An Overview of Stormwater in Michigan: Impacts and Solutions

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Introduction

Stormwater management in urban areas is a major issue for municipalities. As increasing amounts of natural land are converted to impervious surfaces, water that was once largely absorbed by the soil or transpired by vegetation is now conveyed from these hard surfaces by storm drains, pipes, and canals to nearby surface waters. This stormwater runoff results in a variety of negative impacts to aquatic systems. In addition, climate change in the Great Lakes region is predicted to increase the intensity, and perhaps also the total number, of storm events; this will result in greater stormwater runoff, exacerbating its impacts on water resources in Michigan.

The objectives of this white paper are three-fold: 1) provide a brief overview of the impacts of stormwater, 2) examine the potential consequences of climate change on stormwater-related processes; 3) and identify potential solutions, including actions that can be taken at the societal, community, and individual scales.

Urban Stream Syndrome

The term "urban stream syndrome" is a descriptor that addresses the collective ecological degradation experienced by streams draining urban landscapes (Meyer et al. 2005, Walsh et al. 2005b). Although the degree to which individual streams and their receiving water bodies are impacted by stormwater runoff, there are a number of symptoms that are consistently manifested (Table 1).

Table 1. General responses associated with urban stream syndrome (after Walsh et al. 2005b).

Attribute	Response
Hydrology	↑ frequency of overland flow ↑ frequency of erosive flow ↑ magnitude of high flow ↓ lag time to peak flow ↓ recharge to aquifers
Water Quality	↑ nutrients (e.g., nitrogen, phosphorus) ↑ toxicants (e.g., oils, greases, metals) ↑ water temperature ↑ salt
Channel Morphology	↑ channel width ↑ pool depth ↑ scour
Biota	↑ tolerant fish and invertebrates ↓ sensitive fish and invertebrates
Ecosystem Processes	↓ organic matter retention ↓ nutrient uptake
Public Infrastructure	↑ cost for installation and maintenance

The hydrologic impairments are perhaps most obvious, as urban streams become more “flashy” in response to storm events with more frequent and larger flows, and faster ascending and descending limbs of the hydrograph. The major reason for this flashiness is the greater amount of impervious surface in the watershed; instead of water infiltrating into soils and recharging aquifers or being transpired by vegetation, the water moves quickly off of impervious surfaces and is delivered directly to via storm drains and pipes. Ecological impairment has been shown when percent impervious cover of a watershed exceeds 10-15% (Carlson 2004, Steinman et al. 2006), although the actual threshold for impairment will depend on how much impervious area is connected to drains (i.e., effective imperviousness) rather than drains to pervious land features (Walsh et al. 2005a). Reduced infiltration through soils can result in reduced recharge to aquifers, but interestingly, this impact may be offset by leakage from aging stormwater, water supply, and sewer infrastructure (USEPA 2008).

The increased high flows associated with stormwater runoff can have strong effects on channel morphology and stream biota (Table 1). A 1-in (2.5 cm) rain event can result in substantial increases in discharge from storm drains (Fig. 1). This can lead to bank erosion and stream incision, resulting in greater channel width and deeper pools (Paul and Meyer 2001, Walsh et al. 2005a). Ecosystem processes are also affected by stormwater runoff: increased power associated with higher discharge results in less retention of organic matter (an important food resource for many macroinvertebrates) and less opportunity for microbes and autotrophs to take up nutrients (Groffman et al. 2005) (Table 1).

Figure 1. Stormwater discharge from a storm drain entering Mona Lake (Norton Shores, MI). Drain on left is under dry conditions, whereas drain on right is after a 1-inch rain event. Photo credits: Alan Steinman (left); Annoesjka Steinman (right).

Urban stormwater runoff can profoundly affect water quality and, consequently, stream organisms (Table 1). Stormwater runoff from impervious surfaces can contain nutrients (nitrogen, phosphorus), heavy metals (Pb, Zn, Cr, Cu, Mn, Ni, Cd, etc.), pesticides, and toxic organic compounds such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Hatt et al. 2004, Meyer et al. 2005, Walsh et al. 2005a, Christensen et al. 2006). If the aquatic system is nutrient limited, runoff containing nutrients from fertilizers and other sources may encourage microbial growth (Boisson and Perrodin 2006, Steinman et al. 2006, Biddanda et al. 2008). This could lead to nuisance algal blooms that can deplete dissolved oxygen concentrations, negatively impact invertebrates and fish, and reduce the aesthetic appeal of the stream (Carpenter et al. 1998). Alternatively, toxic heavy metals and other pollutants in the storm water can potentially cause a decrease in algal biomass (Paul and Meyer 2001). While toxic contaminants can result directly in death or impairment, even sub-lethal concentrations in run-off can cause the community composition to shift to favor more pollution-tolerant genera, thus reducing species diversity (Sonneman et al. 2001, Newell and Walsh 2005). Elevated nutrient loads associated with stormwater runoff can stimulate primary producers, which in turn can influence higher trophic levels that use these organisms as a food resource. Urban stormwater runoff also can directly influence benthic invertebrates and fishes via increased flows, which can wash out eggs, larvae, or young-of-year (Freeman et al. 2001, Roy et al. 2005). In addition, fishes can be indirectly influenced by urban stormwater runoff through increased sediment loads and increased temperatures (Paul and Meyer 2001, Roy et al. 2005).

Another serious impairment resulting from urban stormwater runoff is thermal pollution. As water moves across heated impervious surfaces, its temperature can increase substantially; when this heated runoff drains into a natural water body, it will increase that system's thermal regime, although the effect is likely to be restricted both in place (near the inflow) and time (beginning of runoff) (cf. Thompson et al. 2008). Ecosystem processes and aquatic organisms that are sensitive to temperature, such as invertebrates and fish specific to cool and cold water streams, can be impacted (cf. Wang and Kanehl 2003, Meyer et al. 2005). Elevated chloride concentrations, which can come from road salt, industrial waste, poorly maintained septic systems, and some agrichemicals threaten the health of freshwater organisms and limit the availability of freshwater in aquifers (Kaushal et al. 2005).

Urban stormwater results in both indirect and direct costs to society. Although these costs are usually not considered part of the urban stream syndrome (Table 1), they are real and should not be overlooked. Indirect costs include the loss of ecosystem services through the degradation of habitat, water quality, and biotic composition. Although no valuation studies have been conducted solely on stormwater, other studies have clearly shown that the reduction in ecosystem services associated with degraded water quality have a cost (cf. Wilson and Carpenter 1999, Loomis et al. 2000, Eisen-Hecht and Kramer 2002). A recent analysis assigned a value in west Michigan for water recreation/fish and wildlife habitat by transferring values from 12 peer-reviewed studies of various recreational activities and environmental amenities (including wildlife habitat) in various locales (for more detail, see http://invest.wri.gvsu.edu/). These values were combined and adjusted to obtain an overall per trip value estimate of $864/acre/yr. Hence, these indirect costs can be significant. However, direct costs also can be substantial. For example, a storm event on January 7th, 2008 in Norton Shores, MI resulted in rainfall rates of greater than 0.55 in/hr and temperatures reaching 57ºF. This rain-on-snow event resulted in significant stormwater runoff through the storm drain discharging to Mona Lake, directly below the Henry Street Bridge. The end of the storm drain is covered with a grate that catches debris, preventing it from reaching the lake. However, debris flowing through the storm drains accumulated behind the grate (Figure 2), resulting in sufficient pressure to pull apart two storm drain sections; the storm water that escaped then eroded the soil beneath the bridge, and undermined the culvert's attachment to the bridge structure (Figure 2). The total cost of culvert replacement and bridge repair to the City of Norton Shores was $480,000, which was an unbudgeted cost.

Figure 2. Images of storm drain culvert with debris accumulated behind grate, forcing the pipe to disconnect (left) and detached drain pipe from bridge structure (right). Photo credit: Muskegon Chronicle.

Link to Climate Change

On a global basis, climate change is anticipated to result in warmer atmospheric temperatures, increases in sea levels, and more frequent extremes of the hydrologic cycle. Although the uncertainty associated with these predictions increases (Busuioc et al. 2001) as one downscales (i.e., narrows the geographic focus of the analysis), the Great Lakes basin is generally projected to experience a rise in both average and extreme precipitation events (IPCC 2007, Easterling 2008).

Model projections for the southern Wisconsin region show that extreme high precipitation events will become 10 to 40% stronger (Patz et al. 2008). In the Great Lakes region, precipitation events of greater than 2 to 2.5 in (5-6 cm) often result in stormwater discharge of contaminants into water bodies (McLellan et al. 2007). The analysis by Patz et al. (2008) revealed that the frequency of events exceeding the 2 to 2.5 in threshold is anticipated to increase by 50 to 120% by the end of the 21st century. They concluded that absent improvements to our waste and stormwater infrastructure, these extreme events may overwhelm the combined sewer systems and lead to overflow events that threaten human health and the recreationally-based economy in the region.

Solutions

There has been considerable attention recently devoted to addressing the problems associated with urban stormwater runoff. Indeed, the federal Clean Water Act was amended to regulate stormwater via the National Pollution Discharge Elimination System (NPDES) program. Subsequent Phase I (1990) and Phase II (1999) Stormwater Rules were issued by the USEPA; despite these rules, which apply to upwards of 500,000 permittees at any given time according to USEPA estimates, progress in addressing stormwater impairment has been slow. Some of the reasons for the lack of progress include insufficient oversight (i.e., self-monitoring), inappropriate regulation (failure to focus on volume of discharge), and limited governmental resources (NRC 2008).

Potential solutions to the problem of stormwater management come in many shapes and sizes. For convenience sake, I have organized them into three general groups, based on scale (Table 2).

Table 2. Potential solutions to address stormwater management.

Solution	Scale	Example
Governance	Societal (large)	Manage by watershed Water quality trading
Best Management Practices	Community (medium)	Rain gardens (structural) Ordinances (non-structural)
Behavior Change	Individual (small)	Apply P-free fertilizer (where appropriate)

Governance-related solutions: Currently, stormwater management in Michigan is addressed, for the most part, at the scale of political boundaries. Water management district (WMDs), which consolidate regulatory authority within naturally occurring watersheds, present an alternative approach to overseeing the water services of the state. The State of Florida has divided itself into five water management districts, which are based on watersheds and other natural, hydrologic and geographic features. These districts integrate permitting, water use regulation, surface and groundwater programs, surveying, land acquisition, outreach, water quality monitoring, and environmental planning in a single agency.

Creation of water management districts in Michigan would require dedicated effort. In Florida, the genesis for the WMDs was extreme climatic conditions in the late 1940s: hurricanes and drought, which led to the loss of human life and property. Florida's subtropical extremes in weather, combined with a desire to populate the region, led the US Congress to adopt the Central and Southern Florida Flood Control Project in 1948. This was followed by Florida legislation in 1949 creating the Central and Southern Florida Flood Control District. In 1972, the Florida Water Resources Act created the state's six (later combined into five) water management districts, and in 1976, Florida voters approved a constitutional amendment giving each district the authority to levy property (*ad valorum*) taxes to help fund their activities. The five districts are each overseen by a Governing Board, whose members are appointed by the Governor and approved by the state Senate. Each of the five districts operates independently and each has slightly different missions. However, they all focus on both water quantity, given water's central role in the state, and water quality, as all the WMDs have priorities that include environmental monitoring, ecosystem restoration, and land acquisition for water quality protection.

It is unclear if the water management district model can be applied to Michigan: What statutory changes would be needed? How would the existing drain commission model interface with WMDs? Is there the political will to make this happen? Humans are a crisis-oriented species, and it took a water crisis to generate the political interest, fortitude, and capital to establish water management districts in Florida. It is recommended that a study be conducted to determine the feasibility and structure of water management districts in the State of Michigan.

Another governance-related solution is the formation of a water quality trading market (Woodward and Kaiser 2003). In principle, trading should create economic incentives that will result in greater efficiencies and improved water quality. Similar approaches have been developed for air quality pollutants. Although developing a water quality trading market involves many facets (cf. Mehan 2008), it may warrant further consideration.

Best Management Practices: structural and non-structural. Also referred to as stormwater control measures (SCMs), best management practices (BMPs) usually fall into structural and non-structural categories (Table 3). Structural BMPs, as the name indicates, involve physical changes to the environment to prevent stormwater from degrading receiving water bodies. Some of the more common structural BMPs include detention ponds (including constructed wetlands), bioretention areas (including rain gardens), vegetated swales, cisterns (for capture and reuse), tree planting, green roofs, pervious pavement, and stormwater retrofits (e.g., oil-water separators, catch basins). Much more information is available from the national BMP database developed by the American Society of Civil Engineers and the Water Environment Federation (www.bmpdatabase.org). Comparing the effectiveness of BMPs is problematic because of inconsistent study methods, lack of relevant design information, and different reporting protocols (Strecker et al. 2001; but see Pennington et al. 2003, Barrett 2005).

Non-structural BMPs may include nonpoint source education, animal waste management, and local ordinances, which can address stormwater management, natural features, wetlands, landscaping, and zoning (Table 3). Stone and Bullen (2006) found that relatively modest changes to municipal land development regulations (e.g., narrowing of lot frontage, reduction in length of front yard setback—which reduces area of driveway, and use of porous paving materials) could reduce development-induced stormwater volumes by over 30%.

Table 3. Examples of non-structural BMPs to manage urban stormwater.

BMP	**Focus**
Ordinance	
- stormwater management	- implement Low Impact Development practices
- natural features/wetlands	- provide protection for natural areas including riparian buffers
- landscaping	- promote native vegetation
- zoning	- promote cluster developments, reduced road widths
Nonpoint Source Education	Prevent pollution from homeowners, local governments, riparian landowners, lake and home associations, commercial lawn care businesses, businesses, and institutions from entering waterways
Animal Waste Management	Animal waste in urbanized watersheds includes both wildlife such as raccoons, geese and deer, and pets (dogs and cats). BMPs include dog waste stations; vegetative barriers around stormwater BMPs, lake front areas, and tributary streams; geese signs; and educational pamphlets.

Behavior Change. Ultimately, we as individuals must assume responsibility for our actions. Unfortunately, humans are usually crisis-oriented, so absent a crisis it can be difficult to effect changes in behavior without resorting to hyperbole and soaring rhetoric of impending doom and gloom. Public education and outreach are valuable tools in explaining to individuals both the importance of stormwater management and personal actions that can be taken to reduce stormwater impacts. However, even well-designed educational efforts can have limited influence if the issue is not of *immediate* relevance to the recipient. By presenting the information in a manner that personalizes it to the audience and by emphasizing those points that relate most closely to their values (i.e., by framing the issue; see Nisbet and Mooney 2007), one increases the likelihood that the individual will take action. Below are some actions that can be taken at the individual level that will help reduce stormwater impacts (see also www.epa.gov/npdes/pubs/solution_to_pollution.pdf):

- Use commercial car wash or wash car on lawn
- Recycle used oil
- Apply fertilizer and insecticide according to recommended amounts
- Plant with native vegetation
- Compost yard waste
- Don't overwater vegetation
- Redirect downspouts away from paved areas
- Pick up pet waste

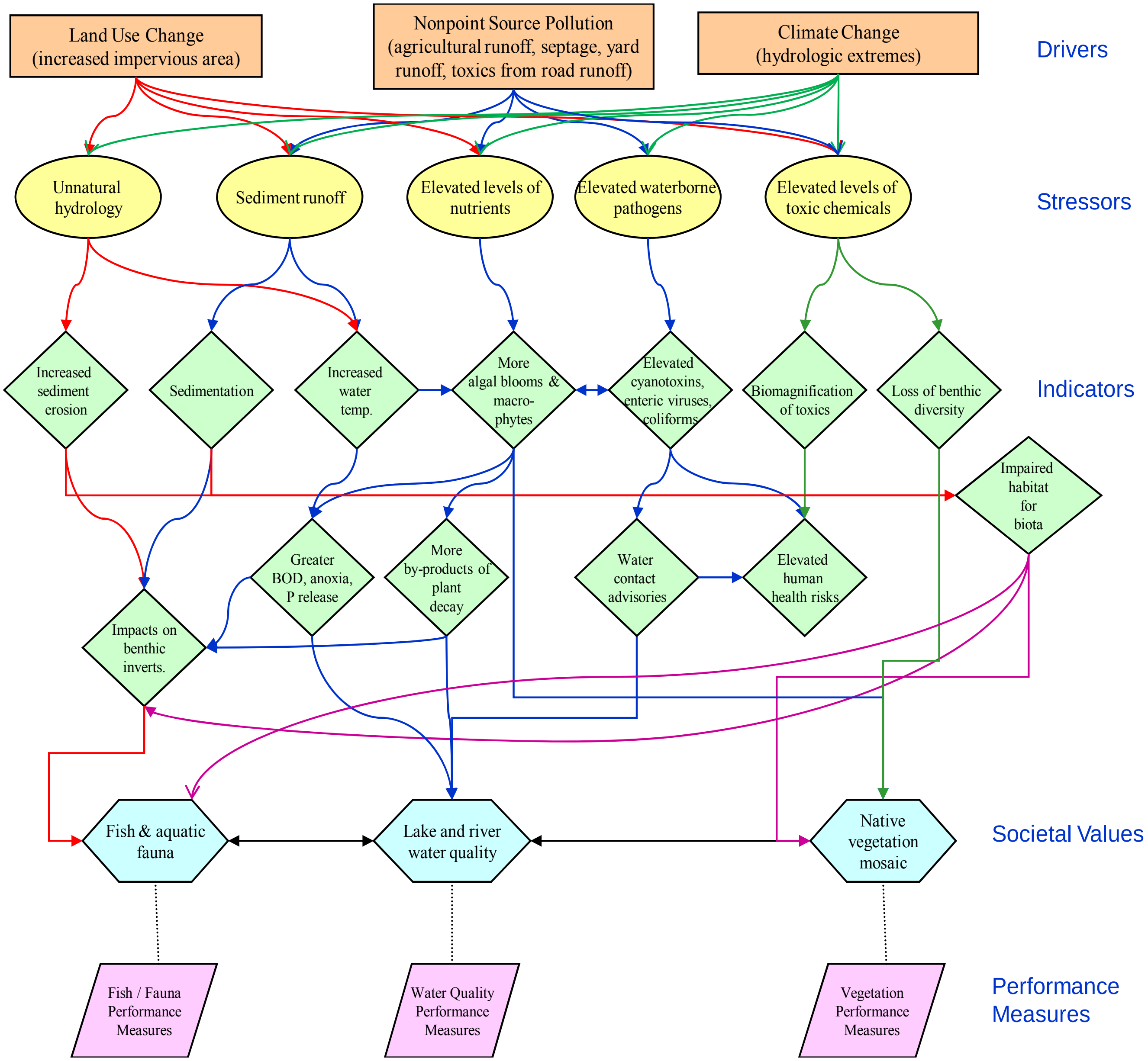
Summary

Managing stormwater runoff is one of the most vexing water resource problems facing urban regions. Despite incomplete understanding and imperfect information, it is essential that resource agencies, institutions, and municipalities continue to move forward to resolve environmental challenges. One mechanism to assist this process is the development of non-quantitative conceptual ecological models. These models provide qualitative explanations of how natural systems have been altered by human-induced stressors, which in turn provides planners, resource managers, and elected officials with the information they need to focus on the best design and assessment strategy (Ogden et al. 2005).

Figure 3 shows a conceptual model for stormwater runoff that begins with the key ecosystem drivers affecting stormwater: increasing urbanization results in more impervious surface; management activities (or lack thereof) result in more nonpoint source pollution that lead to more nutrients, toxics, and sediment; and climate change affects hydrology. Below the drivers are the stressors to the ecosystem. The influence of hydrology on stormwater impacts is pervasive, as this driver connects to all stressors (cf. Walsh et al. 2005b). The stressors impact ecological structure and function, which can also be viewed as potential indicators of those stresses. Ultimately, society determines what values it places on environmental resources and ecosystem services; this model proposes three possible values (fish and aquatic fauna, water quality, and native vegetation), although depending on the ecosystem and the stakeholders, a very different set of societal values may emerge, which in turn may affect the structure of the conceptual model.

Regardless of its architecture, conceptual models provide a framework for thinking about how ecosystems function and how they can be managed. This helps scientists identify information gaps and data needs. In the case of stormwater runoff, the ecological processes are relatively well-understood. But understanding the system is only part of the battle; without political will, public support, and financial resources, our aquatic resources will continue to be negatively impacted by stormwater runoff.

Figure 3. Conceptual model of stormwater runoff.



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