HAPI

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Water Quality, Health, and Place

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Photo by Ann Forsyth

The HEALTH AND PLACE INITIATIVE (HAPI) investigates how to create healthier cities in the future, with a specific emphasis on China. Bringing together experts from the Harvard Graduate School of Design (HGSD) and the Harvard School of Public Health (HSPH), it creates a forum for understanding the multiple issues that face cities in light of rapid urbanization and an aging population worldwide.

Health and Places Initiative
http://research.gsd.harvard.edu/hapi/
Harvard Graduate School of Design

The Research Briefs series summarizes recent research on links between human health and places at the neighborhood or district scale and provides background for a number of other forthcoming products—a set of health assessment tools, planning and urban design guidelines, urban design prototypes, and neighborhood cases. While the Research Briefs draw out implications for practice, it is these other tools that really provide specific, real-world guidance for how to create healthy places.

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Big Ideas

- Contaminated drinking water and lack of proper sanitation both lead to health problems. Deaths from poor water quality are largely preventable. However, these are only partly amenable to planning and design solutions—other actions from individual behaviors to large scale infrastructure and overall policies are key.
- Water supplies in low-income or developing countries are more likely to be contaminated with bacteria or parasites than developed or wealthy countries, and remain a major health risk for large populations (especially children under the age of 5).
- Decentralized water treatment and sanitation practices (at household or point-level) are important for preventing water-borne disease in developing countries. For example, building protected wells and latrines within reasonable walking distance, or chemically treating water before drinking.
- However, there is some evidence that sanitation practices at the individual level (e.g. boiling water, hand washing) demand a high level of adherence to be useful. There is growing water pollution in emerging economies, as urbanization and industrialization increases. Important sources of water pollution include agriculture, mining activities, landfills, and industrial and urban wastewater, as well as natural sources. Strongly regulating and monitoring these polluters and providing buffers between these land uses and water supplies are critical ways to mitigate pollution.
- Centralized water treatment (both for sewage and drinking water) is useful at preventing water-borne diseases, but often impractical in undeveloped, impoverished rural areas.
- In urban areas, a separated system for sewers and storm water drainage can protect water supplies from sewage overflows.
- Ecosystem protection and restoration is an important way to mitigate water pollution and improve water quality. At a small-scale, low impact development and green infrastructure can protect water supplies from polluted storm water runoff in urban environments, especially through vegetative buffers and bioretention methods. However, research is limited on direct effects on health.

What the Research Says

Health Issues

The United Nations latest World Water Development Report (WWDR) (2012) on "Managing Water under Uncertainty and Risk" describes how "Major human health risks from use of unsafe surface and groundwater are related to the presence of pathogenic organisms and toxic substances, from municipal and industrial waste discharges as well as storm-generated non-point-source runoff. In a global context, water contamination with pathogenic substances is acknowledged as the most serious risk factor in relation to human health" (WWAP 2012, 409).

Poor water quality from both point sources (such as factories) and non-point sources (such as chemically treated agricultural fields and run-off from parking lots) is associated with numerous health effects, including a number of waterborne diseases and effects related to toxic exposures (e.g. cancer, poisoning, and organ damage) (see Table 1). For interventions to prevent these health effects, see the Implications section.

Photo by Ann Forsyth

Contaminated water in low-income countries remains a major health risk for large populations (especially children under age of 5).

Table 1. Health effects of poor water quality.[1]

Health Effect	Cause
Water-borne illnesses (e.g. diarrhea, typhoid, cholera, hepatitis)	Bacteria, viruses, poor sanitation
Malnutrition and stunting in children	Water-borne illnesses, parasites
Child mortality	Water-borne illnesses
Maternal mortality	Water-borne illnesses
Chronic blood-loss and iron-deficiency anemia	Parasites (e.g. hookworms), poor sanitation
Cancer	Chromium
Accidental poisoning	Inorganic pollutants: trace metals, lead, mercury, chromium
Fluorosis	Fluoride overexposure
Damage to the brain, kidneys, and lungs	Inorganic pollutants, toxic metals
Damage to neural networks	Inorganic pollutants, toxic metals
Blood and brain disorders	Inorganic pollutants, toxic metals

1. Benova et al. 2014; Dangour et al. 2013; Fink et al. 2011; Hunter 1997; Hunter et al. 2010; Pruss et al. 2002; Schwarzenbach et al. 2010; WWAP (2012, 410, 414).

Photo by Ann Forsyth

Industrial and urban wastewater is an important source of water pollution.

Place Issues

There are many ways in which water quality is linked to places, but only some of them are amenable to improvement through planning and design. Low-income countries experience the greatest burden of disease due to poor water quality. However, broad infrastructure improvements are often impractical in the short term. Therefore, many solutions to immediate problems are likely to be small-scale even as larger scale infrastructure plans are implemented over time.

Water supplies in low-income or developing countries are more likely to be contaminated with bacteria or parasites than developed or wealthy countries, and remain a major health risk[2].

Example: Fink et al.'s (2011) analysis of 171 surveys (n= approximately 1.1 million children under age of 5 years in 70 low- and middle-income countries over the period of 1986-2007) describes how, "Despite continued national and international efforts, access to improved water and sanitation remains limited in many developing countries" (Fink et al. 2011, 1196).

Example: In their policy brief, Hunter et al.'s (2010) statistically analyzed recent global datasets, finding "...the proportion of people with access to safe water was correlated with GDP ($p<0.001$) and government effectiveness ($p<.001$). In a multivariate model, GDP remained the only significant independent covariate. Clearly, therefore, a low GDP is a major challenge facing efforts to improve water supplies" (Hunter et al. 2010, 6).

There are increasing pressures of water pollution in emerging economies.

Example: Schwarzenbach et al. (2010) reviewed 187 articles, focusing on global health and synthetic and natural water pollutants. In their summary points, they state, "At present, cheap production in emerging economies is too often accompanied with unacceptable pollution of natural water" (Schwarzenbach et al. 2010, 127).

2. Alderman et al. 2012; Dangour et al. 2013; Fink et al. 2011; Hunter et al. 2010; WWAP 2012.

Important sources of water pollution include agriculture, mining activities, landfills, industrial and urban wastewater, as well as natural sources (e.g. mineral leeching into water)[3]:

- Persistent organic pollutants come from multiple pollutant sources (waste sites, spills, agriculture, etc.), and as a result of biomagnification in the food chain result in diverse health effects.
- Agricultural land can have pesticide and fertilizer runoff, which pollutes nearby water sources.
- Mining runoff is associated with acids, leaching agents, and heavy metals.
- Industrial/hazardous waste sites contain many pollutant contaminants.

3. Schwarzenbach (2010, 114, 127).

Vulnerable Groups

People in low-income countries often suffer from poor water quality.

Example: This vulnerability is mainly due to rural locations and lack of basic infrastructure and sanitation resources (Alderman et al. 2012; Benova et al. 2014; Dangour et al. 2013; Fink et al. 2011; Hunter et al. 2010, Schwarzenbach et al. 2010, 127).

Photo by Ann Forsyth

There are issues of polluted runoff in urban areas.

China

China's water resources are inadequate, and a high number of lakes and rivers are severely polluted. Polluted water is associated with severe health effects.

Example: Zhang et al. (2010a) reviewed English and Chinese literature of the past 15 years on environmental health in China relating to air and water pollution (52 articles cited). They describe how, "China's water resources are inadequate…only a fifth of the US supply per head and less than a quarter of average world supply. Furthermore, China's water resources are very unevenly distributed. The heavily populated northern river basins contain 44% of the population…but have less than 13% of the water supply… Water shortages compel populations to use contaminated sources, which might explain associations between water scarcity and healthy effects, such as oesophageal cancer" (Zhang et al. 2010a, 1114). Additionally, only half of China's rivers and less than a quarter of its major lakes and reservoirs are suitable for drinking water after treatment (Zhang et al. 2010a 1114–1115). Unsafe drinking water and poor sanitation is a large problem, especially in rural areas (over 40% of rural residents, 6.2% urban residents are estimated to have unsafe drinking water and poor sanitation) (Zhang et al. 2010a, 1111). Additionally, modern industrial water pollution is affecting a huge number of people (exact numbers unknown), estimated to cause 11% of total digestive system cancer cases (~954,500 yearly) (Zhang et al. 2010a, 1111).

Despite dramatic increases in the availability of piped drinking water in the past fifteen years, a huge number of China's major cities do not comply with health-based standards and monitoring for drinking water.

Example: Gong et al. (2012) reviewed the English and Chinese literature of the past 15–20 years on urbanization and health in China (85 articles cited). They describe how, "Despite the massive increase in China's urban population, access to piped drinking water increased from 48% of the urban population in 1990, to nearly 94% in 2007. Provision of piped water, however, has not guaranteed access to safe urban water supplies and the burgeoning urban population is putting immense

strain on municipal water suppliers. A 2006 survey of several thousand suppliers revealed that more than a quarter of municipal drinking water plants and more than half of private plants were not complying with monitoring requirements for water quality. Urbanisation is proceeding rapidly even though nearly half of China's major cities do not comply with health-based standards for drinking water" (Gong et al. 2012, 6, citations removed).

Example: Kaiman (2013) states the severity of the problem in a news article for *The Guardian* newspaper, "Xinhua [official China newswire] reported last year that about one-third of China's resources are groundwater-based, and that only 3% of the country's urban groundwater can be classified as 'clean'."

However, there is some evidence that China has been taking steps and making plans to improve water quality and improve environmental sustainability.

Example: He et al. (2012) reviewed Chinese and English literature on the history, current status, and future of environmental management in China (over 50 articles cited). They describe how, "Economic growth has been prioritized over environmental protection for most of the last 60 years, meaning that China now has some of the most polluted skies and waterways in the world" (He et al. 2012, 25, citations removed). However, recently China's goals may be changing. He describes how China's Millennium Development Goals (MDGs) Report (2010) outlines many "environmental and ecological projects such as returning farmland to forests and grasslands, improving the quality of lakes and wetlands, protecting water and top soil, forest protection, water and air pollution control, wildlife protection, creation of nature reserves, energy efficiency, and renewable resources development" (He et al. 2012, 26). Finally, the 12th Five-Year Plan (2011-2015) of the National People's Congress, "sets goals for a wide variety of environmental infrastructures, including wastewater and solid waste treatment" (He et al. 2012, 34).

Things for Certain (or semi-Certain)

Table 2. Things for certain (or semi-certain)[4]

Statement	Planning and Design Implication
Large populations in low-income countries are getting sick and dying from waterborne diseases, due to lack of access to clean water and sanitation.	• Investment in centralized water and sewer treatment (where possible) • Separated system for sewage and storm water in urban areas • Decentralized protected wells and latrines within reasonable walking distance; local water vendors • Programs to improve water quality at the household or individual level (harvest rainwater, dual-pipe systems, filtration/chemical water treatment)
Water pollution is a serious water quality issue globally, especially for emerging economies.	• Governmental and industry regulations, policies and codes, especially for mining, landfills, spill sites • Land use control/zoning/ buffering pollutant sources away from drinking water • Reduction in proportion of impervious surface in direct connection to stream network • Riparian buffers • Low-impact development • Preservation and restoration of ecosystems • Programs to incentivize green chemicals, monitoring and clean up technologies

4. Alderman et al. (2012), Benova et al. (2014), Brabec et al. (2002), Dangour et al. (2013), Fink et al. (2011), Haller et al. (2007), Hunter et al. (2010), Hutton et al. (2007) Schwarzenbach et al. (2010, 127), UNEP (2010), WHO (2011).

Things up in the Air

Improving public health through water quality is complicated and it is not always clear what the best approach may be.

Example: Hunter et al.'s (2010, 8) literature review on water supply and health (67 articles) describes, "that many uncertainties remain about how to improve public health through improvements in the water supply."

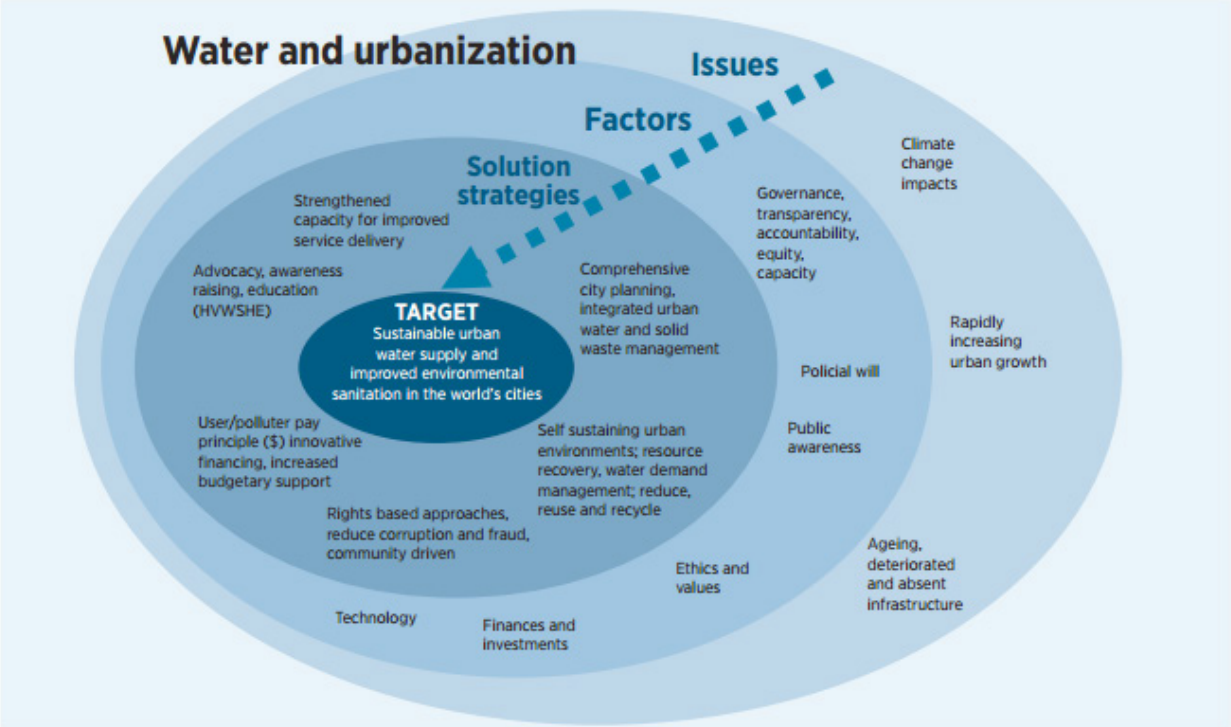
Example: Schwarzenbach et al.'s (2010, 127) literature review explains (184 articles), "Owing to the enormous variability of micropollutants, mitigating a given chemical water problem is commonly a quite challenging task. Each case requires its own interdisciplinary scientific knowledge and methods, and each has its own technical, economical, and societal dimensions."

The United Nation's World Water Assessment Programme illustrates some of the challenges of improving water quality in the age of rapid urbanization (see Figure 1 below). Planning and design solutions can play a moderate role in protecting water supplies and improving environmental sanitation. However, there is a large role for government, policy and advocacy.

The short- and long-term effects on human health from the increasing global chemical pollution of natural water are uncertain (Schwarzenbach 2010, 127).

Example: Schwarzenbach et al.'s (2010) literature review summarizes how, "The increasing global chemical pollution of natural water with largely unknown short- and long-term effects on aquatic life and on human health is one of the key problems facing humanity" (Schwarzenbach et al. 2010, 127).

Figure 1. Issues and solutions related to water and urbanization.



Source: WWAP 2012, 427, used with permission.

Climate change will aggravate water quality issues, but exactly how water quality may be affected by climate change has many uncertainties, and will vary widely by region.

Example: Whitehead et al. (2009) reviewed literature and recent models of how water quality might be affected by climate change in the UK. They describe how, "Potential impacts on water supply have received much attention, but relatively little is known about the concomitant changes in water quality. Projected changes in air temperature and rainfall could affect river flows and, hence, the mobility and dilution of contaminants. Increased water temperatures will affect chemical reaction kinetics, and, combined with deteriorations in quality, freshwater ecological status. With increased flows there will be changes in stream power and, hence, sediment loads with the potential to alter the morphology of rivers and the transfer of sediments to lakes, thereby impacting freshwater habitats in both lake and stream systems" (Whitehead et al. 2009, 101).

Trace amounts of pharmaceuticals in drinking water is unlikely to be a problem for human health.

Example: The World Health Organization's (2012) report Pharmaceuticals in Drinking Water found, "Analysis of the results indicated that appreciable adverse health impacts to humans are very unlikely from exposure to trace concentrations of pharmaceuticals that could potentially be found in drinking water. Concentrations of pharmaceuticals in drinking-water are generally more than 1000-fold below the MTD, which is the lowest clinically active dosage. The findings from these three case-studies are in line with the evidence published over the past decade, which suggests that appreciable risks to health arising from exposure to trace levels of pharmaceuticals in drinking-water are extremely unlikely" (WHO 2012, ix-x).

Implications

In these HAPI Research Briefs we aimed to find implications for planning and design at roughly the neighborhood level. These could include quantifiable standards, more qualitative but yet evidence-supported insights, and other good practices. Not every topic has a full complement of these implications.

Standards

The World Health Organization's latest *Guidelines for Drinking Water Quality* (2011), offer specific microbial thresholds for both large-scale, centralized water processing, as well as individual household treatment (WHO 2011, see Chapter 7). Similarly, it offers specific thresholds (where available) of chemicals and pollutants (including radiological aspects) relevant to health (WHO 2011, see Chapters 8 and 9). **Specific thresholds for microbes and radiation are clearer than chemicals and pollutants.**

Other countries also often have national water quality guidelines (e.g. United States Environmental Protection Agency). However, in order to be useful in preventing bacteria, viruses and parasites, it has been proposed that high adherence (>90%, as close to 100% as possible) is needed for water quality interventions. Such claims, such as in the example below, are worthy of further investigation.

Example: Brown and Clasen (2012) conducted a quantitative microbial risk model to determine health gain effectiveness with various levels of adherence to water treatment interventions. It was found that, "A decline in adherence from 100% to 90% reduces predicted health gains by up to 96%, with sharpest declines when pre-treatment water quality is of higher risk" (Brown and Clasen 2012, e36735). They conclude, "Results suggest that high adherence is essential in order to realize potential health gains from HWT" (Brown and Clasen 2012, e36735).

Example: Montgomery and Elimelech (2007) published an overview article (45 articles cited) on water and sanitation in developing countries. While sanitation and hygiene interventions at the "point of use" (POU) are useful at reducing the rates of diarrheal diseases, they describe how, "The performance of POU treatments is highly dependent on source water quality and the degree to which households adhere to the operation and maintenance requirements…An additional challenge is determining whether health outcomes are primarily due to POU treatment or confounding factors, such as hand washing, education, economic well-being, and culture" (Montgomery and Elimelech 2007, 21).

Insights

There are multiple planning and design interventions that can be done to prevent and mitigate the health effect of water pollution and contamination. These can be broken down into several categories of strategy: preventing or at least reducing pollution, treating pollution, and preserving and restoring eco-systems.

Preventing Pollution

The easiest, cheapest, and most useful way to improve water quality is to prevent it from becoming polluted in the first place (UNEP 2010, 8). According to the UNEP, "Pollution prevention strategies reduce or eliminate the use of hazardous substances, pollutants, and contaminants; modify equipment and technologies so they generate less waste; and reduce fugitive releases and water consumption" (UNEP 2010, 8).

Photo by Ann Forsyth

Protected wells within reasonable walking distance are one way to improve water quality in low-income countries.

Table 3. Planning and design strategies to prevent water pollution and contamination.[5]

Strategy	Approaches
Watershed protection plan	• Source protection through zoning, buffers, etc.
Upgraded sewage treatment/ Improved sanitation	• Centralized municipal water treatment, larger capacities or strategies listed below. • Decentralized protected latrines within reasonable walking distance • Dual-pipe systems in houses (for drinking versus waste water) • Separation of storm-water and sanitary sewer water in water treatment infrastructure
Improved water supply/ Choice of water source	• Source protection, capacity building • Water source (e.g. protected wells) within reasonable walking distance (e.g. <1,000 m) of dwelling • Regulated local water vendors in developing countries • Harvest household rainwater
Governmental and industry regulations	• Especially for mining, landfills, spill sites
Land use control	• Zoning/buffering pollutant sources away from water sources
Economic incentives	• E.g. for green biodegradable chemicals, or polluter fees

5. Adams and Foster (1992), Bernstein 1997, Haller et al. (2007), Hunter et al. (2010), 1, Hutton et al. (2007), O'Connor et al. (2002), Schwarzenbach (2010, 128), WHO (2011, 94, 97, 99).

Photo by Ann Forsyth

Zoning greenspace buffers near water is a good land use control measure to protect and improve water quality.

Treating Pollution

In addition to preventing water pollution and contamination, many water sources require treatment and cleaning to improve water quality before use. According to the UNEP (2010), "Both high-tech, energy-intensive technologies and low-tech, low-energy, ecologically focused approaches exist to treat contaminated water. More effort to expand the deployment of these approaches is needed; they need to be scaled up rapidly to deal with the tremendous amount of untreated wastes entering waterways every day; and water and wastewater utilities need financial, administrative, and technical assistance to implement these approaches" (UNEP 2010, 8).

Table 4. Conventional infrastructure interventions to treat water pollution and contamination.[6]

Strategy	Approaches
Centralized water and sewer treatment	• House piped water supply and sewer connection • Wastewater engineering treatment and reuse
Programs to treat water at an individual level before use	• Boiling • Filtration • Chemical water treatment
Conventional development infrastructure (end-of-pipe practice, centralized approach, regional approach, or traditional approach)	• Centralized stormwater management ponds • Conveyance-piping systems • Pond/curb inlet structures • Constructed concrete roadside ditches • Curb and gutter infrastructure
Programs to incentivize new technologies	• Pollutant cleanup
Water quality standards and guidelines	• Policies, plans • Water safety plans (system assessment, monitoring, management and communication)

6. Ahiablame (2012), Fielbelkorn et al. (2012, 622), Haller (2007), Hutton (2007), O'Connor (2002, 74), Schwarzenbach et al. (2002, 127-128), Tchobanoglous et al. (2002), WHO (2011)

Preserving and Restoring Eco-systems

Example: Last, but not least, "Healthy ecosystems provide important water quality functions by filtering and cleaning contaminated water. By protecting and restoring natural ecosystems, broad improvements in water quality and economic well-being can occur. In turn, ecosystem protection and restoration must be considered a basic element of sustainable water quality efforts" (UNEP 2010, 8).

Table 5. Planning, design, and green infrastructure interventions to preserve and restore eco-systems.[7]

Strategy	Approaches
Watershed protection zones and plans	• Target buffer zones, • Stormwater management • Water quality monitoring
Vegetative buffers	• Riparian buffers • Streamside forest buffers
Wellhead protection zones and plans	• Target buffer zones (time of travel for contaminants)
Reduce proportion of impervious surface in direct connection to stream network	• Where possible preserve forested land • Wetlands and open space near stream networks

7. Brabec et al. (2002), Lehr and Keeley eds. (2005, 524), National Research Council (2000), O'Connor et al. (2002), Parkyn (2004), Sweeney and Newbold (2014), Witten et al. (1995), , Zhang et al. (2010b)

Photo by Ann Forsyth

Protecting and restoring ecosystems is an important way to improve water quality.

Other Good Practices

Green infrastructure and low impact development (such as bioretention/rain gardens) may reduce some negative effects of storm water runoff (at a small scale) – but design is key.

Bioretention/Rain Gardens

Example: Ahiablame et al. (2012) reviewed more than 250 articles in the global literature on usefulness of low-impact development practices. They found, "Average retention of bacteria in bioretention ranges from 70% to 99% (Table 1)" (Ahiablame et al. 2012, 4258).

Green Roofs have not yet been proven to have an effect on water quality.

Example: Berndtsson (2010) reviewed 18 articles on green roof's performance towards management of runoff water quantity and quality. She concludes, "It is found that general statements about the potential beneficial role of vegetated roofs in urban environment are common through the current literature. However, the scientific evidence of the various benefits is still insufficient" (Berndtsson 2010, 358).

Example: Similarly, Ahiablame et al. (2012, 4258) found that, "Nutrient removal using green roofs presents some challenges." Furthermore, "Similarly to nutrients, research on the ability of green roofs in removing metals from stormwater resulted in varying findings" (Ahiablame et al. 2012, 4259).

Photo by Ann Forsyth

Rain gardens can help slow and clean urban stormwater runoff.

Permeable Pavements

Example: Ahiablame et al. (2012) review of the global literature on usefulness of low-impact development practices found, "Average runoff reduction from porous pavements varies between 50% and 93%" (Ahiablame et al. 2012, 4259). Furthermore, "The removal of TSS [total suspended solids] and nutrients by permeable pavements has been reported in a number of studies with average reductions ranging from 0% to 94%" (Ahiablame et al. 2012, 4260). Finally, "Average metal reduction by porous pavements has been reported to vary between 20% and 99%" (Ahiablame et al. 2012, 4260).

Swale Systems

Example: Ahiablame et al. (2012) review of the global literature on usefulness of low-impact development practices found, "Average [runoff] retention in swales varies between 14% and 98% for nutrients and TSS [total suspended solids], and up to 93% for metals" (Ahiablame et al. 2012, 4261).

Photo by Ann Forsyth

However, green roofs have not yet been proven to have an effect on water quality.

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