STACKED BEST MANAGEMENT PRACTICES: EVALUATING THE VARIABLES OF BMPS FOR INCREASED WATER QUALITY, ECOLOGICAL BENEFITS, AND AESTHETIC DESIGN CONSIDERATIONS

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1 ABSTRACT:

Over the past fifty years, water management and design has embarked on a new journey of resource allocation and disparity. A new generation of designers of the built environment are seeking innovative approaches to address the growing demands on our freshwater resources. Best management practices (BMPs) are often the first solution that are employed, however, stacked BMPs are making their way into the discussion of stormwater management for the first time. Stacking BMPs refers to combining multiple BMPs within a single landscape to mirror the flexibility of nature. This review explores the preliminary means of how these ephemeral and flexible landscapes can be achieved in the built urban and suburban environment and by what means we can achieve this - either through altering our design practices or our perception of what a BMP is within a stormwater based landscape. We examine how stacked BMPs can be applied as an alternative approach to singular BMPs in landscape application in order to better evaluate the current methods and practices for stormwater design and ultimately, proposing alternative methods better suited to the coming needs of future generations. In this critical review, we explore the current literature around stacked BMPs primarily focusing on water quality, ecological benefits, and aesthetic values of a stacked BMP as a design approach. Results reveal that, even though our water management styles are evolving to envelope ecological and social considerations - designers still prefer implementing single BMP systems that are heavily engineered for site specific capacities.

1.1 Keywords:

Stormwater, stacked bmp, green infrastructure, water quality, climate change, design, landscape architecture

2 INTRODUCTION

One of the most common effects of climate change has been the ever increasing intensity and irregularity of storm events in both urban and rural landscapes. Past approaches to engineered stormwater management have shown to be successful only in so much as the extent of the storm they are designed to manage. Most BMPs serve one or two fundamental stormwater management functions, however, they are relatively limited in addressing, simultaneously, the following common water management design goals: improved water quality, ecological diversity benefits, and inclusive aesthetic design.

Over the past two decades, a more environmental approach that mimics natural on-site infiltration –commonly referred to as on-site stormwater management- has been increasingly adopted. Onsite stormwater management utilizes best management practices (BMPs) to apply this sustainable alternative to addressing unpredictable rain events. These BMPs target stormwater management on site and increase infiltration to recharge groundwater supply. This is also widely considered a type of green infrastructure that has seen a rapid growth in application over the past twenty years as well. These are typically applied as stand-alone systems with the most common being: Wetland Basins, Grass Filter Strips, Riparian Swales, Bio-retention, Wetland channels, Infiltration pond/Basins, Composite / Bio reactor, Detention Basins, Rain Gardens, Media Filters, Porous Pavement, Retention Pond /Basins, and Tree Planters (see table 1). A burgeoning approach to stormwater management is stacking a variety of BMPs in a single landscape.

This review examines the existing literature of variables that are needed to design a stacked BMP system and explores the current practices and challenges of water quality modeling, ecological benefits and aesthetic design considerations. As this is a recent and evolving conversation in water management, more research regarding the design practices and considerations of stacked BMPs is needed. This critical review aims to fill this gap in literature and address some of the strengths and weaknesses of a stacked approach to stormwater management.

2.1 Background

Today, a broad range of best management practices exist for designs to implement into landscape settings. Regardless of BMP types, the goal of incorporating stormwater management into urban or rural infrastructure remains the same—to improve water quality and regulate volume flow to prevent flooding. We know that BMPs as individual systems have the potential to greatly impact the water quality, ecological diversity as well as the aesthetic value of a landscape design. However, these systems are highly engineered to serve a single purpose (water quality improvement, flood protection, groundwater recharge, etc.) and do not allow for the frequent drastic weather changes or for the agency of ecology (Reed, 2010) to evolve independent of the design. Only recently, did BMP application consider the aesthetic values these systems add to a landscape (Echols & Pennypacker 2008) and surrounding communities. A new generation of design is emerging, that incorporates a stacked approach to BMPs into the larger green infrastructure goals (Christianson et al. 2017, Korger et al. 2015, Sith et al., 2019, Villarreal et al., 2004, Damodaram et. al. 2010).

While water quality efficiencies, ecological benefits and design aesthetics of BMPs as individual systems is an ever growing body of knowledge, that include discussions from engineers, designers, planners, and stakeholders alike (Hayden et al. 2015, Korger et al. 2015, Li et al., 2019, Villarreal et al, 2004, Damodaram et. al. 2010). However, the concept of stacking multiple BMPs together in a single system is a relatively novel concept. Amongst stormwater engineers, the practice of 'Daisy-chain' systems, or systems where multiple stormwater management areas designed for a single function connect and/or flow into each other, is a somewhat common practice, but is not to be confused with stacking BMP systems. Although the 'daisy chain' approach to stormwater management is efficient in terms of water volume control and increasing water quality, it is not always ideal in areas with limited space or resources. Stacking refers to multiple BMPs combined and redesigned in order to be flexible and to create a single stormwater system that is an integrated part of the landscape, rather than separately functioning unit apart. In the sections below, we examine the water quality modeling, ecological benefits, and aesthetic values of a stacked BMP design approach. Our sources, though limited on actual stacked BMP case studies, include research journals, reports from various municipalities, and design manuals. Within each section, we identify the emerging practices of integrative design in stormwater management, and then highlight the challenges and what are the future considerations.

Table 1. Summary of the predominant BMPs and their corresponding design specifications and water management capabilities.

BMP Method	Classification	Design Considerations	Water Volume Accommodations
Wetland Basin	Wetland basins are engineered systems that utilize plants, soil, and organisms to remove a range of pollutants from water.	The average size of wetland basins should be ≥ 10 acres. The average slope for wetland basins is ≤ 3:12;	the average rainfall between 69-79 in (1750mm-2000mm) of rain per year.4
Grass Filter Strip	An area of land maintained in permanent vegetation found primarily on agricultural land and is designed to improve water, soil and air quality.	The minimum recommended length of filter strips is 25 feet, with the minimum total size of the buffer strip is 0.3 acres.	Typical specifications ensure an estimated capacity of between 0.1 – 0.15 m/s. Filter Strip Volume Reduction = Filter Strip Areas x Infiltration Rate x Storm Duration.
Riparian Swale	Encompass not only the active water channel, but also the exposed bars and areas of ponded water near the channel, including floodplain surfaces above and outside the channel banks.	Side slopes ranges from 3:1 to 5:1. One key feature of vegetated swale design is that they can be well-integrated into the landscape character of the surrounding area.	They are sized to temporarily store and infiltrate during a 1-inch storm event, while providing conveyance for up to the 10-year storm event with freeboard; flows for up to the 10-year storm event
Bioretention	Consist of a soil bed planted with vegetation and underdrain system where Stormwater runoff is filtered through the planting bed, infiltrating into the existing subsoil layer below, removing pollutants and conveying discharge	Bioretention are best served when the grade of contributing slopes is >1% and <5%.The planting soil bed is recommended to consist of a mix of materials, including sand, silt, and clay, per percentage, providing the appropriate environment for water and nutrients to be available to vegetation.	The bioretention surface area is approximately 3-6% of the contributing drainage. These systems have an average capacity of <5 ft3/s, with the underdrain piping system connecting to infrastructure or freshwater system.
Wetland channel	A conveyance BMP designed to both slow stormwater runoff and allow time for both biological uptake and settling of sediment through dense vegetation before the untreated stormwater enters natural, or existing wetlands	The mature channel geometry, in order to pass the flow rate of ≤ 2.0 ft/s, requires a channel depth between 1.5-3.0 feet, with the bottom width being no less than 3.0 feet. Vegetation plays a crucial role in swale treatment capacity, flow attenuation, and stabilization	The channel should also provide enough capacity to contain the flow during a 100-year storm event, with the bottom width of the should being increased when additional capacity is needed.
Infiltration pond/Basin	Acts as a recharge basin that manage stormwater runoff in order to prevent downstream erosion and are often used throughout urban landscapes, remove a variety of pollutants from stormwater	The surface is generally composed of a two-inch pea gravel or river stone layer, with substrates including filter beds, filter fabric and bottom soil. Soils are recommended to contain both <40% silt/clay and <20% clay content and have a slope no steeper than 3:1.	Infiltration basins vary in size, with the general basin covering 5-50 acres.
Composite / Bio reactor	Consist of a buried trench, filled in with woodchips, in which farmland tile drainage water flows, before finally entering the surface water.	Bioreactors can be applied in agricultural landscape or large land area types for the purpose of enhancing water quality.	Designed to treat from 30-50 drained acres averaging in size of ~4 feet deep by ~100 feet long and ~20 feet wide.
Detention Basin	Facilities built adjacent to tributaries of rivers, streams, lakes, and bays.	Loose, well-drained loam is recommended for detention basins, with clay-based soils not being optimal. Flat basins with gently sloping sides are needed before constructing, and it should be lower than the area to be drained.	The overall basin area is recommended to be >20 acres, with the embankment slope being ≤ 2.5:1.
Rain Garden	Small facilities that treat stormwater by pooling water on the surface, allowing filtering and settling of suspended solids and sediment at the mulch layer, prior to entering the plant/soil/microbe complex media.	The soil should contain 5-8% compost, and 20-95% soil with slopes ranging from 3:1, or 2:1 when space is limited. The vegetation should be chosen to evapotranspire stormwater, create pathways for infiltration, while also providing habitat for animals and insects.	Can provide for the infiltration of relatively small volumes of stormwater runoff, often managing stormwater on a lot-by-lot basis (versus the total development site).
Media Filter	Media filters are structures, or excavated areas, containing a layer of sand, compost, organic material, peat or other filter media.	In order to avoid premature clogging and increased maintenance, media filters that operate under a lower hydraulic loading rate typically include finer gradations of media that are able to remove higher volumes of pollutants.	Designed to convey at least a ten-year, 24-hour storm event and if there is a detention facility, the filter needs to convey the 100-year, 24-hour storm event.

Porous Pavement	An alternative to typical pavement types that allow stormwater to filter through the pavement itself to underlying gravel reservoir in order to either to temporarily store or infiltrate water.	Porous pavement can be used to replace traditional impervious surfaces in a variety of locations, including: low-speed roads, alleys, parking lots, driveways, sidewalks, plazas, and patios.	The capacity of the underlying reservoir limits the contributing area and permeable pavement may accept runoff contributed by adjacent impervious areas, such as driving lanes or rooftops.
Retention Pond /Basin	The function of a retention basin is to capture additional stormwater surge, which cannot enter into a stormwater drainage system, thereby slowly releasing it into the surrounding waterway.	Basins should include differing depths, to accommodate varying vegetation types and perennial plants ideal for aquatic habitat. Species should be selected based on overall water depth tolerance, as well as aesthetic value and/or phytoremediation performance.	Retention basins are recommended to have a total area of >20 acres, with the basin slopes being no steeper than 3:1 or flatter than 20:1.
Tree Planter	A small area that is contained and vegetated with trees in order to conveys, collects, filter and treat stormwater runoff.	The combined effect of trees' ability to intercept, evapotranspire rainfall, and promote infiltration of water into the soil allows reduction in both the rate and overall proportion of rainfall runoff.	Street tree planters can intercept 6.5 – 66.5% of annual rainfall, compared to 10 – 46% of annual rainfall for natural forests.

3. BMP WATER MODELING FOR QUALITY AND EFFICIENCY

Water quality modeling research on BMPs are relatively well-understood, so also are the various efficiencies and modeling approaches for BMP assessment. Numerous models, such as SWAT, AGNPS, AnnAG NPS, and HSPF are available for use, yet designers and practitioners are often unaware or not educated as to the appropriateness of which models are available and apply to certain conditions. (Douglas et al., 2013, Geng et al., 2009, Tuppard et al., 2011, Xie et al., 2015). These watershed models are also often limited, due to the scale of several more structural BMPs which are commonly implemented at a field-size scope. (White & Arnold 2009). More direct, specific models have been crafted for these interventions, such as modeling software that focuses specifically on the efficiencies of filter strips and riparian buffers, allowing for a more accurate set of results (Tuppard et al., 2011). Utilizing several of the aforementioned models, the *International Stormwater BMP Database* (IBMP) has collected a wide range of data sets from a vast anthology of BMPs currently in use, and then determined their abilities for improved water quality in: Total suspended solids (TSS), Enterococcus, Fecal Coliform, Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Nickel, Zinc, Phosphorus, and Nitrogen (table 2).

Table 2. Water quality capacity of common BMPs Data collected from the 2016 International Database for BMPs. Blank spaces indicate unavailable data (IMBMP 2016).

	Solids	Bacteria		Metals								Nutrients	
BMP	TSS	Enterococcus	Fecal Coliform	Arsenic	Cadmium	Chromium	Copper	Iron	Lead	Nickel	Zinc	Phosphorus	Nitrogen
Wetland Basin	X	X	X		X		X		X		X	X	X
Grass Filter Strip	X			X	X	X	X	X	X			X	X
Riparian Swale	X		X	X	X	X	X		X	X	X	X	X
Bioretention	X	X			X	X	X	X	X	X	X	X	X
Wetland channel	X		X		X	X	X		X		X	X	X
Infiltration pond/Basin	X								X		X	X	X
Composite /	X		X		X		X	X	X		X	X	X

Bio reactor													
Detention Basin	X		X	X	X	X	X	X	X	X	X	X	X
Rain Garden	X												
Media Filter	X		X	X	X	X	X	X	X	X	X	X	X
Porous Pavemen t	X			X	X	X	X	X	X	X	X	X	X
Retention Pond /Basin	X		X	X	X	X	X	X	X	X	X	X	X
Tree Planter	X											X	X

3.1 Current practices

The most frequently used BMP modeling software typically falls under the category of watershed models for pollutants and sediments. The most commonly used by researchers and practitioners are the *Soil and Water Assessment Tool* (SWAT). Another modeling tool that is used to evaluate the effect of management decisions impacting water, sediment and chemical loading as well as the impact of management decisions on water and watersheds as a whole is the *Agricultural Non-Point Source Pollution Model* (AGNPS). AnnAGNPS PL, is another modeling tool that functions as continuous-simulation for pollutant loading as a batch-processer. *Vegetative Filter Strip Modeling System* (VFSMOD) is an event-based model routing system that examines the incoming hydrograph and sediment graph to simulate outflow, accumulation and trapping of sediments under field conditions (Sabbagh et al., 2010). VFSMOD-W: which is a vegetative filter strip modeling system that studies the hydrology, sediment and pollutant transport, specifically through a vegetative filter strip (Fox et al., 2010). The *Riparian Ecosystem Management Model*, or REMM, is a simulation structure that considers typical three-buffer riparian zones (Lowrance et al., 2005). Current practices for modeling the efficiencies of BMPs (stacked or otherwise) all contain multivariate simulations of real-time flow forecasts, stream flow model velocity and rainfall and/or runoff and/or flood values (Christianson et. al 2017). Additional components include a precipitation forecast and flow forecasting of streams, rivers, lakes, and reservoirs, and estimate the rate of evaporation. These features are useful for water resources assessment in the field, however, they are limited by the current and historic water flow and weather patterns (Li et al., 2019, Xie et al. 2015) and do not address the growing irregularities cause by climate change.

3.2 Challenges and future considerations

There are several challenges that impede designers from utilizing and implementing knowledge derived from water modeling software. The first being that practitioners are often unaware of the appropriateness of models for certain conditions (Xie at al. 2015). Several structural BMPs are commonly implemented at the field scale at which the utility of watershed models is limited (White & Arnold 2009). More factors need to be considered, such as limiting climatic factors, farmer preference, costs and practicality of implementation (Ibid). It also denotes that designers cannot make a conclusive selection of the ideal BMPs without an outside expert's decision (Geng et al. 2009). Lack of time-based estimates of BMPs efficiency is also a challenge, due to the nature of the model database and the collected data (Ibid). Future research is needed to develop modeling approaches that quantify specific variables that watershed planners can adequately consider before proposing a design solution (Douglas et al., 2013). For these widely used BMPs (e.g., filter strips, riparian buffers, and detention ponds), specific assessment models have been developed (Tuppard et al., 2011). However, there is a need more detailed information as references to improve the operation process of data access and search efficiency of a stacked BMPs database (Geng et al., 2009).

A more realistic assessment of this complex approach to water systems design and management will enable designers and municipalities to better forecast climate change events, manage water infrastructure, and identify strategic needs that can benefit society. Digital modeling tools are a unique planning tool that can, in many cases, act as a natural extension of engineering in order to improve stormwater management. However, its conception and application is limited to those with sufficient training in the modeling software, almost always, to a singular BMP and not a stacked design.

4. ECOLOGICAL BENEFITS OF STACKING BMPS

In terms of the current literature regarding ecological benefits of stacked BMPs, some research exists, however, it merely relates to the rural environment. According to research developed by Christianson et al, stacking BMPs can enhance overall water quality, particularly within agricultural areas, as well as accomplish the following: reduce nitrogen and sediment, significantly reduce all non-point source (NPS) loads, enhance freshwater provisioning (FWP), and suppress crop disease (Christianson et. al 2017). In their research, it is recommended that layering (stacking) of multiple BMPs is more advantageous than solely one treatment. If non-point-source pollution (NPSP) cannot be solved through ecological patch-level, landscape-level interventions should be implemented through adjusting landscape patterns, namely through increasing highly heterogeneous-patched or highly-connected corridors (Ibid). An example of an ecologically oriented rural stacked BMP can be seen in figure 1.

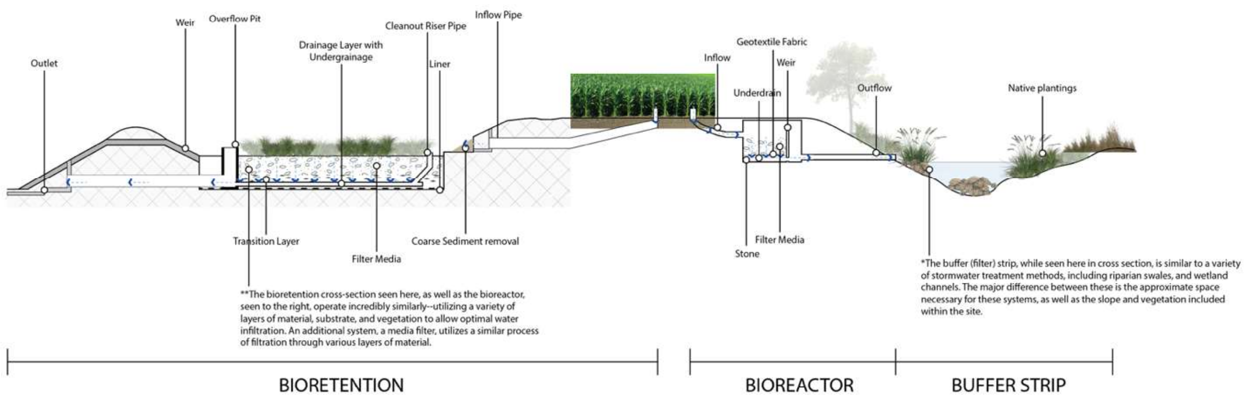

Fig. 1. Aesthetic and *design suggestions for stacked bioretention, bioreactor and buffer strip in a rural landscape (Image by C. Letterly).*

4.1 Current practices

In practice, when implemented in isolation, individual BMPs alone may not have the capacity to make a significant improvement in water quality, especially if nutrient loads are excessively high. However, when designers have multiple BMPs stacked within a landscape (e.g., slotted pipe draining into a two-stage ditch, with low-grade weirs), this leads to enhanced water quality, and ultimately ecological resilience (Kroger et al., 2015). The stacking of BMPs application could enhance the effectiveness of reducing nitrogen and sediment compared to single application, thus increasing the quality of aquatic habitat in riparian ecologies (Maharaj et al., 2016). A combination of BMPs significantly reduces all NPS loads, and thus improves soil, plant and fauna biodiversity (Sith et al., 2019). The stacked approach to BMPs was the most efficient way to enhance Freshwater Provisioning (FWP), which is a critical ecosystem service that is highly affected by climate change variability as well as land use and land management (Li et al., 2019). By combined application of BMPs, they can effectively suppress crop disease without using fungicides (Hempfling et al., 2017). Compound use of BMPs is recommended compared to only implementing a single application (Yaowu, 2015).

In practice of designed landscapes that are multileveled and flexible to change, ecological scholar and designer Chris Reed states that “ecological systems—in their multiple forms and manifestations, as mechanisms and/or models—forms the basis for a newly charged set of design practices: flexible, responsive, and adaptable as projects evolve and accumulate over time.” (Reed, 2010).

4.2 Challenges and future considerations

Non-point source pollution (NPSP) is one of the leading causes of degradation to our freshwater aquatic ecologies, and addressing this cannot be solved by simply applying BMPs at an ecological patch level. Rather, landscape-level interventions should be implemented by adjusting landscape patterns, increasing highly-heterogeneity biodiversity and/or highly-connected corridors (Yaowu, 2015). The dynamic change of impaired aquatic habitats brought on by watersheds exceeding total maximum daily loads (TMDL), and irregularity fostered by climate change, new challenges have arisen for designers choosing BMPs; especially whether stacking BMPs provides ecological benefits in and around a specific site (Williams et al., 2017). The stacking of BMPs for ecological benefits begs further research in order to better understand the true impact that this approach to design has on the surrounding ecology, with research focusing specifically around additive, multiplicative, or cumulative functions. (Kroger et al., 2015).

5. DESIGN AESTHETICS AND SOCIAL ACCEPTANCE

In terms of the design aesthetics and social acceptance of stacked BMPs, economics are one of the only areas that have seen significant study of benefits. Another area of research on the adoption of stacked BMPs is at the residential scale, and examining homeowner preferences. The exploration of Artful rainwater design (ARD) as a means for fostering amenities that enhance a site's attractiveness or value, is another area of stormwater management and BMP design that has seen a sudden rise within the design professions. An example of an urban stacked BMP can be seen in figure 2.

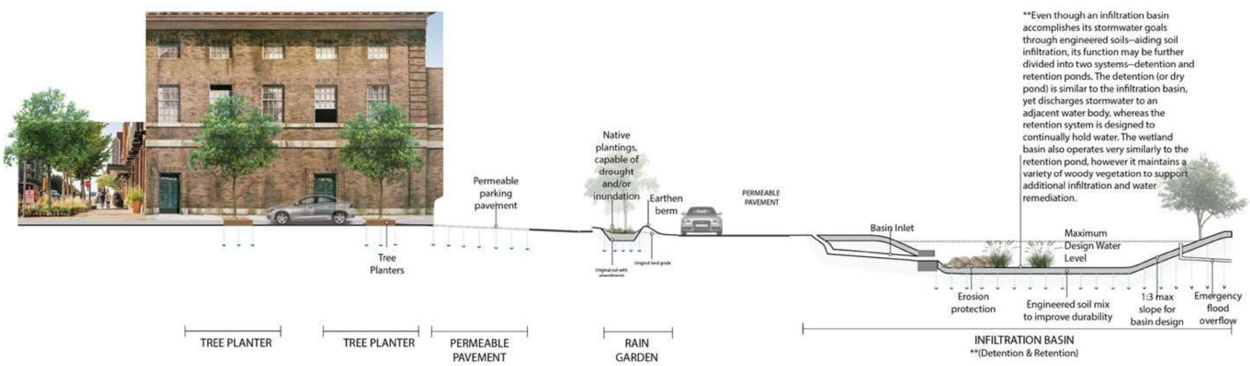

Fig. 2. Aesthetic and *design suggestions for stacked tree planters, permeable pavement, rain garden, and infiltration basin in an urban landscape (Image by C. Letterly).*

5.1 Current practices

According to a recent study conducted by Christianson et. al., a stacked approach to BMPs, when utilizing conservation dollars, may prove to be the most cost-effective options, especially when considering nutrient reduction goals (Christianson et. al 2017). However, the major obstacle in this instance is a lack of understanding of either the social trade-offs or synergies between layered practices. On a smaller scale, other research indicates that homeowners prefer an intermediate number of BMPs stacked within residential landscapes; this being preferred for both their aesthetic preference and ecological concern (Hayden et. al 2015). In order to incorporate more and varying BMPs, new aesthetic norms are waiting to be formed within these residential zones. When deciding whether or not to adopt the stacked approach to BMPs, a designer or practitioner must first consider: size (area), water volume capacity, surface and subsurface requirements, slope percentage limitations, and whether it is infiltration based or surface movement (Table 3).

Table 3. Design guidelines for individual BMPs. Blank spaces indicate unavailable data. Data collected from the International BMP Database (IMBMP 2016).

BMP	Size (Area) acres	Capacity (Vol) Cubic feet /sec	Surface	Subsurface	Slope Percent	Infiltration vs Surface Movement
Wetland Basin	≥10		vegetation	M	<1/3	infiltration
Grass Filter Strip	≥0.03		vegetation	soil	<1/10	infiltration
Riparian Swale			vegetation	soil	1/5-1/3	movement
Bioretention	F	<5	mulch	M	1/100-5/100	infiltration
Wetland channel		15-48	vegetation	loam	<15/100	movement
Infiltration pond/Basin	15-50		gravel	filter fabric	<1/3	infiltration
Composite / Bio reactor			vegetation	woodchips		infiltration
Detention Basin	≥20		vegetation	subsoil, riprap	1/20-1/3	infiltration
Rain Garden	F	F	vegetation	soil	1/3-1/2	infiltration
Media Filter	F	0.01-0.02	lighter media	F		infiltration
Porous Pavement			F	F		infiltration
Retention Pond /Basin	>20		vegetation	subsoil, riprap	1/20-1/3	infiltration
Tree Planter		F	F	F		infiltration

When examining stormwater best management practices as an aesthetic alone, the growing trend of artful rainwater design has been a widely adopted practice by both landscape architects and planners alike. A recent study of ARD conducted by Echols and Pennypacker (2008), demonstrated a variety of benefits within a landscape when aesthetics are incorporated into the design process. These include: increased property values, incentive for revision of current stormwater regulations, increase public education to the ecological aspects of stormwater, successful case studies for site wide stormwater management, promote the value of maintenance of stormwater management systems due to the value they bring to the site, and promote designs that creatively address stormwater management in any site, regardless of location (Echols & Pennypacker 2008).

5.2 Challenges and future considerations

One of the largest challenges that face designers and planners when considering aesthetics and social acceptance of stacked BMPs is the lack of understanding of either the trade-offs or synergies between layered practices (Christianson et. al 2017).The new aesthetic standards are often inhibited by policy and current design standards that prohibit creative stormwater design solutions being implemented into the landscape regardless residential or urban (Hayden et. al 2015). Further research needs emphasize the compatibility of BMPs within landscape aesthetics in order to better address this gap in knowledge (Warner et al., 2017). Furthermore, the compatibility of BMPs within residential landscapes must be emphasized to accommodate a greater overall adoption and acceptance.

Other challenges that have been presented by the ARD movement include: unique designs bring unique maintenance, inspection, and management expectations and requirements; aesthetic values and ideas are rarely considered and integrated in the early design phases of projects; very little information is available on the best retrofit opportunities and life cycle costs of artistic stormwater management facilities (Echols & Pennypacker 2008).

6 DISCUSSIONS

This review of a stacked approach to integrated best management practice design for stormwater demonstrates that current approaches to stormwater management as highly engineered, singular systems, are not the only option for designers, and there is an alternative more sustainable option available in stacking them. These systems are physically and technologically complex and can be particularly well designed for strict environmental compliance; however, they are highly interdependent and will seldom work effectively in a multifaceted system that is prone to frequent change. Current BMP designs, within the larger conversation of green infrastructure, have the potential to increase water quality, provide ecological benefits and improve aesthetic conditions, however a more integrated design approach in needed in the face of current weather patterns continual change in intensity and frequency. A stacked approach has the potential to better protect the environment and the public landscape with innovation to address extreme weather events while also allowing for improved community resiliency for more effective recovery after climate events. However, more research is essential to enhance a more resilient approach to water management. This review suggests a number of important implications for designers, researchers, and policy makers alike. With several important implications for the wider design world, the following section briefly examines the implications for water sustainability.

For designers, the current body of literature presented in this study suggests that increased consideration of stormwater designs that are aesthetically strong and socially inclusive is greatly needed. We recommend that designers consider how increasing on-site stormwater retention and infiltration can improve the visual aesthetics of urban and rural areas through improved aquatic connectivity and aesthetic appeal of stormwater sources and treatments (see figures 1 & 2). This stacked approach to stormwater management design has the potential to combine ecological services found in both urban and rural landscapes as well as provide additional water quality and flood protection. Designers should also consider the relationship between improvements in visual beauty and improvements in stormwater retention with regard to urban planning as well as a realistic assessment of stacked BMPs as a means for water systems design and management. Either through education or practice, providing opportunities for designers to explore new aesthetic norms of stacked BMPs into the designed landscape will offer a greater overall adoption and acceptance of this emerging approach to stormwater management.

This review has implications for a range of interdisciplinary researchers: from scientists who study interactions between water use by ground-based observation and others, who examine water quality and ecological relationships. Given the constraints to reduce NPSP levels imposed by physical and political parameters, namely design interventions at the ecological patch level rather than the landscape-level, future research needs to focus on how to address this concern on a larger site scale. By researching interventions that are implemented by adjusting landscape patterns and increasing highly-heterogeneity biodiversity and/or highly-connected corridors, a better understating of the ecological and water quality benefits can be assessed. The technology to manufacture this information through advanced modeling software has greatly improved as well as the ability to predict and design for conditions. However, technical and legal limits have imposed further challenges on the kind of data that is able to be generated. For example, the use of satellite images of field boundaries may be limited or otherwise prohibited. This latter restriction only strengthens the need for ongoing research of remote sensing techniques for ground observations, based on modeling data, of stacked BMPs. The future design capabilities of stacked BMPs, combined together with understanding the true impact that this approach has on the surrounding ecology, is an area of research that is in ever increasing demand.

The implications for policy makers are multifaceted, but equally significant. Loss of freshwater resources for communities and urban landscapes is a problem that will only continue to grow unless direct action is taken to halt its decline. Policy makers need to take climate change into account in their municipal goals and adaptation plans with regards to stormwater management requirements. A practical, long-term program is needed that will monitor the environmental changes being caused by climate change and ensure that pollution is reduced while maintaining a healthy social and ecological environment. Policy makers should also consider the aesthetics and social acceptance of stormwater management, specifically the stacked BMP approach, as a means of financial trade-offs or synergies between these multilayered practices. The effects of municipal requirements of stormwater management on flood prone populations will only become more pronounced in the coming years if policy does not require development to plan for long-term implications of their designs, specifically their stormwater management plans.

7 CONCLUSIONS

As we continue to implement highly engineered stormwater systems for our landscapes and strive for the ideal site specific practice, a more resilient approach to green infrastructure is needed. However, the vast majority of water management systems step further away for this goal of mirroring natural systems flexibility and overall ability to evolve to change, and rather stagnate our landscapes in single function and single use designs. There has been significant development over the past 20 years toward understanding best management practices and their impact on green infrastructure and promoting environmental fitness. Specifically with regards to ecological adaptability, designers are encouraged to construct stormwater landscapes to be more flexible, responsive, and adaptable in order to evolve to the unprecedented changes the future brings. However, these are based on single BMP units and not on the combined effect of a stacked approach. In this review, we have explored the limited literature available on the water quality abilities of a stacked approach to BMPs, their ecological benefits, and the significance of the aesthetic consideration in design. Moreover, as our knowledge of their value increases, the scientific community has yet to reach a consensus on the role of stacked BMPs in the implementation of green infrastructure. Furthermore, given that green infrastructure is an area of design that is still relatively recent in regards to successful case studies that knowledge can be drawn from, the lack of long-term lifecycle analysis of stacked BMPs creates its own challenge to accurately measure the impact this alternative design approach can have on water quality and ecosystem health. There have been a number of other challenges that have impeded an increase in the adoption of stacked BMP design. These obstacles include a lack of reachable information to designers and policy makers alike due to the overly technical nature of stormwater modeling. Also, the lack of current information in the city's stormwater policy is a significant challenge, as many municipal codes haven’t changed or been reevaluated to reflect the growing trends as a result of climate change. Lastly, a need for significant financing for the investment in ecological and aesthetically inclusive stormwater management systems at the national level is considered essential. Both designers and researchers need to continue challenging the conventional approaches to stormwater management and BMP design and provide feasible options to our communities, in order to create more resilient and integrated stormwater management systems that can ensure access to freshwater quality for future generations.

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