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STORMWATER BEST MANAGEMENT PRACTICES

A First Guide For Landscape Architects

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Dry pond in Gilbert, AZ. Photo by Bob Chappel taken April 2009

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INTRODUCTION

Impermeable surfaces surround us in the form of roads, parking lots and rooftops. Rain from these surfaces cannot be absorbed where it falls but rather increases in magnitude inundating natural bodies of water further downstream with unnaturally high flows. Many of these impermeable surfaces have accumulated contaminants such as oil, nitrogen, phosphorus, organic chemicals and heavy metals. Consequently, stormwater not only erodes river banks because of high flows but also pollutes these natural water bodies. It seems important to find ways of dealing with stormwater in a way that does not do harm to these enviroments.

HISTORICAL SETTING

To prevent flooding and improve hygiene in built up areas, underground canals were built leading stormwater, together with sewage, directly to rivers, streams, lakes or the sea. This solved the immediate problem of flooding and unsanitary conditions in urban environs but created other problems further down the pipe. Subsequently, during the latter first half of the 20th century, treatment plants were developed to prevent the undeniable damage raw sewage was causing to the environment. Both stormwater and sewage were treated in these facilities. Many of these combined systems are still in use today. The systems normally work adequately but, when it rains heavily, they back up causing low-lying basements to flood with raw sewage from the overflow.

In Sweden, during the 1960s, double canals became the new norm: one transporting raw sewage to treatment plants, and one transporting stormwater. This kept raw sewage isolated during flooding. However, stormwater was again released untreated into the recipient, causing erosion and contaminating it with the aforementioned pollutants.

During the 1970s, municipalities developed underground retention and treatment systems that delayed and treated the stormwater near to where it fell. This prevented the extreme surges that had caused erosion and flooding further downstream. This type of system, although addressing some of the problems associated with stormwater, still falls short. It is very costly and does not allow for treatment afforded by vegetation, nor does it take advantage of the aesthetic and recreational value of water. Consequently, in recent years, Best Management Practices (BMPs) involve the use of more and more above ground systems, which are being built to treat stormwater as a resource. Landscape architects are often involved in designing these systems, especially in urban environments where they have recreational and aesthetic value.

THESIS STATEMENT

In this paper I am going to overview BMPs for stormwater systems design. What techniques and principles can landscape architects use to create good storm water management systems? I am limiting my discussion to BMP systems that also fulfill an aesthetic or recreational role. Echols and Pennypacker (2008) use the term "Artful Rainwater Design (ARD)" to describe systems of this kind. ARDs may contain elements such as ponds, open canals, bioswales, rain gardens or green roofs.

METHOD

I collected my information primarily from literature written on BMPs but also through contact with experts and by visiting ARD sites. The written material has been in books, journal articles and thesis papers.

I began by searching the library database for Swedish references by searching with the word "dagvatten" which means stormwater in English. To find articles from other countries written in English, I searched Google Scholar with "stormwater" as a search word.

My tutor Per Berg suggested I contact another professor at the Department of Urban and Rural Development at SLU, Professor Clas Florgård. Florgård suggested I visit Augustenborg in Malmö and also referred me to Pär Söderblom, the landscape architect responsible for the green roofs at Augustenborg. Professor Berg also recommended that I visit "Vattenparken" (The Water Park) in Enköping together with one of my classmates Petra Löfgren who is writing her paper on Vattenparken. Before going there I also contacted Ulf Pilö who is the chief of operations at the water and sewage utility in Enköping.

I asked Petra Löfgren what literature she had found on the park and whom I could contact in order to receive copies of the same. Ulf Pilö gave me a short video on the park, together with some data about tests made on the water quality when it enters and leaves the park. Petra and I visited the park together.

Before visiting the Augustenborg site, I contacted Söderblom to see if it would be possible to meet and discuss the system. This unfortunately was not possible. I was, however, able to ask him some questions and receive answers by way of e-mail. Furthermore he directed me to literature and others involved in the project. I also contacted the Botanical Greenroof Garden at Augustenborg but it was unfortunately closed during my visit to the area.

RESULT

SITE SPECIFIC BMP CONSIDERATIONS

To determine the best strategy for managing stormwater, several characteristics of the particular site must be known, such as:

What kind of soil structure is there?

Soil structure and type are important in determining the feasibility of the system. If the soil is compacted, water will not infiltrate but pool up or, and if on a grade, it will flow along the surface. Compacted soil can, however, be an advantage if the intention is to have a pool of water such as a wet pond.

What is the hydrology?

A high water table can make infiltration nearly impossible.

How valuable is the land?

This is important in determining the economic feasibility of one system over another, based on how much space each requires.

What are the present land uses?

It is important to consider these factors to ensure the system's safety and suitability. The character of the BMP should harmonize with existing architecture.

How much stormwater are we dealing with?

This is dependent on several factors such as the drainage area and climate and will affect the land area required for the BMP. The rate of precipitation and duration of the storm are critical.

How polluted is the stormwater?

The degree of pollution dictates the thoroughness of treatment required.

What kind of environment do we wish to create with the system?

Possibilities include the creation of sites intended to have a strict urban character or sites intended to imitate nature. Recreational and aesthetic values may or may not take precedence over BMP functions.

CLASSIFICATION OF STORMWATER & RECIPIENT

A first step in determining what type of BMP system is best suited for a site is to gather information regarding what kind of stormwater is going to enter the system and what quantity and quality of stormwater should come out (Claytor & Schueler 1996). The stormwater quality before entering the site is dependent on the usage of the runoff surfaces and the targeted stormwater quality exiting the site is dependent on how sensitive the recipient is to pollution, warming and erosion. Stormwater pollution levels and the receiving water bodies sensitivity to pollution are classified to further aid in deciding what kind of BMP would be best suited to the situation.

Bengt Krusemo (2007), from the architectural and engineering firm Bjerking who specialize in BMPs categorizes stormwater into four different classes.

Stormwater with low levels of pollutants

Generally speaking, suburban areas, roads with less than 8,000 vehicles traversing them each day and parks have low levels of pollutants.

Stormwater with medium levels of pollutants

Urban areas and roads trafficked by 8,000-15,000 vehicles have medium levels of pollutants.

Stormwater with medium-high levels of pollutants

Large parking lots and roads trafficked by 15,000-30,000 vehicles per day have medium-high levels of pollutants.

Stormwater with high levels of pollutants

Roads with more than 30,000 vehicles per day are presumed to have high amounts of stormwater pollutants.

Krusemo (2007) also classifies receiving water bodies (including groundwater) into three degrees of sensitivity to pollutants.

Very sensitive to pollutants

Only stormwater with low levels of pollutants should be directed to these water bodies. All other stormwater should be treated before entering or redirected to another less sensitive water body.

Moderately sensitive to pollutants

Stormwater with medium levels of pollutants should be treated, however, less stringant filtering can be applied.

Less sensitive to pollutants

These water bodies can receive untreated stormwater with medium levels of pollutants. Stormwater with medium-high or high levels of pollutants should, however, always be treated.

THREE BASIC PROCESSES OF STORMWATER MANAGEMENT

Retention

Retaining stormwater means that the stormwater is consumed on the premises either by transpiration through plants, evaporation, or filtration through the natural soil to the groundwater aquifer. The ability of BMPs to retain stormwater is limited by space available, soil structure and vegetation.

Detention

Detention means that stormwater is slowed down by various means, which prevents damaging peak flows from eroding riverbanks or causing water treatment plants from exceeding their capacity. Detention can be achieved via a choked outtake (smaller pipe out than in), by spreading the stormwater over a larger area, or lengthening its route to the recipient by diverting it through further BMP features.

Filtering

Filtering the stormwater is another task BMP systems are intended to do. This may occur by sedimentation, consumption of pollutants by vegetation and microorganisms, or by filtration through non-organic media such as sand.

Vegetation and microorganisms can deal with soluble pollutants whereas mechanical filters such as sand are most effective at removing particles that contain phosphorous and heavy metals. Vegetation may take up heavy metals and phosphorous but re-release much of what they absorb when they whither down. A potential way of removing these pollutants is by cutting back and disposing of the clippings.

ARTFUL RAINWATER DESIGNS IN USE TODAY

There are several types of ARD systems each suited for different conditions and requirements. Systems may include bioretention filters, ponds or green roofs.

Stormwater filtering systems

Stormwater filtering systems filter stormwater of pollutants before the stormwater continues its way down the main stormwater conveyance system or is allowed to seep down to groundwater. Stormwater filtering systems are primarily intended to remove pollutants from stormwater but also have some effect in controlling flowrates. Both offline and online filtering systems exist. In offline filters, stormwater is diverted from the main conveyance system, filtered, and then returned to it. Offline systems are designed to accept a limited amount of stormwater. During exceptional events, only the first flush is filtered which often contains the greatest amount of contaminants. Additional flows bypass these filters. Online systems are actually part of the conveyance system and all stormwater from an area, regardless of the quantity, goes through them. Stormwater filtering systems are often built below the surface and have no aesthetic value. Surface systems like bioretention stormwater filters and bioswales, on the other hand, can add greatly to a location's beauty.

According to Claytor and Schueler (1996) stormwater filtering systems contain several components:

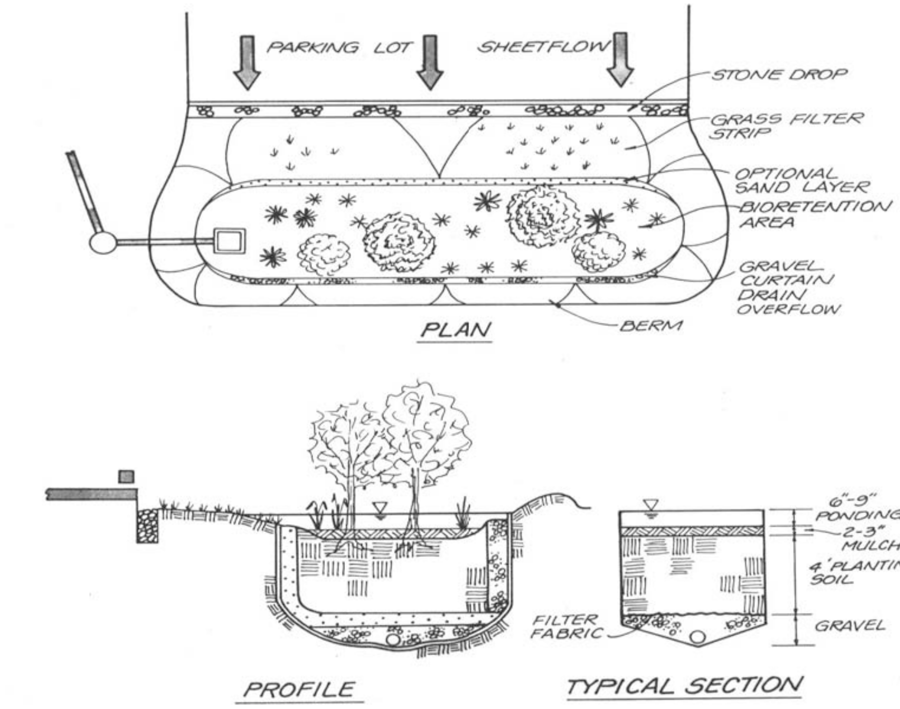
Inflow regulation: This regulates the flow of stormwater entering the filter.

Pretreatment: This prevents large particles from entering the filter thereby preventing premature clogging.

Filter bed and filter medium: The filter medium is what actually does the filtering and can be a variety of things such as sand, peat, gravel, grass or compost. The filter bed is the area the filter medium is contained in. The key factors of a filter bed are its area, how deep it is and the layers within it.

Outflow mechanism: This is what controls the release of stormwater from the filter back to the conveyance system or groundwater. It is often a perforated pipe that collects the stormwater over an impermeable membrane. On the other hand, it could also be a permeable membrane that allows the stormwater to continue to percolate down to groundwater.

Bioretention filtering systems - otherwise known as rain gardens are modeled after naturally occurring systems. They may have a prefilter called a filter strip. A filter strip is a grassy area between an impervious surface and the main bioretention filter. In order for filter strips to work properly, it is important that



Plan and section of a bioretention system in a parking lot: Claytor and Schueler,1996 (figure 1.8).

stormwater entering filter strips enters as sheet flow. This is to prevent the filter being short-circuited by the formation of concentrated streams. To ensure sheet flow, stormwater should not travel distances greater than 45 meters on pervious surfaces and no more the 22 meter on paved surfaces (Claytor & Schueler 1996).

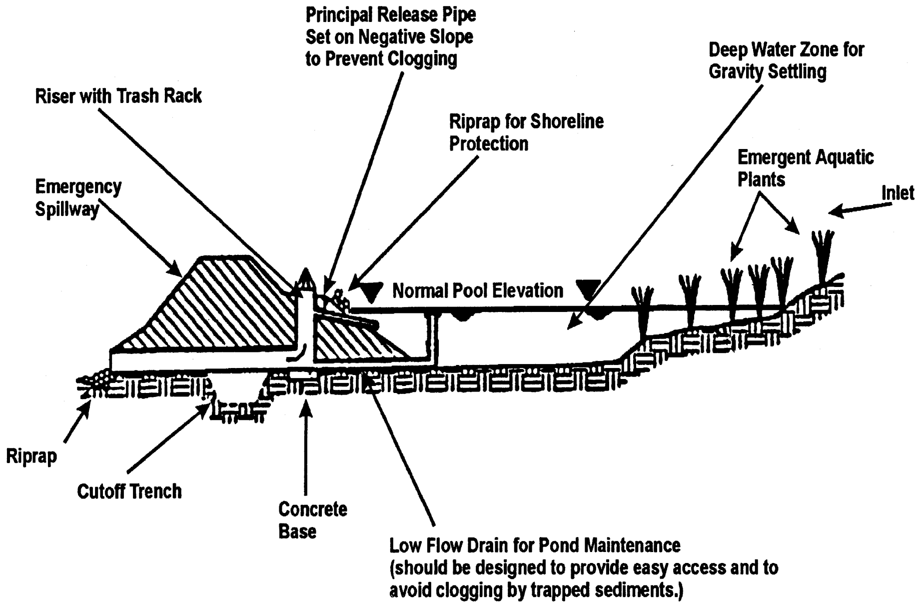
Bioswales - are broad ditches with a gentle slope designed to filter and retain stormwater. They have check dams that slow down the stormwater's progression and allow infiltration. Bioswales can take on many forms. Generally, bioswales can be contained in approximately one per cent of the land area draining into them. Since bioswales are linear, they work well along impermeable surfaces such as roads and sidewalks. According to Claytor and Schueler (1996) there are three main types of bioswales (vegetated channels): grassed channels and wet and dry swales.

a) Grassed channels are designed to handle small amounts of rain that fall frequently. Grass channels do most of their filtering in the top three centimeters of soil. This is because stormwater usually moves through them quickly.

b) Dry swales are intended to drain completely usually within a day of the storm event. This occurs due to a very permeable layer that allows the stormwater to percolate below ground level. Dry swales may have a perforated pipe at the bottom of the filter mass to collect and return the stormwater to the conveyance system or allow the stormwater to drain into the soil below.

c) Wet swales are also intended to temporarily hold stormwater, usually for a period of about 24 hours. They are often built where the water table is high and function as wetland systems. Unlike dry swales, they do not have an underlying filter bed and are formed in the soil already existing on the site. Wet swales filter stormwater, similarly to wetlands, through sedimentation and uptake by vegetation and microorganisms.

Ponds



Wet pond section: Maryland Department of the Environment, 1986 cited in Barr Engineering Company, 2001 (p. 254).

Ponds can be designed in various ways and for various purposes. A stormwater pond needs to be able to absorb large quantities of stormwater when it rains and still be aesthetically pleasing during dry periods. There are three fundamental types of ponds for stormwater management: wet ponds, extended wet ponds and dry ponds.

a) Wet ponds have a constant water level and are primarily designed to filter water, not to control flow. As stormwater is added to the system, water already contained in the pond is drained off. Particles settle out of the stormwater and vegetation and microorganisms take up soluble pollutants. Microorganisms reduce nitrogen levels through a process called denitrification. Denitrification occurs in anaerobic conditions and requires carbon in the process. This carbon is generally supplied by vegetation. Wet ponds can add high aesthetic and recreational value to an environment, if done effectively. Paths can be built near their shore allowing greater access. Wet ponds can, however, easily become filled with unsightly algae and release noxious odors and it may also be difficult to maintain the desired water level. These problems seem to be most prevalent in small ponds. Large ponds, however, require more space and considerable areas draining into them to maintain their water level. Drainage areas should be at least 10 hectares in size and the ponds should have an area of at least 0.1 hectares (Barr Engineering Company

2001). Wet ponds should also have shallow tables to provide habitat for emergent vegetation (ibid.).

b) Extended wet ponds both filter and detain stormwater. They have a constant pool of water but also a freeboard that can detain stormwater during storm events. This water is then slowly released from the pond until the level has returned to normal. Extended wet ponds are less suited for recreational purposes because their shorelines change preventing structures such as paths and benches being built close to them.

c) Dry ponds are also designed to filter and detain stormwater. They, however, dry out completely between storm events. Dry ponds may have a permeable bottom through which stormwater can percolate down to groundwater. In other instances there is an impermeable bottom and a choked outtake that delays the stormwater on its way to the recipient. This arrangement allows pollutants to settle out of the stormwater before entering the receiving natural water body and thereby preventing the erosion of river banks.

Green roofs

Green roof at Augustenborg. Photo by Scott Wahl taken April 2009

Green roofs are roofs covered with vegetation, typically sedum. Green roofs not only consume stormwater, but also add an extra layer of insulation to roofs and extend the life of roofing materials underneath by protecting them from UV rays and rapid changes in temperature. The green roofs provide habitat for wildlife in heavily built-up areas and are aesthetically pleasing. Interestingly the vegetation on green roofs is not the primary factor in stormwater retention. In their study on the effectiveness of green roofs, Van Woehrt et al. (2005) concluded that the substrate on which the vegetation grows is what absorbs most of the water. Nevertheless they found that the vegetation serves in other ways, such as preventing erosion of the substrate and cooling the building by way of transpiration. Green roofs are also pleasant to look at with their varying color and organic texture.

EXAMPLES OF ARTFUL RAINWATER DESIGNS

Augustenborg in Malmö

Augustenborg in Malmö is an apartment complex where stormwater is detained in extended wet ponds and open canals and is designed to be an integral part of the landscaping of the complex. Additionally a school next to the residential area and a storage facility that bears the Augustenborg Green Roof Botanical Garden are part of the project. Rainwater is collected from the impermeable surfaces, such as roofs and walkways, and is directed to the ponds through canals and gutters. Before the BMP system was built, basements in the area would flood when it rained heavily because the combined stormwater sewage system could not handle the loads. The ARD, completed in 2001, was designed to reflect the 1950s architecture of the apartment buildings (Krantz, Hjerpe, 2002). This is reflected in the straight lines of the canals and the use of cement, limestone and the black-painted metal railings.

Later additions to the system at Augustenborg had a more contemporary organic look with grass-covered swales instead of cement canals. This was because of criticism received from residents that the often dry cement canals were unsightly and collected litter (ibid). There are now several ponds in the complex in various forms. The ponds are shallow and lined with cement. The ponds were designed to be shallow in order to limit the risk of drowning; as a result the ponds have become overgrown with algae. The cement bottoms also prevent other aquatic plants from taking root, thus further giving the algae the upper hand in competing for resources. This, among other things, has been the cause of widespread disenchantment among residents. In fact two of the ponds were rebuilt to reduce the algae growth. The Augustenborg project was intended to be a model that others could follow. Much has been learned from the project.

Pär Söderblom (2004) made some comments of lessons learned from Augustenborg:

- Consider using dry ponds instead of wet ponds that are attractive whether they are filled with water or not.
- Wet ponds should be larger and deeper to prevent algae growth but have a gentle slope to prevent accidents.
- The ponds should also have a bottom plug to make draining and cleaning easier.
- Maintenance for the entire area should be the responsibility of one organization to prevent gaps in maintenance at the borders.
- Consider grass-lined canals instead of cement canals because they stay cleaner looking and collect less litter.
- Avoid open drainage canals through plantings, since they have a tendency to clog up and, thus, not work effectively.
- Ponds with circulating water should have an anaerobic filter, such as a filter of coarse gravel, to reduce nitrogen levels.

Algae-filled pond at Augustenborg. Photo by Scott Wahl taken April 2009

Cement and sandstone canal with grass-covered overflow area at Augustenborg. Photo by Scott Wahl taken April 2009

Vattenparken in Enköping

Vattenparken in Enköping was designed to treat and delay the stormwater of half of Enköping's impermeable surfaces (a 1700 hectare area) before it is released into Enköping River (Teknikförvaltningen 2004). Additionally, the park was intended to expand the habitat for plants and animals and to create an aesthetically pleasing park for the people living nearby to enjoy (Teknikförvaltningen 2004).
The park is made up of a narrow winding pond, grassy meadows and grass-covered mounds. The entire treatment system also contains a dry pond and a field where most of the pollutant particles are meant to be trapped. We followed the

Orthofoto of Vattenparken 1:3500 ©Lantmäteriet Gävle 2009. Medgivande I 2008/1959

water's path through the park. When the stormwater first enters the park it is led along through a narrow canal, together with water that has already gone through the system. The water then goes to the dry pond where there is time for many of the particles to settle. From the dry pond it is pumped up to sprayers that spray the water onto a field of grass. The water runs through the grass and soil down to a ditch leaving even more particles as it travels. This is where most of the pollutants are removed and the water is oxygenated, reducing any undesirable odors. From the ditch the stormwater enters the pond at one of its deepest sections (1.5 m). Where the stormwater enters the pond, I observed many small fish and other larger fish preying on them. The ponds were not intended to have fish and it is unknown how they got there. The fish eat the vegetation and thereby reduce the effect of the cleaning process (Teknikförvaltningen 2004). From the deep area the stormwater continues towards an area with a depth of 0.7 m and then through the shallowest area, one in which the water level is about 20 cm deep. This goes over to again greater depths forcing the stormwater to pass changing environments. The different depths are intended to allow for a larger variety of flora and fauna, water temperatures and oxygen levels. In the deepest sections plants such as water lily

Nymphaea and amphibious bistort *Persicaria amphibia* are intended to grow. This is also where microorganisms that prefer the anaerobic conditions in the deeper waters do some of their most important work in a denitrificaton process. Nitrate (NO_{3-}) and nitrite (NO_{2-}) are the two most common forms of nitrogen in stormwater and are used as energy for digesting carbon from decaying organic matter. In this process harmless nitrogen gas (N_2) is produced that then escapes into the atmosphere permanently reducing nitrogen levels in the water. In contrast, vegetation in the pond also absorbs nitrogen and phosphorous when it grows but it releases the pollutants back to the water when it dies back. Further along the stormwater's path, through the long and narrow pond, is an area around 0.7 m deep. Living conditions here are optimal for water plants such as unbranched bur-reed *Sparganium emersum Rehmann* and waterplantain *Alisma plantago-aquatica*. The stormwater continues its journey through the park to a shallow area around 0.2 m in depth. Conditions here are ideal for plants best-suited to the shallow waters such as greater pond sedge *Carex riparia Curtis* and slender-tufted sedge *Carex acuta L.* Whether these plants actually dominate in the area was difficult for me to tell due to the time of year that I visited the site. What I did see at the shallower depths were dried stalks of cattail *Typhaceae* and common reed *Phragmites australis*. The stormwater circulates through the park several times passing varying vegetation and depths and is then slowly released to a canal spilling into Enköping River (Teknikförvaltningen 2004).

DISCUSSION

COMPARISON BETWEEN VATTENPARKEN AND AUGUSTENBORG

Vattenparken and Augustenborg exemplify the application of very different Best Management Practices, although both are intended to be used for recreational purposes. Vattenparken incorporates a system that centrally treats, detains and retains highly polluted stormwater on the outskirts of Enköping before later being released into a natural water body. Augustenborg's system is primarily meant to detain rather than treat or retain fairly clean stormwater primarily coming from roof tops. In Augustenborg, stormwater is returned to the combined underground stormwater/sewage system. Vattenparken, on the other hand, is not really part of the built-up environment like the Augustenborg system. It is built on a former agricultural field that provided few recreational benefits. Vattenparken clearly provides more recreational opportunities than the field it is built upon. On the other hand, Augustenborg does not clearly do so. Augustenborg's ARD is built right next to where the rainwater falls on and near people's homes and is meant to integrate into the residents' daily lives. This creates greater demands on its functioning as a replacement for a traditional garden. Building Augustenborg's system required the removal of large trees, grass lawns and pleasant seating areas, disgruntling residents in the process. People are likely to have higher demands on the environments they live in than for a park on the outskirts of town like Vattenparken.

SUMMARY OF TYPICAL ARDs AND THEIR USES

- Bioretention systems are especially suited to parking lots.
- Bioswales are ideal for treating stormwater from linear structures like roads and sidewalks.
- Ponds are most successful in parks where greater areas are available and people are less sensitive to unpleasantries such as algae growth.
- Green roofs are very effective in dealing with stormwater besides cooling, providing habitat and embodying aesthetic qualities.

CONCLUSION

Studying all the different options available to landscape architects in creating an Artful Rainwater Design, I have come to realize that there are many different systems appropriate to various conditions. There are situations where functions such as retention, detention and filtration weigh differently in the decision process. Careful site analysis of aspects such as soil structure, hydrology, land value, land uses, stormwater quality, and sensitivity to pollution of the receiving water body are imperative to creating a successful above ground system. Beyond the standard BMP functions, systems need to be accepted by the people whose environments are affected by them. This requires the participation of these people in the design process as well as consideration of aesthetics and recreational opportunities. By studying the systems in Augustenborg and Vattenparken I came to the conclusion that planners must consider how systems will be maintained and how they will impact people's lives. The need for managing stormwater near its source has given rise to great opportunities for landscape architects to create beautiful outdoor spaces using stormwater as a resource. It is vital, however, that they function properly so that people will continue to support them. Otherwise the opportunity may be lost and systems may return underground.

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