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BIORETENTION DESIGN: ONE SIZE DOESN'T FIT ALL

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Abstract

Unlike most regulating authorities in the USA, the State of North Carolina has adopted various design standards for bioretention depending upon the practice's location in the state. Regional geography and target pollutants dictate the design of the practice, namely the required media depth, the presence of a designed internal water storage zone, and the "credit" awarded a given design. The state has based its variable design requirements on research conducted at North Carolina State University, which has also been supplemented by work of others outside North Carolina. Some specific changes included (1) the need for low phosphorus fill media in nutrient sensitive watersheds, (2) the requirement to have at least 1 m of soil in cold water regions of the state and a minimum of 0.6m of media for pathogen indicator species sequestration and die-off, (3) the requirement to use internal water storage zones in all locations with underlying soils in either Hydrologic Soil Groups (HSGs) of A (sandy) or B (sandy loam), and (4) the rewarding of additional pollutant treatment credit associated with bioretention if the cells are located in North Carolina's sandy coastal plain or sand hills. The paper will highlight the benefits of active communication between regulators and the state's land grant university, which includes state design manual review by faculty, students, and staff at NC State.

1. INTRODUCTION

To mitigate problems associated with land development, engineers and land use planners have designed and implemented (so called in the USA) Low Impact Development (LID) practices, or in Australia, Water Sensitive Urban Design (WSUD). Common LID/WSUD practices include bioretention areas, cisterns (rainwater harvesting), permeable pavement, vegetated swales, level spreader-vegetated filter strips and reduction of impervious areas. WSUD practices employ a number of mechanisms to improve water quality and reduce runoff before it enters natural water bodies. A goal of these practices is to remove pollutants common to urban stormwater. WSUD practices are also designed to mitigate peak flows, runoff volume, and time to peak, all of which help meet target hydrologic processes of the watershed.

One of the most frequent LID/WSUD practices that is being used in the state of North Carolina is the bioretention cell (also referred to as a rain garden). Bioretention is a mulch/soil/plant-based BMP that typically contains an engineered soil media ranging from 0.7 to 1 meter in depth (Davis et al., 2009). In North Carolina, USA, the recommended media composition is 85-88% sand, 3-5% organic matter, and 8-12% fine particles (Hunt and Lord, 2006; NCDENR, 2009). Media composition is widely variable among jurisdictions outside NC (Davis et al., 2009). While the media provides the primary mechanism for pollutant removal and comprises the majority of a bioretention cell, there is also a surface mulch layer, assorted vegetations types, and an underdrain surrounded by a gravel envelope (Figure 1). Appropriate devices are installed for inflow, outflow, and overflow. A pair of bioretention installations in the Mid-Atlantic USA region is presented in Figure 2.

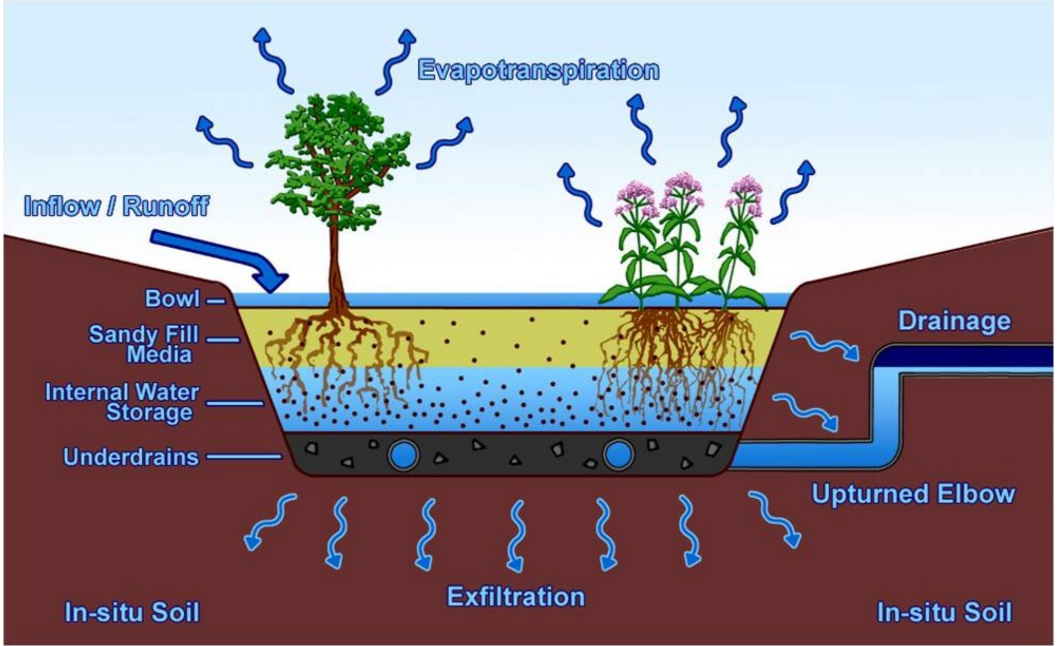

Figure 1. Bioretention Cell Cross-section schematic.

Figure 2. Example Bioretention Cells in Louisburg (a) and Wilmington (b), NC, USA.

Comment [ED11]: Where are these figures?

Many studies have been conducted showing the high efficiency of pollutant removal exhibited by bioretention. Metals, nutrients, oil and grease, and thermal pollution can all be mitigated through the use of bioretention (Bratieres et al., 2008; Davis, 2007; Hatt et al., 2009; Hsieh et al., 2007; Hsieh and Davis, 2005; Hunt et al., 2008;

Jones and Hunt, 2009). Hydrologic benefits such as groundwater recharge and peak flow reduction are also evident (Davis, 2008; Li et al., 2009). Davis et al. (2009) gives an overview of the most current bioretention research findings, including specifics on design guidelines. They also conclude that while performance of bioretention is well researched, the specific design parameters responsible for optimal performance have not been studied as extensively.

The US state of North Carolina has begun to account for different performance of bioretention cells when awarding nutrient removal "credit" to bioretention to reflect some of the above research. The purpose of this paper is to (1) demonstrate how one generic bioretention configuration is not appropriate across the climate and geography of a relatively diverse state like North Carolina and (2) explain how different design configurations are encouraged in different regions of North Carolina by its environmental regulating authority, the North Carolina Department of Environment and Natural Resources (NCDENR).

2. STUDY SITES DESCRIPTIONS

Several study sites in North Carolina were the basis for changes to the NCDENR design standards. Brief descriptions of each are provided below. The order of study sites is presented chronologically from oldest to youngest.

Greensboro, G1 and G2.

Two bioretention cells were located at a shopping centre in Greensboro, NC. Both cells had 1.2 m of fill media, neither of which would currently meet NCDENR's fill media design specification. Both cells contained phosphorus-enriched fill media, apparently due to the media being supplied by a local farmer. The bioretention cells also differed with G1 containing an internal water storage (IWS) layer (also known as a submerged zone) (Figure 1) that was approximately 0.6 m deep. Cell G2 did not have an IWS layer. The cells were monitored from 2002 thourgh 2004. Details about the two cells are provided in Hunt et al. (2006).

Comment [ED12]: Since this conference is in Aus, maybe you can just say also "(also known as a submerged zone)" just to clarify what an IWS is.

Hal Marshal Bioretention cell, HMBC.

The HMBC cell was located in Charlotte, North Carolina and was monitored from February, 2004 to March, 2006. The bioretention differed from the Greensboro cells because its fill media specifically designed to not have a high phosphorus content. The HMBC received drainage from a 0.37 ha asphalt parking lot and had a surface area of 229 m^2, which included a 3m diameter forebay at the cell inlet. The cell media depth was 120 cm (Hunt et al., 2008).

Graham, Graham N and Graham S.

Both Graham N and Graham S cells were located in Graham, North Carolina, and were monitored from September 2006 to August 2007. The distinguishing feature of these bioretention cells was that their vegetative cover was entirely turf grass. Runoff from a 0.36 ha catchment area of 33% asphalt parking lot and 60% lawn drained to a forebay and was equally diverted to the two cells. Both cells had surface areas of 227 m^2 with media depths of 75 cm and 105 cm (including 15 cm of gravel in each), for Graham N and Graham S, respectively. Both cells used a media without much embedded phosphorus and both employed an IWS layer, with Graham N having a 0.45 m IWS and Graham S using a 0.75 m IWS (Passeport et al., 2009).

Rocky Mount, RM grass and RM mulch.

Two cells located in Rocky Mount, North Carolina, were monitored from September 14, 2007 to December, 2009. RMgrass was a grassed cell, while RMmulch was covered by mulch, trees, perennials, and shrubs. RMgrass received drainage from 0.22 hectares of parking lot (75% impervious), and RMmulch received runoff from 0.25 hectares of parking lot (72% impervious). RMgrass and RMmulch had surface areas of 146 m^2 and 142 m^2, with media depths of 1.1m and 0.96 m, respectively. Both cell media depths included 0.15 m of gravel and contained internal water storage zones (IWS) initially 1.02 m and 0.87 m deep that were reduced 0.3 m on January 12, 2009. No differentiation was made among the data from a water quality perspective. The disinguishing feature of this site was its location in a sandy soil portion of the state, the Upper Coastal Plain. A larger fraction of runoff was expected to infiltrate from these cells. Brown and Hunt (in review) discuss the study in detail.

Wilmington, Port City Java, PCJ-deep and PCJ-shallow.

Two side-by-side cells located in Wilmington, North Carolina, were monitored from Fall 2007 through February 2010. Both cells were mostly comprised of bermuda turf grass with a few shrubs. Indicator species for pathogenic bacteria were specifically collected at this site. The main difference between the two bioretention cells was their media depth, as the "deep" media cell was comprised of approximately 0.6 m of fill media, while the shallow cell had only 0.25 m of fill media. The two media depths were loaded proportionally the same from a hydraulic load per cubic metre of fill media basis. The fill media used was that which was on site, which conveniently corresponded to NCDENR's required fill media soil particle size distribution (8 to 10 percent silts and clays). The contributing drainage area to each was nearly 100% impervious surface (parking lot). Details of the cells are provided in Hathaway et al. (in review).

Comment [ED13]: What were these planted with?

2.1 Collecting Data

Comment [ED14]: Was overflow ever measured? Please do not comment on this, I am thinking aloud.

All cell configurations included a 0.25 mm tipping bucket rain gauge (ISCO 674 or Global water model), automated samplers with data loggers (ISCO 6712, ISCO 6712FR, or Sigma 900 max) and an outflow weir. Inflow rates were calculated using the USDA- NRCS curve number methodology (USDA-NRCS, 2004), because each watershed was highly impermeable and reliable precipitation was collected on site. Data from all sites were collected similarly. Installed automated samplers coupled with data loggers automatically collected flow-weighted and rainfall composite samples to determine event mean concentrations. All site samples were sealed immediately, placed on ice, and transported to a certified laboratory for analysis. All samples were analyzed within 24 hours of collection.

Comment [ED15]: So inflow was not measured? We often find large differences between estimated effective impervious areas and actual effective impervious areas. I would have thought the curve number is also sensitive to such a thing?

3. RESULTS

The purpose of this paper is not to provide a detailed analysis for each of the above-mentioned studies, but to document how the state of North Carolina adjusted design standards per the research results. However, a brief summary of each project's findings is presented in subsequent sections. Before the data summary is presented, the NCDENR design guidance is presented as Table 1 to illustrate how bioretention design has evolved in North Carolina from 2003 (when the first study was being completed).

Table 1. Summary of NCDENR Bioretention Design Standards for North Carolina, USA.

Design Metric	**Guidance**
Fill Media Depth	1.2 m minimum
Fill Media Type	No defined guidance other than to require a drawdown rate of 0.0035 mm/s to 0.042 mm/s (0.5 in/hr to 6 in/hr)
Bowl Storage Volume	Capture all runoff from 25 mm storm event.
Water Depth in Bowl	0.15 to 0.225 m
Vegetation Type	Trees, Shrubs, and Mulch only.
Underdrainage Configuration	Underdrains needed in all Bioretention Cells (BRC's), unless Sand. All underdrains assumed to not create an internal sump for storage
Pollutant Removal Efficiencies	N – 25%; P – none assigned; Pathogens – none assigned; TSS – 85%
Differentiation in Design per location in state?	None. One size fits all.

Comment [ED16]: Maybe just define

3.1 Greensboro

The field studies confirmed high annual total nitrogen mass removal rates at two conventionally drained bioretention cells 40% reduction each. Nitrate-nitrogen mass removal rates varied between 13% and75%, and calculated annual mass removal of zinc, copper, and lead from one Greensboro cell were 98, 99, and 81%, respectively. *All high mass removal rates were due to a substantial decrease in outflow volume.* The ratio of volume of water leaving the bioretention cell versus that which entered the cell varied from 0.07 (summer) to 0.54 (winter). There was a significant (p<0.05) change in the ratio of outflow volume to inflow volume when comparing warm seasons to winter. The cell using a fill soil media with a lower phosphorus index (P-index), Greensboro cell G1, had much higher phosphorus removal than Greensboro cell G2, which used a high P-index fill media. Fill media selection appeared to be critical for total phosphorus removal (Clark and Pitt 2009, Hatt et al. 2009), as fill media with a low P-index and relatively high CEC appear to remove phosphorus much more readily.

Comment [ED17]: Could it also be that the inflow was over predicted (because of an over estimation in effective imperviousness) and hence the systems seemed even more effective because of this? No need to adjust paper.

Comment [ED18]: I am sure others have found similar – maybe cite some of these? Davis? FAWB?

3.2. Charlotte (Hal Marshall)

Flow-weighted, composite water quality samples were collected for 23 events and analyzed for TKN, NH4-N, NO2-3-N, TP, TSS, BOD-5, Cu, Zn, Fe, and Pb. Grab samples were collected from 19 storms for fecal coliform and 14 events for *Escherichia coli* (*E. coli*). There were significant reductions (p<0.05) in the concentrations of TN, TKN, NH4-N, BOD-5, fecal coliform, *E. coli*, TSS, Cu, Zn, and Pb. Iron concentrations significantly increased (p<0.05). $NO_{2\text{-}3}$-N concentrations were essentially unchanged. Concentration-based efficiency ratios for TN, TKN, NH4-N, TP, and TSS were 0.32, 0.44, 0.73, 0.31, and 0.60, respectively. Fecal coliform and *E coli* efficiency ratios were 0.69 and 0.71, respectively. Efficiency ratios for Zn, Cu, and Pb were 0.77, 0.54, and 0.31, respectively. Concentrations of Fe increased by 330%. The peak outflow of the bioretention cell for 16 storms with less than 42 mm of rainfall was at least 96.5% less than the peak inflow, with a mean peak flow reduction being 99%. These results indicated that in an urban environment, bioretention systems can reduce concentrations of most target pollutants, including faecal bacteria indicator species. Additionally, bioretention can effectively reduce peak runoff from small to midsize storm events. Because the fill media used at HMBC was low in phosphorus (low P-Index), the positive phosphorus sequestration was both expected and important to regulators, as the state's new (at the time) fill media specification had been tested and shown to provide ample treatment of P in runoff.

Comment [ED19]: Is this again to do with the filter media selection…I assume so?

Comment [ED110]: These are concentrations or loads?

3.3 Graham

Overall, except for $NO_{2,3}$–N, effluent nitrogen species event mean concentrations (EMCs) and loads were significantly ($p<0.05$) lower than those of the inflow, and nitrogen species load reductions ranged from 47 to 88%. Apart from fall and winter, during which a longer hydraulic contact time seemed to be needed, the IWSs appeared to improve denitrification. Total phosphorus (TP) and OPO_4-P EMCs were significantly lower than those of the inlet. Reductions were 58% (South) and 63% (North) for TP and 78% (North) and 74% (South) for OPO_4–P. There was no significant difference in TP and OPO_4–P loads between the inlet and the two outlets, because events with higher outflow (1) did not have a substantial difference in loads and (2) because large events dominated the calculation. Moreover, effluent concentrations for both phosphorus species were low, relative to other studies. The best nutrient EMC and load reductions occurred during the warm and humid seasons. When considering effluent concentrations in addition to removal rates, the grassed cells showed promising results for faecal coliform (FC) and nutrient pollution abatement when compared to conventionally vegetated bioretention (trees, shrubs, and mulch) previously studied in North Carolina. The study reaffirmed the importance of a fill media that is able to capture – and not leach – phosphorus. The internal water storage features of the two cells may have correlated to the superior performance of the cells relative to other BRC's examined in North Carolina. Not surprisingly, the cell with the deeper IWS had lower outflow frequency than the cell with the shallower IWS. Finally, the study highlighted that a BRC with a turf grass cover can mitigate pollutant loads. While this was not unexpected, it was important to document this benefit in a field study for NCDENR regulators. Anecdotal observation of the cells proved that mowing along the verge was sometimes difficult, resulting in "scalped" grass. However, the grass was collected in the mower's grass catcher and no build up of a confining layer occurred. No change in the dewatering rate was evident, either.

3.4 Rocky Mount

The previously mentioned studies in tighter (more clayey) soil regions of North Carolina have shown that that incorporating the IWS design feature enhances infiltration and reduces outflow from bioretention. The two bioretention cells in Rocky Mount, NC, were monitored for two, year-long periods, to measure the impact of varying IWS zone depths over underlying sandier soils. The bioretention cell with sand underlying soil (Mulch/Shrub cell) had nearly 99% of the runoff completely eliminated from outflow. However, the contact time in the media was less than three hours so minimal nutrient removal was achieved. The other bioretention cell had a sandy-loam underlying soil (Grassed cell), which modestly restricted flow, and it was able to eliminate runoff by 87% during the monitoring period with the deeper IWS zone depth (0.87 m) and 72% when the IWS zone depth was reduced (0.56 m). The longer contact time in the media allowed for efficiency ratios (on a concentration basis) of all the nitrogen species and TSS to exceed 50% for events monitored with outflow. As an additional metric of performance, the parking lot runoff and runoff treated by both the Grassed and Mulch/Shrub cells were compared to concentrations consistent with "good" and "fair" benthic health in streams (McNett et al., 2010). Runoff from the parking lot was only of "fair" water quality for TN and TP, with runoff treated by the Mulch/Shrub cell not improving upon the "fair" water quality for TN (possibly due to lack of contact time). Runoff treated by the sandy-loam underlying cell improved to "good" water quality for TN and TP.

This study illustrated three very important points: (1) when underlying soils are sufficiently sandy, the fraction of runoff that infiltrates can be very high. (2) The use of IWS clearly enhances the amount of infiltration provided by a BRC, thereby reducing outflow volumes. (3) It is possible to have a bioretention cell that percolates too rapidly for meaningful concentration reduction for nitrogen constituents.

Comment [ED111]: ISZ – is this a change in terminology – should it be IWS? I assume so. Does ISZ stand for Internal Submerged Zone?

Comment [ED112]: I might just be confused, but if the EMCs at the outlet are lower, and you would assume the systems were retaining some water (as others did), then you would get load removal as well? Maybe you can just explain in a sentence this interesting result.

Comment [ED113]: Maybe just define this as Faecal coliforms somewhere first. What were the results of this – maybe you can just show some removal rates since you conclude that grass covered cells are recommended for microbe removal.

Comment [ED114]: Too many relatives :)

Comment [ED115]: Can you maybe mention any problems you encountered when using these grass cells? Mowing – decrease k? decomposition of cut grass? Others?

Comment [ED116]: By tighter you mean...?

Comment [ED117]: I like this, can you maybe just do this each time you refer to efficiency ratios? I.e. say if it is load or conc based?

Comment [ED118]: I am a bit confused...again...us Aussies get confused easily! Anyway, do you mean the parking lot runoff was even ok for direct release into streams? I should also finish reading the paragraph since the answer I now know!

Comment [ED119]: Maybe this should be reworded to suggest that it is actually the reduction in volumes, not necessarily the amount of infiltration?

3.5 Wilmington

The systems were found to perform differently for indicator bacteria based on multiple performance evaluation metrics. PCJ-deep showed concentration reductions of 70% and 89% for *E coli* and enterococci, respectively. Effluent concentrations from PCJ-deepcompared well to USEPA target values and other studies in literature. Conversely, PCJ-shallow showed concentration "reductions" of -119% and -102% for *E coli* and enterococci, respectively. Effluent concentrations from PCJ-shallow were substantially higher than USEPA target values and other studies in literature. Multiple factors were evaluated to determine the cause of performance differences between the two cells. Soil depth was identified as the most important factor. The 0.25 m of fill soil in PCJ-shallow-exhibited poorer runoff detention and theoretically resulted in higher soil water flux and decreased contact time relative to PCJ-deep. These differences seemingly led to diminished indicator bacteria sequestration. The results of this study suggest soil depth is an important design parameter for bioretention which should be carefully selected. Further, minimum soil depths appear to exist, below which decreased sequestration of faecal indicator bacteria may be experienced. The cell with the deeper media (0.6 m) appeared to be a realistic minimum for use in locations where pathogen removal is targeted, unless unit hydraulic loading is otherwise managed.

Comment [ED120]: I think you change names here from something you referred to in your methods to this Bioretention-D and S – maybe just be consistent. Methods says there are two cells, called: **PCJ-deep and PCJ-shallow**

Comment [ED121]: This comment does not need to be reflected upon in the document, but I am interested to know if this is your true feeling, that filter media depth is key for microbe removal? Personally, I am not convinced, but then again I have no idea about the details of this study either.

4. REFLECTING RESEARCH IN BIORETENTION DESIGN STANDARDS

Per the research described previously, NCDENR has changed bioretention standards to reflect target pollutant and location in the state. These changes are summarized in Table 2.

Comment [ED122]: Table needs a caption. Also, maybe it would be worthwhile combining the tables so direct comparisons can be made between the original and the new standards?

4.1. Changes to Media Depth and Type

The NC studies, as well as several others conducted in the USA and Australia clearly showed that 1.2 m minimum depth was too restrictive. However, a minimum depth can be reached for removing select pollutants (such as pathogen indicator species). NCDENR now allows a minimum fill media depth of 0.6 m. A somewhat deeper media depth, however, 0.9 m, is recommended in locations where nitrogen and phosphorus is to be removed. The reason for this is that deeper media depth will provide a longer contact time, which appears to be necessary for reduction of nitrogen. NCDENR's allowance for a shallower media depth (than 1.2 m) has made bioretention construction more cost effective, thus promoting its use.

Table 2. Summary of Pollutant-Specific Design Parameters for Bioretention Cells in North Carolina

Design Parameter	**Nutrient Removal Design**		**Pathogen Removal Design**
Fill Media Depth	0.9 m recommended		0.6 m minimum
Fill Media Type	8 – 12 % Fines (silt + clay). Low P-Index (10-30). OM < 5% total volume		8-12% Fines.
Bowl Storage Volume	Runoff from 25 mm event		Runoff from 25 mm event[1]
Water Depth in Bowl	0.225 to 0.3 m		0.225 to 0.3 m
Vegetation Type	Any		Any, with grassed system recommended.
Underdrainage Configuration	Internal Water Storage (IWS) Zone Recommended/ Encouraged		Any. IWS can not encroach top 0.3 m of media
Pollutant Removal Efficiencies	Coastal Plain (with IWS)	Piedmont (with IWS)	Statewide: High
	60% N, 60% P	40% N, 45% P	

[1] Except along coast, where runoff from a 38 mm event needs to be captured.

Comment [ED123]: I am so interested into where this info stems from...

Because of the initial finding from Hunt et al. (2006) in Greensboro, the media composition required by NCDENR changed dramatically. Previous to 2003, BRC media could have – and usually did have – substantial amounts of compost or other organic amendments. This improved infiltration rates of the media and aided in plant growth, but had a profound negative impact on nutrient export from the cell. NCDENR restricted the compost/organic fraction of the media to no more than 5% of total volume. This revised media has been evaluated several times and each time good nutrient removal has been observed (except when hydraulic contact time was insufficient/too short. The NCDENR design requires ALL fill media to be tested by the state's soils lab to verify that the phosphorus content (P-Index) is low (10-30). Any bioretention cell that fails the P-Index requirement is subject to mandatory excavation and replacement with a proper, nutrient-removing fill media.

4.2 Bowl Storage Volume and Maximum Ponding Depth

This is one area of design that remains inadequately researched. Per anecdotal observation, deeper ponding depths are now allowed (increase of 0.075 m from earlier standards). The caveat for the slightly deeper ponding depth is that the BRC's must have dedicated maintenance. Developers continue to push for allowing a deeper ponding depth so that the footprint of the bioretention cell is decreased. To date, their hopes have not been realized.

Comment [ED124]: We have modelled the impacts of this for higher flow rate filters and found insignificant decrease in footprint size.

Another design element that has been challenged is the requirement to provide storage for the entire runoff volume, which (incorrectly) assumes that no infiltration occurs during an event. NCDENR continues to promote "full volume capture," because it is conservative.

Comment [ED125]: Hmmm, not a great idea. But then again, it is conservative!

4.3 Vegetation Type

Tree and shrub systems are no longer mandated. In fact, for bioretentioin cells designed for pathogen removal, a turf grass-covered bioretention cell is encouraged, due to light penetration. Studies in Australia have shown that vegetation clearly enhances bioretention performance (Lucas and Greenway, 2008; Bratieres et al. 2008), so BRC's are required to be vegetated in the state. (Some designers had previously questioned the need to provide any vegetation in part due to maintenance concerns.)

Comment [ED126]: Can you please include some more values to back this change – i.e. in the results in section 3, can you please include microbe removal rates for grassed systems?

4.4 Underdrain Configuration

One of the major changes adopted by NCDENR was to actively promote the use of Internal Water Storage (IWS) zones in bioretention cells. The state promotes their use by providing a higher nutrient removal credit when IWS systems are used, particularly in the coastal plain (sandy soil region) as discussed in the next section. To employ IWS the state requires a minimum of 0.9 m fill media depth. The IWS may not encroach the top 0.3 m of media, but is not suggested to be further than 0.6 m from the top of the media. Effectively, most designers now specify the IWS reach with 0.45 m of the cell's surface. The reason to limit encroachment is to keep a zone of the bioretention cell constantly aerobic to maintain good pathogen and phosphorus removal.

IWS has not been actively promoted in bioretention cells solely designed for pathogen sequestration, as there are some concerns that keeping the media wetter near the surface could limit a biortention cell's effectiveness to sequester and kill bacteria pathogens. Nutrient removal is the driver for IWS in North Carolina.

Comment [ED127]: We have founf that iws reduces some microbe removal, whilst increases others...

4.5 Performance Differentiation across NC regions

Because the coastal plain, coastal barrier islands, and sandhills are substantially sandier than the rest of the state, bioretention cells can be expected to infiltrate a larger fraction of runoff when employed in the sandy regions. This was clearly illustrated by Brown and Hunt's (in review) study in Rocky Mount. Because nutrient removal credit is solely based on the mass of pollutant leaving the bioretention (or any stormwater management practice) at the outlet, the more runoff able to infiltrate, the lower the effluent pollutant load.

NCDENR's new pollutant removal credit system reflects this, as bioretention cells employing an IWS layer in a region with sandy underlying soil receives substantially more nutrient removal credit (e.g., 60% of N) than one employed in a tighter underlying soil associated with the rest of the state (e.g., 40% of N).

While not discussed in this paper, deeper media depths (1.2 m) are required for bioretention cells in the mountains of western North Carolina where trout populations are present, per research by Jones and Hunt (2009). Thus, depending on eco-region, the required bioretention cell may have a different design.

5. SUMMARY

Until 2009 bioretention design had followed a one size fits-all approach. Members of the research community as well as key regulators realized this was a shortcoming of the NCDENR design standards at the time. In 2009 bioretention design standards substantially changed, allowing bioretention to be designed based upon regional conditions and pollutants of conern.

The design changes followed a series of extensive field tests conducted by North Carolina State University and elsewhere in the United States and Australia. Some of the most important changes to the state of North Carolina's standard was a relaxation of the 1.2 m fill media depth requirement, the incorporation of an infiltration enhancement underdrainage configuration (IWS layer), the requirement to utilize a low phosphorus soil media, and allowing the use of many different types of vegetation for surface cover. NCDENR, through a credit allocation system, actively promotes specific bioretention designs in regions of North Carolina by awarding more nutrient removal credit if underlying soils are sandy and an IWS layer is employed.

Substantial design changes remain to be implemented, such as proportional sizing of surface area and media volume as well as identifying optimum ponding volume depth and duration. Still, the changes employed by North Carolina's environment regulatory agency have promoted more cost-effective and regionally-specific bioretention designs to be constructed.

ACKNOWLEDGEMENTS

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