USING GREEN INFRASTRUCTURE IN KARST REGIONS

For decades rapid development around the country has led to a proliferation of impervious surfaces, such as rooftops and parking lots, making stormwater runoff one of the leading causes of water pollution in the country. Rainwater collects on impervious surfaces, picks up contaminants and flows into local streams and rivers. In parts of the country that have karst topography, stormwater pollution poses an even greater challenge. The porous rocks allow polluted runoff to quickly contaminate groundwater, and concentrated flows of stormwater erode and destabilize the bedrock. Green Infrastructure (also referred to as Low Impact Development and Environmental Site Design) can help resolve this intractable problem by using green space to minimize the impacts of stormwater runoff. Many communities in karst regions have been reluctant to use green infrastructure techniques because they can promote infiltration and cause water quality problems. With proper precautions, green infrastructure can guide a community's stormwater management efforts and help preserve vulnerable water resources for future generations.

GREEN INFRASTRUCTURE

Green infrastructure encompasses a collection of stormwater management practices that collect and filter runoff and prevent it from polluting waterways and groundwater. There is a wide variety of green infrastructure techniques that range from on-site practices such as rain barrels and green roofs to landscape-scale projects such as protecting stream buffers and wetlands. Unlike conventional methods that treat rainwater as a waste product, green infrastructure treats rainwater as a resource by retaining or infiltrating runoff. Green infrastructure seeks to supplant or provide treatment for the impervious surfaces such as roofs and pavement typical of traditional development and construction methods. Rain and snowmelt from impervious surfaces rapidly runs off into surrounding waterways, carrying with it heavy metals, toxics, oil and other pollutants found on roads and parking lots.

Green infrastructure offers a variety of benefits that traditional stormwater management techniques do not. They provide cleaner water by reducing erosion and polluted stormwater flows to local waterways. Techniques such as bioinfiltration retain and infiltrate water, reducing floods, replenishing groundwater resources and buffering against droughts. Some practices such as green roofs not only improve water quality but also reduce urban heat island effects, lower building energy costs and reduce air pollution by absorbing particulate matter. Green infrastructure can provide site level solutions which can reduce a building's stormwater impact. Replicated across multiple sites, the benefits add up. Green infrastructure also includes planning solutions and larger scale techniques, such as constructed wetlands, which absorb and filter stormwater, providing larger scale reduction and filtration services. Traditional infrastructure is still useful in certain situations and comprises the overwhelming majority of existing stormwater systems, and green techniques work well in concert with them by reducing overall wet weather flows into sewer pipes and treatment plants during rain storms.

KARST TOPOGRAPHY

Karst topography is a landscape made up of carbonate rock such as limestone or dolomite that has dissolved through interaction with groundwater. These rocks break down rapidly when they come in contact with groundwater because they contain high concentrations of the mineral calcite. When rain falls to the earth, it is slightly acidic due to absorption of carbon dioxide (CO2). As it passes through the soil, it picks up more CO2 and grows more acidic. The acidity of the water creates a chemical reaction when it comes in contact with the calcite in the bedrock, causing the rock to dissolve and break down. Groundwater passes through fissures and cracks in the rock, widening the openings and creating larger passages, caves and sinkholes. Over time, these holes can greatly reduce the stability of the bedrock, sometimes resulting in sinkholes that can collapse rapidly and cause property damage. Sinkholes and fissures also allow contaminated stormwater runoff to discharge directly to aquifers without the filtration and pollutant removal that would normally occur during groundwater infiltration. Pollutants carried in stormwater can rapidly contaminate aquifers underlying highly soluble limestone and dolomite formations. Groundwater typically moves rapidly through karst aquifers, reducing interaction with the rock and limiting the chemical and microbial breakdown of contaminants.[1] As a result, once contaminated water enters a karst aquifer, there is little potential for pollutant removal.

GREEN INFRASTRUCTURE IN KARST REGIONS

The fragile nature of karst topography means that development can have an additional environmental impact and makes stormwater management particularly challenging. Many communities in karst regions have failed to recognize the danger presented by improper stormwater management and have allowed development to proceed in sensitive areas. The expansion of impervious surfaces concentrates runoff in certain areas rather than spreading it across the landscape. As a result, large volumes of stormwater often flow to a few sinkholes, rapidly undermining the bedrock, increasing groundwater pollution and resulting in flooding. Cities such as Bowling Green, Kentucky have experienced significant sinkhole flooding due to development that increased downstream stormwater runoff.[2] Stormwater management techniques meant to counter these negative impacts have often only worsened the problem. A number of communities and individual developers have filled sinkholes, hoping to reduce groundwater contamination. This has often led to greater downstream flooding and water pollution as water travels down slope to other sinkholes.[3]

There is a growing consensus that strategies based on preserving pre-development hydrology and maintaining critical vegetated areas can minimize groundwater pollution and flooding in karst regions. Preserving pre-development hydrology and utilizing the water quality benefits of vegetated ecosystems are central principles of green infrastructure. Green infrastructure techniques may finally provide the answer to the long-standing question of how to best manage stormwater in geologically-sensitive regions. However, green infrastructure techniques cannot be applied uniformly in all karst areas. A subset of green stormwater practices promotes infiltration, which could destabilize bedrock. Although green infrastructure techniques remove pollutants and improve the quality of runoff with treatment by soil and vegetation, increased infiltration in karst formations is problematic. Karst terrain is not uniform, and different rock formations have varying susceptibility to sinkholes. Pure limestone formations

are eroded very easily; therefore green infrastructure techniques that promote any infiltration should be installed with impermeable liners and underdrains to prevent water migration from the stormwater control practice into the surrounding karst formations. The design of these techniques will be similar to urban applications where the passage of stormwater from green installations into surrounding soils is undesirable because of soil contamination, compacted soils, or utilities. Green practices with impermeable liners provide stormwater treatment while preventing unwanted consequences of infiltration into native soils. The underdrain system directs excess stormwater to a conventional stormwater system after treatment rather than into the ground.[4] Sites overlying more heterogeneous formations are less susceptible to sinkholes, and techniques such as curb cuts that promote limited infiltration may be used.

A successful approach to stormwater management in karst areas will rely on the central principles of green infrastructure – minimizing impervious surfaces, retaining pre-development hydrology and using ecosystem benefits to provide a variety of environmental benefits. Impervious cover should not exceed 15% in a given watershed to avoid significant water quality impacts on karst aquifers.[5] In karst terrains, it is especially important to protect critical land areas. Undisturbed land with well-vegetated topsoil can slow and infiltrate runoff without eroding the bedrock or causing water quality problems. One study in the Spring Creek Watershed near State College, PA found that a pasture receiving significant upstream runoff from developed areas reduced runoff volume and velocity by 60% while filtering out pollutants.[6] This pasture and other critical natural areas are able to absorb and filter stormwater in a landscape that is otherwise unable to process and safely infiltrate runoff. Disturbing this area would not only reduce its ability to absorb runoff, it would also make it a conduit for the upstream stormwater from impervious areas. There would be a double impact on downstream water resources if it were developed.

Recharge zones such as sinkholes should also be protected by creating a buffer that creates a vegetated strip around the sinkhole or restricts certain land uses. Vegetated buffers can slow runoff and trap contaminants before they reach the underlying aquifer. They have been found to trap 80-90% of sediment and chemicals carried in runoff, with greater contaminant removal found as buffer width increases.[7] Unfortunately, in many cases buffer zones are determined without taking into account local circumstances. Many environmental guidelines limit activities within 50-100 feet of the bottom of a sinkhole, while the drainage area to the sinkhole could be much larger. Buffers should be extended to the lip of the sinkhole. It may be impractical in some cases to establish a vegetated buffer or restrict activity throughout the entire recharge zone of a sinkhole. However, concentric buffers with varying levels of protections can achieve strong protection of groundwater quality without imposing unreasonable burdens on surrounding land users. Physical buffers immediately next to sinkholes can prohibit any disturbance and aim to preserve the natural hydrology of the area. The larger drainage area can be kept free of potentially damaging activities such as pesticide use or be subject to other less-intrusive management schemes.[8] The City of San Antonio has used these strategies successfully to protect the karstic Edwards Aquifer, which is the primary source of the city's water supply. The city has spent millions of dollars to protect critical land overlying the aquifer, prioritizing land around sinkholes and major faults.[9]

TABLE 1 – GREEN INFRASTRUCTURE TECHNIQUES

Infiltration Based	Non-Infiltration Based
Bioretention	Rain barrels
Bio-filter	Cisterns
Seepage pits	Downspout disconnections
Pervious pavement	Reduced road widths
Infiltration trenches	Curb and gutter elimination
Vegetative swale	Curb cuts
Buffer strip	Green roofs

Adapted from Northern Shenandoah Valley Regional Low Impact Development Manual

In addition to protecting critical land areas, a variety of green infrastructure techniques can mitigate the impacts of stormwater runoff. Rain barrels, cisterns, curb cuts and green roofs can be used throughout regions underlain by karst areas because they involve little or no infiltration (see table 1). By retaining rainfall, these techniques reduce runoff and the potential for groundwater contamination while providing numerous other environmental benefits. Minimizing driveway or road width can also reduce the amount of stormwater by limiting impervious surface. Developers can reduce the impacts of new construction by following the existing topography and minimizing grading throughout the new landscape.[10] During construction, contractors should disturb as small an area as possible and minimize erosion, which can fill sinkholes and cause flooding.

MAPPING

Proper stormwater management in karst areas must be guided by detailed knowledge of the underlying bedrock and critical recharge areas.[11] High resolution maps and fieldwork can identify karst features, but are costly and not available to many communities. One survey in Virginia found that only 36% of surveyed communities had maps or data on karst features in the area. Even those communities that have data often rely on USGS maps and aerial photography, which often contain insufficient detail to identify many karst features. Unstable bedrock and vulnerable recharge areas may be overlooked as a result. Highway and utility corridors built on vulnerable areas have caused significant groundwater contamination in parts of Virginia because the siting was based on inadequate assessments of karst features.[12] Major karst mapping initiatives have been undertaken in south-central Texas, Mower County, MN and the Suwanee river basin in Florida. While this may be beyond the resources of many communities, investigations should be undertaken at the local level to locate sinkholes and minimize the potential for groundwater contamination.

CONCLUSION

Green infrastructure provides a number of practices and techniques that can help communities overcome the difficulties typically associated with stormwater management in areas underlain by karst formations. By protecting critical natural areas and using smaller-scale techniques to retain stormwater, it is possible to reduce the amount of polluted runoff contaminating aquifers and undermining bedrock. In the process, communities can reduce flood damages and protect vital water supplies for future generations.

1. Belo, Bradley. *Natural Hazard Mitigation Planning for Karst Terrains in Virginia*. Virginia Polytechnic Institute, 2003.

2. *Ibid.*

3. Fennessey, Lawrence. *Defining Natural Land Areas Critical for Stormwater Control in Karst Regions*. Proceedings of the 2003 Pennsylvania Stormwater Management Symposium [Villanova, 16-17 October 2003]. Villanova: Villanova University, 2003.

4. Hyland, Sara. "Analysis of Sinkhole Susceptibility and Karst Distribution in the Northern Shenandoah Valley, Virginia: Implications for Low Impact Development (LID) Site Suitability Models." Virginia Polytechnic University, 2005.

5. Veni, George. "A Geomorphological Strategy for Conducting Environmental Impact Assessments in Karst Areas." *Geomorphology* 31 (1999): 151-180.

6. Fennessey, Lawrence. *Defining Natural Land Areas Critical for Stormwater Control in Karst Regions*. Proceedings of the 2003 Pennsylvania Stormwater Management Symposium [Villanova, 16-17 October 2003]. Villanova: Villanova University, 2003.

7. Barfield et al. "Water Quality Impacts of Natural Filter Strips in Karst Areas." *Transactions of the American Society of Agricultural Engineers* 41.2 (1998): 371-380.

Petersen, A. and Vondracek, B. "Water Quality in Relation to Vegetative Buffers around Sinkholes in Karst Terrain." *Journal of Soil and Water Conservation* 61.6 (2006): 380-390.

8. Kastning, Ernst and Karen Kastning. *Buffer Zones in Karst Terranes*. Proceedings of the Karst-Water Environment Symposium [Roanoke, VA, 30-31 October 1997]. Blacksburg: Virginia Polytechnic Institute and State University, 1997.

9. Stone, Dan and Geary Schindel. "The Application of GIS in Support of Land Acquisition for the Protection of Sensitive Groundwater Recharge Properties in the Edwards Aquifer of South-Central Texas." *Journal of Cave and Karst Studies* 64.1 (2002): 38-44.

10. Blick, Sandra et al. *New Jersey Stormwater Best Management Practices Manual*. New Jersey Department of Environmental Management, 2004.

11. Belo, Bradley. *Natural Hazard Mitigation Planning for Karst Terrains in Virginia*. Virginia Polytechnic Institute, 2003.

12. Kastning, Ernst and Karen Kastning. *Buffer Zones in Karst Terranes*. Proceedings of the Karst-Water Environment Symposium [Roanoke, VA, 30-31 October 1997]. Blacksburg: Virginia Polytechnic Institute and State University, 1997.

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