Ecosystem structure and hydrologic function of urban deserts


1. INTRODUCTION

Urbanization is occurring rapidly in semi-arid areas and has far reaching, but largely unquantified, impacts on the water budget of cities. Urbanization affects the partitioning of precipitation into infiltration, evapotranspiration (ET), surface runoff, and groundwater recharge relative to pre-urbanized conditions (Figure 1). These effects are most dramatic in arid cities. Modifications to ecosystem structure resulting from urbanization (such as changes in land use/land cover [LULC], land management, and engineering of the drainage network) as well as human decisions about outdoor water use (of which we will refer to as urban ecosystem function) will affect the nature of horizontal hydrologic fluxes (surface runoff, stormwater network flow) and vertical hydrologic fluxes (ET and infiltration, which may lead to groundwater recharge). Urban modifications also impact the surface energy balance through changes in albedo, thermal inertia and emissivity, and shading, among others, that are introduced through the elements of the built environment (roads, buildings, pavement). As such, understanding how structural modifications of the water and energy budgets associated with urbanization affect horizontal and vertical fluxes operating over different spatial and temporal scales is critical for informed management. This is particularly important in urban ecosystems where water is a scarce resource, such as the semi-arid southwestern U.S., where a population boom in the last 50 years has lead to large cities (Phoenix, Las Vegas, Los Angeles, San Diego, etc.) that are reliant on the functioning of an engineered urban ecosystem. Thus, to establish the effects of urbanization and future changes in climate, we need to determine how land use, human decisions about water use, and climate change affect the vertical and horizontal components of the urban water budget.

2. RESEARCH OBJECTIVE

Balancing the sustainable management of urban water while maximizing other ecosystem services (i.e., evapotranspiration to mitigate the urban heat island) requires a holistic approach that considers ecohydrological processes over multiple spatial and temporal scales and, in particular, cross-scale interactions and feedbacks. Thus, the primary objective of this research is to determine how urban ecosystem structure affects the spatotemporal characteristics of the horizontal and vertical components of the urban water budget, and how they are influenced by: 1) the hydrological characteristics of single landscape units; 2) the aggregate behavior of multiple spatial units, which is manifest in the form of the small-scale surface runoff response; and the connectivity of flow through the catchment and basin as determined by the type and extent of stormwater infrastructure and its spatial form.

3. STUDY AREA

Our study area is in the Indian Bend Wash Catchment in Phoenix, AZ (Figure 3). Post-development conditions include natural or low-density development in the upper basin with minimal stormwater infrastructure, and more heavily urbanized and developed stormwater infrastructure in the lower catchment. As a result, the basin provides a suitable spatial domain for the proposed research, as it encompasses the effects of urbanization (of different forms) across multiple spatial scales, and the spatial scale of dynamic interplay of the many processes that together control the response to rainfall.

4. RESULTS

Effects of stormwater infrastructure on the runoff response: Comparison of stormwater pipe infrastructure with wash and retention basin infrastructure at a spatial scale of ~100 ha

Stormwater infrastructure has a great effect on runoff coefficients, with much higher stormwater coefficients from pipe infrastructure than for wash and retention basin infrastructure (Figure 3).

With an increase in the amount of event rainfall, runoff coefficients are relatively constant for pipe infrastructure but increase for wash and retention basin infrastructure.

Figure 3 (right). Runoff coefficients for two catchments of comparable, that differ in terms of stormwater infrastructure: for rainfall-runoff events of various sizes. The runoff coefficients is the proportion of water entering the catchment as rainfall that leaves as runoff. Figure 4 (above). Scatter plot showing the relationship between the contributing area and the total event runoff for 6 catchments for an event in 5th October 2010. Figure 5 (right). Hydrograph for each of the 6 sites shown in Figure 4. The total amount of stormwater runoff shows an overall increase with an increase in catchment area. Figure 6 (left) shows the complexity of stormwater runoff response that is induced by different types of stormwater infrastructure at smaller spatial scales. At smaller spatial scales the runoff response is relatively flashy for catchments where runoff is efficiently conveyed through the channel network (Figure 5). However, for the wash and retention basin site, the hydrograph is less flashy and is not characteristic by high rates of flow. At larger spatial scales, the hydrograph s are not as flashy and are not characterized by multiple peaks.

5. SUMMARY

During our first year of monitoring the runoff response in these nested catchments, we have revealed some interesting dynamics, in particular the vastly different hydrologic responses from catchments with differences in stormwater infrastructure. Future research plans include installing three gauging stations on the 3rd Order channel to characterize the fully different types of stormwater infrastructure across different spatial scales, and to monitor a wider range of rainfall-runoff events in both summer and winter rainfall seasons. Future research endeavors will also investigate more fully the effects of the horizontal redistribution of water on other components of the water budget, such as groundwater recharge and evapotranspiration.