IMPACTS OF URBANIZATION ON STREAM WATER QUANTITY AND QUALITY IN THE UNITED STATES

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INTRODUCTION

Since the 1950s, the world's urban population has grown more than 400% to 3.9 billion today. About 60% of the total population is expected to live in urban areas by the year 2025. For the United States (U.S.), 80% of the population lives in urban areas. The Earth has entered into the Anthropocene, a new geological epoch dominated by urbanization and people. It has become increasingly important to understand the impacts of urbanization on ecosystem structure and functions, society, and culture (McDonald *et al.*, 2011).

The most obvious and direct impact of urbanization on watersheds is altering the hydrologic cycle that controls the flow of energy and matter in ecosystems. Water resources in urban environments are increasingly stressed around the world due to increasing population, rapid land use change, and climate change and variability (McDonald *et al.*, 2011). Anthropogenic structures such as irrigation canals, wells, reservoirs, dams, and paved roads have shaped the natural watershed landscapes. In many population centers, megacities in particular, water availability has severely limited environmental, social, and economic development. Civilizations developed around water, and in turn human activities, have altered the quantity, quality, and distribution of water on earth.

This article reviews our understanding about the impacts of urbanization on water quantity and quality with a focus on linkages of the physical, biological, chemical, and socioeconomic processes (Paul and Meyer, 2001). We discuss current approaches to minimizing the urbanization footprint on streamflow across developing landscapes.

IMPACTS OF URBANIZATION ON THE STREAMFLOW QUANTITY AND QUALITY

Urbanization affects microclimate, surface water dynamics, groundwater recharge, stream geomorphology, biogeochemistry, and stream ecology (O'Driscoll *et al.*, 2010). Consequently, water quantity, quality (i.e., sediment, nutrient dynamics, and other pollutants), and watershed functions are impacted (Sun and Lockaby, 2012). A summary of the processes related to urbanization is presented in Figure 1.

Water Quantity

Forest clearing or converting forest lands to urban uses increases surface albedo (reflection of solar radiation), decreases net radiation, reduces latent heat, enhances summer storm intensity, and causes heat island effects (O'Driscoll *et al.*, 2010). Removing forest vegetation cover reduces plant transpiration and canopy interception, and alters soil infiltration capacity. These factors result in a dramatic increase in overland flow (O'-Driscoll *et al.*, 2010) due to decreases of total water loss and infiltration. The magnitude of streamflow change due to land use/land cover change depends on the severity of disturbances (e.g., percentage of forest removal, soil compaction, extent of impervious area, road density), local climate (radiation inputs, rainfall patterns), soil and geology (Sun and Lockaby, 2012) (Figure 2). Forest hydrologists have long recognized that urbanization elevates peakflows and baseflows due to the reduction of forest ET. The Baltimore Ecosystem Study (BES), a unique urban Long-term Ecological Research network (LTER) site specifically examines urbanization impacts on ecosystem processes, including water quantity and quality. Computer modeling has been widely used to understand the extent of urbanization at watershed to regional scale (Caldwell *et al.*, 2012).

Some combination of factors such as infrastructure renovation, improved design of new water and sanitation systems, and expanded implementation of watershed services management will be needed to provide clean water for expanding human populations.

The impacts of urbanization and land cover change on streamflow hydrographs depend on the climatic regime and magnitude of disturbance represented by total impervious area (Figure 2). For example, watersheds with a 43% impervious surface area can double their runoff after urbanization. A higher absolute change is expected in total flow, peakflow, or stormflow in a wet climate, such as the Southeast, Pacific Northwest, and Northeast than in a drier climate, such as the southwestern U.S due to the likely differential changes in evapotranspiration rates. However, the relative changes may be greater in arid climates (Caldwell *et al.*, 2012). One example is presented to show the spatial variability of water yield response to urbanization across the U.S. (Caldwell *et al.*, 2012) (Figure 3). In addition, soils and geology are important factors to evaluate urbanization effects.

Water Quality

Impacts of urbanization on water quality are primarily caused by two key factors – significant production of pollutants and reduction of retention capacity of watersheds as a result of increased impervious surfaces (Sun and Lockaby, 2012). Conversion of portions of watersheds from forest to urban cover often elevates sediment and nutrient concentrations by tens to hundreds of times

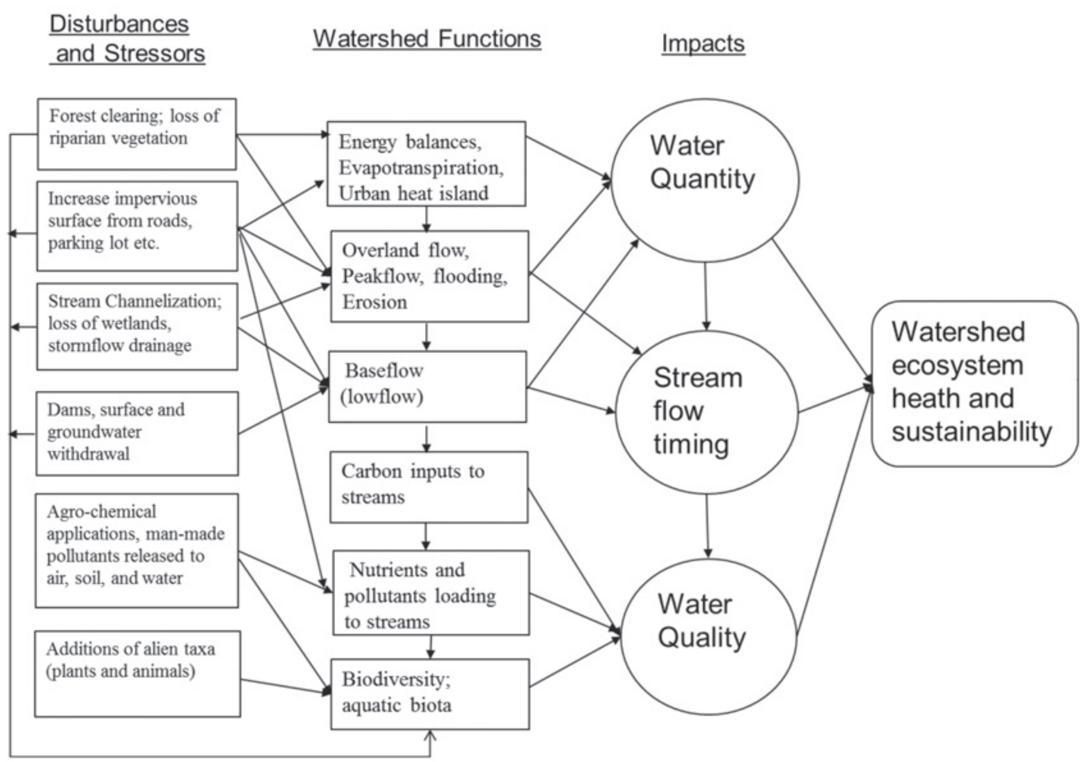

Figure 1. Urbanization Induced Disturbances and Stressors and Their Impacts on Watershed Ecosystem Functions.

in surface waters. The threshold of imperviousness at which water quality and flow regime changes occur varies from 5% to 20% of the watershed area (Figure 2). In addition to sediment and nutrients, more concerns to human health are that urban waters often contain pharmaceuticals such as antibiotics, analgesics, narcotics, and psychotherapeutics, pesticides, heavy metals, pathogenic microbial populations, and organic pollutants such as PCBs (USGS, 1999). Conventional water treatment facilities may be limited in their capability to remove some urban pollutants. Concentrations of fecal coliform and *e. coli* are frequently elevated in urban streams compared to natural streams. The abundance, diversity, and health of fish, amphibians, reptiles, and invertebrates are declining due to water pollution. Stream biota are affected by increased flow velocity and timing, changes in stream bed substrate, and increases in physiochemical and /or biological contaminants (Paul and Meyer, 2001).

MANAGEMENT OPTIONS TO REDUCE URBANIZATION IMPACTS ON WATER

Protecting water resources across urbanizing land scapes requires management of land cover at the watershed scale by adopting urban best management practices (BMPs) and protecting source headwaters. Based on the concept of watershed services, the contemporary watershed management goal is to influence land management practices within a watershed and prevent development from occurring or otherwise minimize impact in critical locations that are particularly sensitive to water quality and quantity. Although difficult to quantify, the opportunity cost of maintaining forest land cover in a watershed is likely less costly than allowing urbanization to occur and applying conventional approaches to water treatment to mitigate the water quality impacts. The watershed ecosystem service methodology requires integration among socioeconomic, hydrologic, environmental, and other considerations while addressing issues such as fragmented ownership objectives, development of a valuation system, and compliance assessment. These approaches are complex but are becoming better refined in many parts of the world as water becomes a more scarce commodity.

SUMMARY

Urbanization dramatically affects ecosystem processes, and consequently water quantity and quality in streams. Alterations of watershed hydrologic cycles are the root causes of the stream ecosystem degradation observed on today's urban landscapes. There are gaps in our understanding of the interactions among processes associated with urbanization (land conversion, increasing impervious areas, new pollutants), hydrological functions (water budget change, infiltration and ET processes), and ecological functions (biota change) at different temporal and spatial scales. Rising populations and increased development pose major threats to future sup-

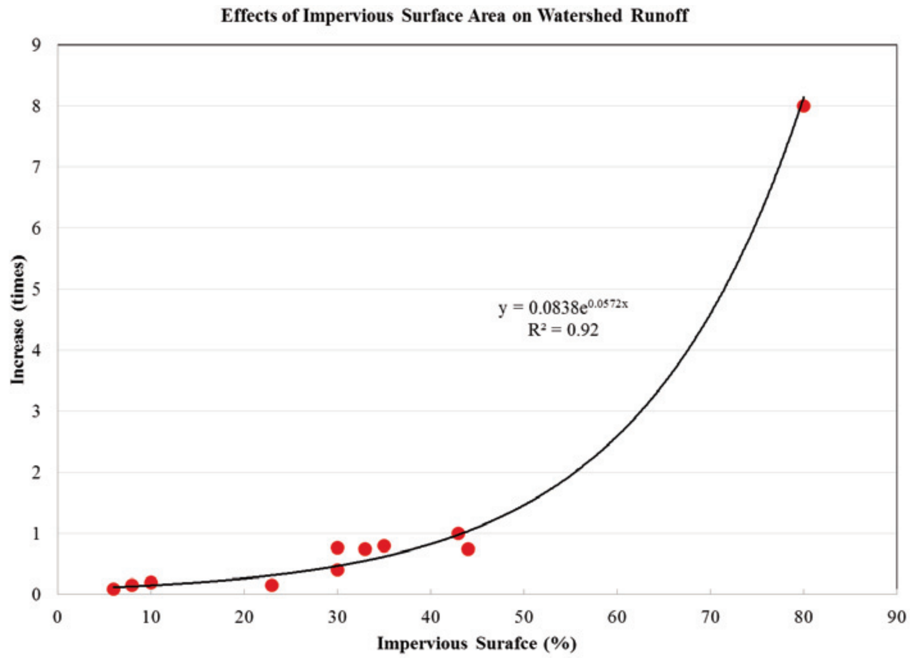

Figure 2. Exponential Increases of Watershed Runoff Due to Impervious Surface Area in Urbanized Watersheds (data from Sun and Lockaby, 2011).

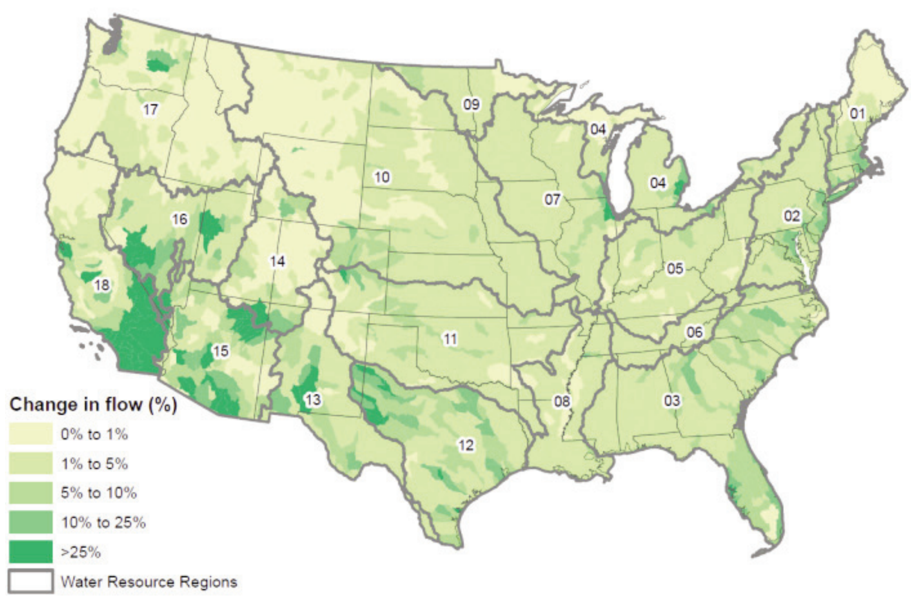

Figure 3. WaSSI Modeled Relative Change in Mean Annual Flow Due to Impervious Cover in 2010 in Comparison to Land Covers Without Impervious Surface (data from Caldwell *et al.*, 2012). (The WaSSI model is parameterized at the 8-digit Hydrologic Unit Code watershed scale and assumes precipitation fell on impervious covers becomes direct runoff and is directly routed to the watershed outlets.)

plies of clean water. These threats will be exacerbated in many areas by periodic droughts and wider ranges of temperature and precipitation associated with human-caused climate change. An urbanizing environment is likely to be more susceptible to negative climate change impacts due to the loss of buffering capacity of natural ecosystem services. Some combination of factors such as infrastructure renovation, improved design of new water and sanitation systems, and expanded implementation of watershed services management will be needed to provide clean water for expanding human populations.

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