Ecosystem structure and hydrologic function of urban deserts

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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 [LU/LC], landscaping, and engineering of the drainage network) as well as human decisions about outdoor water use (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 landscaping (mesic, xeric or combinations) and 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 successful water 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 climate stressors on the urban water balance 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.

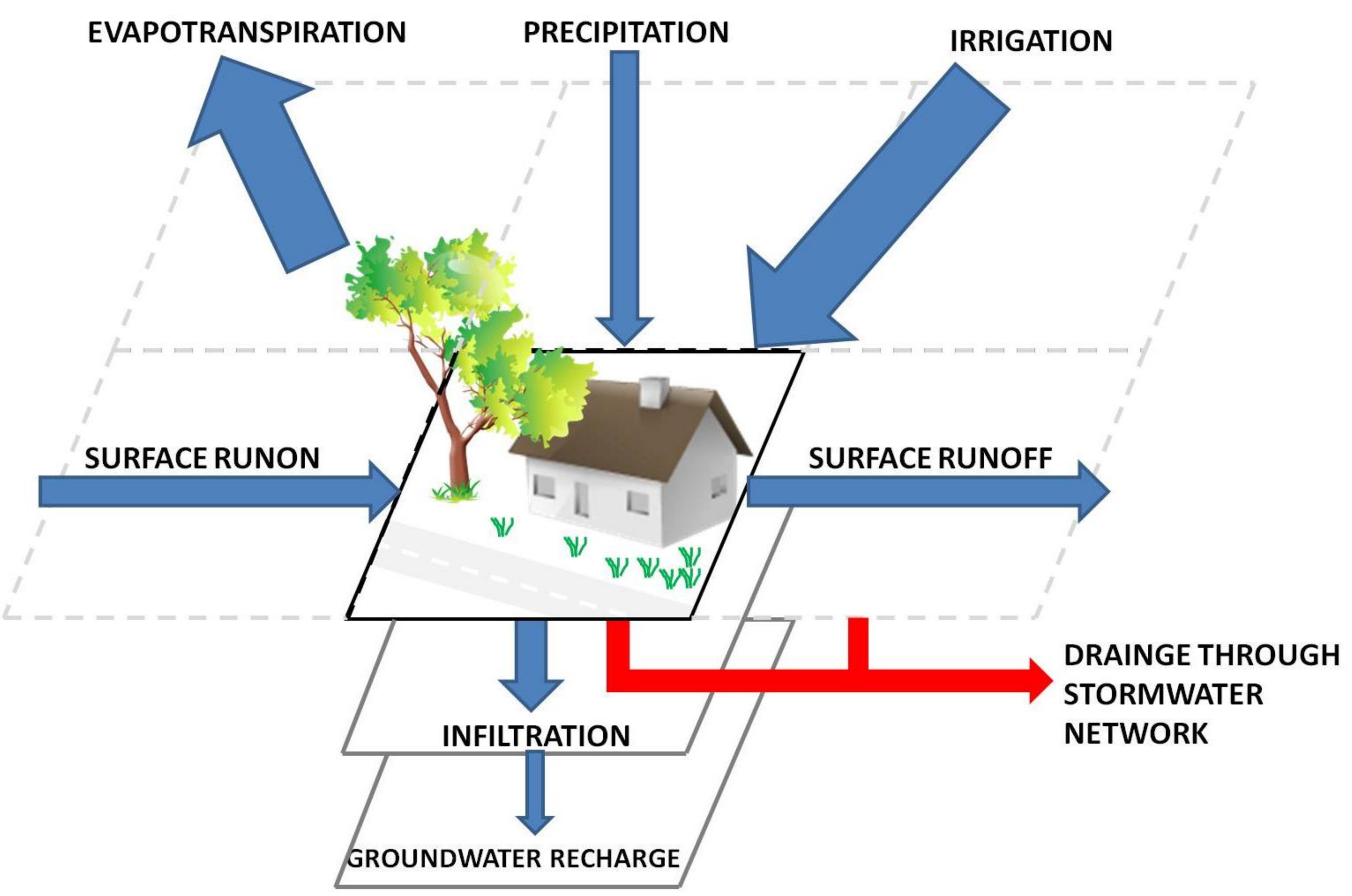
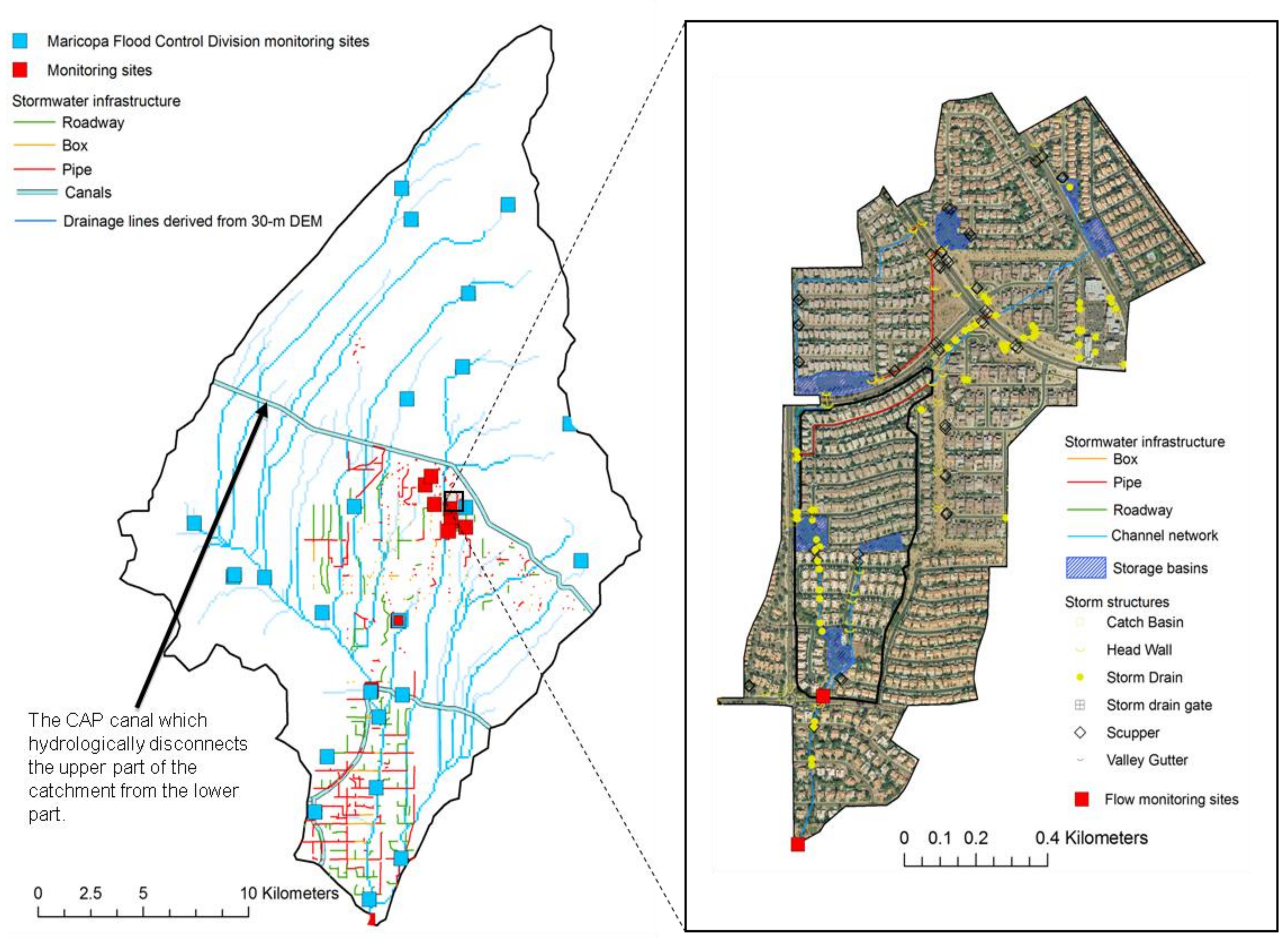


Figure 1. Key hydrological processes in a semi-arid urban ecosystem. Structural characteristics of a single spatial unit (a residential home) and human decisions about water use determine the amount of ET, infiltration and runoff generation. The spatial configuration of multiple spatial units (in residential, commercial, industrial areas), in terms of their structural characteristics and their hydrological connectivity via major drainage lines (such as streets, stormwater pipes, and surface channels) determines the propagation of small-scale ecohydrological activities to broader spatial scales. The redistribution of water within the ecosystem affects surface runoff and the spatial distribution of deliberate water use (e.g. irrigation), which further affects the spatial characteristics of vertical fluxes (infiltration and ET).



2. RESEARCH OBJECTIVE

Balancing the sustainable management of urban water while maximizing other ecosystems services (i.e., evaporative cooling 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 spatiotemporal characteristics of the horizontal and vertical components of the urban water budget, and how they are influenced by: 1) the hydrological budgets 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 3) the connectivity of flow through the catchment, 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, this basin provides a suitable spatial domain for the proposed research, as it encompasses the effects of urbanization (of different forms) across multiple spatial scales. At the largest spatial scale, the Central Arizona Project (CAP) canal effectively splits this catchment into two, such that the upper and lower areas are largely hydrologically disconnected. Runoff from the northern region is retained in a large-scale retention basin upslope of the canal (i.e. two golf courses). Our study sites are located south of the CAP canal. Irrigation in this region constitutes a major water input to the system, with typical residential and commercial water application rates from drip systems of ~80 to 200 cm/yr, which allows for wide diversity of vegetation that would otherwise not be possible under natural desert conditions. Twelve stormwater gauging stations are located across a large range of spatial scales, from <5 ha to >15000 ha, for the purpose of measuring horizontal fluxes in this urban ecosystem. At the smaller spatial scales (<100 ha), sub-basins were selected to represent homogenous stormwater infrastructure, including areas that are primarily served by stormwater pipes and others that utilize the natural channel network for stormwater disposal, some of which are interspersed with retention basins.

Figure 3. Location of stormwater monitoring sites within the Indian Bend Wash catchment, in central Arizona. Flow gauging stations that are part of the CAP LTER stormwater monitoring network (red squares, center map) gauge flow from catchments across multiple spatial scales, from catchments with contributing areas of <5 ha up to >15000 ha. Other gauging stations operated by the Flood Control District of Maricopa County (blue squares) add to this network, providing a detailed spatial coverage of stormwater monitoring in this catchment. The insert shows a close-up of two nested sub-catchments (20 ha and 100 ha) within the Indian Bend Wash catchment that are currently monitored, which typify retention basin and wash stormwater infrastructure.

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 runoff 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.

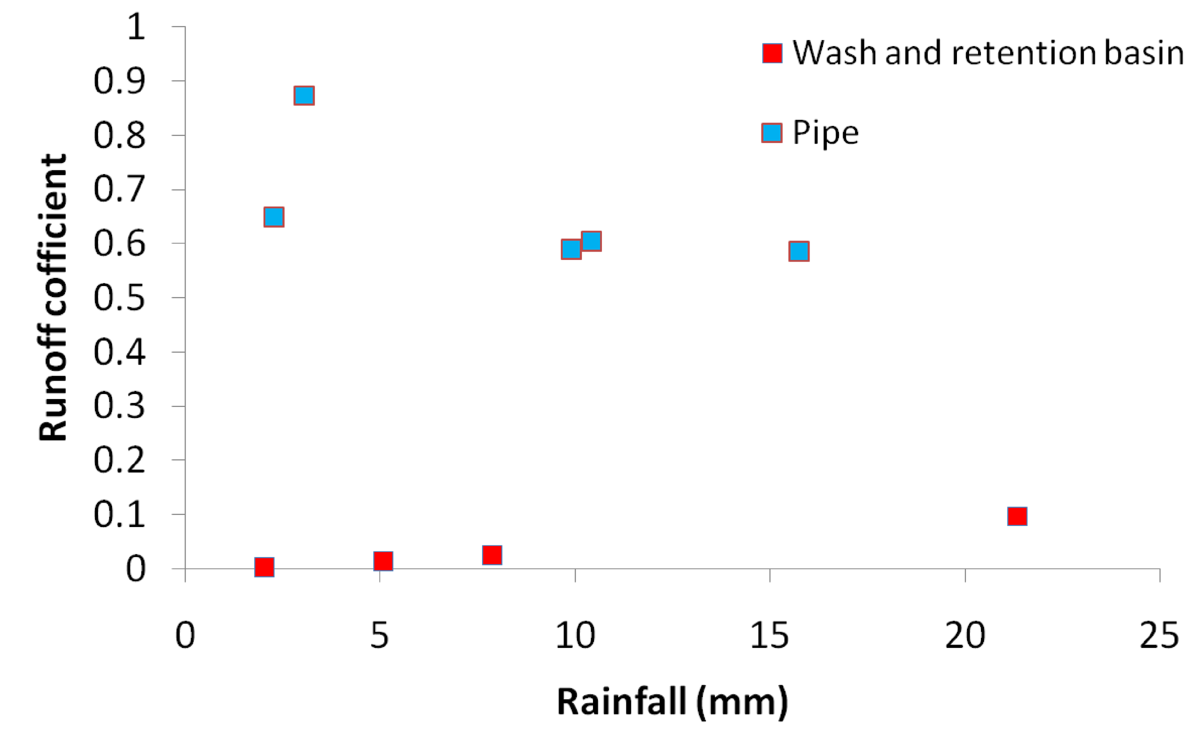
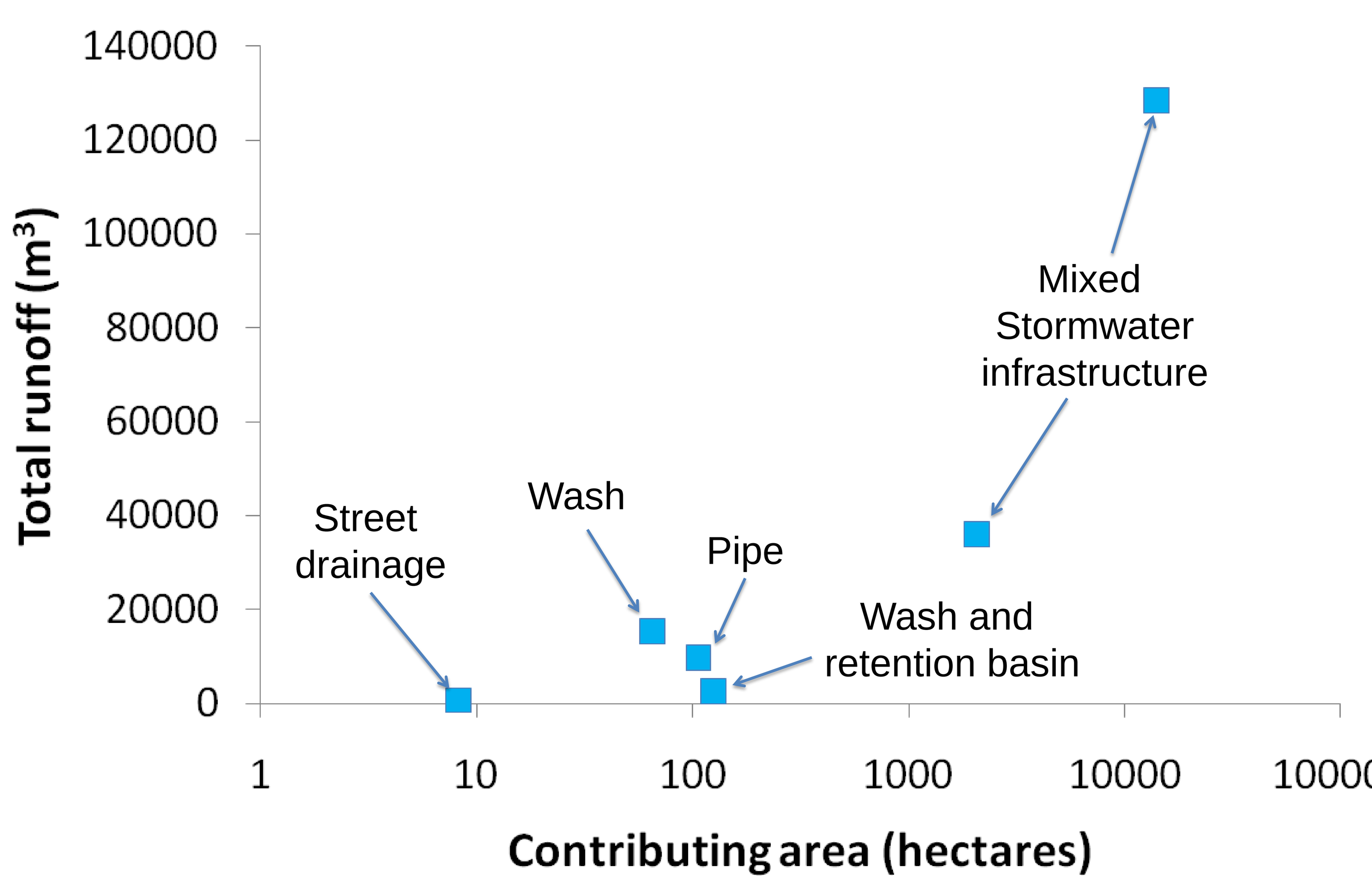


Figure 3 (right). Runoff coefficients for two catchments of comparable size, that differ in terms of stormwater infrastructure ,for rainfall-runoff events of various sizes. The runoff coefficients is the proportion of water entering the catchment as rainfall that leaves as runoff.

Change in runoff response with change in spatial scale for an event on 5th October 2010



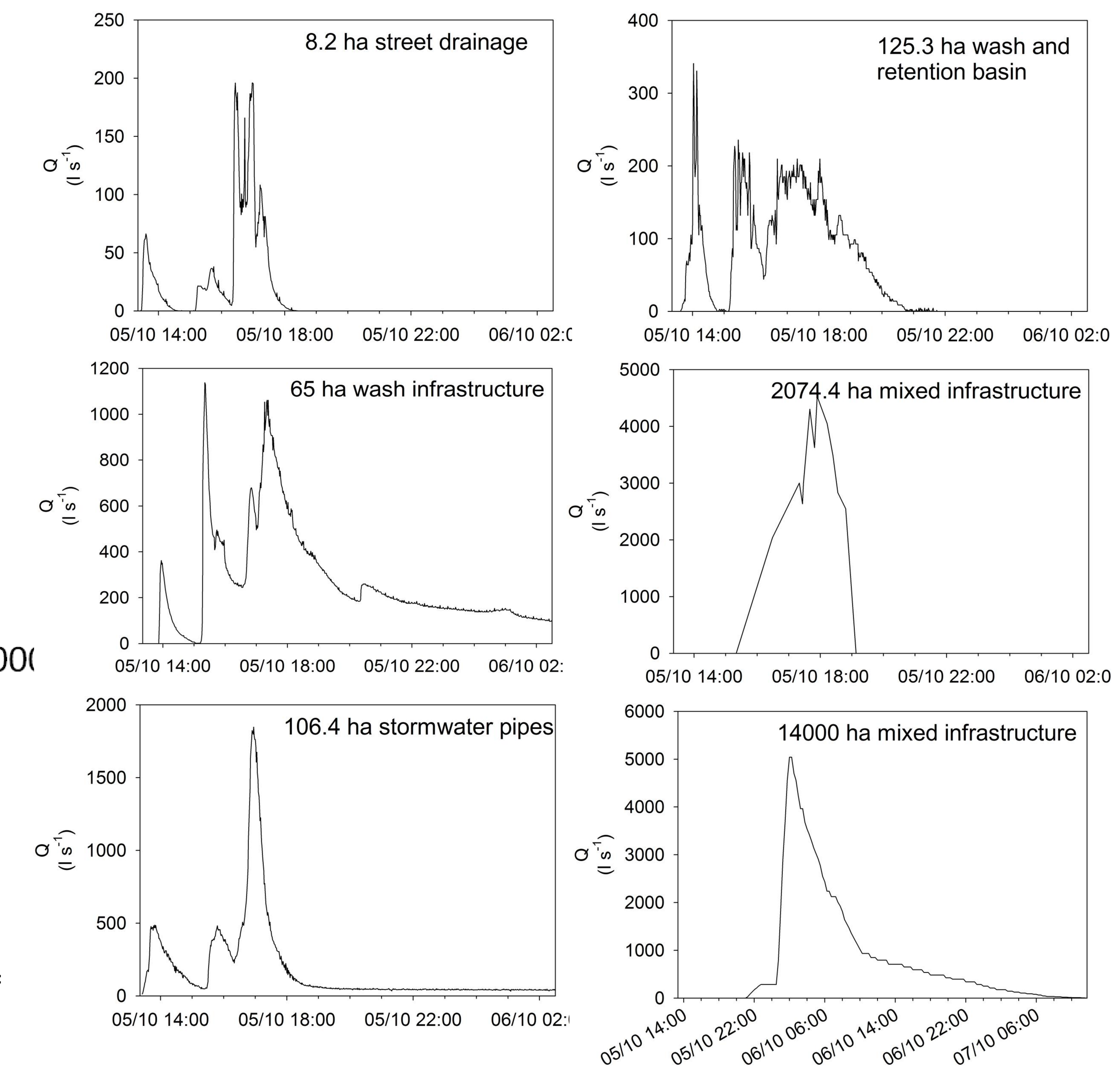


Figure 4 (above). Scatter plot showing the relationship between the contributing area and total event runoff for 6 catchments for an event on 5th October 2010.
Figure 5 (right). Hydrographs for each of the 6 sites shown in Figure 4.

The total amount of stormwater runoff shows an overall increase with an increase in spatial scale. However, Figure 4 clearly shows the complexity of 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 flash 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 hydrological responses from catchments with differences in stormwater infrastructure. Future research plans include installing three more study sites to characterize more fully the 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 endeavours 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.

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