Appendix C: Updated BMP Removal Efficiencies from the National Pollutant Removal Database (2007) & Acceptable BMP Table for Virginia

1. Introduction

CWP analyzed recent BMP data to update BMP removal efficiencies and identify BMPs suitable for Virginia stormwater management guidance. The appendix summarizes the following:

- BMP Update – Deriving an Acceptable BMP List - analyzes BMPs currently recommended in Virginia and compares them with updated pollutant removal efficiencies. Recommendations are made on whether each BMP should be eliminated, kept, or treated as a credit/pretreatment.
- Design Factors that Affect Pollutant Removal - recommends that two pollutant removal efficiencies be assigned to each type of BMP based on the concept that higher pollutant removal efficiencies can be achieved through better design standards.
- Affect of the Irreducible Pollutant Concentration – discusses the concept of the Irreducible Pollutant Concentration and the importance of utilizing LID Credits in conjunction with structural practices to address both volume and pollutant concentrations.
- Additional Resources – provides citations for noteworthy stormwater manuals and BMP design references.
- Updated BMP Removal Efficiencies – provides box and whisker plots for various types of BMPs summarizing updated data from the National Pollutant Removal Database.

2. BMP Update – Deriving an Acceptable BMP List

The purpose of this task was to evaluate Virginia's currently recommended BMPs and provide recommendations for revising and updating the list based on:

- Analysis of current use and experience in VA
- Updated pollutant removal data
- Available design reference information
- Available methods to incorporate BSD/LID

Figure 1 generally illustrates the approach for coming up with a list of acceptable BMPs and associated use (e.g, treatment, credit/pretreatment).

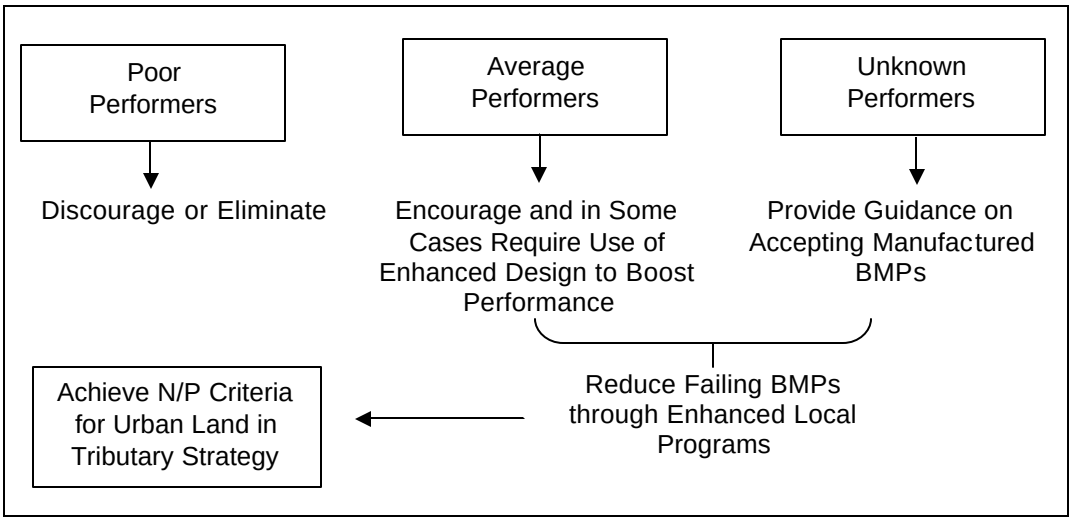

Figure 1. General Approach for Selecting Acceptable BMPs

Table 1 summarizes the recommendations for each of the BMPs called out in Virginia's Stormwater Management Handbook and suggests the addition of several LID practices as stormwater credits. This table incorporates the 2007 updates to the National Pollutant Removal Database. These numbers were utilized to determine the "poor performers" which were then either eliminated or downgraded to pre-treatment/credit. For each BMP, a recommendation is made on whether to keep it for primary treatment, use it only for pretreatment or credits, or eliminate it as an acceptable BMP for water quality treatment (it may still be used for detention and/or channel protection criteria) (see **Table 2**).

Pre-treatment techniques can be used to provide storage or limited pollutant removal before stormwater runoff enters the primary treatment BMP. Credits can be used to promote and provide incentives for the use of non-structural practices, such as LID techniques. In most cases LID credits must be combined with structural practices to meet stormwater requirements. The key benefit of non-structural practices is that they can reduce the generation of stormwater from the site; thereby reducing the size and cost of stormwater storage. Additional information on LID Credits is provided in Section 2 of the Nutrient Design System.

Table 1. Recommendations for Acceptable BMPs

BMP	Median Pollutant Removal Efficiency (%) (ranges in parantheses) (CWP, 2007)		Recommendation	VA Handbook Reference
	TP	TN		
Wet Pond (Retention Basin)	**52** (12-91)	**31** (-12-76)	Keep – provide 2nd design option for enhanced pollutant removal	MS 3.06
Extended Detention	**20** (0-48)	**24** (-19-43)	Eliminate as stand-along WQ treatment – poor pollutant removal performance	MS 3.07
Constructed Wetland	**48** (-55-100)	**24** (-49-76)	Keep - provide 2nd design option for enhanced pollutant removal	MS 3.09

Table 1. Recommendations for Acceptable BMPs				
	Median Pollutant Removal Efficiency (%) (ranges in parantheses) (CWP, 2007)			
Bioretention	**5** (-100-65)	**46** (-2-61)	Keep – update current specifications to minimize export of P from soil media; provide 2nd design option for enhanced pollutant removal	MS 3.11 & 3.11A
Other Filtering Practices	**59** (-79-88)	**32** (17-71)	Keep	MS 3.12 (Sand Filters)
Infiltration	**65** (0-100)	**42** (0-82)	Keep - provide 2nd design option for enhanced pollutant removal	MS 3.10 + TB #3
Water Quality Swale	**24** (-100 – 99)	**56** (8 - 99)	Keep - provide 2nd design option for enhanced pollutant removal	MS 3.13 (Grassed Swale)
Reforesting Riparian Area	N/A	N/A	Add as credit – also consider differentiating between supplementing an existing RPA area and protecting riparian area where none is required (i.e., non-RPA areas)	Not addressed
Open Space Conservation	N/A	N/A	Add as credit – also consider differentiating between open space areas that do not receive or treat stormwater runoff and those that do (i.e., areas w/hydrologic function)	Not addressed
On-Lot Infiltration Practices	N/A	N/A	Add as credit– somewhat addressed under Rooftop Downspout System; add additional techniques such as rain gardens	MS 3.10C
Rainwater Harvesting	N/A	N/A	Add as credit	Not addressed
On-lot Soil Amendments	N/A	N/A	Add as credit	Not addressed
Pervious Parking	N/A	N/A	Incorporate as design option for Infiltration and Filtering Practice. Also add as credit	MS 3.10D – need to add other options (e.g., paver blocks)
Green Roof	N/A	N/A	Add as credit	Not addressed
Grass Channels	15*	N/A	Eliminate from structural practices (but keep WQ Swale) and convert to credit	MS 3.13 (Grassed Swale)
Other Impervious Disconnection	N/A	N/A	Add as credit	Not addressed
Vegetated Filter Strip	10*	N/A	Eliminate from structural practice but keep as pre-treatment option. Include as option for "Other Impervious Disconnection" and include with "good rural development practices"	MS 3.14
Manufactured BMPs	15-50*	N/A	Update - provide additional guidance on accepting manufactured BMPs and testing protocols	MS 3.15 + TB #6
*Removal efficiencies obtained from VA Stormwater Management Handbook				

Table 2. Acceptable BMP List for Virginia's Revised Regulations		
BMP	**Treatment**	**Pretreatment and/or Credit**
Wet Pond	✓	
Bioretention	✓	
Infiltration	✓	
Constructed Wetland	✓	
WQ Swale	✓	
Filtering Practice	✓	
Reforesting Riparian Area		✓
Expanding & Protecting Riparian Area		✓
Open Space Conservation		✓
Open Space Conservation w/ Hydrologic Function		✓
On-Lot Rain Garden, Dry Well, Infiltration Practice		✓
Rainwater Harvesting		✓
On-Lot Soil Amendments		✓
Pervious Parking		✓
Green Roof		✓
Grass Channels		✓
Other Impervious Disconnection (including Vegetated Filter Strip)		✓
Manufactured BMPs (filtering)	✓	
Manufactured BMPs (hydrodynamic)		✓

3. Design Factors that Affect Pollutant Removal

Studies of BMP pollutant removal efficiency indicate a wide variability of BMP performance based on a variety of factors, including: design features, influent concentration, particle size distribution of runoff, rainfall depth and intensity, flow rates, soils, and other site factors. Stormwater management criteria commonly assign the median pollutant removal efficiency, but this often masks the role of certain design factors in reducing or enhancing performance.

For the Nutrient Design System**,** BMP categories were divided into two groups to isolate the design features that can boost removal efficiency. For instance, bioretention designs include Bioretention #1 and Bioretention #2. The first category can be seen as the "standard" design, while the second category includes sizing and design features

that have been shown in research to improve performance beyond the median removal efficiency.

Table 3 documents the recommended BMP removal rates for use in updates to Virginia's stormwater management criteria. These rates were based on 2007 updates to the National Pollutant Removal Database (provided in **Table 1**) and design information from recent research. Example criteria for Bioretention #1 and Bioretention #2 are illustrated in Section 3 of the Nutrient Design System.

Table 3. Recommended BMP Removal Rates

BMP Type	TP Removal Efficiency	TN Removal Efficiency
Wet Pond 1	50%	30%
Wet Pond 2	75%	40%
Bioretention 1	45%	45%
Bioretention 2	55%	55%
Infiltration 1	65%	40%
Infiltration 2	95%	65%
Constructed Wetland 1	45%	25%
Constructed Wetland 2	75%	55%
WQ Swale 1	25%	45%
WQ Swale 2	45%	55%
Filtering Practice	65%	50%

4. Affect of the Irreducible Concentration

The concept of the irreducible concentration refers to a stormwater BMP's inability to reduce pollutant concentrations below a certain level. Irreducible concentrations represent the internal production of nutrients and turbidity within a pond or wetland that may turn some pollutants back into the water column where they may be displaced during the next storm event. In other cases, the irreducible concentration may reflect the limitations of particular removal pathways (e.g., filtration) utilized in a stormwater practice.

The existence of an irreducible concentration suggests that there are limits to improving treatment efficiency with structural BMPs in series. Simply put, if the first BMP reduces the pollutant concentration near the irreducible concentration, it is not likely that a second or third will result in any further improvement. **Figure 2** illustrates the "best we can do" with available technology.

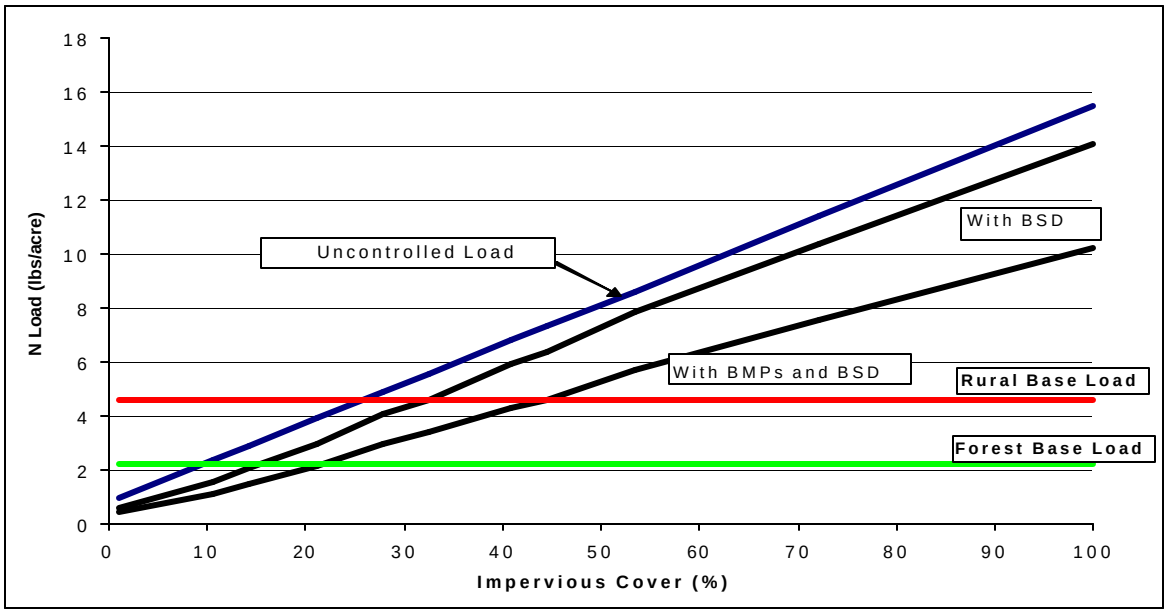

Figure 2. Nitrogen Loading without controls, with BSD, and with a combination of BMPs and BSD (note that loading from septic systems not included in rural base load)

Based on this finding, a "treatment train" approach is recommended, whereby a series of practices are utilized to reduce runoff volume, reduce pollutant generation at the source, treat runoff in the conveyance system, pretreatment, and structural BMPs. This is different than putting two or more structural BMPs in series (e.g., as end-of-pipe treatment) to try to achieve higher removal rates. If advanced BMPs cannot reduce outflow concentrations below certain irreducible levels, the only way to further reduce loads is to reduce runoff volume. Recent research has shown that LID and BSD techniques can be successful at doing this. **Table 4** reviews 17 recent studies on the runoff reduction capability of LID practices. The volume achieved by LID ranges from 40 to 99% with a median reduction of about 75%, compared to the runoff reduction achieved by ponds and wetlands which is typically less than 5%. Therefore, the recommended approach is to use LID Credits in conjunction with structural practices to address both volume and pollutant concentrations.

Table 4. Review of Recent Research on Volumetric Runoff Reduction by LID Practices		
LID Practice	**% Runoff Reduction**	Reference
Bioretention	99	Dietz and Clausen (2006)
Bioretention	58	Seters et al (2006)
Bioretention	98	Rushton (2002)
Bioretention	50	Hunt et al (2006)
Bioretention	40 to 60	Smith and Hunt (2007)
Bioretention	75	Ballestro et al (2006)
Bioretention	80	Traver et al (2006)
Bioretention	73	Lloyd et al (2002)
Biofiltration Swale	98	Horner et al (2003)
Biofiltration Swale	94	Jefferies (2004)
Bioflitration Swale	46 to 54	Stagge (2006)
Permeable Pavement	75	Rushton (2002)
Permeable Pavement	99	Seters et al (2006)
Permeable Pavement	95 to 97	Traver et al (2006)
Permeable Pavement	60 to 90	Hunt and Lord (2006)
Permeable Pavement	50	Jefferies (2004)
Rainwater Harvesting	60 to 90	Coombes et al (2004)

5. Additional Resources

Table 5 provides some information on several recent state-level stormwater design manuals that will serve as good references for Virginia's update of the Handbook. **Table 6** is a more comprehensive list of the best current BMP design references from around the country, categorized by type of BMP.

Table 5. Other Noteworthy State Manuals	
Manual	**Noteworthy Features**
Maryland Stormwater Design Manual (2000)	▪ First state manual to include stormwater credits for Better Site Design
Maryland Critical Area 10% Rule Guidance Manual (2003)	▪ Provides specific guidance for Intensively Developed Areas (IDAs) within MD's Critical Areas, so is a good reference for infill and redevelopment situations
Pennsylvania Stormwater Best Management Practices Manual (2006)	▪ Recent manual that incorporates site design and non-structural BMPs into overall stormwater site plan.
Minnesota Stormwater Manual (2006)	▪ Includes updated stormwater credits for both water quality and quantity

Table 6. Best BMP Design References

Category	State/Province/Local	Manual	Website
Wet Ponds	Vermont	Vermont Stormwater Management Manual	http://www.anr.state.vt.us/dec/waterq/stormwater.htm
	Austin, TX	Environmental Criteria Manual	http://www.cityofaustin.org/watershed/publications.htm
	Maryland	Maryland Stormwater Design Manual	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp
	New York	New York State Stormwater Management Design Manual	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/index.html
Bioretention	Prince George's Co, MD	Bioretention Manual	http://www.goprincegeorgescounty.com/Government/AgencyIndex/DER/ESD/Bioretention/bioretention.asp?nivel
	Lake Co, OH	Bioretention Guidance	http://www2.lakecountyohio.org/smd/Forms.htm
	Washington	Low Impact Development Technical Guidance Manual for Puget Sound	http://www.psat.wa.gov/Publications/LID_tech_manual05/lid_index.htm
	Wisconsin	Stormwater Management Technical Standards	http://www.dnr.state.wi.us/org/water/wm/nps/stormwater/techstds.htm#Post
Infiltration	Pennsylvania	Draft Pennsylvania Stormwater Best Management Practices Manual	http://www.dep.state.pa.us/dep/subject/advcoun/Stormwater/stormwatercomm.htm
	Delaware	Green Technology: The Delaware Urban Runoff Management	http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20&%20Specs_06-05.pdf
	New York	New York State Stormwater Management Design Manual	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/index.html
	Maryland	Maryland Stormwater Design Manual	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp
Stormwater Wetlands	Vermont	Vermont Stormwater Management Manual	http://www.anr.state.vt.us/dec/waterq/stormwater.htm
	Connecticut	2004 Stormwater Quality Manual	http://dep.state.ct.us/wtr/stormwater/strmwtrman.htm#download
	Washington	Stormwater Management Manual for Western Washington	http://www.ecy.wa.gov/programs/wq/stormwater/manual.html
	Minnesota	Minnesota Stormwater Manual	http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html
Open Channels	New York	New York State Stormwater Management Design Manual	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/index.html
	Vermont	Vermont Stormwater Management Manual	http://www.anr.state.vt.us/dec/waterq/stormwater.htm
	Western Washington	Stormwater Management Manual for Western Washington	http://www.ecy.wa.gov/programs/wq/stormwater/manual.html#How_to_Find_the_Stormwater_Manual_on_the
	Northern Mariana Islands and Guam	Draft CNMI and Guam Stormwater Management Manual	http://www.guamepa.govguam.net/programs/water/index.html
Filtration	District of Columbia	Stormwater Management Guidebook	Currently Not Available Online
	Minnesota	Minnesota Stormwater Manual	http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html
	Maryland	Maryland Stormwater Design Manual	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp
	Center for Watershed Protection	Design of Stormwater Filtering Systems	http://www.cwp.org/PublicationStore/special.htm

6. BMP Removal Efficiency Graphs

Figures 3 through 9 are "box and whisker" plots for the various categories of BMPs, as updated in the National Pollutant Removal Database (2007). Recent studies, updated through 2006), were added to the existing data set. CWP also grouped the data into appropriate BMP categories.

The plots summarize the following features from the data:

- Median Efficiency = where light grey and dark grey bars meet
- Average Efficiency = small diamond
- 25th Percentile = bottom of light grey bar
- 75th Percentile = top of dark grey bar
- Highest value = top of line
- Lowest value = bottom of line

The plots show removal efficiencies for the following pollutants:

- TSS = Total Suspended Solids
- TP = Total Phosphorus
- Sol P = Soluble Phosphorus
- TN = Total Nitrogen
- NOx = Nitrogen as Nitrate (NO_2) & Nitrite (NO_3)
- Cu = Copper
- Zn = Zinc
- Bacteria = Bacteriological indicators (e. coli or fecal coliform)

As can be seen from the plots, the data ranges tend to be very high. This reflects a great deal of variability in design, construction, age of BMP, and maintenance, as well as study conditions (e.g., range of rainfall events monitored, influent concentrations, etc.).

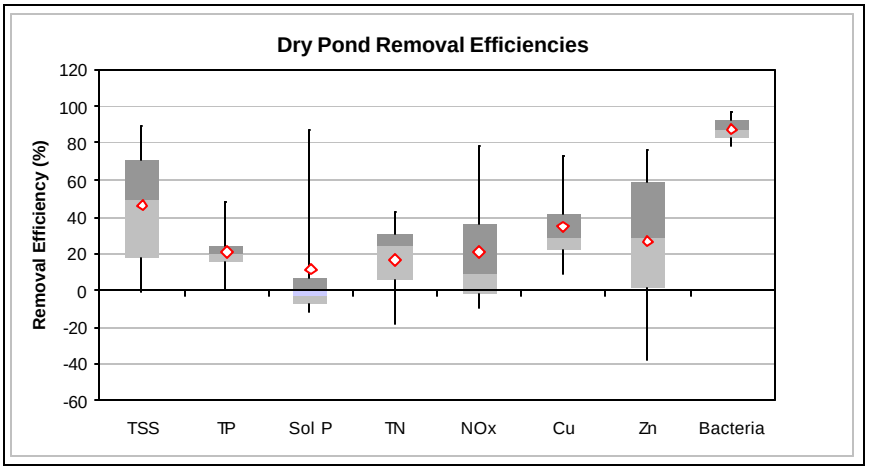

Figure 3: Box & Whisker Plot for Dry Ponds

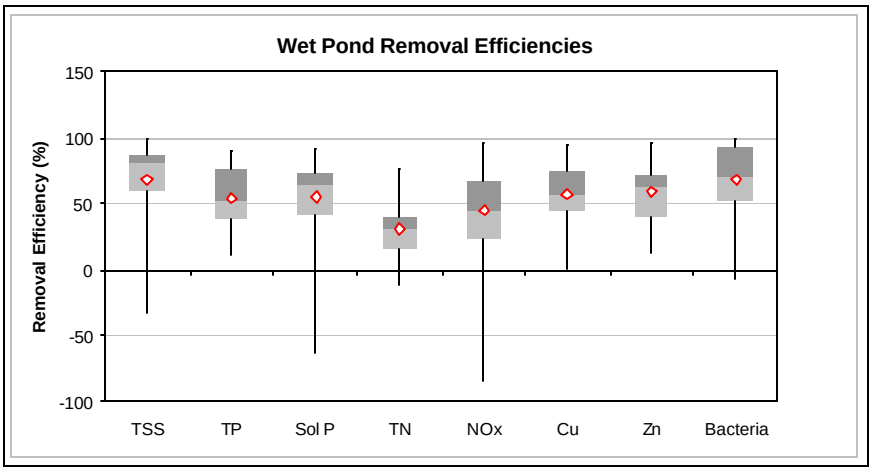

Figure 4: Box & Whisker Plot for Wet Ponds

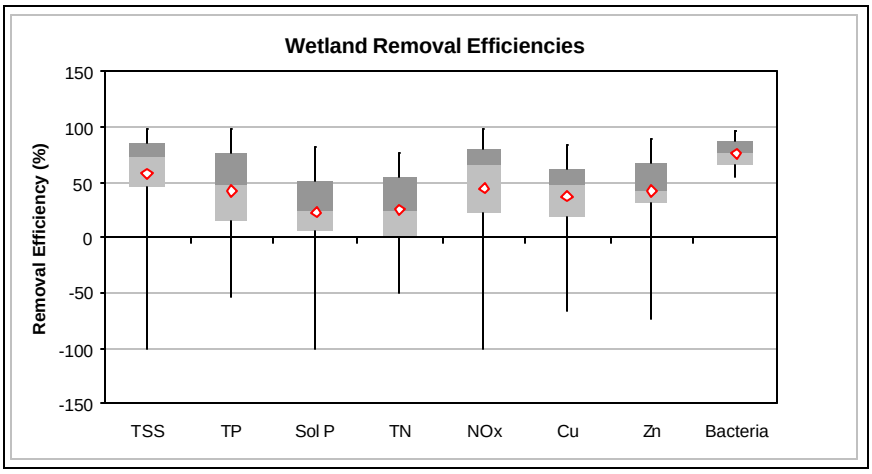

Figure 5: Box & Whisker Plot for Stormwater Wetlands

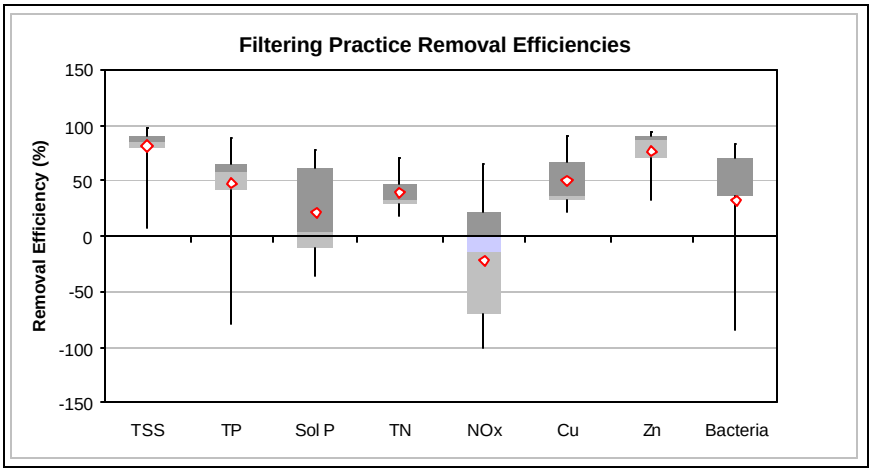

Figure 6: Box & Whisker Plot for Filtering Practices

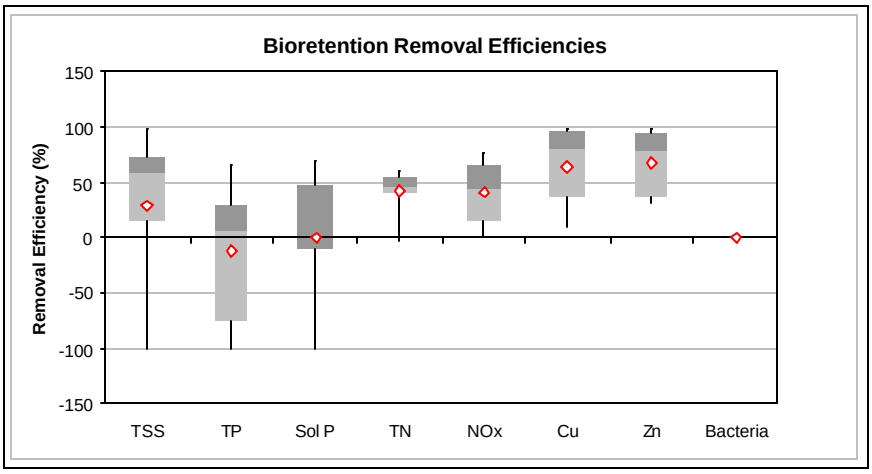

Figure 7: Box & Whisker Plot for Bioretention

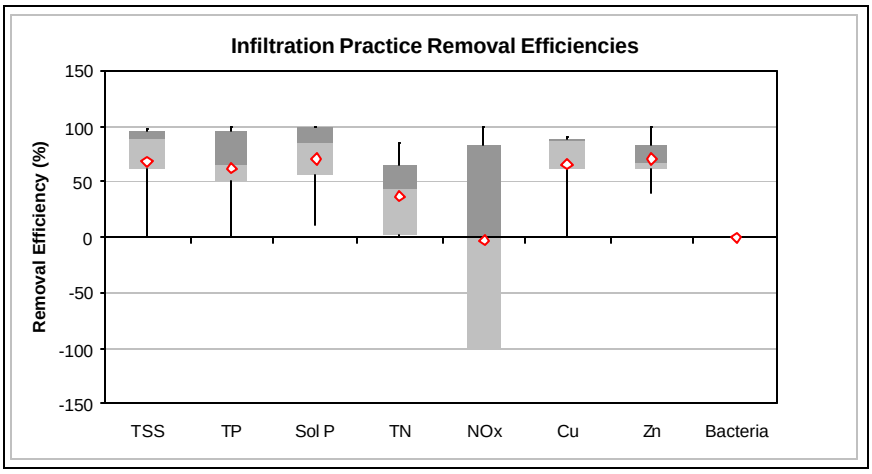

Figure 8: Box & Whisker Plot for Infiltration Practices

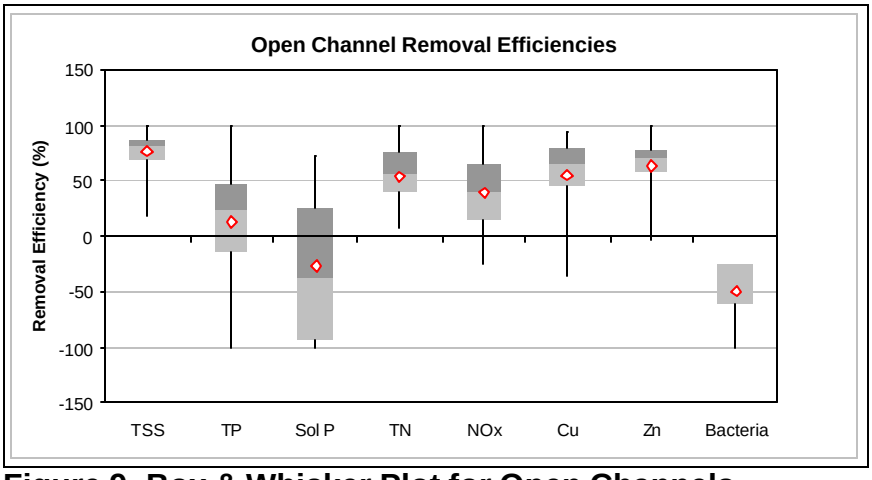

Figure 9: Box & Whisker Plot for Open Channels

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