher soil organic-matter content and finer-textured bed substrates that create a greater reactive surface area. Findings from this study suggest that grass-lined ephemeral streams can potentially attenuate metals and possibly nutrients, providing a valuable service that will help sustain high-quality water resources in this region.

Conclusions

Research has demonstrated that increases in impervious surfaces in the Southwest can greatly increase the amount of stormwater runoff delivered to sites of potential recharge. However, landscape configuration and effective contributing areas are important controls on the sensitivity of watersheds to runoff production. Increases in urbanization do not necessarily lead to lower-quality runoff; factors such as the spatial arrangement of the urbanized area and nonpoint sources of solutes (as suggested by fecal indicator bacteria), may have greater impact on runoff quality. Combined, these findings suggest that watershed configuration warrants careful consideration by stormwater managers in order to minimize tradeoffs between water quantity and quality and sustain renewable groundwater resources. ■

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