Cyrus Philbrick

Weiskel

Climate Change

**Urban hydrology in a changing climate: Assessing public and environmental response**

**in the Pacific Northwest**

Human populations are increasingly urbanizing. At the start of the 21st century, more people live in cities than rural environments for the first time in human history (Grimm, 2008). A study by the Worldwatch Institute estimates that 83 % of people in Europe and the Americas will live in cities by 2025 (Sheehan, 2001). Cities, located disproportionately along rivers and coastlines, occupy much of the earth’s most agriculturally and biologically productive land. Flood management techniques have allowed humans to live in ever-closer contact with rivers (Grimm, 2008). By constructing dams, channeling rivers, and levying floodplains, humans have impaired ecosystems to suit their social, economic, and agricultural desires. Climate change could alter hydrological cycles in ways that will expose these impairments as near-sighted. This report assesses the hydrological impacts of climate change on the Puget Sound region, one of the most rapidly urbanizing regions in the United States (Alberti et al, 2006), as a microcosm of globally changing water flow regimes. Global Climate Models (GCMs) suggest changing patterns of precipitation and runoff within the Puget Sound will increase flooding events that threaten both public health and the health of surrounding environments. Our self-inflicted changing environment should force us to rethink the human place within hydrological cycles of watersheds. Diagnosing the most harmful developmental stressors of watersheds will allow us to seek solutions that restore or contribute to more resilient ecosystems, which serve public health as well as the natural environments we live within.

Many studies use GCMs to suggest that climate change will impact the hydrological cycle of the Pacific Northwest. Most climate models predict increasing temperatures and increasing winter precipitation throughout the Northwest (Barnett et al, 2005). Such conditions will increase winter flooding in rainfall-dominated basins (Praskievicz and Chang, 2009). Snow-dominated basins like the Columbia River will experience peak runoffs earlier in the Spring and decreased water flows during summers as the bulk of snow melt will occur earlier in the year. Transient basins, which receive mixtures of snow and rain throughout the year, will experience the largest transformation of water release. Transient basins like the Yakima watershed currently experience two runoff peaks, one during winter and another in late spring. Such basins will shift to rain-dominated regimes, losing their spring peak and experiencing a greater peak flow during winter. Elsner et al (2010) suggest that the snow water equivalent (SWE) of the Yakima basin will shift significantly by 2020. The basin’s SWE will decrease by 70 % by the 2080s (Elsner et al, 2010).

Even in the water-rich Northwestern United States, climate change will likely exacerbate conflicts over competing uses for water resources. Human energy and agricultural desires will clash with environmental ones. One prominent example occurs between the case to use the Columbia River to generate hydropower and the case to allow the river flow necessary to serve needs of spawning salmon, an emblematic fish of the region. Using a macroscale hydrologic model and a downscaled GCM, Payne et al (2005) attempt to shed light on this issue by modeling different management scenarios of the Columbia River basin. In assessing the river’s future peak flows, which will occur earlier and earlier during the year, the authors find that the river could meet the flow requirements for salmon by shifting reservoir releases earlier in the season. But doing so would decrease hydropower production by 9-35%. Human water management decisions will make more vulnerable those species already suffering closing reproductive windows due to climate change.

Conventional stormwater management tactics in urban environments historically pit human engineering against environmental health. Modern cities typically rely on drainage networks of pipes to funnel stormwater into sewage systems or rivers to keep water flowing through and under cities as quickly as possible. Such designs once aimed to uphold the structure and health of cities – to prevent floods, decrease the erosion potential of runoff, and safeguard against disease. But in forcing water to bypass terrestrial pathways, these piping networks often prevent a number of potentially beneficial interactions between riparian vegetation and inflowing water. They prevent riparian growth as well as vegetation benefits such as nutrient usage and retention, pollution cleansing, and erosion control. Piping water into sewage systems also flushes nutrients and pollutants directly into downstream aquatic ecosystems, causing eutrophic and toxic conditions. In addition, urban landscapes designed to flush stormwater can threaten human health during times of flooding. Curriero et al (2001) reports a correlation between waterborne disease outbreaks and precipitation intensity in the second half of the 20th century. Among 548 outbreaks between 1948 and 1994, 68% were associated with events falling within the 80th percentile of precipitation intensity. Outbreaks were plausibly caused by runoffs from leaching septic tanks, stormwater overflows, and runoffs from upstream agricultural lands (Curriero et al, 2001). Disease outbreaks are more likely to occur in older or less developed cities that use combined sewage systems, which bear both stormwater and sewage in one pipe. But even modern cities by American standards, like Seattle, still maintain some combined sewage systems that experience significant sewage overflow. In 2010 Seattle witnessed more than 190 million gallons of combined raw sewage and stormwater spill into creeks, lakes, the Duwamish Waterway, and Puget Sound (seattle.gov). Future increases in precipitation and flooding carry more dire risks to public and environmental health.

In addition to conventional urban drainage systems, conventional urban landscapes drive what many urban hydrologists refer to as “urban stream syndrome.” Urban stream syndrome describes the widespread ecological degradation of streams draining urban land (Walsh, 2005). Primary symptoms include: a flashier hydrograph (or more frequent and larger flow events), increasing concentrations of nutrients and contaminants, and reduced biotic richness that favors dominance of tolerant species and truncated ecosystem complexity. Studies suggest the main culprit of urban stream syndrome to be the high amount of impervious surfaces that accompany urban development. Roads, roofs, and parking lots coat cities. Their hard surfaces prevent water infiltration and rapidly transport runoff. Many studies suggest a close relationship between total impervious area (TIA) and the biological condition of surrounding aquatic ecosystems. Recent studies have searched for the threshold level of impervious area that begins to cause environmental degradation. Conway et al (2007), for example, suggest a threshold TIA of 2.4 – 5.1 % results in negative water quality impacts.

Recent studies push for a more sensitive understanding of the causes of ecological degradation. Booth et al (2004) argue that total impervious area serves as a proxy for biological condition but cannot alone predict environmental health. This study suggests considering the impacts of other factors such as watershed geology, soil permeability and depth, topography, channel network, climate, and human behavior. Walsh et al (2005) also suggests a more sensitive assessment of urban landscapes and the causes of urban stream syndrome. This study posits that biological health is associated with the area of catchment directly connected, or piped, to streams rather than draining to surrounding pervious land. It also suggests that the deforestation of riparian zone limits the potential for stream recovery because deforestation affects geomorphology, available nutrients, macroinvertebrate health, and algal biomass. All of these effects occur with some degree of independence from the effects of urban development. Alberti et al (2006) builds on these previous suggestions by arguing for a more refined modeling and understanding of the ways different patterns and sub-patterns of urban development affect runoff and ecological condition. Studying the Puget Sound lowland area, Alberti et al study four variables of urban development: land-use intensity, land-use composition, landscape configuration, and the connectivity of impervious area to watersheds. The study concludes that no single variable explains the complex relationship between urban development and ecological condition. Different landscape patterns, such as mean patch size of urban land or the number of road crossings (that aid to the connectivity of impervious area), contribute significantly to ecological affects (Alberti et al, 2006).

A more refined knowledge of the causes of ecological degradation in specific regions would allow better modeling of both the impacts of climate changes on aquatic ecosystems and the impacts of new urban development. Poff et al (2002) note the need for “hydro-geomorphic habitat modeling” that could quantitatively predict the habitat needed to provide a specified degree of ecological integrity. Praskievicz and Chang (2009) suggest, however, that future models require better integration of the interactions between climate change and different types of urban development. For example, models could account for climate impacts on different vegetation and soil dynamics. Hotter and wetter climates will affect where, how, and which plants grow. Praskievicz and Chang (2009) also suggest that more refined climate models require better downscaling from GCM to regional and basin scales. Better models of future climate and hydrological response would let policy makers and developers create urban designs that would most effectively mitigate and adapt to new environmental stresses.

Mitigation and adaptation responses to altered hydrological cycles need to fit within a larger scope of sustainable development, driven by goals of anti-sprawl and use of renewable resources that also sustain surrounding ecosystems. A water management strategy should employ a holistic framework such as “Water Sensitive Urban Design” (WSUD) as outlined by Lloyd et al (2002). This framework aims to create opportunities for efficient use and reuse of water resources that consider the importance of water quality to match water availability with need. Primarily, urban spaces can be redesigned to reduce runoff and peak flows by decreasing the amount of impervious areas and decreasing the hydraulic connectivity between hard surfaces and receiving streams. The use of pervious pavements and green surfaces aids hydrological cycles via evapotranspiration and groundwater recharge. Infrastructure should collect, convey, or detain stormwater in ways that improve water quality and allow reuse (Lloyd et al, 2002). For example, it can divert runoff to garden beds or other bio-filtration systems that naturally remove sediments and pollutants before water discharges to streams or recharges groundwater supplies. Stormwater can be integrated into urban landscapes by employing multiple-use corridors of green space. These spaces could serve to buffer polluted stormwater from receiving streams and to provide recreational spaces for city inhabitants to enjoy outdoor exercise. WSUD also emphasizes harvesting and storing non-potable water in filtered rain buckets or underground cisterns. Finally, urban design could work to increase depression storage, either in groundwater or constructed basins, by decreasing the runoff entering piping and sewage systems. It could force runoff to remain on the surface and divert to areas that allow sound infiltration and groundwater recharge. We need to conduct more research to determine the best bio-filtration systems given different regional soil type, topography, and geology.

Future urban designs will need to confront the “density conundrum” highlighted by Hamin et al (2006), a study that foresees potential conflicts between measures trying to mitigate, and measures trying to adapt to, climate change. Mitigating climate change generally requires denser urban environments that reduce vehicle miles traveled and wasted infrastructure energy use. At the same time, adapting to climate change requires making space available tor water management strategies that buffers severe storm events, allows species migration, and aids urban cooling. We need to seek answers that reconcile increasing population density with a deepening capacity to adapt to increasing environmental perturbations in the forms of floods and droughts. The best infrastructure responses to future threats seek ways to bring green space within urban settlements to replace impervious surface cover. In addition to draping rooftops with gardens, green space can be focused along transportation routes and floodplains. Creating multi-use ribbons and corridors could serve to increase urban agricultural production while strengthening the natural protective capacity of floodplains. Peripheries of cities should be reserved for larger blocks of open space, like parks or natural beaches that can serve recreational use and to protect against threats like sea level change.

Such changes in urban design could mean massive transformations and upheavals of infrastructures of older cities. Or they could require gentler modifications to cities better oriented to accept them. Cities in the Pacific Northwest, such as Seattle, have urban designs that rely on significant amounts of green space and more dynamic landscape patterns compared to other American cities. But even relatively “greener” and wetter cities like Seattle need to combine new policies, enforcement systems, and education to transform economies, infrastructure, and culture in a way that deepens public reverence for renewable resources. Cities need more stringent design requirements for new housing units and commercial buildings that promote more sustainable and less stressful water use. For example, new buildings could be required to implement water reuse schemes or systems that recycle graywater rather than using more energy-intensive potable water reserves. Public education campaigns and programs could help inform people of infrastructure changes and the public’s role in using urban spaces in ways that support more resilient ecosystems and public health. Adapting to new hydrological cycles means learning to live both with them and within them.

**Works Cited**

Alberti, M., Booth, D., Hill, K., Coburn, K., Avolio, C., Coe, S., and Spirandelli, D. (2007). The impact of urban patterns on aquatic ecosystems in Puget lowland sub-basins: An empirical analysis. *Landscape and Urban Planning,* 80, 345–361

Barnett, T., Malone, R., Pennel, W., Stammer, D., Semtner, B., and Washington, W. (2004). The effects of climate change on water resources in the west: introduction and overview. *Climatic Change,* 62, 1–11,

Booth, D., Karr, J., Schauman, S., Konrad, C., Morley, S., Larson, M.G., and Burges, S.J. (2005). Reviving urban streams: Land use, hydrology, biology, and human behavior. *Journal of the American Water Resources Assoc.* American Water Resources Association. October.

Conway, T.M. (2007). Impervious surface as an indicator of pH and specific conductance in the

urbanizing coastal zone of New Jersey, USA. *Journal of Environmental Management*,85, 308–16.

Curriero, F.C., Patz, J.A., Rose, J.B., and Lele, S. (2001). The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948 – 1994. *Am J Public Health*. 91(8), 1194–1199.

Grimm, N.B et al. (2008). Global change and the ecology of cities. *Science*, 319, 756 – 60.

Elsner, M.M., Cuo, L., Voisin, N., Deems, J.S., Hamlet, A.F., Vano, J.A., Mickelson, K., Lee, S., and Lettenmaier, D.P. (2010). Implications of 21st century climate change for the hydrology of Washington state. *Climactic Change*, 102, 225 – 260. DOI: 10.1007/s10584-010-9855-0

Hamin, E.M. and Gurran, N. (2008). Urban form and climate change: Balancing adaptation and mitigation in the U.S. and Australia. Habitat International, 30, 1-8.

Lloyd, S.D., Wong, T.H.F., and Chesterfield, C.J. (2002). Cooperative Research Centre for Catchment Hydrology, *Wastewater sensitive urban design – a stormwater management perspective* (Report 02/10). Melbourne, Australia: Melbourne Water Corporation.

Payne, J.T., Wood, A.W., Hamlet, A.F., Palmer, R.N. and Lettenmeier, D.P. 2004: Mitigating the effects of climate change on the water resources of the Columbia River Basin. *Climatic Change*,62, 233–56.

Poff, L.N. (2002). Ecological response to and management of increased flooding caused by climate change. *Phil. Trans. R. Soc. Lond. A*,360, 1497-1510. DOI: 10.1098/rsta.2002.1012.

Praskievicz, S., and Chang, H. (2009). A review of hydrological modelling of basin-scale climate change and urban development impacts. *Progress in Physical Geography*,33, 650. DOI: 10.1177/0309133309348098

Seattle Public Utilities. (June, 2012). “Sewage Overflow Prevention.” Retrieved from [http://www.cityofseattle.net/util/Services/Drainage\_&\_Sewer/Keep\_Water\_Safe\_&\_Clean/CSO/index.htm](http://www.cityofseattle.net/util/Services/Drainage_%26_Sewer/Keep_Water_Safe_%26_Clean/CSO/index.htm).

Sheehan, M.O. (2001). *City Limits: Putting the Brakes on Sprawl.* Worldwatch Paper 156, Worldwatch Institute, Washington, D.C.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., and Morgan, R.P. (2005). The urban stream syndrome: current knowledge and the search for a cure. *J. N. Am. Benthol. Soc*., 24(3), 706–723.