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Stormwater Management as Adaptation to Climate Change

By Laura Funkhouser

That rate of rain is much more typical of where I grew up in the Southwest, where you have thunderstorms. Infrastructures in those areas are designed differently. We aren't accustomed in this area to such intense rain events.—Richard Palmer, a professor and water resources engineer at the University of Washington (Kamb 2006)

This [kind of storm] is generally considered one in every 10 years. But that doesn't mean we can all kick back and relax for another 10 years.—Johnny Burg, National Weather Service meteorologist (Kamb 2006)

Spending the rest of one's life in a state of continual and unpredictable change is, to some people, a fantastic opportunity and, to others, a terrifying ordeal. This is, however, the reality reported by the Intergovernmental Panel on Climate Change (IPCC). The IPCC, the most watched scientific body in the world for climate change research and analysis, cites a 90% chance of increased frequency of heavy rainfall events, heat waves, and hot extremes in the 21st century (IPCC 2007), prompting a *Wall Street Journal* columnist to declare over the scientific debate on climate change's existence and human cause (Begley 2007). The catch is no one knows exactly how these extreme weather patterns will play out locally.

This news comes at a time when many fundamental aspects of infrastructure management are being questioned and appear to be changing radically and in ways that will aid adaptation to climate change. Indeed, stormwater managers possess some of the most powerful tools for proactively adapting urban infrastructure to climate change. This article proposes that we become mindful of the many roles that stormwater management can play in adapting the urban environment to climate change.

In the short period that stormwater management came into widespread practice after the National Pollutant Discharge Elimination System Phase II was promulgated in 1999 by the USEPA, it has become much more ambitious than just flood control and water-quality protection. It is soil erosion prevention, water resource conservation, and green infrastructure and groundwater management. Stormwater management occupies a space in the urban landscape that promises to alleviate some of the areas of greatest concern under climate change scenarios, signifying that stormwater managers will play an increasingly leading role in preparing and sustaining urban infrastructure.

As of this writing, 29 states have passed legislation to reduce carbon emissions and 409 mayors have signed an agreement to do the same (Pope 2007). A key study is under way to assess the role of urban forestry for carbon sequestration and multiple climate change benefits (McPherson 2006), and at least one major city is launching a pilot program for residential cisterns (Funkhouser and Fleming 2007). These developments hint at potential new roles for stormwater managers that would have seemed preposterous a few years ago. One obvious new function for stormwater managers is to offset drought effects through rainwater harvesting and infiltration. These techniques would also conserve energy. In California, 19% of the state's electricity and 30% of its natural gas are consumed conveying, treating, distributing, heating, and cooling water from source to end user (Grenoble 2007). Green infrastructure, including green roofs and urban forestry, may prove to be a viable form of carbon sequestration and urban heat sink moderation. Green roofs also can provide insulation, improving a building's energy efficiency.

Hopefully, the dialog on stormwater as adaptation to climate change will be broad and never-ending. In that spirit this article looks at some widely divergent aspects of the industry that are interlinked with climate change adaptation, not to provide answers per se, but to survey a bit of the new terrain.

What Climate Change Might Look Like

Andy Ryan, spokesperson for Seattle Public Utilities (SPU), says, “We don’t know if these [December] storms are [caused by] climate change, but we think this is what it might look like” (McClure and Stiffler 2007).

Ryan was referring to a fierce wind- and rainstorm that swept over Seattle on December 14, 2006, flooding streets and paralyzing traffic for hours. The deluge flooded hundreds of basements, knocked out power for more than a million homes and businesses, downed scores of trees, opened up a 15- by 20-foot sinkhole, and caused a sewage treatment plant to dump tens of millions of raw sewage into Puget Sound (Kamb 2006). Four people were killed and more than 1,500 emergencies were reported that evening (Nalder 2006c).

At the peak of this rainfall event Catie Corpron-Smith tried to stop flooding on East Madison Street by clearing leaves from four storm drains in front of City People’s Garden Store, where she is co-manager of the landscaping department. She watched as her efforts had no impact on the water flow. Instead, a surge from the backed-up storm drains cut a path of death and destruction (Nalder 2006b). The flooding from East Madison, a commercial district, fell like a waterfall down a 40-foot embankment into a residential neighborhood. It broke down a 6-foot retaining wall, ripped out a backyard patio, and then ran down a sloping residential street, gathering speed. At this point a witness said the river running down the street was 4 feet deep. It slammed into Kate Fleming’s home, collapsed a foundation wall, and trapped Fleming in her basement. As emergency crews raced to rescue Fleming, her basement filled with water and she drowned. Fleming died after arriving at the hospital (Nalder 2006b). Twenty-five other basements in Madison Valley also flooded (Nalder 2006a). By January 2007, more than 200 home- and business owners had filed damage claims with the City of Seattle (Galloway 2007), of which 70 were from residents of Madison Valley (McNerthney 2007).

After the flood SPU hired CH2M Hill to investigate and provide a full report, which was not yet complete at publication time. Rainfall data collected from two gauges in the area of the flooding on East Madison Street show that the neighborhood had received two-thirds of an inch in 30 minutes, which for Seattle constitutes a 100-year storm event (Galloway 2007). A giant red bull’s-eye graphically confirms that the highest intensity of rainfall from the storm occurred directly over City People’s Garden Store on East Madison Street.

The hydrologist who interpreted the data stated that storms leading up to the December 14 deluge had saturated the ground, which exacerbated the flooding. He compared the storm to a major rainfall event in 2004 that had about the same precipitation totals but less direct runoff because it was an isolated event (SPU 2006).

This demonstrates something every stormwater manager knows—that a slight variation in rainfall distribution can easily overwhelm a municipal separate storm sewer system’s capacity. It is not the once-in-a-lifetime catastrophic event that cannot be predicted that keeps stormwater managers awake at night, but rather it is increased frequencies of heavy rainfall events and variability in distribution that can be disastrous.

More alarming, perhaps, is that a slight variation in rainfall caused Seattle’s stormwater infrastructure—often pointed to as the most progressive in the nation (Nisenson et al. 2005)—catastrophic failure after a storm of less than an inch an hour. Stormwater professionals had better take notice. With the certainty of global climate change–driven weather effects predicted by the IPCC within the foreseeable future, what goes around comes around and will visit us all on the ground.

Stormwater management has evolved over the past decade with new conceptual models including hydrograph modification management, low-impact development, treatment trains, and techniques such as specialized infiltration applications, rainwater harvesting, porous pavement, green infrastructure, and proprietary filtration and separation devices. Overall there has been a paradigm shift from reactive hard structural engineering strategies toward the preventative soft nonstructural engineering practices and smart growth principles strongly advocated by the USEPA. And yet the field has brought all of these techniques into practice without the benefit of any discussion on climate change and its effects on stormwater management (e.g., a survey of eight key books on stormwater management, the most recent published in November 2006, uncovered not one mention of climate change).

“The world we have known is history,” wrote James Gustave Speath, dean of the School of Forestry and Environmental Studies at Yale University and former chairman of the President’s Council on Environmental Quality, in a letter to the *New York Times* (2006). “A mere 1 degree Fahrenheit global average warming is already raising sea levels,” Speath wrote, “strengthening hurricanes, disrupting ecosystems, threatening parks and protected areas, causing droughts and heat waves, melting the Arctic and glaciers everywhere and killing tens of thousands of people a year. Yet there are several more degrees coming in our grandchildren’s lifetime.”

The good news for our field is that stormwater managers are far better prepared for climate change than other infrastructure professionals. The field of stormwater management was born precisely because urban infrastructure needed to change in order to perform functions for which it was not originally designed. If stormwater management exists to adapt and retrofit infrastructure to offset effects of environmental changes caused by humans, then adaptation has defined the field, putting us ahead of the game in some ways. But will we stay ahead?

Tens of thousands of stormwater professionals in more than 6,000 communities throughout the country are a powerful network that is uniquely qualified and positioned to lead adaptation of the urban environment to an uncertain future. Climate change may usher in the golden age of stormwater management technology.

Climate Change Adaptation Literature

The IPCC reports and scientific output up to this point have mostly been forensic approaches to proving and describing climate change. Studies on impacts of climate change and mitigation of carbon dioxide–generated causes follow closely. Adaptation research has remained in the background, with the exception of reports on impacts to water resources and attempts to downscale climate modeling to predict local drought and shifting rainfall distribution patterns (Fankhauser et al. 1999).

A recent editorial in *Nature* stated that the delay in embracing adaptation is because “the mere idea of adapting to climate change became problematic for those advocating emissions reductions.” However, people are realizing that mitigation will take a long time to reduce effects that we may already be experiencing, unsustainable development has placed an additional burden on the environment, and there is now a call to focus on “damaging climate events that—like [Hurricane] Katrina—will occur regardless of efforts to mitigate emissions” (Peikle Jr. et al. 2007).

A number of city and state studies have examined impacts to water resources, hydroelectric power, health effects, and agricultural industries. The State of Washington’s report, *Impacts of Climate Change on Washington’s Economy*, released in 2006, plainly says, “Climate change impacts are visible in Washington State and their economic effects are becoming apparent.” It identifies snow and glacier water loss, increased wildfires, and changes in peak stream flows as climate change effects that have already occurred. And it outlines the twofold goal of the state, to reduce “emission of heat-trapping gases responsible for climate change [i.e., mitigation], and prepare now for consequences of climate change on ecological systems, natural resources, shorelines, economic sectors and industries, built infrastructure and public health that appear inevitable [i.e., adaptation]” (Bauman et al. 2006).

Although the report acknowledges widespread disruptions to the economy in seven different economic sectors, it does not discuss impacts to local urban infrastructure and commerce. California’s report *Scenarios of Climate Change in California: An Overview*, released in 2006, also leaves out discussion of local urban infrastructure, stormwater, and flood control. Though, like Washington’s report, the California report stresses carbon reduction and also mentions adaptation, stating, “Although it is not the solution to global warming, it is becoming clear that adaptation is an essential complementary strategy to manage some of the project impacts of climate change.” However, California’s report does not promote tactics for adaptation (California Climate Change Center 2006).

In contrast, though the State of Minnesota may get off easy on climate change, its stormwater manual devotes almost two pages to climate change, noting warmer winters, greater annual precipitation, increased variability, and less predictable weather patterns, with recommendations for cold climate best management practice (BMP) design (Minnesota Pollution Control Agency 2005). Minnesota is already looking ahead even though its geographic good fortune ensures it won’t have hurricanes or sea level rise to contend with.

Meanwhile, New York City, which has to contend with considerable threats from sea level rise, has announced it plans to create a plan for adaptation to climate change (Rogers 2007).

Other studies document infrastructure’s frailties. The *Extreme Weather and Climate Change* report, released in 1998, offers an inventory of Canadian flood deaths, displacement, and urban and private property wreckage and cautions that small-scale rain events can cause a great deal of damage, as a “90-minute downpour in Ottawa in August 1996, for example, caused more than $20 million in insured losses plus additional costs for repairs to roads and sewers” (Francis and Hengeveld 1998).

Another report from Canada addressing stormwater infrastructure and climate change, *Report 2003-1: Climate Change and Urban Stormwater Infrastructure in Canada: Context and Case Studies*, was published in 2003. Significantly, the report evaluates the performance of catchments in two archetypal suburban neighborhoods, one built in the 1960s and one currently

under construction. With a 15% increase in rainfall depth it found that both systems would fail (Watt, Waters, and McLean 2003).

But if these types of single-purpose or one-dimensional studies represent “paralysis by analysis” or hesitation to tackle a project with high stakes and few certainties, one article goes where no civil engineer has gone before.

A paper on Boston’s CLIMB (Climate’s Long-term Impacts on Metro Boston) project documents what appears to be the only large-scale integrated urban study to have occurred with the goal of producing a replicable set of processes and principles for analyzing, modeling, and developing a consensus for climate change adaptation strategies (Ruth and Kirshen 2001). The project, funded by the USEPA Office of Strategic Research and Planning from 2002 to 2004, brought the interconnected impacts of climate change on local urban infrastructure (flooding, water and natural resource destruction, power loss, disruption to commercial activities, etc.) and urban socioeconomics into focus.No other publication has been found of comparable insight coupled with fieldwork (N.A. 2007; Kiparsky and Gleick 2003).

The multiyear CLIMB project aimed to document and analyze Boston’s infrastructure systems and also to “investigate the multidimensional climatic, socio-economic and technological driving forces behind infrastructure change in the region,” and to “determine the integrated direct and indirect effects of climate change on infrastructure and its services, using dynamic modeling and scenarios,” in order to “identify present policy and research needs to ease the transition to changed climate,” and finally to “collaborate with stakeholders (Ruth and Kirshen 2001).

The CLIMB project provides leadership for infrastructure professionals where there seems to be a perplexing shortage, particularly after the catastrophic Hurricane Katrina of August 29, 2005, which, according to one study, permanently displaced more than 300,000 urban dwellers from New Orleans alone (City of New Orleans 2006). A late 2005 report issued by the Institute for Business & Home Safety found that even after Katrina’s devastation, only Hawaii and Alaska had taken action with regard to planning mandates for addressing natural hazards (N.A. 2005).

The Myth of the Design Storm

Infrastructure is commonly modeled using a design storm as the standard for a system’s capacity. The underlying assumption in using a design storm relies on knowledge of a theoretical, definitive, unchanging, hundred-year storm; the assumption hinges upon both climatological constancy and close, long-term observation.

However, many understand the implications of extreme weather patterns predicted by the IPCC. The 100-year storm could be the new 10-year storm. The 20-year drought could be the new normal. If the past can no longer be relied upon to predict the future, using a design storm model with 50-year-old rainfall data is thrown into question.

One researcher summed up the problem: “Although stormwater management practices have changed through time, assumptions about climate have remained static and limited to those defined by recent experience and historic measurements” (Watt, Waters, and McLean 2003).

According to stormwater author Andrew Reese, “US Geological Survey statisticians tell us we need at least 25 years of records to estimate the 100-year storm with some reliability [and 10 years for the 10-year storm, 15 for the 25-, and 20 for the 50-]” (Reese 2006). This raises major issues. If the future rainfall pattern is indeterminate, should the design storm be used? Another related issue is that of existing infrastructure. If everything has been sized according to past rainfall record, which may no longer be relevant, could urban infrastructure be dramatically undersized to handle future rainfall events? Further, climate change researchers are quick to point out that local and short-term climate forecasting is in its infancy and is not well suited to detailed hydrologic assessments (Fankhauser et al. 1999; Loaiciga 2003; Xu 1999).

The Army of Corps of Engineers’ investigation of the New Orleans levee system following Hurricane Katrina received criticism from the National Research Council because of the corps’ reluctance to predict the ability of the repaired levees to weather another hurricane (Vartabedian 2006). The corps’ challenges in analyzing risk factors are relevant to stormwater management by illustrating how calculations, which have in the past provided guidance for costly decisions with long-lasting effects, are derailed by too many unknown factors. The corps’ dilemma, shared by stormwater managers, rests in a situation that is not helped by refusing to admit that the knowledge underpinning planning is superseded by environmental instability and changing conditions.

Robert Bea, Center for Catastrophic Risk Management founder, believes that human error is the major factor to determine how robust the repaired levee system will be, stating, “There are no natural disasters; there are only natural hazards and human hubris.” Bea’s point is not that infrastructure engineers are judged solely by the success or failure of their efforts but that they

should be able to overcome any obstacles regardless of changing or unforeseeable conditions and factors. In response, Ed Link, lead investigator for the corps, points to the human problem as being an unknown that can't be factored into risk management, saying, "We have characterized past human error. How we guess at future behavior, I don't know. There is not a body of knowledge and science in that area that would allow us to that" (Vartabedian 2006). In other words, we don't know what we don't know.

Both are straw-man arguments. Bea's inference that human error accounts for the modeling difficulty doesn't hold up because it assumes it is possible to know and quantify all of the variables. Is it possible to pin down a design hurricane? The corps had planned to run 2,000 hurricane scenarios through supercomputers to predict levee integrity. It scaled the project back to 150 hurricane scenarios (Vartabedian 2006). Link's counter-argument sidesteps the more relevant question of whether the corps' computing power could possibly compensate for a lack of reliable data inputs. Wringing certainty from design models, with so much at stake, is a shaky proposition. Further, if the 150 models were to deliver a clear answer to the question of New Orleans' future habitability, what if it's not the answer that politicians or citizens want to hear? Political expedience will not be served by climate change. But who dares to break this news?

The corps' example tells us that managing expectations trumps managing uncertainty. This may not be acceptable for some civil engineers who are used to managing and mitigating risk. But the stakes are higher and the scale of failure threatened by climate change forces the awareness that risks that were once worth taking might no longer be.

Photo: Dan DeLong/Seattle Post-Intelligencer

A slight variation in rainfall in 2006 caused Seattle's stormwater infrastructure system to fail.

Hydrograph Modification

As some cities have already set forth plans for mitigating carbon emission, these plans may set up a situation that could create problems for stormwater infrastructure. The inadequacy of popular urban hydrology modeling techniques to draw accurate representation of what occurs on the ground is commonly voiced as a general complaint in stormwater literature (Ferguson 2003; Reese 2006; Funkhouser 2006a). In spite of criticisms, stormwater infrastructure generally performs well, but the gaps that have been widely noted may become problematic as climate change bends the rules. Two urban land-use trends that have not been generally acknowledged will complicate climate change–driven effects in highly urbanized areas unless stormwater managers work closely with planning departments: smart growth and residential "mansionization."

Derek Booth and Rhett Jackson's widely influential article quantified and described phenomena in 1997 that have come to be known as hydrograph modification. The article proved that small development projects adding just 10% imperviousness to a watershed greatly impacted urban hydrologic systems. As outer suburban Seattle woodlands were rapidly being subsumed by suburban sprawl, they saw that the existing natural streams and creeks that were expected to absorb these changes were impacted in ways not previously considered. Devegetation, deforestation, soil erosion, soil compaction, and the addition of impervious surfaces all greatly changed the amount, speed, pathways, and quality of runoff.

Hydrograph modification is the term for this physical process—development that disturbs landscape functions that naturally mitigate runoff such that runoff volume, intensity, and duration increase. One of the earliest uses of the term being applied to stormwater management was by the San Francisco Bay Regional Water Quality Control Board (SFRWQCB) around 2001 (Funkhouser and Lichten 2007).In 2003, the SFRWQCB asked its constituent counties to include a hydrograph modification management plan element in their stormwater management plan updates.

Santa Clara, CA, was the first county to update its plan. The second, Contra Costa County's Clean Water Program, ambitiously set out to develop a model for creating and implementing a hydrograph modification management plan (HMP) that would be comprehensive and easy to use, a decision influenced by a fair amount of new development. The HMP included simulating pre- and post-project runoff using a continuous rainfall record, generating flow-duration curves from the results, and designing a system that matches the pre-project flow-duration curve [Contra Costa County (California) Clean Water 2004]. In addition to using specific modeling techniques, hydrograph modification management (HMM) is characterized by using low-impact development techniques to offset development impacts. This approach drew heavily from the western Washington hydrologic model (Funkhouser and Bowyer 2007).

While HMM is new and evolving, the Contra Costa County approach has gained acceptance. Though low-impact development techniques and natural system approaches were used decades before the term *hydrograph modification* came into use, HMM's conceptual framework has helped raise awareness of urban watersheds' fine degree of sensitivity to soil and vegetation disruption and increased imperviousness. Yet, since HMM and low-impact development have been primarily applied to significant new development projects, as have most stormwater management strategies, another source of hydrograph modification has been overlooked.

There is an ubiquitous version of hydrograph modification, albeit on a micro-scale. Redevelopment, infill, or home-scaled remodeling in densely populated built-out inner-urban neighborhoods causes incremental hydrograph modification that will compound extreme weather events' effects on urban infrastructure. Continual changes to original housing stock and structures mean that neighborhoods' hydrographs can remain in flux indefinitely, particularly as urban centers pursue higher density as a means of reducing traffic congestion and carbon emissions by locating more people within walking distance of public transportation, commercial districts, and jobs. Seattle's Climate Change Action Plan mandates increased housing density to reduce carbon emissions (Hayes et al. 2006).

Many cities are rightly adopting smart growth strategies regardless of climate change because of its numerous environmental benefits. Smart growth is widely promoted by the USEPA and the American Planning Association to ease traffic congestion, reduce sprawl, preserve open space, and, if implemented properly, manage stormwater through increased housing density by redevelopment, infill, proper siting, and brownfield and grayfield site development (USEPA, *Protecting Water Resources with Smart Growth*).

Another recent trend that causes incremental hydrograph modification is real estate speculation. Some neighborhoods have seen single-family fixer-upper homes demolished and replaced by homes multiple times larger and sold for profit or occupied by owners' extended families who cannot afford a single-family home of their own (Simple Living America Web site).

Both smart growth and "mansionization," if left unchecked, result in incremental increases in imperviousness, leaving neighborhoods vulnerable to flooding.

Could this be one of the factors in the flooding on East Madison Street in Seattle? According to the director of Seattle Public Utilities, the storm drains that were the source of the fatal flooding had not caused problems like that before or even during massive storms of 2004 and 1993 (Nalder 2006a). If East Madison Street's watershed has changed since 2004, the intense storm and saturated soil may have been further aggravated by incremental hydrograph modification.

Seattle's recent real estate trends suggest that incremental hydrograph modification is definitely occurring in certain desirable neighborhoods. In single-family zoned areas in Seattle alone, 492 homes were demolished between 2003 and 2005, with an average of 500 demolished homes each year in all types of zoned areas in Seattle since 1998. New homes built in Seattle since 2000 are 500 square feet larger on average than pre-existing housing stock (Cohen 2007).

If every demolished home in Seattle was replaced with a new home, these data suggest that 250,000 square feet per year of imperviousness would be added each year. While this is not a huge amount of imperviousness, actual imperviousness increases are probably much greater since many of the demolished homes are not replaced by homes but by more densely grouped structures such as condos, town homes, or commercial buildings. Given the distribution and actual scale of redeveloped properties, this trend could greatly impact runoff. The Seattle Climate Change Action Plan calls for 22,000 new homes downtown and in nine inner-urban neighborhoods by 2024 (Hayes et al. 2006).

This is a widespread national pattern. According to the US Census Bureau's *Additions to Residential Structures—Owner Occupied Units* report, 3% of all urban owner-occupied housing units had some kind of outside structure added in 2005, including 674,000 decks, 398,000 additions designated as "other outside" additions, 387,000 porches, 97,000 carports, and 95,000 detached garages (US Census Bureau 2005).

The USEPA's guidance manuals promote smart growth as a stormwater management strategy and emphasize interdepartmental coordination with planning and development permits to ensure that denser development projects mitigate runoff (USEPA, *Protecting Water Resources with Smart Growth*). But are these guidelines being followed?

Some cities may have loosened such requirements for mitigation of runoff to encourage redevelopment or may have based requirements on pre–climate change conditions. However, cities with strict requirements and enforcement benefit from having

already educated and trained homeowners and small developers to form new habits.

Santa Monica, CA, requires all new home remodels to include designs to offset runoff from increased imperviousness. According to the Center for Watershed Protection,

[Santa Monica] has adopted an aggressive runoff control ordinance designed to reduce urban runoff pollution from new development and redevelopment and major remodeling projects. Each project must demonstrate a three-quarter-inch reduction in runoff generated by impermeable surfaces through capture and reuse, infiltration, or treat and release. (N.A. 2006)

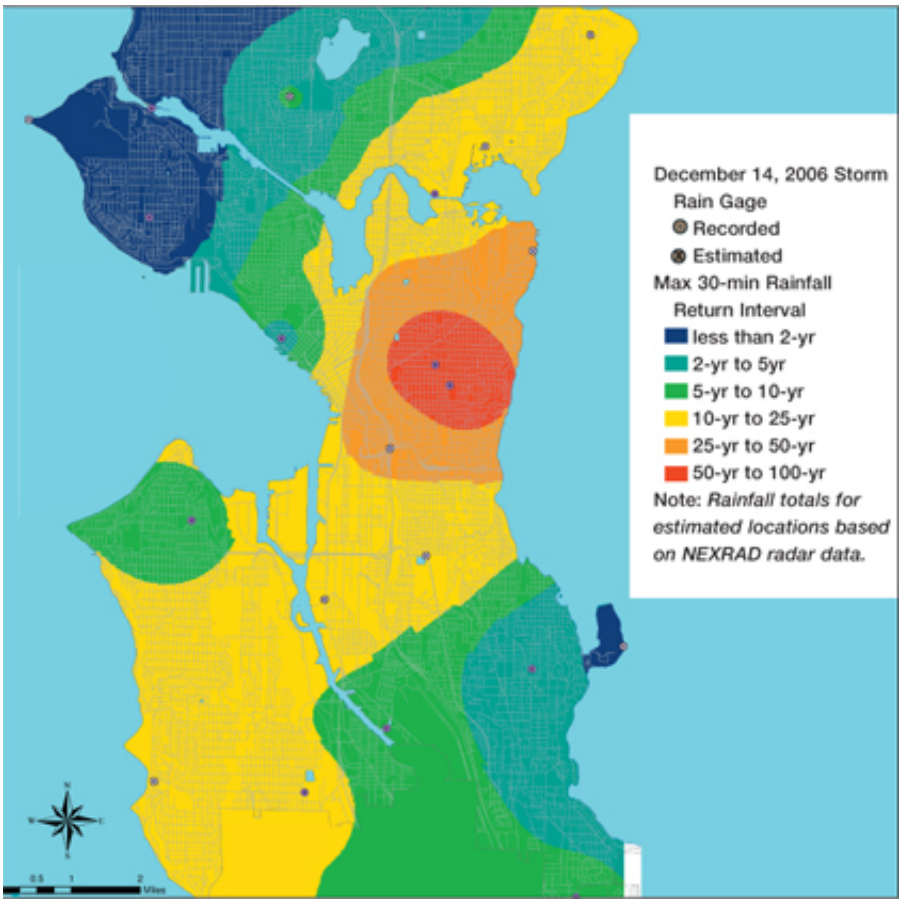
The Wisconsin Department of Natural Resources requires redevelopment projects to reduce runoff by 40% (Nisenson; *et al.* 2005). Not far from Seattle, the City of Lacey, WA, instituted a zero effect drainage discharge ordinance in 1999, possibly the first of its kind in the nation (Tilly 2003).

Disaster Management or Sustainable Infrastructure?

The concept of sustainable infrastructure is a useful frame for defining the approach and goals of adapting infrastructure to climate change. Sustainable infrastructure implies multifunctional applications that are more efficient and cost-effective, self-scaling, flexible, and less damaging to natural systems. The only problem is that the field of sustainable infrastructure is in its infancy and, as such, there is no defined set of principles for designing or implementing sustainable infrastructure in the US.

Sustainability in the built environment generally means building design that optimizes energy efficiency and minimizes environmental impacts. This is a result of the US Green Building Council's LEED (Leadership in Energy and Environmental Design) certification for professionals and minimum standards for sustainable building. Though infrastructure does not yet have its own version of the LEED standard, there are LEED standards for onsite stormwater design (LEED for New Construction v2.2 Registered Project Checklist, *http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1497*. Accessed March 14, 2007).

"Green building" as defined in US Green Building Council literature results from the assemblage of individual "green" components, such as water-efficient landscaping, heat-island-effect roofing, habitat restoration, recycled construction materials, and optimized energy performance (ibid). This definition is a poor fit for stormwater management, which has outgrown this model. Though stormwater began as a mechanistic practice (Debo and Reese 2003), it has moved toward a natural systems approach that works with nature (Tilly 2003) and encompasses and impacts watersheds, rivers, lakes, streams, creeks, oceans, cities, and suburbs. Many interconnected ecosystems are involved, and therefore, sustainability is a far more complex enterprise for stormwater infrastructure than for individual building design.



Source: Seattle Public Utilities

Generally when professionals in our industry speak of sustainable infrastructure, it refers to low-impact development, integrated site design, green infrastructure, or natural system restoration (http://seattle.gov/environment/building.htm). Still, this "assemblage" approach leaves out a number of important components.

One architect, in contrasting green building with sustainable building, makes a number of critical distinctions. Raymond Cole defines green building as reducing resource use and environmental destruction, while sustainable building is defined by simultaneously responding "to changing climate and repair[ing] previously damaged ecosystems." He compares green building's technical emphasis on "resource use environmental loadings and occupant comfort" to sustainable building's technical emphasis on "extending scope to understand behavioural and socio-cultural aspects of technological advance" (Cole 2005).

If the architect's definition of sustainable design sounds too philosophical to be of use, it is, in fact, being practiced by US civil engineers outside of this country. Sustainable infrastructure of a very different kind from the low-impact development type discussed above is used by non-governmental organizations in developing countries. US engineers are increasingly gaining training and experience in this type of sustainable infrastructure design and implementation through volunteer service learning in developing countries (Al-Khafaji and Morse 2006).

Engineers Without Borders (EWB) is a major driver of this kind of sustainable infrastructure and may be the first large engineering organization to operationalize sustainable infrastructure design. As such, EWB is an invaluable laboratory from which to develop new operating standards for adapting to climate change.

As practiced by EWB, sustainable infrastructure results from a set of planning processes, design principles, and "sustainable" applications. The ultimate goal is that "although the projects will relate to a primary technical assignment [potable water, sanitation, energy production, construction, agriculture, etc.], the outcomes will be measured in health, social, ecological, and economic metrics."

EWB has core principles. One is that three communities are central to every project: The community that will benefit, the

engineering community, and the community "back home." The US project teams are encouraged to assemble members from a variety of backgrounds, including public health, environmental studies, sociology, and others. EWB also relies on a whole systems approach to assessment and planning (Al-Khafaj and Morse 2006).

Design processes include giving stakeholders choice of their preferred applications from a range of options and including people from all stakeholder groups in the decision-making process. And finally, EWB provides guidelines for using sustainable low-impact water resource applications and renewable energy including rainwater harvesting, compacted earth catchments, sand filters, solar/UV still water purification (EWB 2005a) and solar, wind, and micro hydropower systems (EWB 2005b).

Engineers who have worked on EWB projects say the biggest difference between these and stateside projects is the amount of public process and level of public involvement. According to Dan Garbely, "On an EWB project where you're dealing with a community of 500 or 2,000, you can take time to talk to people in the community and get a feel for people's perspective. Here [in the United States] a lot of people take our infrastructure for granted. [We have] roads, water comes out of the tap, sewage goes away, and people don't think about it" (Funkhouser 2006a).

The public's awareness of infrastructure is changing as climate change effects are felt. As mentioned earlier, the Boston CLIMB project, supported by the EPA Office of Research and Development, puts the public at the center of its process for creating a climate change adaptation plan. The project focused on five infrastructure systems (transportation and communication, public health, coastal and riverine flood management, water supply and wastewater treatment, and energy) and "their relationships to each other and to socioeconomic development, technological change and human health" (Ruth and Kirshen 2001).

Uniquely, for a project of this scope, stakeholders were involved throughout. This required the selection of "a transparent modeling approach that facilitates understanding of alternative assumptions by project participants and support consensus building for mitigation and adaptation strategies." The goal, instead of producing a top-down forecast that would likely generate skepticism, was "of consensus generation about potential climate futures, their impacts on the region, and possible response strategies." And finally, "The upshot of all this is that significant emphasis needs to be placed on the *processes* by which analytical, modeling and policy results are achieved" (Ruth and Kirshen 2001).

Sustainable infrastructure, then, is more than applications and recreating natural systems. It also means involving the community to serve as a feedback loop for measuring the social, economic, and environmental benefits of infrastructure to the human ecosystem. Given the scale of the necessary adaptations, involving the public in taking on an increased role in implementing and maintaining sustainable applications makes sense from a practical perspective. As the US Census Bureau's *Additions to Residential Structures—Owner Occupied Units* report statistics show, homeowners are already engaged in their own adaptation activities. The task is to align homeowner and community interests with those of infrastructure adaptation.

Adaptive Applications

Hypothetically, what would it look like if stormwater management techniques were applied to climate change challenges? Assuming that climate change impacts were to generate new goals and design considerations for stormwater management, these would likely include (but not be limited to) the following:

Carbon emission reduction
Carbon sequestration
Energy production
Drought effects reduction/water resource protection
Extreme weather/temperature mitigation
Runoff temperature mitigation
Fire hazard reduction
Infrastructure repair/mitigation of combined sewer overflows

The stormwater management toolbox provides many ways to fulfill these new goals. Clearly, sustainable applications rank high. Some sustainable applications are well understood and have been in use for thousands of years. One article traces the use of rainwater harvesting in India from ca. 4,500 B.C. up to the present as a response to climate change (Pandey, Gupta, and Anderson 2003). On the other hand, others, such urban forestry and natural ponds, are still being explored as carbon sequestering techniques. Porous pavement requires little maintenance once installed and is highly effective for groundwater recharge to reduce drought effects (McPherson 2006).

In fact, every stormwater management application has a role to play in climate change adaptation. Culverts and concrete conveyance systems and curb and gutter infrastructure might be retrofitted with micro hydropower systems to harness the renewable energy of rain to provide emergency backup power or mechanical power during heavy storms.

Finally, public outreach may constitute a new category of sustaining infrastructure. This answers the question of who will water all of the new trees being planted to offset carbon emissions. Hundreds of urban forestry nonprofits across the country that are already planting and maintaining trees would likely be happy to do so (Alliance for Community Trees 2007).

The chart below, Adaptive BMPs for Climate Change, is meant to generate ideas and provide a way to assess BMP performance and selection to repurpose stormwater infrastructure for its highest and best use.

Stormwater Management as Adaptation to Climate Change

The predictability of the environment for the past 50 years or so has made urban infrastructure extremely vulnerable to changes in the fundamental conditions on which its design assumptions were based. Our society takes for granted hyper-real, fast-changing, disposable, flexible, remote, nano-scaled, multifunctional, and virtual activities that rely on constantly evolving technologies. But all of this convenience sits on top of infrastructure that has remained fairly analog, fixed, permanent, site-specific, massive-scaled, and generally single-purposed.

Resistance to change is not a 20th century phenomenon. In the early 1800s, fabric workers and weavers in England attacked machines to stop them from replacing their jobs. In resisting the industrial revolution's efficiencies based on mechanization and mass-scaled production, these workers gave us the myth of the killer robot that threatens to take humans' place. This is the first cautionary tale of modernity.

Seattle's storm of 2006 gives us what might be one of the last cautionary tales of modernity. As the foundation of modernity, our stormwater and sewer infrastructure is mass-scaled and still largely mechanistic. Those who cleared storm drain inlets the day Seattle flooded could not save neighborhoods from flooding because the infrastructure's capacity had been exceeded and it could do only one thing—fail.

This situation suggests that we reconsider how and why our infrastructure was designed so that we can reframe the way problems have been approached in the past to avoid widespread failures caused by an unpredictable environment. What is new about the way stormwater managers will effectively handle adaptation to climate change is that the decisions are theirs to make. Instead of waiting for a higher entity to give direction, local stormwater managers can chart their own paths. For the first time in history, stormwater managers have the tools and techniques to animate urban infrastructure as a collaborator in the urban environment rather than something inert and in a continual state of decline.

Topics: Regulatory issues, Low-impact development, Research