Runoff Reduction Revisited

Prepared For:

Government of the District of Columbia
Department of Energy & Environment

Prepared By:

David J. Hirschman, Hirschman Water & Environment, LLC
Greg Hoffmann, P.E. & Ari Daniels, Center for Watershed Protection, Inc.
Jon Hathaway, Ph.D., University of Tennessee[1]
Kelly Lindow, P.E., CityScape Engineering
Marcus Aguilar, Ph.D.
Tom Schueler & David Wood, Chesapeake Stormwater Network

[1] Special thanks to University of Tennessee Doctoral students: Jessica Thompson, Whitney Lisenbee, Padmini Persaud, Andrew Tirpak, Aaron Akin, Victoria Rexhausen

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INTRODUCTION

Updated Research, Updated Design Recommendations

The original technical memorandum on the Runoff Reduction Method (RRM) was produced in 2008, accounting for Best Management Practice (BMP) research conducted through 2007 (CWP & CSN, 2008). The memorandum provided a framework for Virginia's emerging stormwater management program, and the method developed therein has since been adapted and modified for use in other jurisdictions, including the District of Columbia. The District uses a "retention volume" standard based on the type of BMP and storage provided within the BMP. This metric is, in part, a measure of how effective each BMP is at reducing runoff delivered from a given drainage area.

At the time of the original RRM memo, the authors acknowledged the limited number of available studies, particularly for some BMP categories:

> *The biggest caveat to the data. . .is the limited number of studies available that reported BMP runoff reduction or EMC based nutrient removal efficiencies. As a result, some of the numbers listed in the tables will be subject to change as more studies and data become available. The numbers in the tables are the authors' best judgment based on currently-available information.* (CWP & CSN, 2008, p. 9).

Recently, a team consisting of the original RRM authors and other experts conducted an updated analysis of research studies performed from 2007 through 2017. This work was performed for Metro Nashville, as that jurisdiction's program evolved to a mandatory runoff reduction standard (Hirschman et al., 2018). However, Nashville's standard is based strictly on volume, so the research did not include an analysis of the pollutant reduction capabilities of BMPs.

The District expressed an interest in building on the Nashville effort to include pollutants that are important to the District's program as well as BMPs not included in the Nashville study. While the District's stormwater program also uses a volume standard, it has the added challenge of a complex array of TMDLs, including the Chesapeake Bay TMDL. As such, pollutant reductions and effluent concentrations are increasingly relevant. Importantly, the updated research includes the performance of such design enhancements as Internal Water Storage and soil media amendments. These can be valuable for the District's ongoing efforts to update the Stormwater Management Guidebook.

Table I-1 notes the number of studies per practice included in the update, as well as the total number of practices, accounting for the fact that many studies conducted research on multiple practices with design variations (e.g., different underdrain configurations). As can be seen from the table, some practices were represented more heavily than others. Bioretention, permeable pavement, and green roofs are the favored topics of newer research. Other practices – rainwater harvesting, infiltration, impervious surface disconnection, and extended detention – have very little updated research to provide a foundation for design recommendations. This also applies to bioretention variants, such as residential rain gardens, dry swales, and stormwater planters.

Finally, while a number of practices were well-represented by updated studies, volume seemed to be the preferred focus. Nutrients were measured in a subset of these studies, with even fewer accounting for reductions of toxics or bacteria.

Despite these limitations, the newly reviewed studies do provide a more robust body of data to support professional application.

Table I-1. Number of Updated Studies & Individual Practices Studies (accounting for studies that included multiple practices)

BMP Types	# New Studies	# of Individual BMPs Studied
Green Roof	25	37
Rainwater Harvesting	5	37
Impervious Surface Disconnection	9	45
Permeable Pavement	23	37
Bioretention	52	112
Infiltration	8	39
Grass Channels	11	24
Extended Detention Pond	6	10
Wet Pond/Wetland	19	43
Tree Planting/Preservation[1]	N/A	N/A

[1] Tree Planting and Preservation data were analyzed using a spreadsheet tool developed by a separate CWP project.

It should be noted that several recent and ongoing efforts formed a strong backbone for the current study:

- *Updating the Runoff Reduction Method*, Prepared for: Metro Government of Nashville & Davidson County, Tennessee (Hirschman et al., 2018).
- *Potential Benefits of Nutrient and Sediment Practices to Reduce Toxic Contaminants in the Chesapeake Bay Watershed,* Chesapeake Stormwater Network, Prepared for: Toxics Work Group (Schueler & Youngk, 2015).
- *Performance Enhancing Devices for Stormwater Best Management Practices,* Chesapeake Stormwater Network and Center for Watershed Protection (Hirschman et al., 2017).
- *Recommendations of the Expert Panel to Define BMP Effectiveness for Urban Tree Canopy Expansion,* Center for Watershed Protection, Inc. and Virginia Tech, Prepared for: Forestry Work Group and other Chesapeake Bay committees (Law & Hanson, 2016).
- *Annotated Bibliography for Stormwater Structural BMPs/Literature Review – DDOE Structural TMDL Implementation, and Appendix F: BMPs and BMP Implementation* (LimnoTech, 2015).
- Ongoing bacteria research by the Chesapeake Stormwater Network and ad-hoc advisory group.

Recommendations From The District Research Update

Table I-2 summarizes the recommendations of this project based on a review of the studies. The second column in the table summarizes recommendations from the Nashville effort concerning runoff reduction (average annual basis). Note that the Nashville recommendations refer to Level 1 and 2 designs, with the approximate District equivalents being “standard” and “enhanced,” respectively. The third column expands on these for the District. The following sections of this report present a more detailed analysis for each BMP type.

Table I-2. Summary of Recommendations

BMP	Summary of Recommendations from Nashville Update (2018)	Additional Recommendations for DOEE
Green Roof (3.2)	• Adjust Level 1 to 10% times media depth (in inches), with minimum depth of 3 inches • Adjust Level 2 to 12% times media depth, with minimum depth of 4 inches • Maximum runoff reduction for both levels = 90%	• Keep current retention volume value. • Establish roof slope criteria of 8.33% (1:12) or flatter for design without baffles. Slopes between 8.33% and 30% should use baffles designed to retain water. • Allow sensor controlled irrigation for roofs of any depth. • Consider hydraulic loading limits.
Rainwater Harvesting (3.3)	N/A	• Encourage automatic drawdown/release mechanism in the cistern (Cistern Design 3, or similar). When automatic drawdown is employed, encourage connection to secondary runoff reduction practice.
Impervious Surface Disconnection (3.4)	N/A	• Decrease the maximum length for disconnection to 33 feet. • Consider increasing the retention value to 5 cubic feet per 100 square feet.
Permeable Pavement (3.5)	• Decrease Level 1 from 45 to 30% • Increase Level 2 from 75 to 80% • Clarify IWS as Level 2 option with minimum measured infiltration rate	• Decrease maximum contributing drainage area from 5X to 3X the surface area of the permeable pavement. • Geotextile not recommended on bottom of practice. <u>Sizing recommendations</u>: • Standard Design: Retention Value = 30% of Sv. This value is based on volume reduction numbers for designs with underdrains and no infiltration sump. • Enhanced Design: Retention Value = 100% of Sv below underdrain PLUS 30% of Sv in remainder of system.
Bioretention (3.6)	• Increase Level 1 rate from 40 to 60% • Keep Level 2 rate at 80% • Add alternative Level 2 with internal water storage (IWS)	• Consider reducing retention value for enhanced design (with underdrain) from 100% to 80%. Maintain 100% for infiltration design. • For Enhanced Design, consider using Internal Water Storage (IWS) in lieu of elevated underdrain. • For Enhanced Design, consider reactive media amendments in the future. Revisit the type and vegetation, stressing above and below-ground biomass.
Infiltration (3.8)	• Maintain existing sizing and infiltration testing criteria	Maintain current retention volume value.
Grass Channels (part of Open Channels, 3.9)	N/A	• Consider incorporating vegetated check dams.

Table I-2. Summary of Recommendations		
Extended Detention Pond (3.10)	• Increase unlined ED ponds from 15 to 25%, with possible inclusion of soil analysis	• Assign retention value of up to 30%, if there is desire to add specifications for this BMP.
Wet Ponds/Wetlands (3.11)	N/A	• Eliminate current 10% retention value. • Widespread use in District not anticipated; consider when available space and community support exist, as practice could be amenity in parks or open spaces.
Tree Planting, Preservation (3.14)	N/A	• Maintain existing values for Small and Large trees. • Change value for Heritage trees from 40 cubic feet to 30 cubic feet.

What Do The Numbers Mean?

The purpose of this study is to support the District's stormwater and watershed programs. As such, the runoff reduction and pollutant removal rates need to be based on solid technical and scientific resources and provide a logical link to the specifications in the Stormwater Management Guidebook. With this as a guiding principle, it must be acknowledged that there is no standardization in how researchers measure and report volume or pollutant removal data. For volume, some studies base calculations on the total volume of runoff entering and leaving a practice during the entire study period. Others measure volume reduction for numerous individual storm events, and then average the results. Some studies aim to measure and model the mechanisms of evaporation, transpiration, exfiltration, underdrain flow, and overflow. Yet others compare "treatment" sites with control sites. Similarly, for pollutants, various studies report percent removal (with the same variability of methods noted above), influent and effluent concentrations, or even retention of a pollutant within the soil media.

Typical of BMP monitoring, there was a lot of "scatter" in many of the data sets, most notably for pollutant percent removal values. Variability is likely due to design factors, influent concentrations, the size and intensity of monitored storms, drainage areas, monitoring methods, age of BMP and degree of maintenance, and other factors. It would be a daunting task, indeed, to attempt to standardize or normalize these data sets. The approach taken, therefore, was to review the papers carefully, understand what was being measured, and rely on a weight of evidence approach to discern convergences of the data toward certain values. The study team also attempted, wherever possible, to discern the design variables that led to either poor or good results, and these are articulated in the individual BMP sections.

Ideally, these data should be updated on a periodic basis, as new studies are ongoing, with results for both volume and pollutant reductions. This also holds true for TMDL implementation; the understanding of watershed sources and treatment mechanisms for pollutants, such as toxics and bacteria, continues to evolve.

Methodology & Adequacy of Data for Analysis

The methodology for the project included, in general terms, the following steps:

- Building on the updated Nashville studies, team members collected new research studies (i.e. studies not included in the original RRM memorandum). The additional studies focused on pollutant removal for nutrients, heavy metals, and bacteria. All papers were collected into a shared folder and categorized by practice. A spreadsheet was developed to organize data in a systematic way.
- Dr. Hathaway from the University of Tennessee and his graduate students reviewed all of the collected studies. The students entered data into the spreadsheet, documenting study variables, runoff reduction rates, pollutant removals, methods of analysis, number of storms sampled, and other data. Brief study descriptions were also added.
- Subsequently, the other team members conducted thorough reviews of the data. The data were analyzed for basic statistics, such as mean and median pollutant removal rates (concentration and mass load reductions) and effluent concentrations. Volume reductions were also analyzed for practices not included in the Nashville study (e.g., impervious surface disconnection, wet ponds/wetlands, rainwater harvesting). In some cases, outliers were either included or excluded based on the circumstances depicted in the studies. Summary statistics were organized into BMP-specific Excel worksheets.
- Professional judgement was used to determine whether there were adequate data to derive summary values and statistics (e.g., means, medians). In general, the team determined that there were inadequate data for analysis if a particular BMP had fewer than 5 data points for a given pollutant. **Table I-3** depicts the results of this adequate data review for each BMP. Even if data was deemed inadequate, the raw data was still included in the spreadsheet data tables.
- For bacteria research, staff from the Chesapeake Stormwater Network (CSN) were already working on a related study, and the team used the shared spreadsheet to assemble data for both efforts. The finding for bacteria are derived from the CSN study (see section below).
- Similarly, data for tree planting and preservation was previously analyzed by the Center for Watershed Protection (CWP) for the purposes of developing a national tool (see section below).
- Team members distilled BMP design take-home points and recommendations for each practice.
- Throughout the process, the team held conference calls to discuss methodology, issues that arose with comparing data that were collected using different methods, and appropriate recommendations.

Table I-3. Adequacy of Available Data to Generate Summary Statistics[1]											
BMP	**Diss-P**	**TP**	**NOx**	**TN**	**Ar**	**Cu**	**Pb**	**Hg**	**Zn**	**PAH**	**RR**
Green Roof (3.2)											Y
Rainwater Harvesting (3.3)											Y
Impervious Surface Disconnection (3.4)	Y	Y	Y	Y		Y					Y
Permeable Pavement (3.5)	Y	Y	Y	Y		Y	Y		Y		Y
Bioretention (3.6)	Y	Y	Y	Y			Y		Y		Y
Infiltration (3.8)		Y	Y	Y		Y	Y		Y		Y
Grass Channels (part of Open Channels, 3.9)		Y	Y	Y		Y			Y		Y
Extended Detention Pond (3.10)											
Wet Ponds/Wetlands (3.11)	Y	Y	Y	Y		Y	Y		Y		
Tree Planting, Preservation (3.14)	See Tree Planting/Preservation Section for description of CWP Tool										
Diss-P = dissolved phosphorus; TP = total phosphorus; NOx = nitrate/nitrite; TN = total nitrogen; Ar = arsenic; Cu = copper; Pb = lead; Hg = mercury; Zn = zinc; PAH = Polycyclic aromatic hydrocarbons; RR = runoff reduction [1] "Y" indicates 5 or more data points for a given pollutant to generate summary statistics. Shaded cells indicate fewer than 5 data points, and therefore inadequate data.											

As can be seen in **Table I-3**, among the toxics examined, there is a paucity of data for Arsenic, Mercury, and PAHs. Copper, Lead, and Zinc were somewhat better represented. There is also very little recent pollutant removal data for several BMP categories: Green Roofs, Rainwater Harvesting, and Extended Detention. Nutrient data appear adequate for most BMPs, with dissolved Phosphorus data lacking in some categories. The data inadequacies indicated here could point to future research needs.

Approach for BMP Bacteria Research

Elevated fecal indicator bacteria (FIB) levels remain the most frequent cause of water quality impairment in the U.S., and a challenge for state and local governments seeking to implement balanced programs to address multiple priorities at the lowest cost. To date, there are few resources that quickly summarize data on bacteria source tracking and removal techniques in a way that can be easily applied by watershed planners and managers. To address this challenge, the Chesapeake Bay Program's Urban Stormwater Workgroup (USWG) charged the Chesapeake Stormwater Network (CSN) to lead a small ad-hoc team to review and summarize the latest science in three key areas: (1) bacteria land use loading rates; (2) bacteria source analysis techniques; and (3) bacteria removal performance of stormwater BMPs. While some recommendations are provided, they do not represent the official position of the Urban Stormwater Workgroup.

The review focused on studies published post-2000, with additional emphasis on the most recent research. The group found that in general, urban land uses are correlated with high bacteria concentrations in most watersheds, but it is difficult to isolate the specific sub-watershed factors that produce them. Similarly, bacteria removal performance by stormwater BMPs is limited to only a few practices, and removal rates are highly variable. While some BMPs show bacteria removal potential, they are still often unable to meet water quality standards on their own, suggesting that watershed source controls are a necessary part of the solution.

Multiple new techniques are being tested to improve microbial source tracking techniques to make source targeting easier and more effective. Combined with the available BMP performance data, there will likely emerge enough evidence to help watershed managers make better decisions about how to select practices and better target their implementation efforts. A comprehensive approach is still recommended to track FIB sources and combine BMP implementation with enhanced IDDE programs and education and outreach campaigns.

District staff have been participating on the ad-hoc team with CSN. The final report is forthcoming and provide additional information about the role of BMPs in bacteria removal. As a result, the subsequent sections of this report do not address BMP-specific information for bacteria.

Approach for Tree Planting & Preservation

The aforementioned Chesapeake Bay Expert Panel report on urban tree canopy (2016), summarizes relevant research on this topic. Subsequent to this effort, the Center for Watershed Protection developed an national tool using a performance-based credit calculator (Calculator; CWP, 2017). The tool was developed as a part of the "Making Urban Trees Count" project with the U.S. Forest Service. Documentation and a full description of the tool can be found at: https://www.cwp.org/making-urban-trees-count/.

The tool was used to estimate runoff reduction volumes for each tree planting scenario in the District, and how the model results compare with currently recommended runoff reduction credits. The Tree Planting & Preservation section provides detailed descriptions and results from this analysis.

The Study Team

The current study team included the following individuals and organizations:

- David J. Hirschman, Principal, Hirschman Water & Environment, LLC
- Dr. Jon Hathaway, University of Tennessee, Department of Civil & Environmental Engineering; Doctoral Students: Jessica Thompson, Whitney Lisenbee, Padmini Persaud, Andrew Tirpak, Aaron Akin, Victoria Rexhausen
- Greg Hoffmann, Ari Daniels, Laura Gardner: Center for Watershed Protection, Inc.
- Kelly Collins Lindow, Principal and Founder, CityScape Engineering, LLC
- David Wood & Tom Schueler, Chesapeake Stormwater Network
- Dr. Marcus Aguilar

Remaining Sections of This Report

The following sections provide more detailed analyses of the updated research, organized in the same sequence as the selected BMPs are listed in the District's Stormwater Management Guidebook. Note that not all of the Guidebook's BMPs are included, as the project Scope of Work dictated the practices to be included. Some report sections contain more content than others based on the number of studies that were reviewed and the degree to which recommendations were distilled from the research. The numbers in parentheses reference the relevant Guidebook section.

- Green Roof (3.2)
- Rainwater Harvesting (3.3)
- Impervious Surface Disconnection (3.4)
- Permeable Pavement (3.5)
- Bioretention (3.6)
- Infiltration (3.8)
- Grass Channels (part of Open Channels, 3.9)
- Extended Detention Pond (3.10)
- Wet Ponds/Wetlands (3.11)
- Tree Planting & Preservation (3.14)

If there were adequate data available for analysis, the BMP sections include summary data tables and box plots illustrating the ranges of data, as well as mean values, for mass load reductions as well as effluent concentrations. On the plots, the full length of the line shows the data range (including outliers in some cases), the box illustrates 25^{th} and 75^{th} percentile values, and the horizontal line in the box indicates the mean value. Several of the BMPs did not have adequate data to generate these types of plots.

As a final note, this study focused on BMP performance and design modifications highlighted by research findings (largely from peer-reviewed sources). Other innovations in the stormwater field, such as continuous monitoring and adaptive controls, are designed to enhance the performance for a variety of BMPs. More research is likely forthcoming for these innovations. The District can consider coupling application of these newer technologies with the design modifications recommended in this report.

GREEN ROOFS (Guidebook, 3.2)

The green roof research analysis included 25 studies and at least 37 individual practices. Many of the studies were short term field studies performed at a test-plot scale that evaluated performance from individual storm events. Few studies reported performance on an annual basis; however, several studies considered the performance of vegetated versus non-vegetated roofs in order to assess the effect of seasonal vegetation on performance. In general, the runoff and water quality data available on green roofs is limited and variable. Tables are not provided due to the significant inconsistency of the experiment designs and associated results.

Design Factor Notes

Pollutant Removal

- Additional research is needed to better evaluate the heavy metal pollutant removal performance of green roofs.
- Some green roof studies have found reductions in nitrogen (Berndtsson et al., 2009; Bliss et al., 2009), whereas others have shown nitrogen pollutant increases (Aitkenhead-Peterson et al., 2010; Berndtsson et al., 2006; Gnecco et al., 2013; Hathaway et al., 2008; Teemusk and Mander, 2007). Media composition and use of fertilizers likely impact nutrient export from green roofs, but more research is needed to define specific design factors affecting performance.
- Phosphorus concentrations are typically higher in green roof runoff than conventional roof drainage (Berndtsson et al., 2006; Berndtsson et al., 2009; Fassman-Beck and Simcock, 2013; Gnecco et al., 2013; Hathaway et al., 2008; Seidl et al., 2013; Teemusk and Mander, 2007).
- Green roofs are generally not considered water quality treatment practices but may offer pollutant mass reductions as an associated benefit of reduced runoff volume.

Retention Volume

- Vegetation increased runoff reduction rates by 7-10% compared to unvegetated roofs (media or gravel only). These results emphasize the importance of establishing healthy plant coverage on green roofs (Van Woert et al, 2005; Lang et al, 2010).
- Green roof performance varies by season. During warm summer months, significantly more evapotranspiration occurs from the green roof surface than during winter months (Hutchinson et al, 2003; Wadzuk et al, 2013).
- In certain climates, vegetation may require supplemental irrigation during summer months to thrive. In a study performed by Hill et al (2017), sensor controlled or non-irrigated systems had less runoff than standard irrigation system. This study evaluated 4 inch and 6 inch media depths and concluded that daily, timed (non-sensor) irrigation was detrimental to stormwater retention; however, the retention performance of sensor irrigated systems was equivalent to non-irrigated systems.
- Runoff volumes increase with increasing roof slope, resulting in lower retention volume (Van Woert et al, 2005; Getter et al, 2007; Hathaway et al, 2008).

- Thicker media depths demonstrate higher retention volumes (Van Woert et al, 2005; Getter et al, 2007; Hathaway et al, 2008).

Recommendations

- Consider establishing a roof slope criterion of 8.33% (1:12) or flatter for design without baffles. Slopes between 8.33% and 30% must use baffles designed to retain water.
- Allow for soil-moisture sensor-controlled irrigation for roofs of any depth.
- With regard to hydraulic loading limits, none of the evaluated studies considered green roof performance for contributing drainage areas. The District's method of allowing additional drainage area to a green roof is neither supported or refuted by the available research. However, the District needs to ensure that the Sv calculations account for the additional drainage area. A 1,000 sf green roof with 1,000 sf contributing drainage area should get half the credit as a 1,000 sf green roof with no contributing drainage area. In addition, the District should exercise caution when allowing drainage areas that exceed 1:1. Excessive hydraulic loading would likely reduce the degree of treatment and perhaps even exacerbate some of the pollutant leaching issues identified by the research.
- No retention value changes are recommended. The current calculations are similar to the values proposed for Nashville (The District uses 0.15 (default) x depth, where as 10% -12% x depth is proposed for Nashville).

RAINWATER HARVESTING (Guidebook, 3.3)

The rainwater harvesting (RH) research analysis included 5 studies, 3 of which were modeling or experimental studies accounting for 37 individual practices/scenarios. The other two studies were literature reviews that aggregated the data and results from other papers from around the world. While a great deal of data are available, there is a lack of standardization in the experimental methods, and the significantly different uses and intents of RH systems make comparisons difficult.

There was high variability in experiment design, monitoring, conditions, and reporting methods (DeBusk & Hunt, 2012; Campisano, 2017), though some general guidance and takeaways can be reasonably summarized. Steffen (2013) modeled residential rainwater harvesting systems with reuse as the exclusive drawdown. See Table RH-1 for some statistical metrics for the annual runoff reductions reported in the Steffen (2013) study, and Table RH-2 for quick-glance results of annual runoff reduction for mid-Atlantic states from Gee & Hunt (2016).

Design Factor Notes

The single greatest factor affecting how beneficial a rainwater harvesting system can be within a runoff reduction context is available capacity to detain stormwater during a rainfall event. After a storage tank (cistern) is filled from a storm event, it must be at least partially emptied to provide any benefit for the next storm event. When an RH system is connected to water reuse for such functions as toilet flushing or car washing, the available capacity depends directly on the rate at which the water is being used for other purposes.

Gee and Hunt (2016) highlight the differences in effectiveness at runoff reduction employing both passive (orifice as in the District's cistern design #3) and active (complex controls, monitored and pumped) release mechanisms, and modeling those same systems without an automatic release mechanism. The active, passive, and no release mechanisms had runoff reduction of 86%, 74%, and 20-21%, respectively. The lower runoff reduction results from the models representing the systems without release mechanisms are consistent with the Steffen (2013) study, where the outputs from the cistern are exclusively reuse.

DeBusk and Hunt (2012) reference a few studies which, similar to the experimental design of Gee and Hunt (2016), employ storage for reuse and also release. DeBusk and Hunt suggest that the release of stored rainwater to a complementary BMP, such as a bioretention, infiltration trench, or even a rain garden, can be the best use of the released water. Essentially, a rainwater harvesting system can function as additional safe ponding volume for a connected runoff reduction practice. The District's draft Guidebook has three cistern designs, two of which employ some type of release to ensure capacity is available for follow-up storms.

Recommendations

The only recommendation offered is to encourage the use of release/drawdown cistern design in order to avoid reliance on purposeful and possibly unreliable or inconsistent reuse. Slow release to a complementary runoff reduction practice, provided adequate design of the secondary practice will accommodate the additional water input, will add significant pollutant removal to the total system. Even, as a last resort, slow release (over 24 to72 hours) to adjacent impervious area will reduce the peak flows to nearby storm systems and waterways and reduce soil erosion and pollutant flush.

Table RH-1. Annual Runoff Reduction Values by Cistern Size (Steffen, 2013)	**Annual Runoff Reduction (%)**		
	50-gal Cistern	**100-gal Cistern**	**500-gal Cistern**
# individual practices w/ data	7	7	7
Adequate data for analysis?	YES	YES	YES
Minimum	4	7	12
Maximum	12	14	17
Mean	9	11	15
Median	10	12	16
25th Percentile	7	8	14
75th Percentile	11	12	16
Standard Deviation	2.7	2.5	1.7

Table RH-2. Annual Runoff Reduction By Release Mechanism (Gee & Hunt, 2016)	**Annual Runoff Reduction (%)**
2150-gal Cistern WITH passive release	74
2150-gal Cistern W/O release	*20*
3250-gal Cistern WITH active release	86
3250-gal Cistern W/O release	*21*

IMPERVIOUS SURFACE DISCONNECTION (Guidebook, 3.4)

The impervious surface disconnection research analysis included 9 studies and 45 individual practices. All of the studies reviewed assessed simple disconnection to lawns or grassed filter strips. No studies were found that focused on conservation areas, and only one study considered soil amendments (with no obvious effect).

Tables ISD-1 and ISD-2 show results for various pollutant mass load reductions and effluent concentrations. Figures ISD-1 through ISD-2 are summary plots for mass load, nutrient effluents, and metals effluents, respectively. Very few of the studies assessed individual pollutants other than phosphorus and nitrogen, which makes it difficult to draw firm conclusions from these data.

Design Factor Notes

Intuitively, length, slope, hydraulic loading rate, soil infiltration rate, and vegetation are the design factors most likely to affect the runoff reduction capabilities of impervious surface disconnection. Generally, the literature confirms that longer disconnection lengths provide higher volume reduction (e.g. Hunt et al., 2010, Abu-Zreig et al., 2004), but this relationship was not consistent across all studies. Abu-Zreig, et al. (2004) provided the most detailed and controlled comparison of lengths and concluded that increased length improves performance up to a length of approximately 33 feet (10 meters). Beyond this length, no performance improvements were observed.

Several of the studies considered other factors: slope, soil infiltration, and vegetation, and some of them indicated performance differences based on these factors (e.g. Abu-Zrieg et al., 2004 concluded that denser vegetation led to greater runoff reduction and sediment removal). In general, as expected, larger, flatter disconnection areas with greater vegetative coverage were more effective.

Recommendations

- The mean runoff reduction value found for all of the studies was 53% (note: this is higher than the 43% value given in the Metro Nashville report (Hirschman et al., 2018), as a few test sites that had only bare soil were removed from the analysis). The retention value provided in the Guidebook for disconnection to compacted cover is 2 cubic feet per 100 square feet, which, if one assumes that the hydraulic loading rate is 1:1 (contributing drainage area is equal to the disconnection area), is the equivalent of 21% retention. All of the sites studied had a significantly higher loading rate, so it may be appropriate to increase the Guidebook value to 5 cubic feet per 100 square feet for disconnection to a compacted area.. As there is little data available to distinguish the other types of disconnection, providing the same retention value for all three types may be appropriate.
- The Abu-Zreig, et al. (2004) conclusion that retention and pollutant removal did not increase when disconnection length was extended beyond 33 feet is persuasive. Reducing the maximum disconnection length from the current 100 feet is recommended.

Disconnection Summary Table ISD-1: Mass Load Reductions (%)											
	Dissolved P	TP	Nox	TN	Arsenic	Copper	Lead	Mercury	Zinc	PAHs	Runoff Reduction
# individual practices w/ data	10	6	6	10	0	4	0	0	4	0	36
Adequate data for analysis?	Y	Y	Y	Y	N	N	N	N	N	N	Y
Mean	-34	30	47	50	N/A	-11	N/A	N/A	88	N/A	53
Median	-67	46	42	47	N/A	-16	N/A	N/A	87	N/A	52
Minimum	-156	-42	27	38	N/A	-51	N/A	N/A	85	N/A	11
Maximum	56	56	71	69	N/A	38	N/A	N/A	91	N/A	99
25th Percentile	-76	6	38	44	N/A	-51	N/A	N/A	85	N/A	38
75th Percentile	42	54	60	59	N/A	33	N/A	N/A	91	N/A	72
Standard Deviation	72	37	15	10	N/A	46	N/A	N/A	3	N/A	23

Disconnection Summary Table ISD-2: Mean Effluent Concentration: mg/L for nutrients; ug/L for metals										
	Dissolved P	TP	Nox	TN	Arsenic	Copper	Lead	Mercury	Zinc	PAHs
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
# individual practices w/ data	8	4	6	10	0	8	4	0	4	0
Adequate data for analysis?	Y	N	Y	Y	N	Y	N	N	N	N
Mean	0.26	0.16	0.27	1.95	N/A	0.0069	0.006	N/A	0.066	N/A
Median	0.29	0.15	0.21	2.14	N/A	0.0075	0.006	N/A	0.066	N/A
Minimum	0.01	0.08	0.18	0.88	N/A	0.0041	0.006	N/A	0.066	N/A
Maximum	0.46	0.26	0.43	2.68	N/A	0.0090	0.006	N/A	0.066	N/A
25th Percentile	0.04	0.08	0.18	1.20	N/A	0.0047	0.006	N/A	0.066	N/A
75th Percentile	0.46	0.25	0.42	2.68	N/A	0.0090	0.006	N/A	0.066	N/A
Standard Deviation	0.22	0.09	0.12	0.76	N/A	0.0023	0	N/A	0	N/A

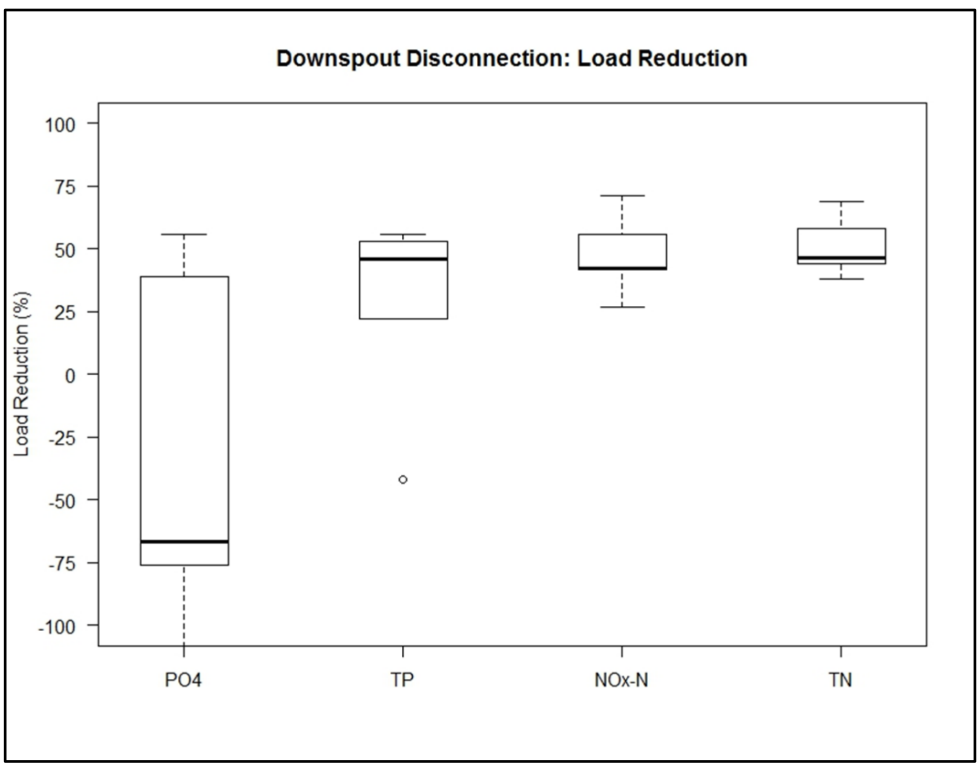

Figure ISD-1. Disconnection Mass Load Reduction Summary Plot

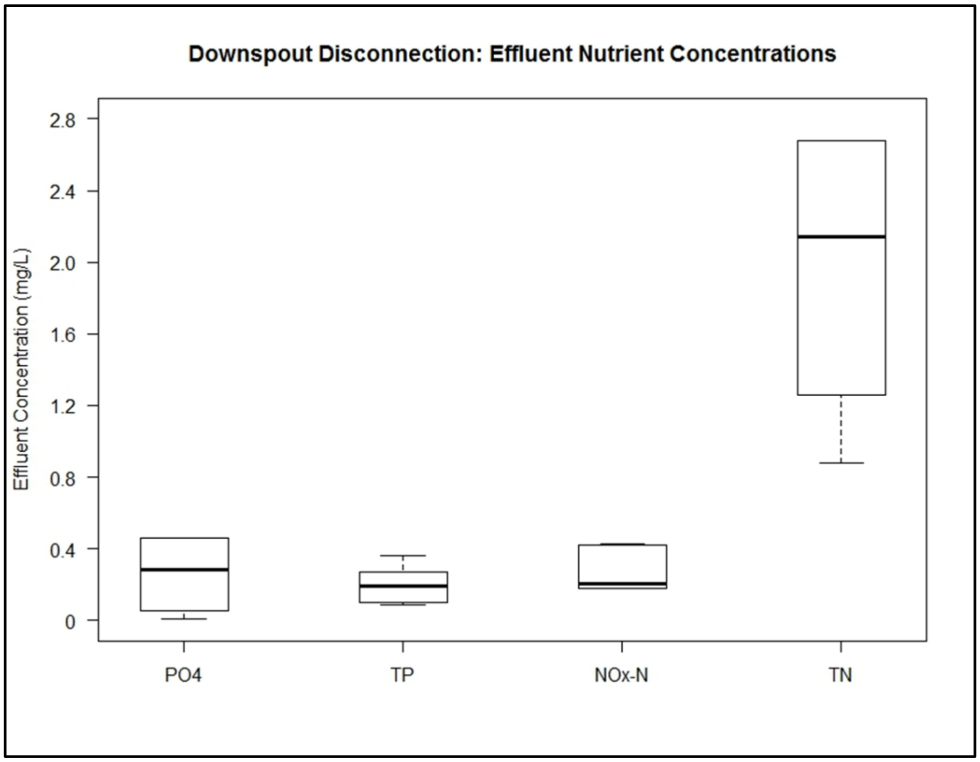

Figure ISD-1. Disconnection Nutrient Effluent Summary Plot

Figure ISD-1. Disconnection Metals Effluent Summary Plot

PERMEABLE PAVEMENT (Guidebook, 3.5)

The permeable pavement research analysis included 23 studies and 37 individual practices . The selection of studies favored field research, however a few of the studies were performed in controlled laboratory conditions with test plot or column studies. Studies varied on whether they measured hydrologic factors (e.g., runoff, volume or peak reduction) and/or pollutant removal for nutrients, metals, and bacteria.

Pollutant load reductions vary widely depending on whether a permeable pavement system is designed for filtration (with an underdrain, "standard" design) or to promote volume reduction ("enhanced" design). Based on the available data, reductions in pollutant event mean concentrations (EMCs) were the preferred variable to compare performance among individual studies.

Tables PP-1 and PP-2 and Figures PP-1 and PP-2 show results for pollutant EMC reductions and effluent concentrations, respectively. Most of the reviewed studies reported influent (or runoff from a standard pavement control) EMC and permeable pavement effluent EMC values, along with total volume of inflow versus outflow. Mass pollutant removal data was less prevalent in the reported study results, although this information could likely be calculated with further analysis.

Design Factor Notes

Upon detailed review of individual studies and consideration of specific design factors, clear trends are observed from the data set. Permeable pavements demonstrate medium to high removals of heavy metals, including copper (Cu), lead (Pb), and zinc (Zn). Average pollutant concentration reductions for these metals were in the 50 to 70% range. Little to no performance data were available for arsenic and mercury. Particulate metals accumulate in the surface void space of the permeable pavement system, and several long-term studies have demonstrated low risk for migration of these metals into the underlying layers or for groundwater contamination (Legret and Colandini, 1999; Pagotto *et al.*, 2000; Dierkes *et al.,* 2002; Brattebo and Booth, 2003; Eck *et al*., 2012). When a pavement surface is vacuum swept during routine maintenance, metals are removed along with sediment. On urban sites where underlying soils have high existing metal concentrations, there may be an initial leaching of metals following construction (Winston et al, 2015).

Although the data set is limited, permeable pavements also show promise for removal of PAHs within the pavement base layers (Legret and Colandini, 1999; Pagotto et al, 2000; Boving et al., 2008).

Nutrient removal rates are much more variable. Most studies show potential for moderate to high phosphorus removal (both dissolved and total) when the underlying soils have low phosphorus content. Numerous studies have suggested that aerobic conditions, which result as permeable pavements drain, can result in nitrification of ammonia-nitrogen (NH_4-N) to nitrate-nitrogen (NO_3-N). In multiple studies, permeable pavement had substantially lower NH_4-N and total Kjeldhal nitrogen (TKN) concentrations, but higher NO_3-N concentrations compared to runoff from asphalt (Bean *et al.*, 2007, Collins *et al.*, 2010; Roseen et al, 2011; Drake et al, 2012; Eck et al, 2012; Winston et al, 2015; Smolek and Hunt, 2016). This could be a concern for leaching of the form of N that is the most bioavailable in receiving waters.

However, this is not an uncommon trend among stormwater controls (including some bioretention). The reported total nitrogen (TN) removal rates vary widely, from negative 25% to positive 68%, with an average removal of 18%.

Below is a summary of key design factors affecting good or poor pollutant removal and retention volume performance:

Permeable Pavement: reasons for poor performance (lowest quartile of results)

- Existing soils that contain high concentrations of heavy metals or phosphorus may cause pollutant leaching through the permeable pavement system. Sediment disturbed during construction may wash through, carrying any sediment-bound pollutants (phosphorus, lead, cadmium, copper and zinc) (Winston et al, 2015). Over time, this washout is expected to decrease, but could remain problematic if the pavement has internal berms, terraces, or slopes comprised of the native soils. In these scenarios, the use of geotextiles or liners are recommended to reduce contamination. Note that geotextiles or liners are NOT recommended where contamination is not a concern; there is an elevated risk of clogging when using these materials.
- Increasing the contributing drainage area or hydraulic loading ratio to the permeable pavement surface area beyond 3:1 decreased retention volume performance (Winston et al, 2015; Smolek and Hunt, 2015).
- Permeable pavements installed over poorly draining soils with an underdrain but without an infiltration sump provide low volume reduction. When compared to runoff from conventional asphalt, these practices averaged about 30% (range 7-43%) reductions in annual runoff volumes (Collins et al, 2008; Fassman and Blackbourn, 2010; Drake at al, 2012).

Permeable Pavement: reasons for good performance (highest quartile of results)

- Studies show very little surface runoff from maintained permeable pavements. Consequently, practices in well drained soils with adequate storage and no underdrain yield very high runoff reduction volumes and pollutant load removals.
- Ripping or trenching of the subgrade may help improve infiltration rates in poorly draining soils (Tyner et al, 2009; Wardynski et al, 2013).
- Recent research supports improved performance of the “enhanced” design standard. In slow-draining soils, the inclusion of an infiltration sump can enhance volume reduction by promoting slow infiltration (Collins et al, 2008; Wardynski et al, 2013; Winston et al, 2015). Significant results were noted for infiltration sumps of 6 inches or greater and when the underlying soil infiltration rate was greater than 0.01 inches per hour.

Recommendations

- Revise Figure 3.13 to match description of Standard Design. Figure shows a filter layer but description indicates that this is not needed for a standard design.
- For Standard Design and Enhanced Design, the "water quality filter layer" appears to be just a layer of choker stone, not any sort of filter media. Recommend calling choker layer instead of filter layer.
- Decrease the maximum contributing drainage area from 5 to 3 times the surface area of the permeable pavement.
- Geotextile is not recommended on the bottom of practice but can be placed along any internal earth berms to prevent long-term sediment washing.
- Sizing recommendations:
    - Standard Design: Retention Value = 30% of Sv. This value is based on volume reduction numbers for designs with underdrains and no infiltration sump.
    - Enhanced Design: Retention Value = 100% Sv below underdrain PLUS 30% of Sv in remainder of system.

Permeable Pavement Summary Table PP-1: EMC Reductions (%)										
	Dissolved P	**TP**	**Nox**	**TN**	**Arsenic**	**Copper**	**Lead****	**Mercury**	**Zinc**	**PAHs**
# individual practices w/ data	9	14	17	13	0	16	10	1	16	1
Adequate data for analysis?	Y	Y	Y	Y	N	Y	Y	N	Y	N
Mean	29.7	50.7	-68.5	17.8	N/A	59.8	63.4	87.8	72.9	92.0
Median	29.0	57.2	-46.0	19.1	N/A	65.3	89.0	87.8	79.5	92.0
Minimum	29.0	-21.0	-114.0	-25.0	N/A	-16.0	-20.0	0.0	10.0	0.0
Maximum	83.0	96.5	69.0	68.4	N/A	96.0	98.0	87.8	97.0	92.0
25th Percentile	13.0	26.5	-124.7	-4.3	N/A	49.8	19.0	N/A	64.8	N/A
75th Percentile	79.0	80.3	-5.5	40.2	N/A	82.3	92.8	N/A	87.0	N/A
Standard Deviation	56.5	34.7	96.3	29.8	N/A	30.7	45.0	N/A	22.3	N/A
							** excluded Winston 2015 data. Implication, if soils contain high lead levels, PP may initially export following construction			

Permeable Pavement Summary Table PP-2: Mean Effluent Concentration: mg/L for nutrients; ug/L for metals										
	Dissolved P	**TP**	**Nox**	**TN**	**Arsenic**	**Copper**	**Lead**	**Mercury**	**Zinc**	**PAHs**
	(mg/L)	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(ug/L)**	**(ug/L)**	**(ug/L)**	**(ug/L)**	**(ug/L)**	**(ug/L)**
# individual practices w/ data	8	17	20	18	0	13	8	1	14	1
Adequate data for analysis?	Y	Y	Y	Y	N	Y	Y	N	Y	N
Mean	**0.028**	**0.091**	**0.666**	**1.504**	N/A	**7.723**	**2.523**	**5.30**	**19.836**	**0.090**
Median	0.021	0.080	0.485	1.325	N/A	5.280	1.310	5.30	16.150	0.090
Minimum	0.013	0.050	0.410	1.210	N/A	0.860	1.090	0.00	6.800	0.000
Maximum	0.080	0.410	2.100	5.170	N/A	20.000	8.700	5.30	77.000	0.090
25th Percentile	0.015	0.046	0.410	0.857	N/A	2.265	1.000	N/A	8.173	N/A
75th Percentile	0.029	0.097	0.870	1.738	N/A	12.650	3.465	N/A	21.250	N/A
Standard Deviation	0.022	0.087	0.463	1.066	N/A	6.363	2.693	N/A	18.106	N/A

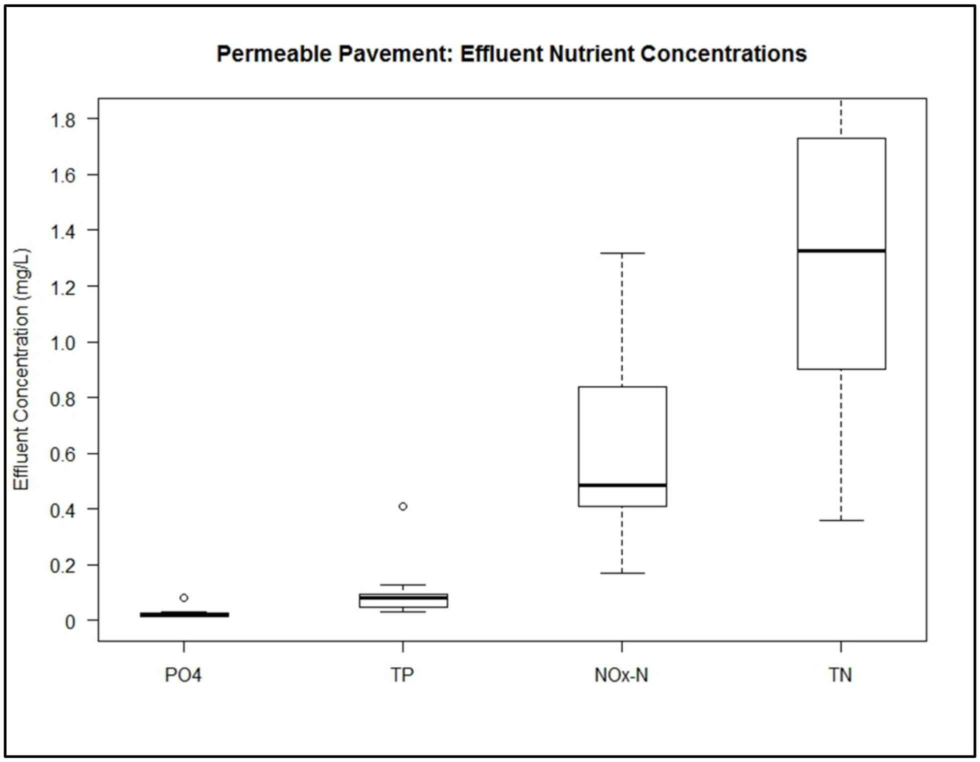

Figure PP-1. Permeable Pavement Nutrient Effluent Concentrations Summary Plot

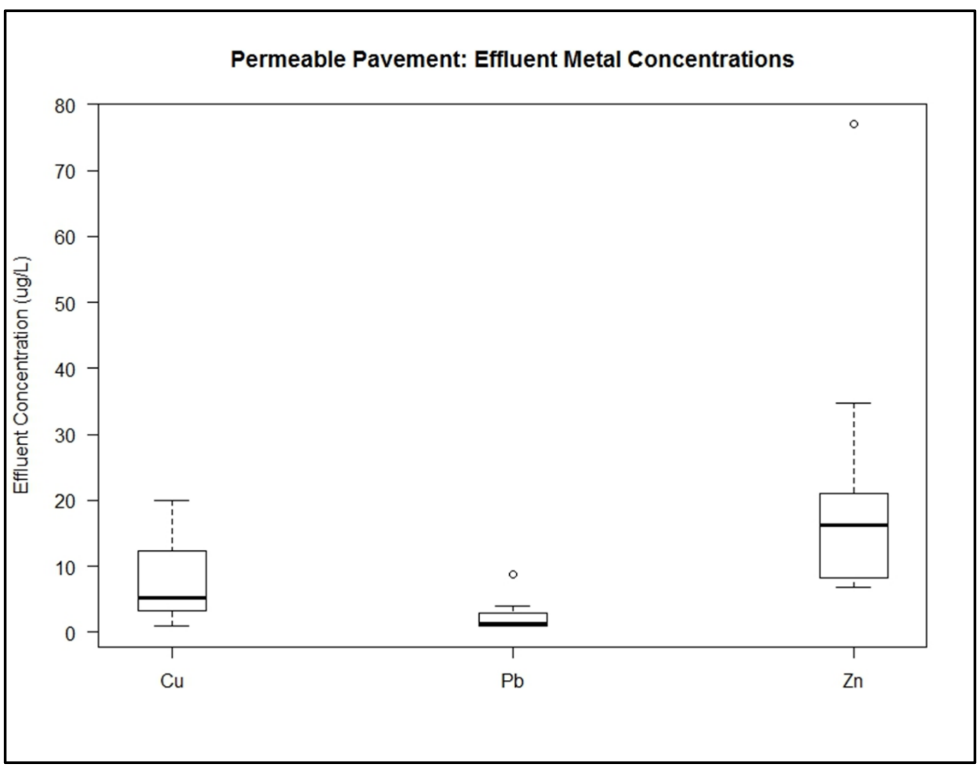

Figure PP-1. Permeable Pavement Metals Effluent Concentrations Summary Plot

BIORETENTION (Guidebook, 3.6)

The bioretention research analysis included 52 studies and 112 individual practices . The selection of studies favored field research. Some of the research on metals and bacteria took place in controlled laboratory conditions with mesocosm, batch, or column studies. Studies varied on whether they measured hydrologic factors (e.g., volume or peak reduction) and/or pollutant removal for nutrients, metals, and bacteria.

Tables BR-1 and BR-2 and Figures BR-2 and BR-3 show results for various pollutant mass load reductions and effluent concentrations, respectively.

Design Factor Notes

A consistent trend in research on pollutant reductions is tremendous variability in results, ranging from negative removals to close to 100% on the positive side. The updated research on bioretention follows this trend (see ranges in Tables BR-1 and BR-2). However, it is also instructive to review the studies to ascertain the design factors or other reasons that are presumed to contribute to "good" or "poor" results. For the updated bioretention research, this type of analysis yields the following observations:

<u>Bioretention: reasons for poor performance (lowest quartile of results)</u>

- Too much organic matter in the soil media (Winston et al., 2015; Hatt et al., 2009).
- Intrusion of groundwater or baseflow into the cell (Brown et al., 2011).
- Low inflow concentrations that may be at irreducible levels (Brown & Hunt, 2011, 2012; Luell et al., 2011; McNett et al., 2011).
- Clogging or lack of maintenance (Brown & Hunt, 2012).
- Undersized, shallow media, or lined cells (Brown & Hunt, 2011; Luell et al., 2011; McNett, 2011).
- Nitrogen inputs to the media or incomplete conversion of organic or particulate nitrogen to more soluble forms (NOx) (Line & Hunt, 2009; see also Li & Davis, 2014 for discussion of nitrogen cycling within bioretention).

<u>Bioretention: reasons for good performance (highest quartile of results)</u>

- Almost all of the best results for nutrients were attributed to inclusion of an Internal Water Storage (IWS) layer (DeBusk & Wynn, 2011; Brown & Hunt, 2011; Gilchrest et al., 2013; Luell et al., 2011; McNett et al., 2011; Roseen & Stone, 2013). This design modification targets removal of dissolved forms of nutrients, especially nitrogen, as the dissolved fraction is most prone to leaching.
- Other studies saw enhanced performance by incorporating reactive elements (iron or aluminum) into the media (Liu & Davis, 2013).

Both IWS and reactive media are addressed in the Chesapeake Stormwater Network report on *Performance Enhancing Devices for Stormwater Best Management Practices*, which supports the findings of this current analysis (Hirschman et al., 2017).

The Role of Runoff/Volume Reduction in Pollutant Removal

Many studies indicate that runoff reduction is a key, or even the primary, mechanism to also reduce pollutant loads (Line & Hunt, 2009; Liu & Davis, 2013; Stagge et al., 2012; Wadzuk et al., 2017; Winston et al., 2016). In some cases, even when nutrient concentrations increased from inlet to outlet, mass load reductions were positive due to runoff reduction (Winston et al., 2015). Runoff reduction also contributes to reducing peak flows and extending the time to peak (Davis et al., 2012; Brown & Hunt, 2011b; Li et al., 2009; Selbig & Balster, 2010).

It should be noted that even if mass load reductions are positive, it is not desirable to have bioretention practices leaching nutrients into downstream waters. Increases in pollutant concentrations can cause more acute water quality issues in some cases (depending on the pollutant). However, the research does support the District's use of storage and retention as a standard.

Are Practices Being Over-Drained?

There is some support in the research for continued use of low organic matter, permeable soils (Davis et al., 2012). However, there is a countervailing argument that the practices are "over-drained," reducing residence time and processing of pollutants. Some researchers indicate that existing infiltration testing standards are too restrictive, and that infiltration/exfiltration plus evapotranspiration will account for large percentages of runoff reduction, provided the practices are adequately sized or oversized for the drainage area (Selbig & Balster, 2010; Wadzuk et al., 2017).

This may be a tricky question for the District. The standard bioretention design uses a relatively shallow, very sandy soil media and underdrains. While this helps ensure that there is no standing water and that retention capacity is available during a storm as water drains from the practice, there may a cost with regard to pollutant processing as well as the actual cost to build the practices (e.g. extra excavation and materials).

Practices built where there are horizontal and vertical constraints on available space will likely have to live with these trade-offs. However, where surface areas and media depths can be increased, it may be worth slowing the drainage to tolerable rates (e.g., not creating nuisance conditions, with some conservative estimates built in). IWS is one strategy to do this, and limiting or reducing underdrains may be another.

Metals Accumulation in Soil Media

The few studies included in this analysis that measured metals reduction did show good removal in bioretention for Copper, Lead, and Zinc (mass removals ranging from around 60% to 99%). However, there are not enough studies to draw any firm conclusions. Additional research, while not measuring removal rates, did address metals accumulation in the soil media and the risk of metals leaching or accumulating to the point of reaching regulatory clean-up levels.

Sumner Jones and Davis (2013) founds that metals bound strongly to the media and accumulated primarily near inlet points. However, there was low bioavailability and many years of capacity to absorb additional metals loads. Routine maintenance (e.g., removal of sediment), especially close to inlets, should be able to avoid triggering clean-up levels. Paus and colleagues also studied metals accumulation through column and batch experiments. That team reports greater than 25 years of effective metals removal in most cases. However, NaCl (salt) caused some of the metals to leach from the media (primarily Cadmium and Zinc), albeit in small amounts. They also found that increasing the compost content to around 30% by volume enhanced metals removal, but acknowledged the downside of this for likely leaching of nutrients (Paus et al., 2014a, 2014b, 2014c).

The Chesapeake Stormwater Network report, *Potential Benefits of Nutrient and Sediment Practices to Reduce Toxic Contaminants in the Chesapeake Bay Watershed* (Schueler & Youngk, 2015) provides further guidance on the ability of practices to removal toxics, including urban trace metals. That report suggests benchmarking metals removal to sediment, and that practices are capable of removing approximately 25% of metals loads, and potentially 40% as BMP designs continue to improve. Maintenance tasks, such as removal and replacement of mulch and removal of sediments, are important for continued metals removal. The report also stresses the importance of pollution prevention and source reductions when it comes to toxics, such as metals. BMPs only remove some of the metals load once they are generated in the watershed.

Recommendations

Internal Water Storage (IWS)

As stated above, IWS has been documented to promote both runoff reduction as well as pollutant removal. IWS is similar in function to the current “enhanced” design of the elevated underdrain, but may provide additional water quality benefits. IWS can take up some storage, especially during high intensity events, but generally promotes greater runoff reduction across multiple storm events.

IWS seems to enhance pollutant removal in soils that are somewhat limited for infiltration (e.g., more on the clayey side). In sandier soils, there is not enough residence time within the IWS for the modification to affect runoff reduction performance (Brown & Hunt, 2011).

There are several design issues to consider with IWS:

- The depth of the IWS zone and whether the zone should intercept the soil media layer needs further analysis. If the media layer is intercepted, then it is recommended to leave at least the top 18” of media in an unsaturated condition (Brown & Hunt, 2011). For D.C., this would obviously limit the use of IWS for enhanced designs, which is likely the appropriate application, since it would be a substitute for the current underdrain sump. Further analysis of IWS specifications is taking place in a separate study being undertaken by some of the authors.
- Just because water exfiltrates out of the practice does not mean it disappears. In the highly-urban setting such as the District, it will be important to confirm that this water is not creating problems elsewhere (e.g., with foundations, road sub-base, etc.). There may already be a track record in this regard with the underdrain sump designs.

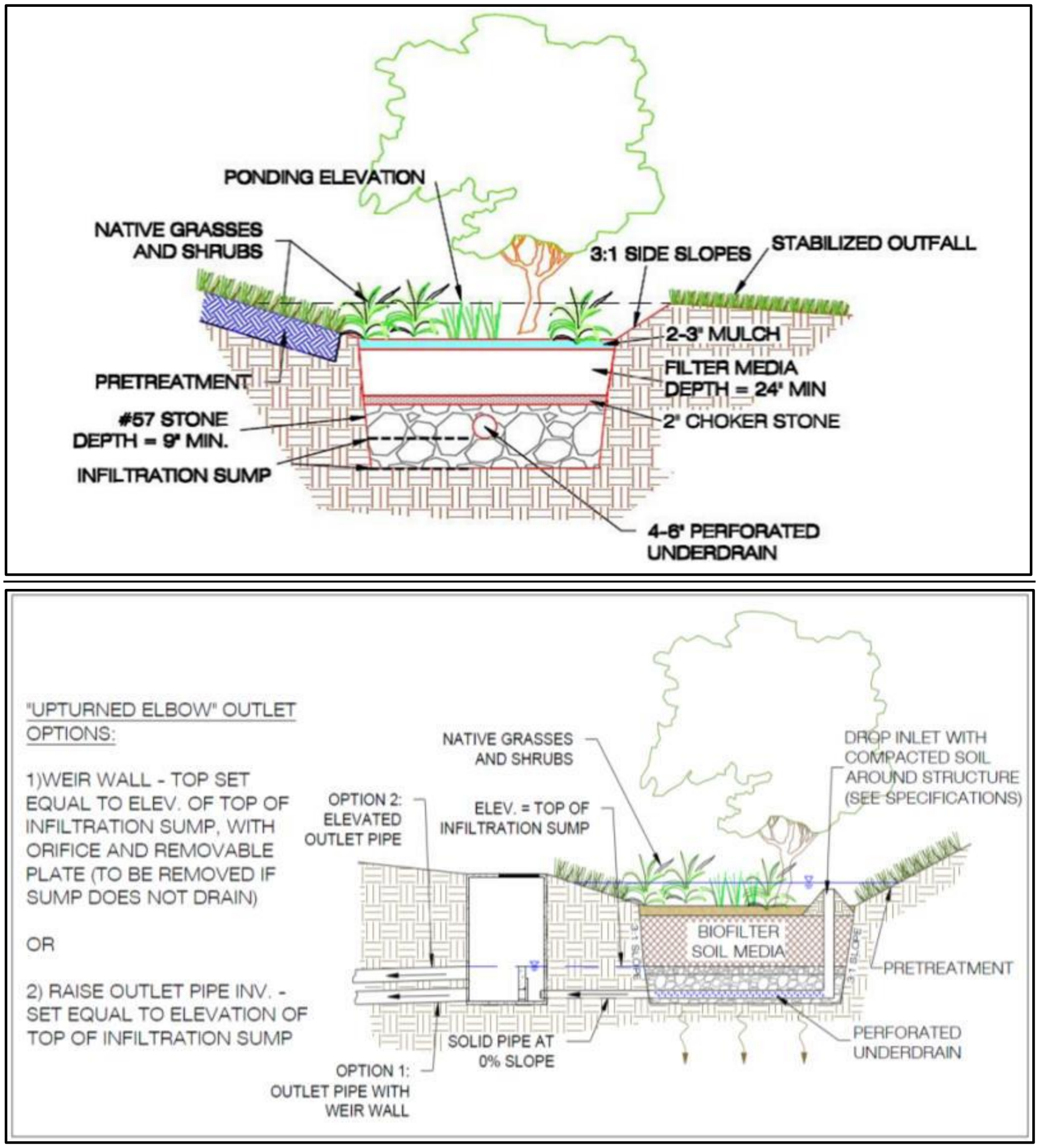

Figure BR-1. Comparison of the current District "Enhanced" design using an infiltration sump BELOW the underdrain (top) versus the "Upturned Elbow/Internal Water Storage" design that ponds temporarily ABOVE the underdrain invert (bottom). Sources: Top: District of Columbia Stormwater Management Guidebook, 2013, Figure 3.18; Bottom: Virginia BMP Specification #9, 2013, Figure 9.4d.

<u>Media Amendments</u>

Most bioretention research on adding iron and/or aluminum media amendments have taken place in a controlled laboratory setting. The field research in this area has confirmed enhanced pollutant removal (Liu & Davis, 2013; Roseen & Stone, 2013; see also discussion on reactive media in Hirschman et al., 2017). Work is currently underway to develop Chesapeake Bay specifications for use of these materials.

While it may take some time to incorporate these media amendments into the District's specifications, it is highly likely that Bay Watershed specifications will move in this direction. There are several local sources for the material, such as the Washington Aqueduct water treatment facility.

For the District, media amendments could become part of the enhanced design, or, preferably, become part of the standard soil media recipe, once sources and mixing rates and techniques are developed (work in progress through a Center for Watershed Protection grant).

<u>Other Recommendations/Considerations</u>

- Consider decreasing the enhanced design retention value from 100% to 80%, since there is some loss of volume through the underdrain in many cases.
- The type of vegetation does matter. Deeper rooted vegetation extending down into the soil media layer and dense underground biomass retains more moisture compared to shallower root systems, such as turf grass (Selbig & Balster, 2010; see also discussion of vegetation in Hirschman et al., 2017).
- Pre-treatment, as intended, can increase the life of a practice and decrease maintenance burden (Lewellyn et al., 2016).

Bioretention Summary Table BR-1: Mass Load Reductions (%)

	Dissolved P	TP	Nox	TN	Arsenic	Copper	Lead	Mercury	Zinc	PAHs
# individual practices w/ data	14	19	18	18	0	4	5	0	6	0
Adequate data for analysis?	Y	Y	Y	Y	N/A	N	Y	N	Y	N
Mean	-9	43	-50	26	N/A	57	82	N/A	84	N/A
Median	23	44	-21	28	N/A	62	80	N/A	86	N/A
Minimum	-274	-13	-471	-64	N/A	6	66	N/A	60	N/A
Maximum	96	99	96	99	N/A	98	98	N/A	99	N/A
25th Percentile	-44	11	-103	7	N/A	19	72	N/A	74	N/A
75th Percentile	64	83	57	49	N/A	90	93	N/A	96	N/A
Standard Deviation	107	35	138	41	N/A	38	12	N/A	14	N/A

Bioretention Summary Table BR-2: Mean Effluent Concentration: mg/L for nutrients; ug/L for metals

	Dissolved P (mg/L)	TP (mg/L)	Nox (mg/L)	TN (mg/L)	Arsenic (ug/L)	Copper (ug/L)	Lead (ug/L)	Mercury (ug/L)	Zinc (ug/L)	PAHs (ug/L)
# individual practices w/ data	11	23	14	23	0	4	2	0	4	0
Adequate data for analysis?	Y	Y	Y	Y	N	N	N	N	N	N/A
Mean	0.02	0.104	0.49	1.18	N/A	4.58	1.77	N/A	11.05	N/A
Median	0.03	0.081	0.33	1.13	N/A	3.76	1.77	N/A	7.60	N/A
Minimum	0.01	0.05	0.10	0.37	N/A	1.00	1.03	N/A	1.00	N/A
Maximum	0.07	0.25	1.40	3.09	N/A	9.79	2.50	N/A	28.00	N/A
25th Percentile	0.01	0.060	0.15	0.73	N/A	1.50	N/A	N/A	1.00	N/A
75th Percentile	0.03	0.130	0.78	1.39	N/A	8.47	N/A	N/A	24.55	N/A
Standard Deviation	0.02	0.057	0.40	0.70	N/A	3.76	1	N/A	12.90	N/A

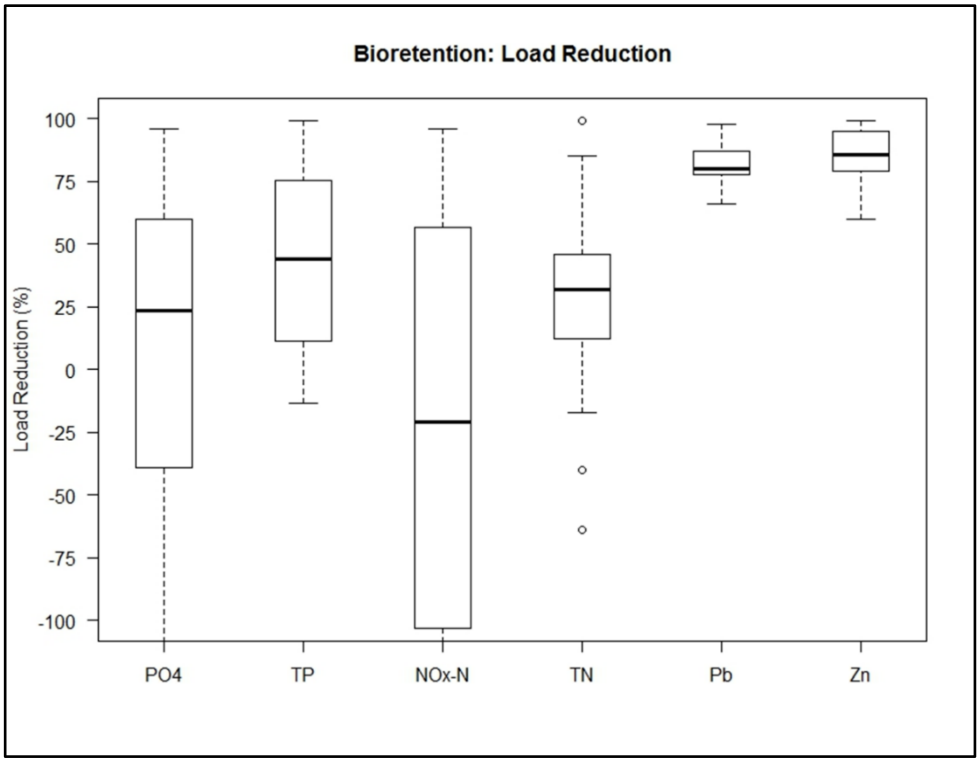

Figure BR-2. Bioretention Mass Load Reduction Summary Plot

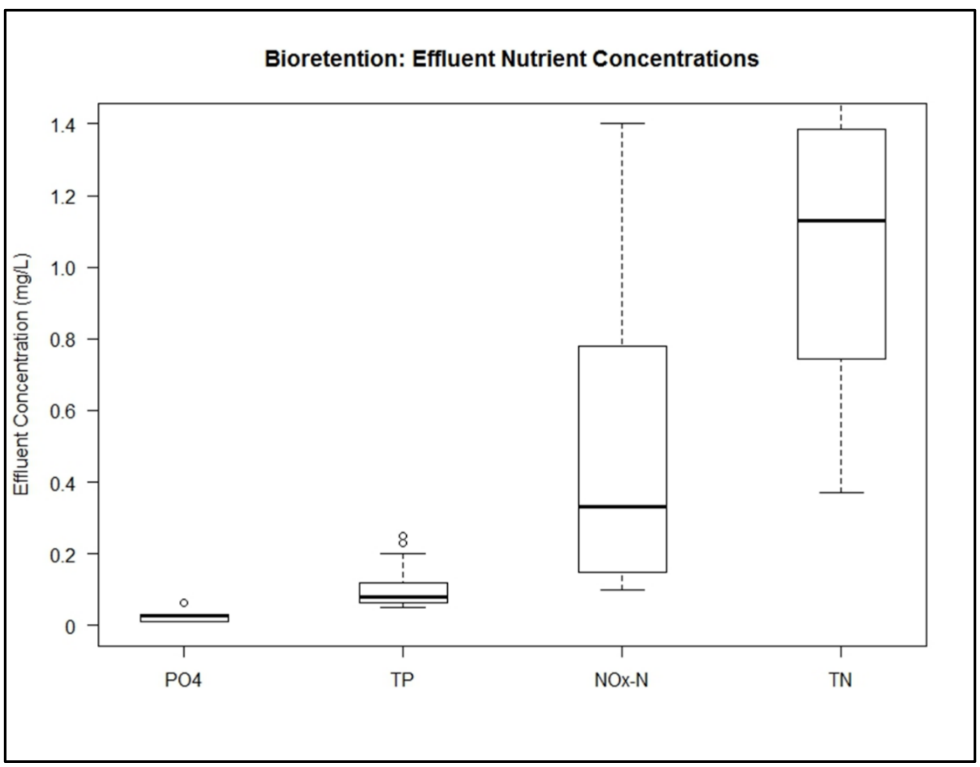

Figure BR-3. Bioretention Nutrient Effluent Summary Plot

INFILTRATION (Guidebook, 3.8)

The infiltration practice (trench or basin) research analysis included 8 studies and at least 39 individual practices. Similar to other practices evaluated herein, the studies focused on annual runoff reduction averages, and thus must be translated to the District's event-based standard. Also similar to other practices, there is variability in the observed methods and results, so it is challenging to draw firm conclusions about performance. However, some design guidance can be distilled from the research on runoff reduction and pollutant removal functions of infiltration.

Table IT-1 provides pollutant mass load reductions for infiltration trench practices. Figures IT-1 through IT-3 illustrate mass load reductions, nutrient effluent concentrations, and metals effluent concentrations, respectively.

Design Factor Notes

Difficulty Replicating Realistic Conditions

Several of the study practices resembled sand filters or bioretention filters due to design modifications necessary to facilitate sample collection. That is, the water must be withdrawn at some point, cutting the infiltration process short of its ultimate cycle. Therefore, the pollutant removal efficiencies may be conservative and not reach the possible efficiencies of a real-world setting. One exception among the studies reviewed is Hatt et al (2007) in that the variations of the laboratory infiltration practices did model groundwater at varying depths, therefore simulating certain specific realistic or practical conditions.

Infiltration Not Guaranteed

Despite an infiltration test being an integral component of the pre-installation design process, the best current testing methods do not fully capture subsurface conditions and variability. Both in the reviewed studies and in the Center for Watershed Protection's (the Center) recent experience, the potential failure of infiltration practices has been strongly highlighted. Even with a carefully constructed experiment in a laboratory, Hatt et al (2007) still had multiple clogging failures. Anecdotally, installations have unexpected failures or unanticipated unsatisfactory performance, despite best practices being followed through design and installation.

Pollutant Removal

Based on the literature review and our team's experience, some general conclusions related to pollutant removal are reasonable. Total nitrogen and total phosphorus mass loads are reduced to some degree, while dissolved nitrogen is consistently increased. Copper, lead, and zinc mass loads are also consistently and significantly reduced. See Table IT-1 for values.

Recommendations

Runoff Reduction

Based on the District's method for assigning a runoff retention volume to a stormwater BMP (100% for infiltration), no change is recommended based on the research.

Infiltration Trench Summary Table IT-1: Mass Load Reductions (%)										
	Dissolved P	TP	NOx	TN	Arsenic	Copper	Lead	Mercury	Zinc	PAHs
# individual practices w/ data	0	8	6	8	0	7	7	0	7	0
Adequate data for analysis?	N	Y	Y	Y	N	Y	Y	N	Y	N
Mean	N/A	71	-1	54	N/A	75	81	N/A	61	N/A
Median	N/A	75	8	44	N/A	68	80	N/A	73	N/A
Minimum	N/A	53	-46	37	N/A	62	74	N/A	38	N/A
Maximum	N/A	94	12	95	N/A	99	90	N/A	89	N/A
25th Percentile	N/A	53	-12	41	N/A	62	77	N/A	38	N/A
75th Percentile	N/A	83	12	74	N/A	86	84	N/A	77	N/A
Standard Deviation	N/A	17	23	22	N/A	15	5	N/A	22	N/A

Infiltration Trench Summary Table IT-2: Mean Effluent Concentration: mg/L for nutrients; ug/L for metals										
	Dissolved P	TP	Nox	TN	Arsenic	Copper	Lead	Mercury	Zinc	PAHs
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
# individual practices w/ data	7	9	8	9	0	8	9	0	9	6
Adequate data for analysis?	Y	Y	Y	Y	N	Y	Y	N	Y	N
Mean	0.05	0.14	0.42	1.27	N/A	14.17	69.70	N/A	15.41	N/A
Median	0.01	0.04	0.26	0.73	N/A	0.05	0.03	N/A	0.08	N/A
Minimum	0.00	0.01	0.13	0.38	N/A	0.03	0.01	N/A	0.04	N/A
Maximum	0.24	0.55	1.45	3.40	N/A	113.00	627.00	N/A	138.00	N/A
25th Percentile	0.00	0.02	0.19	0.42	N/A	0.04	0.02	N/A	0.05	N/A
75th Percentile	0.07	0.24	0.49	2.44	N/A	0.08	0.06	N/A	0.15	N/A
Standard Deviation	0.09	0.19	0.43	1.18	N/A	39.93	208.99	N/A	45.97	N/A

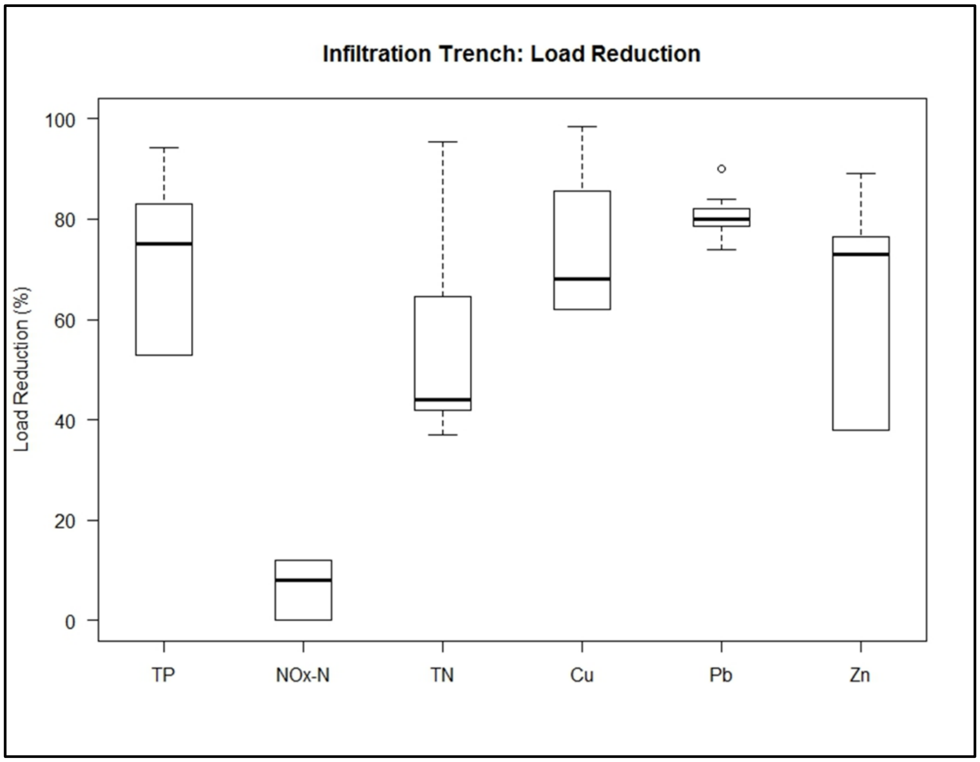

Figure IT-1. Infiltration Trench Mass Load Reduction Summary Plot

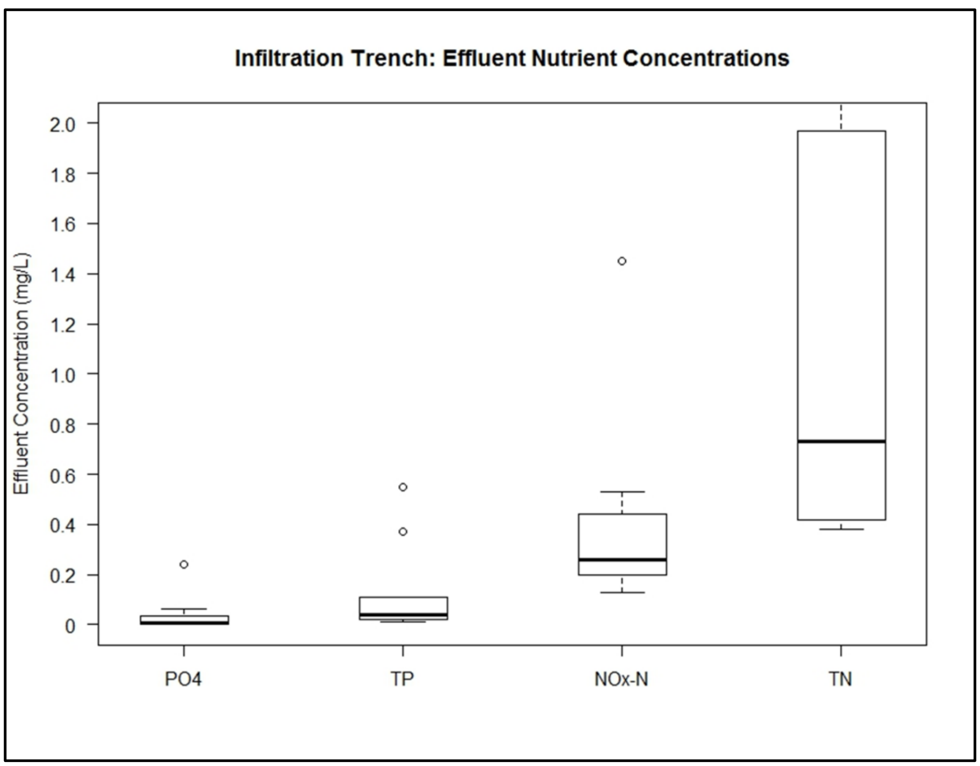

Figure IT-2. Infiltration Trench Nutrient Effluent Concentration Summary Plot

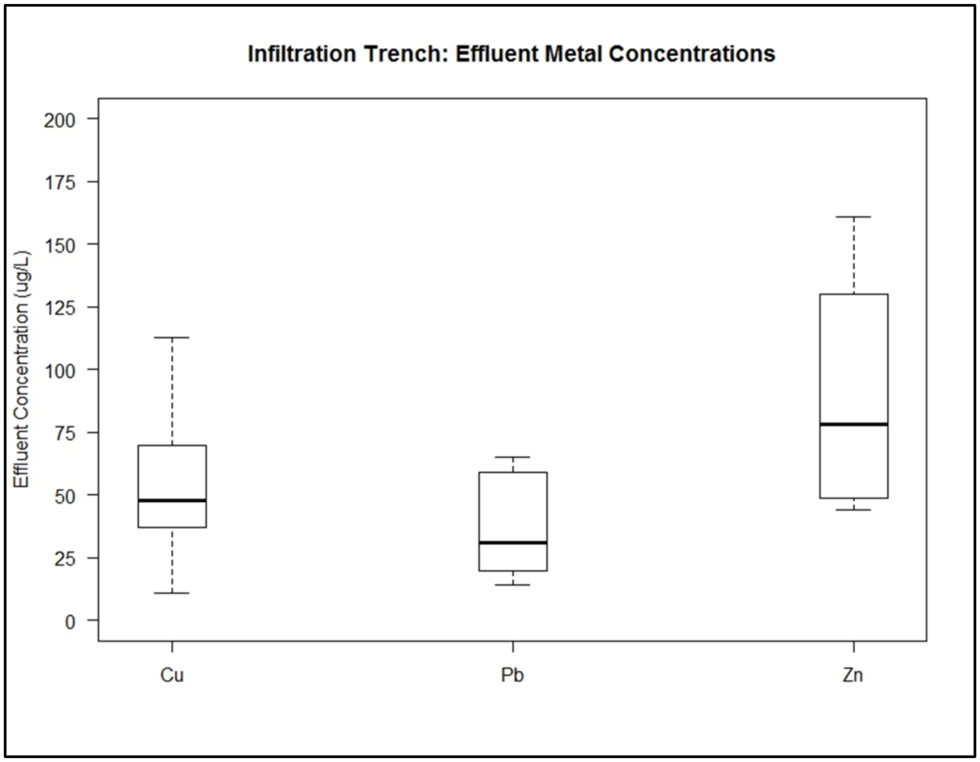

Figure IT-3. Infiltration Trench Metals Effluent Concentration Summary Plot

GRASS CHANNELS (Guidebook, 3.9 O-1)

The grass channel research analysis included 11 studies covering desktop and field-based research on 24 individual practices or model scenarios. However, most of the data were derived from 3 studies covering 6 practices. Tables GC-1 and GC-2 provide summaries for mass load reductions and effluent concentrations, and Figures GC-1 and GC-2 show box plots for these data.

Several basic takeaways are apparent in the trends in the data, which stand as generalizations warranting further research or investigation.

Design Factor Notes

Stagge et al (2012), which is related to a similar publication (Davis et al. 2012), examined two grass channels, without check dams and then retrofit with check dams. From this study, further investigation is warranted on the pollutant removal impacts of check dams. The study suggests that the vegetated check dams are the difference between possible pollutant load *increases* (no check dams) versus significant decreases (with check dams).

Stagge et al (2012) also observed that NO_3 mass load is increased when no vegetated (Panicum virgatum 'Heavy Metal') check dams are present, whereas mass load is reduced significantly if check dams are present. The same study observed similar behavior with Total Phosphorus. Grass channels provide a net reduction of copper and zinc, with consistent results across 4 studies and at least 6 practices. As explained below, these mass load reductions are due in large part to reductions in volume.

As for runoff reduction, Davis et al. (2012) observes that swales completely absorb the smallest 40% of runoff events. Moderate events (the next 40%) were reduced, with vegetated check dams contributing to hydraulic performance and volume reductions as high as 62% compared to a concrete ditch. For the highest 20% of flows, the swales function solely as conveyance, as the swale treatment capacity is exceeded.

Recommendations

Check dams increase residence time and allow for vegetation and (when present) infiltration to affect pollutant loads in the stormwater. Check dams are recommended, but some further investigation is warranted to determine whether the check dams themselves, or the vegetated check dam variants, have a greater influence on pollutant removal. The mechanism(s) by which the pollutants are removed is unclear. Stone check dams act to a degree like horizontal filters, akin to sand filters if the pore size is small enough. Vegetated check dams, especially those with warm season grasses or plants with pollutant uptake capabilities, may have additional benefits.

Grass Channel Summary Table GC-1: Mass Load Reductions (%)										
	Dissolved P	TP	Nox	TN	Arsenic	Copper	Lead	Mercury	Zinc	PAHs	Runoff Reduction
# individual practices w/ data	2	6	10	6	0	6	1	0	6	0	5
Adequate data for analysis?	No	Yes	Yes	Yes	No	Yes	No	No	Yes	No	Yes
Mean	N/A	7	47	40	N/A	62	85	N/A	70	N/A	40
Median	N/A	8	64	55	N/A	60	85	N/A	85	N/A	34
Minimum	N/A	-49	-25	-26	N/A	42	85	N/A	18	N/A	23
Maximum	N/A	69	89	86	N/A	82	85	N/A	93	N/A	63
25th Percentile	N/A	-33	24	-11	N/A	43	N/A	N/A	44	N/A	25
75th Percentile	N/A	41	72	79	N/A	81	N/A	N/A	90	N/A	57
Standard Deviation	N/A	42	39	46	N/A	20	N/A	N/A	29	N/A	17

Grass Channel Summary Table GC-2: Mean Effluent Concentration: mg/L for nutrients; ug/L for metals										
	Dissolved P	TP	Nox	TN	Arsenic	Copper	Lead	Mercury	Zinc	PAHs
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
# individual practices w/ data	1	7	7	7	0	1	1	0	1	0
Adequate data for analysis?	No	Yes	Yes	Yes	No	No	No	No	No	No
Mean	N/A	0.20	0.90	2.60	N/A	N/A	N/A	N/A	N/A	N/A
Median	N/A	0.20	0.76	2.27	N/A	N/A	N/A	N/A	N/A	N/A
Minimum	N/A	0.11	0.21	1.62	N/A	N/A	N/A	N/A	N/A	N/A
Maximum	N/A	0.53	1.96	4.34	N/A	N/A	N/A	N/A	N/A	N/A
25th Percentile	N/A	0.16	0.29	1.65	N/A	N/A	N/A	N/A	N/A	N/A
75th Percentile	N/A	0.29	1.80	3.24	N/A	N/A	N/A	N/A	N/A	N/A
Standard Deviation	N/A	0.14	0.71	0.97	N/A	N/A	N/A	N/A	N/A	N/A

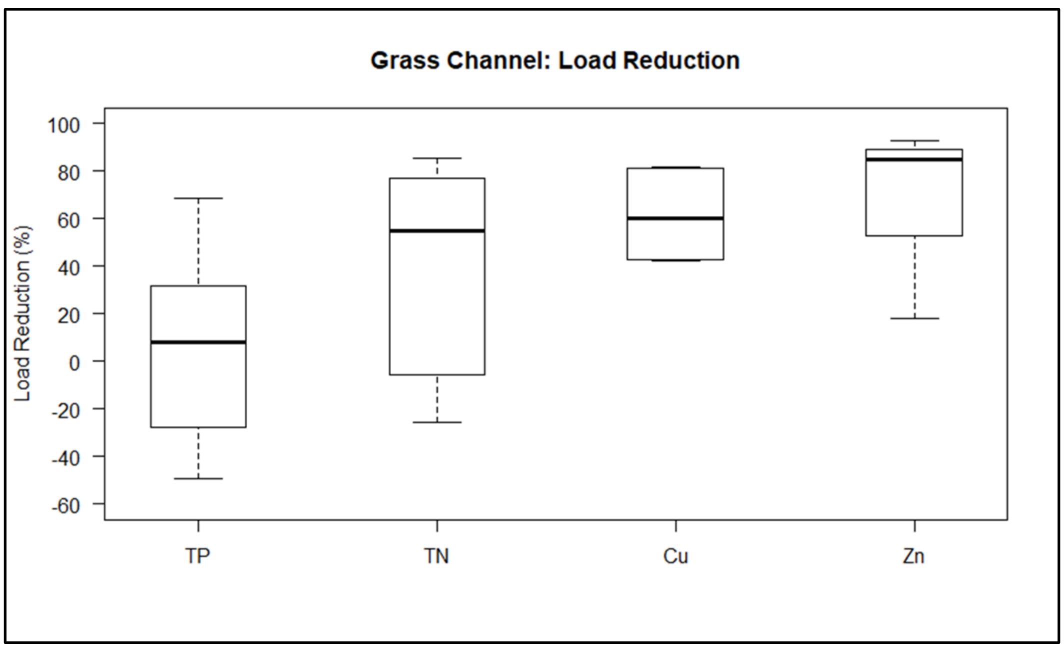

Figure GC-1. Grass Channel Mass Load Reduction Summary Plot

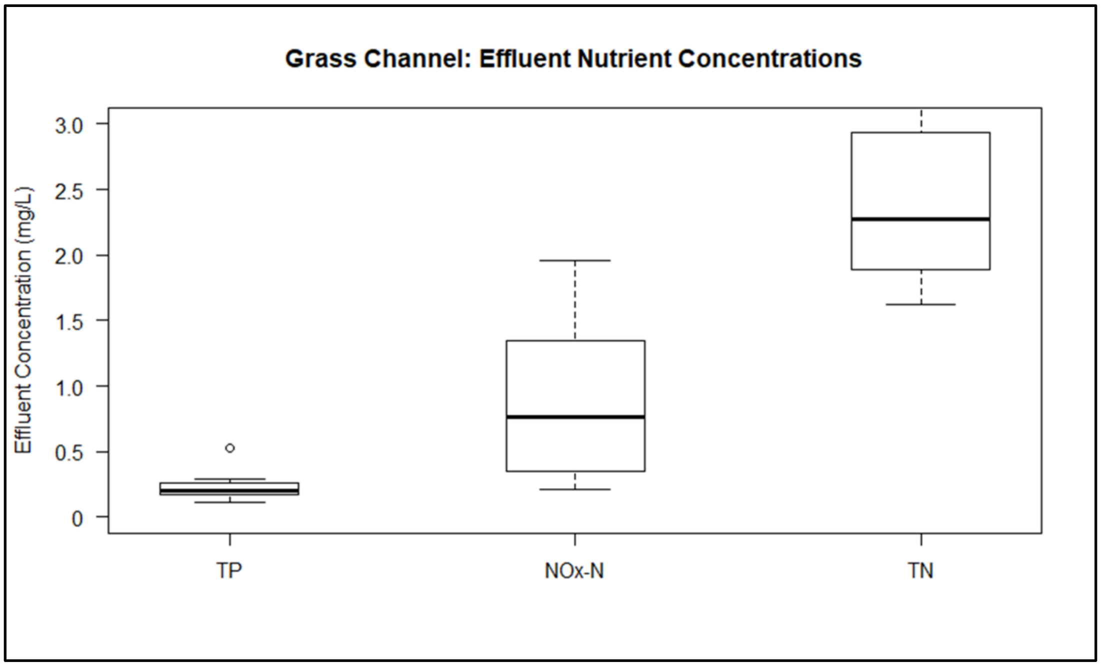

Figure GC-1. Grass Channel Effluent Nutrient Concentration Summary Plot

EXTENDED DETENTION POND (Guidebook, 3.10)

Extended detention (ED) ponds are designed to improve water quality by storing smaller storm events for approximately 24 hours. While ED ponds are included under section 3.10 in the Guidebook, there are not specific requirements for how extended detention should be designed, and no specification for ED ponds that do not include a permanent pool. The retention value assigned to ED ponds in the District is based on the permanent pool volume rather than the extended detention volume.

The extended detention pond research analysis included 6 studies and 10 individual practices . The selection of studies favored practices treating runoff from transportation corridors, with half of the studies being generated from the California Department of Transportation. The studies most commonly reported on the hydrologic/hydraulic function of these systems, with less than 5 studies reporting water quality performance for any given pollutant.

Due to the lack of water quality data present in literature, there is insufficient information to provide recommendations on this practice and this summary will focus on volume reduction. As such, no tables or figures were generated. Additional studies are needed to better quantify the performance of these practices.

Design Factor Notes

In principle, the design factors that would provide for increased runoff volume reduction in extended detention (ED) ponds are: (1) increased pond surface area providing higher evaporation potential, (2) increased hydraulic residence time or drawdown time providing higher evaporation potential, (3) infiltration capacity of native soils and (4) transpiration by emergent vegetation. However, as ED pond monitoring studies typically do not focus on runoff volume reduction, it was not possible to substantiate these logical hydrologic pathways with empirical data.

Recommendations

Several of the analyzed studies record volume reduction as an ancillary part of the monitoring program and have reported these data to the International Stormwater BMP Database. In an analysis of the available data as of 2011, Geosyntec Consultants and Wright Water Engineers calculated the total volume reduction of each individual study, then calculated the median of all studies as 33%. This is similar to the results of an earlier analysis by Strecker (2004) – average %RR = 30% -- included in the initial RRM. Although the District does not currently have a specification for the type of dry ED ponds studied, the studies analyzed herein suggest that a retention value as high as 30% may be justifiable given permeable in situ soils within the pond.

Table ED-1. Results of Extended Detention (ED) pond monitoring studies as median percent runoff reduction (%RR) for all storm events monitored		
Source Study Reference	**Site**	**Median %RR**
Huber et al., 2006; Liptan, 2001	Lexington Hills	67
Hussain et al., 2005	Carver County	50
Yu et al., 1994	Massie Road	37
CALTRANS, 2004	I-5/Manchester	37
CALTRANS, 2004	I-5/SR-56	24
CALTRANS, 2004	I-5/SR-78	18
Stanley, 1996	Greenville Pond, NC	7

WETLANDS (Guidebook, 3.11), WET PONDS (Guidebook, 3.10)

Constructed wetlands were studied more extensively in the 1980's and 1990's, and a review of much of this work is given in Carleton et al. (2001). This previous work suggests that removal performance of nutrients, total suspended solids, and total metals in constructed stormwater wetlands can be adequately explained using the key input variables of inflow rate and detention time. Although hydraulic sizing of wetlands is known to affect pollutant removal, no clear evidence has yet been presented that wetlands can provide runoff volume reduction. This is in part because these systems are sometimes designed with constant but fluctuating inflow from a perennial source, but also due to the difficulty of accurately measuring all the components of the water balance in these systems for discrete storm events.

For this review, 19 field monitoring studies (not previously reviewed) were included, with one study (Hathaway, et al. 2007) presenting the results from several other studies for comparison. For this review, data from several wet detention ponds were also included. Summary results are shown in Tables WET-1 (EMC % reduction) and WET-2 (effluent concentrations). Figures WET-1 and WET-2 show box plots for nutrient and metals effluent concentrations, respectively.

The physicochemical removal processes are similar between these systems, with the primary differences being specified vegetation and that wet ponds are not perennially flowing systems. Linear wetlands, known as "wetland swales" were also included in this review (Winston et al. 2012), as they function similar to typical wetlands, but with design focused on conveyance instead of storage.

Data for a total of 43 individual practices were analyzed, encompassing a broad range of sizes and design configurations. The review provided a considerable amount of performance data. However, the variability in performance for the various water quality constituents across these practices makes it difficult to distill these data into a single value, or to provide design recommendations beyond what is already known about wetland function. For example, the removal of Total Phosphorus (TP) across 24 monitored wetlands ranged from 18% to 54% (first and third quartile respectively), with a median TP removal of 44%. Even for a single practice, performance results varied dramatically – for example the Wood Hollow Wet Pond in Austin, TX, varied in TP removal from 27% to 64% (Q1 and Q3, respectively) over 13 storm events.

One new innovative study (Erickson et al. 2018) attempted to improve phosphate removal by routing a portion of perennial flow and storm flow through a sand filter amended with iron filings in two different pond configurations. The results of this study were promising: 26% and 64% of the influent phosphate load retained by the two different configurations, though the upper performance value was not considerably different than results from other traditional designs.

Design Factor Notes

Although the literature reviewed provides consistent evidence that constructed wetlands can provide positive pollutant removal for most constituents (not enough data are available for Arsenic and Mercury), the wide variability of performance within a study makes it difficult to definitively relate average performance to specific design characteristics. However, there are a few key points from the literature that may inform future design factors:

- Overall, practices successfully reduced nitrogen concentrations (except for two practices in Mallin et al. 2002 and one City of Austin practice). This is likely due to the anaerobic conditions in the wetlands, coexisting with aerobic microsites, leading to denitrification. This is demonstrated clearly in Winston et al. (2012) by the boxplots comparing TN effluent from wetland swales versus adjacent dry swales.
- No evidence could be found in this review that suggested that the District should allow for a stormwater retention value for wetlands, as none of the studies characterized the hydrologic benefit of the practices monitored. Likewise, none of the wet pond studies provided hydrologic data. These findings are consistent with the results of Geosyntec Consultants & Wright Water Engineers (2011) review of volume reduction in the International Stormwater BMP Database.
- There was a considerable amount of bacteria data available, and overall performance was positive (median removal = 57%), though Krometis et al. (2002) reported net export of both fecal coliforms and enterococci. Krometis et al. hypothesize that this could have been caused by the persistence of enterococci in the environment, and the resuspension of microbe-bound particles during high flow events.

Recommendations

The potential for community concern about large, perennially wet ponds is likely to prevent the widespread use of wetlands, wet ponds, or wet swales in the District. Further, as noted above, no evidence was found indicating runoff reduction in wetlands and ponds. Therefore, the retention value for these practices should be eliminated. However, in situations with sufficient space and community support (e.g., parks, open space), these types of practices may be warranted in watersheds with relatively high nitrogen loading and/or perhaps known sources of bacteria.

Wetland/Wet Pond Summary Table WET-1: EMC Reduction (%)										
	Dissolved P	TP	NOx	TN	Arsenic	Copper	Lead	Mercury	Zinc	PAHs
# individual practices w/ data	14	26	16	22	3	20	20	3	22	0
Adequate data for analysis?	Y	Y	Y	Y	N	Y	Y	N	Y	N
Mean	8%	32%	54%	30%	N/A	-24%	45%	N/A	43%	N/A
Median	34%	42%	51%	35%	N/A	54%	69%	N/A	48%	N/A
Minimum	-266%	-56%	-5%	-41%	N/A	-1418%	-250%	N/A	-52%	N/A
Maximum	77%	87%	85%	58%	N/A	96%	98%	N/A	98%	N/A
25th Percentile	4%	15%	39%	20%	N/A	40%	36%	N/A	27%	N/A
75th Percentile	57%	54%	72%	50%	N/A	66%	80%	N/A	73%	N/A
Standard Deviation	91%	27%	25%	25%	N/A	330%	76%	N/A	39%	N/A

Wetland/Wet Pond Summary Table WET-2: Mean Effluent Concentration: mg/L for nutrients; ug/L for metals										
	Dissolved P	TP	NOx	TN	Arsenic	Copper**	Lead**	Mercury	Zinc	PAHs
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
# individual practices w/ data	10	17	10	13	0	13	13	3	15	0
Adequate data for analysis?	Y	Y	Y	Y	N	Y	Y	N	Y	N
Mean	0.11	0.179	0.314	1.210	N/A	0.106	0.237	0.006	4.540	N/A
Median	0.05	0.120	0.287	1.150	N/A	0.006	0.005	0.005	0.037	N/A
Minimum	0.02	0.045	0.136	0.513	N/A	0.002	0.001	0.004	0.005	N/A
Maximum	0.43	0.880	0.732	2.400	N/A	0.780	1.570	0.010	40.800	N/A
25th Percentile	0.03	0.069	0.183	1.000	N/A	0.003	0.003	N/A	0.022	N/A
75th Percentile	0.11	0.219	0.378	1.478	N/A	0.008	0.014	N/A	0.932	N/A
Standard Deviation	0.13	0.211	0.187	0.574	N/A	0.251	0.565	N/A	11.422	N/A
						** Copper data in table excludes outlier of 14.27 ug/L. Lead excludes outlier of 7.33 ug/L. Both from Mallin et al., 2002.				

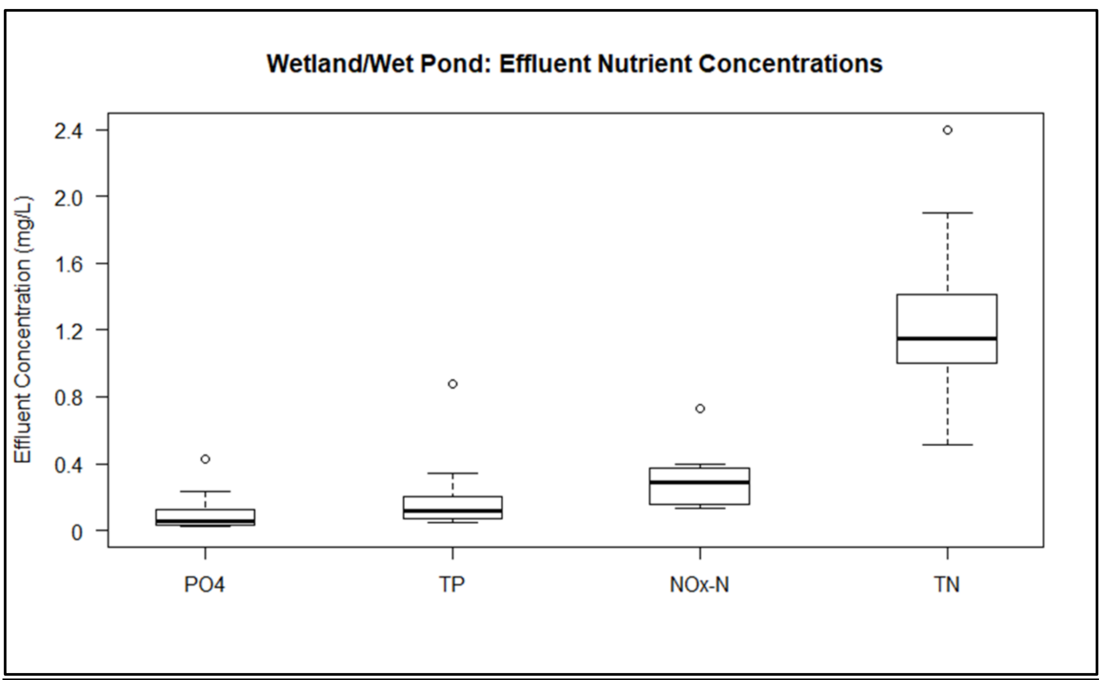

Figure WET-1. Wetland/Wet Pond Effluent Nutrient Concentrations

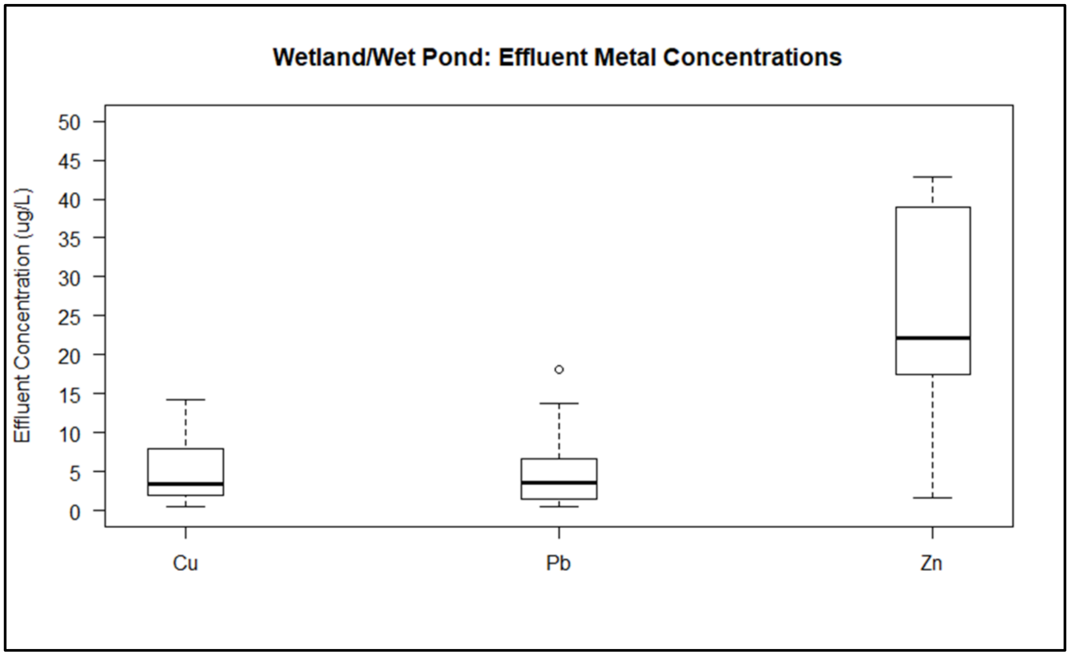

Figure WET-2. Wetland/Wet Pond Effluent Metals Concentrations

TREE PLANTING AND PRESERVATION (Guidebook, 3.14)

This section describes the results of an analysis used to evaluate and recommend changes to the currently proposed Planting and Preservation retention values used by the District. Runoff reduction volumes were estimated using the Stormwater Performance-Based Credit Calculator (the Calculator; CWP, 2017), which was developed by the Center for Watershed Protection as a part of the "Making Urban Trees Count" project with the US Forest Service. Documentation and a full description of the tools described in this section can be found at: https://www.cwp.org/making-urban-trees-count/. This section describes some of the key assumptions incorporated into the calculator, how each tree planting scenario in DC was portrayed, and how the model results compare with currently recommended runoff reduction credits in the District.

The Calculator is a spreadsheet-based calculation tool that calculates the runoff reduction volume and pollutant removal achieved by a tree, given that tree's size and type (e.g., Large Broadleaf, Small Conifer), the surface over which the tree is planted (e.g., Grass-Hydrologic Soil Group C, Impervious), and the nearest weather station (e.g. Washington, DC). The calculator provides some default values such as the canopy area and tree diameter at breast height (DBH), which can be adjusted by the user.

The Calculator was derived from results of an annual water balance model, which incorporated weather data from stations across the United States (Hynicka and Caraco, 2017). Some key assumptions in developing the model, which impact on how scenarios are evaluated for this analysis include the following:

- Trees impact only the area directly below their canopy; no runoff from adjacent areas is directed to the tree.
- When trees are planted over soil, they provide runoff reduction by intercepting rainfall in the tree canopy, and by increasing soil permeability.
- When trees are planted over impervious cover, they only reduce runoff through interception.
- Trees are modeled at maturity.
- The hydrologic benefits of the Calculator are estimated by developing a runoff curve number adjustment that is equivalent to runoff reduction benefits calculated using the water balance model.

Tree Planting and Preservation Scenarios

There are currently two categories of retention value for trees in the District, both of which apply only to "large" trees: tree planting, and tree preservation. However, five different tree planting and preservation categories have been proposed, including three classes of tree preservation (small, large, and heritage) and two classes of tree planting (small and large). In developing the modeling scenarios, some basic assumptions to distinguish between planting and preservation and to represent each tree size (Table TREE-1) were made.

Planting versus Preservation

Since the calculator represents trees at maturity, no attempt to “age in” planted trees when compared with preserved trees was made. Rather, the difference between these two scenarios was represented by reflecting a different surface below the tree. It was assumed that planted trees are distributed equally between impervious surfaces and C soils. By contrast, preserved trees were represented with canopy over pervious surfaces, with the argument being that mature, healthy trees are mostly in locations where the soil beneath the tree canopy has been maintained.

Tree Size

Tree size was represented either by the DBH (for a heritage tree) or the tree canopy diameter. Since the Calculator includes default values for these characteristics depending on the tree type, these values were modified to reflect the trees selected. It was assumed that canopy area is proportional to DBH, so that a proportional increase in either parameter corresponds with the same increase in the other. For example, decreasing the canopy area by 20% was combined with a 20% reduction in the DBH.

Table TREE-1: Representation of Tree Planting/Preservation in the Performance-Based Calculator

<table>
<tr><th colspan="2">Class</th><th rowspan="2">Assumed Size[1]</th><th rowspan="2">Calculator Tree Type[2]</th><th rowspan="2">Calculator Default Size</th><th rowspan="2">Adjustments to Calculator Defaults</th><th rowspan="2">Land Cover[3]</th></tr>
<tr><th>Tree Type</th><th>Preservation/ Planting</th></tr>
<tr><td rowspan="2">Small</td><td>Preservation</td><td rowspan="2">30’ Canopy Diameter</td><td rowspan="2">BDM</td><td rowspan="2">990 sf Canopy
18” DBH</td><td rowspan="2">Reduce Canopy to 710 sf
Reduce DBH to 13”</td><td>Turf</td></tr>
<tr><td>Planting</td><td>50% Turf, 50% Impervious</td></tr>
<tr><td rowspan="2">Large</td><td>Preservation</td><td rowspan="2">40’ Canopy Diameter</td><td rowspan="3">BDL</td><td rowspan="3">1,720 sf Canopy
30” DBH</td><td rowspan="2">Reduce Canopy to 1,256 sf
Reduce DBH to 22”</td><td>Turf</td></tr>
<tr><td>Planting</td><td>50% Turf, 50% Impervious</td></tr>
<tr><td>Heritage</td><td>Preservation</td><td>32” DBH</td><td>Increase DBH to 32”
Increase Canopy to 1,820 sf</td><td>Turf</td></tr>
<tr><td colspan="7">1: DBH: Diameter at breast height
2: BDM: Broadleaf Deciduous Medium; BDL: Broadleaf Deciduous Large
3: Turf: Turf Planted over Hydrologic Soil Group C soils</td></tr>
</table>

Runoff Reduction Results

The Calculator was used to calculate runoff from both impervious and turf cover for each of the tree types. For the preservation scenarios, runoff reduction was estimated as the turf only, while the tree planting scenarios were estimated as an average of the impervious and turf covers. The results (Table TREE-2) suggest that:

- The proposed value for small tree planting and the current value for large tree planting are approximately 30% lower than the Calculator estimates
- The proposed value for small tree preservation and the current value for large tree preservation are very close to the Calculator estimates (within 10%)
- The proposed value for heritage tree preservation is much larger (40%) than the Calculator estimates.

Table TREE-2: Calculated Runoff Reduction versus Current/Proposed Retention Values

Class		Estimated Runoff Reduction (cf)			Current /Proposed Retention Value[2] (cf)	Difference (Estimate-Proposed Value) (cf)	Relative Difference
Tree Type	Preservation/ Planting	Impervious	Turf[1]	Weighted Average			
Small	Preservation	N/A	11.0	11.0	10	-1	-9%
	Planting	3.0	11.0	7.0	5	-2	-29%
Large	Preservation	N/A	19.4	19.4	20	0.6	+3%
	Planting	8.1	19.4	13.8	10	-3.8	-28%
Heritage	Preservation	N/A	28.1	28.1	40	11.9	+42%

1: Turf over HSG C Soils

2: Retention values for planting and preservation of large trees are currently in place. Retention values for planting of small trees and preservation of small and heritage trees have been proposed.

Recommendations

It is recommended that the current and proposed retention values for small and large trees remain the same. For tree preservation, this decision is recommended because the estimated and current values are almost the same. Although the recommended values for tree planting are somewhat lower than the estimates (almost 30%), using these lower values is arguably a better reflection of the state of planted trees, which may never reach maturity, and often need to be replanted due to mortality.

The heritage tree preservation value, on the other hand, is considerably higher than the retention value predicted by the Calculator. Even after increasing the canopy and DBH to reflect the very large trees estimated with this credit, the proposed value was still much higher than the estimate. Changing the retention value for heritage tree preservation to 30 cubic feet from the proposed 40 cubic feet is recommended.

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