

Rethinking Bioretention Design Concepts

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Abstract

Since its initial development and application in 1993 (Clar, et al., 1993), the Bioretention system also referred to as “rain gardens” has rapidly become one of the most versatile and widely used BMPs throughout the US and many parts of the world. It has recently become identified as a preferred site practice for green building design and LEEDS certification.

A recent review of Bioretention design guidance being used throughout the US revealed that with some relatively minor changes, the design concepts contained in the original design manual remain unchanged. This paper provides a critical review of some elements of the original design concepts and introduces new directions for the evolution of this BMP.

The design elements examined in this paper include:

- ❖ The allowable ponding depth
- ❖ The minimum width and length parameters
- ❖ The depth and type of the soil/filter media
- ❖ The design of bioretention as an infiltration practice
- ❖ Plant materials

Introduction

Our collective knowledge related to the design and construction of bioretention systems is still relatively small. Since the initial introduction of this control practice in 1993 (Clar et al., 1993) relatively there have been only relatively minor improvements. This paper builds upon the authors’ experience with the design and construction of bioretention systems over the past 15 years and examines the possibility for improving or optimizing the design elements of selected parameters. These include the allowable ponding depth, the minimum width and length parameters, the depth and type of soil/filter media, the design of bioretention as infiltration practices, and the selection of appropriate plant materials.

Allowable Ponding Depth.

Local jurisdictions are adopting allowable ponding depth criteria that typically range from six (6) inches to 18 inches (Lucas, 2005). There is generally very little discussion or guidance on the technical basis for this ponding depth. A review of the technical factors that govern the determination and selection of this design parameter is worthwhile. It is important to remember that selecting a 12 inch depth instead of a 6 inch depth reduces the surface area of the facility by 50 percent and using a 24 inch depth would further reduce the surface area requirement to 25 percent of the initial design thus generating substantial reductions in system construction cost.

Table 1, was developed as part of the Maryland Standards and Specifications for Infiltration Practices (Clar & McCuen, 1984). The table provides the maximum

Table 1. Maximum Allowable Ponding and Storage Depths (Inches)

Soil Texture	Hydrologic Soil Group	F* (in/hr)	Max Allowable Ponding Time (hrs)			Max Allowable Storage Time (hrs)			Remarks
			24	48	72	24	48	72	
<i>Sand</i>	A	8.27	198	397	595	496	992	1489	
<i>Loamy Sand</i>	A	2.41	58	116	174	145	290	434	
<i>Sandy Loam</i>	B	1.02	24	49	73	61	122	183	
<i>Loam</i>	B	0.52	13	25	37	31	62	93	
<i>Silt Loam</i>	C	0.27	6	13	19	16	32	49	
<i>Sandy Clay Loam</i>	C	0.17	4	8	12	10	20	31	
<i>Clay Loam</i>	D	0.09	2	4	6	5	11	16	Ponding depth limited
<i>Silty Clay Loam</i>	D	0.06	1.4	3	4	4	7	11	“
<i>Sandy Clay</i>	D	0.05	1.2	2.4	4	3	6	9	“
<i>Silty Clay</i>	D	0.04	0.96	1.92	3	2	6	7	“
<i>Clay</i>	D	0.02	0.48	0.96	1.44	1	2	4	“

F* is the saturated hydraulic conductivity rate as reported by Rawls, Brakensiek and Saxton, 1982 (See Table 2)

allowable ponding time for each USDA textural classification, based on various allowable ponding time strategies. The most common ponding time strategy being used by local governments is 48 hours, although a good case could be made for a 72 hour policy. It can be observed that all A, B, and C hydrologic soil groupings can meet the 6 (six) inch ponding criteria with a 48 hour dewatering strategy. All A and B soils as well as the silt loam (F = 0.27) can meet the 12 inch ponding depth with a 48 hour dewatering

strategy. Also it can be observed that all A and B soils can meet a 24 inch ponding criteria with a 48 hour dewatering strategy.

Consequently it appears that most local criteria for ponding depth are under utilizing the infiltration capacities of existing soils and may be directly responsible for unnecessary expenses in the application of LID practices such as bioretention.

Minimum Width and Length Parameters.

Many local guidance manuals for bioretention design include criteria for minimum and maximum values of width and length parameters. A review of a number of local programs is presented in Table 2 (Lucas, 2005). The most common guidance follows the

Table 3. Bioretention Criteria for Length and Width (Lucas, 2005)

SOURCE	LENGTH (ft)	WIDTH
Prince George’s Co, DER, MD (Clar, et al, 1993)	> 30-40	>10-15
Pennsylvania (PACD, 2001)	Same as PGDER	Same as PGDER
US EPA	Same as PGDER	
New York (NYSDEC)	Sized according to Darcy’s law	
Vermont (VTDEC)	Length:width = 2:1	
Los Angeles, CA	> 40	15-25
Georgia (ARC, 2001)	Identical to Vermont manual	
North Carolina (Hunt & White)	Sized according to Darcy’s law	
Vancouver (GVSDD, 1999)	> 5 meters	> 3 meters
Idaho (IDDEQ, 2001)	Surface area < 1 acre	

initial recommendations developed by Prince George’s County (Clar, et al, 1993) which recommends a minimum width range of 10-15 feet and a minimum length of 30-40 feet.

Practical experience, however, indicates that the actual minimum width criteria is only four feet. This would consist of a bioretention cell with a 2 foot bottom width, six inch ponding depth and 2:1 side slope and no freeboard allowance. If a freeboard depth of 6 inches is provided, then the minimum width increases to six feet. A system of this size might be found on a residential lot and be used for handling runoff from a roof downspout or driveway.

Practical experience also suggest that there is no science based limit on a maximum value for width. The actual maximum value for width will typically be determined by considerations for the reach of the equipment used to excavate the cell and apply the gravel and soil mix, as well as the topography of the site.

With respect to minimum length, practical experience also reveals that there is no science based minimum. Some jurisdictions suggest that the length be twice the width, which

would based on a minimum width of 4 to 6 feet would result in minimum length values of 8 to 10 feet. More typically, site conditions, particularly topography in conjunction with the storage volume of runoff required will largely determine the minimum requirements for length and width.

Depth and Type of Soil/Filter Media

The depth and type of the soil/filter media is probably one of the least understood aspect of the bioretention design. It is important to remember that when we first developed the bioretention guidelines for Prince George's County, there were no precedents for a system of this type and for the most part we limited to a literature review and desktop exercise (Clar, et al. 1993). The original intent was to create a living upland soil/plant filter that would in time replicate the functioning of a forest system. Now that we have 15 years of hands on experience to build upon, another assessment is warranted.

The initial concerns with respect to the specification of a soil/media filter was to provide a well-drained soil and a suitable growth medium for the plant materials. A worst case scenario was envisioned where the bioretention cell would be located in a landscape island in the middle of a parking lot.

The initial guidelines for soil materials was based on the properties of Table 1. Three soil textural classifications were selected, loamy sand, sandy loam and loam. It can be observed that these three soil types all had infiltration rates of 0.52 inches per hour which coincided with the Maryland minimum requirements for infiltration practices of 0.52 inches per hour. The sand textural classification was not selected because it was perceived to have high too rapid a flow rate at 8.27 inches per hour and also we had concerns related to droughty soils and plant survival.

The initial guidelines also recommended a soil media depth of 30 to 48 inches primarily designed to assure that the plant material would have a suitable growth medium. The depth of the media was not selected based on optimizing pollutant removal functions since it was assumed that this function would pretty much occur naturally based on the literature review of pollutant removal rates in forested systems as well as the EPA Literature related to the application of secondary effluent to living filters.

Since these initial guidelines were published a number of bells and whistles have been added to the original design concept. Some of the most frequent modifications include the use of under-drains, the use of manufactured filter media, the use of chimney drains, and the use of various combinations of gravel jackets. Some of these modifications are worthwhile while others have the potential to undermine the intent of the original design. In many instances these bells and whistles add substantially to either the material or construction cost and become a roadblock to the use of these practices.

With respect to the filter media, Prince George's County, having experienced a number of construction failures of these systems quickly moved to adopt the use of under-drains and a revised soil media mix which consisted of 50-60 % concrete sand, 20 % well aged

organic material such as double shredded mulch, pine fines or composted leaf mulch. While this mix has proven to work quite well, it has raised the cost of the soil mix from \$15-18 / cubic yard to \$35-40 / cubic yard. It is important to note that the cause of the bioretention failures was not approached from a technical basis, but rather the changes in soil media were primarily a knee jerk reaction. Since the initial failures in Prince George's county numerous bioretention systems have been built using the original soil specs and appear to be working very well.

A possible explanation for the early failures experienced in Prince George's County may be have resulted from the absence of having testing requirements for the soil materials brought on site. Another possible explanation may be associated with the use of the loam textural classification. This material may contain up to 33% clay in the soil mix. If this material is handled and compacted the resulting mix may lose some of its permeability characteristics.

The State of Delaware also experienced some initial failures in the construction of bioretention systems. In response it also adopted the use of under-drains and developed a manufactured soil mix which consists of 1/3 concrete sand, 1/3 peat moss and 1/2 double shredded mulch (Lucas, 2005). This mix displays very high permeability rates in the range of 8-15 inches per hour, and has also resulted in a price increase for the material in the range of \$60-80, which is generated very strong opposition and complaints from engineers and developers in the State. A related concern with this type of media mix is its durability and life cycle and the associated long term maintenance costs for these type of systems. Since 67 % of the mix is biodegradable there is a concern for compaction and settlement of the media as well the frequency of replenishment of the media and the associated impact to the plant materials in the media.

The knowledge gained from these experiences helps to establish or reinforce the need for certain design objectives for LID practices. Ideally LID practices should be designed to around sustainability principles which include simplicity of design, high life cycle and low construction and maintenance costs.

Well Drained Soils. The original design guidelines did not address the situation of what to do if a site contains good natural soils such as those included in the specifications. Consequently, today we may have situations where we are excavating and removing perfectly good natural soils such as sand loams, loamy sands or loams and replacing these soils with manufactured media. This approach is in conflict with sustainability criteria, and thus we would suggest that when county soil surveys and/or soil testing identifies the presence of these soils, the bioretention design approach should simply consists of excavating the bioretention site area for the required ponding depth, mixing 3-4 inches of well aged organic material such as composted, leaf mulch, double shredded much or pine fines, and planting the vegetation. This approach will meet the new design objective of simplicity of design, high life cycle and low construction and maintenance costs.

When very sandy soils are encountered they can also be treated in the same manner as described above with a simple modification. The sandy soils should be over excavated by

six inches or so and then 3-4 inches of good topsoil and 3 inches of organic material can all be mixed into the sand media to provided and improved soil condition to support plant growth and improve pollutant removal.

Moderately and Poorly Drained Soils. Moderately and poorly drained soils which are very frequently encountered required more work. These soils will typically require that they be excavated and replaced with better drained media and also that under-drains be used. It would be useful to conduct additional experiments with the concept of soil rejuvenation and enhancement as suggested by Dr. Frank Gouin (University of Maryland), who has pioneered soil rejuvenation techniques for compacted urban soils and clay soils. Also ongoing demonstration experiments by NRCS indicates that soil rejuvenation techniques can be used to restore the infiltration capabilities of agricultural soils. Some local stormwater programs, most notably the Washington State Department of Ecology has published the document, “Guidelines and resources for implementing Soil Quality and Depth BMP T5.13” (<http://www.soilsforsalmon.org/cases.htm>)

Design of Bioretention as an Infiltration Practice

Many stormwater practitioners perceive bioretention primarily as a filter BMP to be used for water quality control. This perception greatly undervalues the potential of bioretention practices to provide quantity control including both volume control and peak discharge control for both small and large storm events. With many local stormwater programs moving towards volume control, the importance of bioretention as an infiltration practice becomes more important, and yet there is currently very little guidance available for the design of bioretention as an infiltration practice. A couple of recent exceptions include the RECARGA model developed by the University of Wisconsin (2006), and the New Jersey groundwater recharge spreadsheet (NJ 2004).

An element that warrants discussion is related to minimum allowable infiltration rate to be used for design. Our current mindset with respect to allowable infiltration rates dates back to our earlier experience with infiltration practices associated with peak discharge control policies. Many jurisdictions adopted minimum infiltration rates ranging from 0.52 inches to 1.02 inches to assure that complete dewatering of the infiltration facility would occur. However today many jurisdictions are progressing from a single function control strategy for peak discharge to a multiple parameter control strategies that include; groundwater recharge, water quality control, channel protection and peak discharge. This progression to multiple parameters control strategies give rise to the questions of whether the minimum infiltration rates established during the eighties are still reasonable for multiple parameter control strategies.

In this paper we argue that the data presented in Table 1 clearly demonstrates that the currently established minimum infiltration rates be still be useful for peak discharge control, but may be overkill with respect to groundwater recharge, water quality control, and channel protection objectives. For example Table 1 shows that a silt loam with an infiltration rate of 0.27 inches per hour can pond and dewater 13 inches of water in a 48 hour period. Similarly a sandy clay loan can pond and dewater 8 inches of water in a 48

hour period. The RECARGA model (Figure 1) illustrates how this information can be used to design a combination system that provides an infiltration reservoir and an under drain for positive dewatering of excessive flows. In addition Table 1 demonstrates that when sandy soils are present the contribution of bioretention infiltration systems can make a significant contribution to volume control.

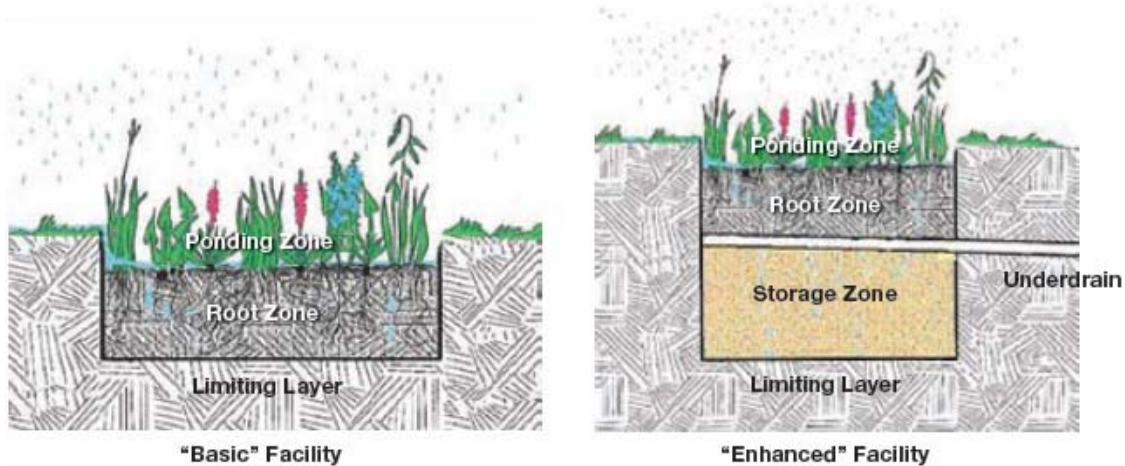


Figure 1 Basic Bioretention Models (Wisconsin, 2006)

Plant Materials

The role of plant materials in bioretention design is still poorly documented and understood. The type of plant materials that should be used, the density of planting and the benefits of plant materials are all issues that need to be better documented.

Plant Density. Some stormwater designers are concerned that having a dense plant material coverage could reduce the volume available for water storage and reduce infiltration. However, all of the bioretention systems that we have observed appear to function better as the plant density increases. In general we would recommend that the entire bottom and sides of the bioretention area be planted. The recommended plant spacing for each plant species will generally ensure that at establishment at least 50 % or more of the bioretention system surface is open. This will change over time as the plants mature and grow, and if that should prove to be a concern, which to date if we have not seen, the plant density could be reduced and the removed plant could be transferred to another site.

Soil Infiltration. In general the plant roots should improve the permeability of the soil mixture, not impede it. Ongoing research related to soil infiltration rates associated with plant materials is concluding that there are many natural processes that re effective in restoring and/or enhancing infiltration rates is soils (Lucas and Greenway, 2007). They report that vegetation roots penetrate confining layers, opening up soil structure, and root turnover promotes the formation of macropores. The beneficial effects of native plants on infiltration rates is reported to persists even in depositional situations where sediments accumulates, which is a very important characteristic for a stormwater BMP. They

conclude that the presence of vegetation can result in infiltration rates several order of magnitude higher than predicted by underlying soil properties.

Water Quality. The water quality benefits of these plant materials is not well documented or generally understood by many stormwater practitioners. Ongoing research by Lucas and Greenway (2007) among others, however is beginning to provide documented evidence of these benefits specially with respect to both phosphorus and nitrogen, two our most frequent sources of pollution.

Plant Types. With respect to the selection of plant materials it is generally recommended that common natives species be used. Many local programs such as Prince George's County, MD have developed extensive listings of suitable plant materials, and also provide guidance on their soil and light preferences.

Summary and Conclusions

This paper has provided a brief discussion of selected design elements and considerations related to bioretention design and construction technology. Our intent is to stimulate and encourage further review and improvement in our understanding and utilization of this control practice. As the paper has demonstrated there are a number of opportunities and challenges related to many of the design parameters of the bioretention system. These include the allowable ponding depth, the minimum width and length parameters, the depth and type of soil / filter media, the design of bioretention as an infiltration practice and the proper selection and use of plant materials.

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