Final

WHITE PAPER
for
Stormwater Management Program Effectiveness Literature Review

Traditional BMPs Retrofitting

April 2013

Prepared for:
Association of Washington Cities
and
Washington State Department of Ecology

Prepared by:
Carla B. Milesi
Cardno TEC, Inc.
2825 Eastlake Avenue East, Suite 300
Seattle, Washington 98102

EXECUTIVE SUMMARY

Over the last ten years much attention has been paid to managing or addressing the stormwater runoff issue, with a particular focus on the use of stormwater Best Management Practices (BMPs, Sample et al. 2003). The primary purpose of using BMPs is to protect beneficial uses of water resources through the reduction of storm flow, pollutant loads and pollutant concentrations (WSDOT 2012).

While BMPs have been incorporated into much of the development that occurred over the past decade, development prior to this included little to no runoff treatment or flow control facilities. As a result stormwater from these areas remains unmanaged and is considered a major contributor to stormwater pollution (WERF 2009). One way municipalities are looking to address the issue of stormwater in these urban areas is by retrofitting urban parcels by adding BMPs to provide stormwater treatment and flow control.

BMPs are widely used and their effectiveness is well documented for site-specific applications, however, there is still some uncertainty about their effectiveness over a range of applications and circumstances (Ackerman and Stein 2008). This is due to the fact that BMPs are typically monitored in the field under certain settings, which can make it difficult to generalize or extrapolate the findings. BMP effectiveness models are a tool that are meant to provide a way to predict the pollutant removal ability under varying environmental conditions.

This paper summarizes articles included within the effectiveness study literature database (Ecology 2011a) for the Traditional BMP Stormwater Management Plan (SWMP) topic. In particular, the paper discusses the following Effectiveness Study Topic Null Hypotheses relating retrofitting existing development to include BMPs and the accuracy of model predicted effectiveness of stormwater BMPs.

Hypothesis: Retrofitting using water quality treatment devices does not reduce pollutant loads.

Several studies have looked at the effect retrofitting using BMPs has on pollutants in stormwater. These studies have been conducted both in the field and by using BMP effectiveness models. In general the articles included within the literature database indicate retrofitting using water quality treatment devices can reduce pollutant loads.

Based on a review and summarization of the articles included in the literature database it is recommended that additional studies be completed. Some suggestions include:

1. Perform field studies on existing urban retrofitted BMPs within western Washington to assess their effectiveness at removing a variety of pollutants.
2. Survey local municipalities to assess the feasibility of adding BMPs to existing developed areas. Investigate what sort of incentives landowners would need to take part in a program
3. Conduct a more extensive literature search on which retrofitted BMPs, or combination of retrofitted BMPs, are most effective at removing specific pollutants of interest.
4. Conduct field studies or more extensive literature search on studies that compare model predicted BMP effectiveness to field verified BMP effectiveness.

5. The majority of BMP effectiveness models were developed for agricultural and forested environments. Improve the models by incorporating more urban stormwater runoff data that will provide predicted results that are more practical for use by the stormwater management industry.

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS ii

1.0 Introduction and Problem Statement 1

1.1 Scope of this Paper 1

1.2 Problem Statement 1

2.0 Literature Summary and Talking Points 3

2.1 Does Retrofitting using water quality treatment devices reduce pollutant loads? 3

2.1.1 Question: Which combinations of retrofit BMPs in a basin are most effective at reducing pollutants to receiving waters? 4

2.1.2 Question: To what extent does retrofitting using water quality treatment devices reduce urban stormwater pollution to receiving water bodies? 5

2.1.3 Question: Once installed, do model predicted quantities of stormwater controls in a basin reduce stormwater impacts enough to support the receiving water's designated beneficial uses? 6

3.0 Conclusions and Recommendations 7

4.0 References 8

ABBREVIATIONS AND ACRONYMS

BMPs	Best Management Practices
Caltrans	California Department of Transportation
CTR	California Toxics Rule
mgL^{-1}	micrograms per liter
NPDES	National Pollutant Discharge Elimination System
SWMP	Stormwater Management Plan
TMDL	Total Maximum Daily Load
TSS	total suspended solids
USEPA	United States Environmental Protection Agency
WinSlamm	Source Loading and Management Model for Windows

1.0 INTRODUCTION AND PROBLEM STATEMENT

The Stormwater Work Group (SWG) is a group of stakeholders made up of federal, tribal, state and local governments, as well as business, environmental, agriculture and research interests. They are tasked with developing a Stormwater Monitoring and Assessment Strategy for the Puget Sound Region. The Effectiveness Study Selection Subgroup (subgroup) was formed by the SWG in October 2010 to help with the process of identifying potential effectiveness studies to be conducted during the next National Pollutant Discharge Elimination System (NPDES) municipal stormwater permit cycle. The subgroup developed a list of 22 ranked effectiveness study topics and associated questions. To help answer these questions, an Effectiveness Study Literature Review was conducted and a literature database was created (Ecology 2011a). The literature database contains over 300 publications, including journal articles, books, public information flyers and agency reports.

1.1 SCOPE OF THIS PAPER

This paper aims to summarize the publications within the effectiveness literature database (Ecology 2011a) that related to the ranked effective study and the Stormwater Management Plan (SWMP) Traditional BMPs topic #10. The paper specifically address the following Effectiveness Study Topic Null Hypothesis relating to retrofitting areas to include BMPs and the accuracy of model predicted effectiveness of stormwater BMPs.

Null Hypothesis: Retrofitting using water quality treatment devices does not reduce pollutant loads.

- Which combinations of retrofit BMPs in a basin are most effective at reducing pollutants to receiving waters?
- To what extent does retrofitting, using water quality treatment devices, reduce urban stormwater pollution to receiving water bodies?
- Once installed, do model predicted quantities of stormwater controls in a basin reduce stormwater impacts enough to support the receiving water's designated beneficial uses?

Funding for this white paper was provided the Washington State Department of Ecology.

1.2 PROBLEM STATEMENT

Across the United States, unmanaged stormwater runoff contributes to serious pollution and flooding issues in streams, rivers, lakes, and other receiving water bodies. In Washington State it is estimated that one third of all of the polluted waters in the state are polluted by unmanaged stormwater runoff (King County 2010).

Over the last 10 years much attention has been given to managing or addressing the stormwater runoff issue, with a particular focus on the use of stormwater Best Management Practices (BMPs, Sample et al. 2003). The primary purpose of using BMPs is to protect beneficial uses of water resources through the reduction of pollutant loads and concentrations (WSDOT 2012).

While a large focus has been on addressing stormwater from new developments and incorporating BMPs into the design of new projects, stormwater from existing urban areas often remains unmanaged and is considered a major contributor to stormwater pollution (WERF

2009). One way municipalities are looking to address the issue of stormwater issues in these urban areas is by retrofitting urban parcels by adding BMPs to treat the stormwater and provide flow control.

Despite the widespread use of BMPs there is still some uncertainty over their effectiveness over a range of applications and circumstances (Ackerman and Stein 2008). This is due to the fact that BMPs are typically monitored in the field under certain settings, and relying on empirical evaluation can make it difficult to generalize or extrapolate the findings. BMP effectiveness models are a tool that is meant to provide a way to predict the pollutant removal ability under varying environmental conditions.

2.0 LITERATURE SUMMARY AND TALKING POINTS

The Traditional BMP null hypotheses and ranked questions for Topic #10 are presented in Table 1. Publications from the database of effectiveness study literature (Ecology 2011a) were reviewed to research the null hypotheses and address the ranked questions. This section presents a summary of the publications reviewed and, where possible, answers to the ranked questions.

Table 1 Ranked Effectiveness Questions for Traditional BMPs Topic 10 (Ecology 2011b)

Rank[1]	Null Hypothesis	Questions
10	Retrofitting using water quality treatment devices does not reduce pollutant loads.	• Which combinations of retrofit BMPs in a basin are most effective at reducing pollutants to receiving waters?
		• To what extent does retrofitting using water quality treatment devices reduce urban stormwater pollution to receiving water bodies?
		• Once installed, do model predicted quantities of stormwater controls in a basin reduce stormwater impacts enough to support the receiving water's designated beneficial uses?

Notes:

1 Rank assigned by the SWG.

2.1 DOES RETROFITTING USING WATER QUALITY TREATMENT DEVICES REDUCE POLLUTANT LOADS?

A few studies included in the literature database looked at the effect of retrofitting using BMPs on pollutants in stormwater. The California Department of Transportation (CALTRANS) constructed five Austin-style sand filters within existing maintenance yards and park-and-ride facilities in Los Angeles and San Diego (Barrett 2003). The sand filters were analyzed for a variety of common stormwater pollutants, including total suspended solids (TSS), total and dissolved copper, lead and zinc, nutrients, total petroleum hydrocarbons, and fecal coliform. The concentrations of TSS and particle associated pollutants in the effluent was consistently low, and significant removal of dissolved constituents was seen at higher influent concentrations (Barrett 2003).

Another study conducted in Boston used the Source Loading and Management Model for Windows (WinSLAMM) to evaluate the potential reductions of phosphorus loading by retrofitting two developed sites with various arrangements of wet detention ponds and biofiltration cells (Hurley and Forman 2011). The sites drained to the Charles River which has a phosphorus Total Maximum Daily Load (TMDL) that was issued in 2007. The TMDL requires a 65 percent reduction in phosphorus loading from industrial, commercial, institutional, and high density residential land uses in the watershed (Hurley and Forman 2011). The model indicated that the 65 percent reduction goal could be met for the developed sites if they were retrofitted with a detention pond or biofilter than covered 5 percent of the site's area and received 100 percent of the runoff (Hurley and Forman 2011).

A final study included in the literature database looked at the effects of retrofitting an existing BMP in Austin, Texas to improve the pollutant removal ability. In this study an extended

detention basin was retrofitted to provide batch treatment rather than flow through treatment of stormwater runoff. The USEPA reports that the likely TSS removal efficiency for extended detention basins is between 50-95 percent (Shamma et al. 2002). However, additional literature indicates the removal efficiency is closer to 60 or 70 percent (Middleton and Barrett 2008). The extended detention basin that was retrofitted to a batch treatment system had TSS removal efficiencies of 91 percent, even with relatively low influent concentrations (Middleton and Barrett 2008). In addition there were statistically significant reductions in the concentrations of total copper, lead, and zinc, chemical oxygen demand, total phosphorus, nitrate and nitrite, and total Kjeldahl nitrogen. Overall the retrofitted or modified basin had substantially better pollutant removal than the conventional extended detention basins (Middleton and Barrett 2008).

An additional study no included in the literature database was conducted by King County, Ecology, City of Kirkland, and WSDOT. This study looked at seven mitigation scenarios within the Juanita Creek basin and used the Hydrologic Simulation Program-Fortran (HSPF) model to evaluate their potential to improve flow and water quality. The study found that one mitigation scenario, which included a combination of rain gardens and dry/wet ponds, greatly reduced annual loads from existing and future unmitigated conditions for TSS, dissolved and total copper, nitrate-nitrite, total nitrogen, orthophosphate, and total phosphorus (King County et al 2012). The annual loads of ammonia did increase due to decaying organic matter.

In general the articles included within the literature database indicate retrofitting using water quality treatment devices can reduce pollutant loads. The subsections below summarize the publications within the effectiveness literature database that related to the Traditional BMP Ranked List of Effectiveness Topic #10 and Potential Questions approved by the Stormwater Work Group. These summaries are meant to assist local stormwater management program staff in gaining a better understanding of the topic of retrofit BMPs and models that predict BMP effectiveness. In general, retrofitting developed areas to install BMPs reduces stormwater pollution and there don't appear to be enough studies to determine if model predicted quantities of stormwater control reduce stormwater impacts.

2.1.1 Question: Which combinations of retrofit BMPs in a basin are most effective at reducing pollutants to receiving waters?

There were no studies found in the effectiveness literature database that assessed various combinations of retrofit BMPs to compare their pollutant removal ability. A study completed by King County, Ecology, City of Kirkland, and WSDOT used a model to assess the effectiveness of seven different mitigation scenarios, presented in Table 2 (King County et al. 2012). The goal of the mitigation is to restore water quality and flow conditions supportive of aquatic beneficial uses. The ECY08 scenario was the best performing mitigation scenario and the only one that achieved this goal. This scenario included a basin-wide retrofit using a combination of rain gardens and combined detention/wet ponds.

Table 2. Flow and water quality mitigation scenarios (King County et al. 2012).

Scenario	Description
LEVEL2	Future land use with King County Level 2 stormwater ponds applied basin-wide.
LID40	Future land use with 40% total impervious area (TIA) captured by rain gardens.
LID80	Future land use with 80% total impervious area (TIA) captured by rain gardens.
ECY08	Ecology-proposed matching durations to 8% of the 2-year forested to the 50-year forested, using a combination LID80 and stormwater detention ponds stacked on basic wetponds applied basin wide.
LID40+	Combination of LID40 throughout the basin and King County Level 2 stormwater detention ponds stacked on basic wetponds in three catchments.
LVL2WET	Future land use with King County Level 2 stormwater detention ponds stacked on basic wetponds applied basin-wide.
CISTERNS	Future land use where roof area runoff from a mild wet season of rainfall is captured then released July-Sept each calendar year at a constant rate.

2.1.2 Question: To what extent does retrofitting using water quality treatment devices reduce urban stormwater pollution to receiving water bodies?

Retrofitting urban parcels by adding BMPs is one way municipalities are looking to manage the issue of stormwater runoff in already developed areas. CALTRANS retrofitted five maintenance yards or park-and-ride facilities by constructing Austin-style sand filters (Barrett 2003). The sand filters were analyzed for a variety of common stormwater pollutants, including TSS, total and dissolved copper, lead and zinc, nutrients, total petroleum hydrocarbons, and fecal coliform. The retrofit sand filters removed 90 percent of TSS concentrations, with an average effluent concentration of 7.8 mgL^{-1} (+/- 1.2 mgL^{-1}) (Barrett 2003). Removals of total copper, total lead, and total zinc were 50 percent, 87 percent, and 80 percent, respectively. In addition, sand filters are generally expected to have limited removal ability for dissolved constituents, yet for dissolved copper and other metals the data from this study indicate significant reduction in concentration when the influent concentrations were sufficiently high (Barrett 2003).

As noted in Section 2.1, a study in Boston used the model WinSLAMM to evaluate the potential phosphorus reductions achieved by retrofitting two developed sites with various arrangements of wet detention ponds and biofiltration cells (Hurley and Forman 2011). The sites drained to the Charles River which has a TMDL which requires a 65 percent reduction in phosphorus loading from industrial, commercial, institutional, and high density residential land uses in the watershed (Hurley and Forman 2011). The model indicated that the 65 percent reduction goal could be met for the developed sites if they were retrofitted with a detention pond or biofilter than covered five percent of the site's area and received 100 percent of the runoff (Hurley and Forman 2011).

One study also looked at the effects of retrofitting an existing BMP in Austin, Texas to improve the pollutant removal ability. In this study an extended detention basin was retrofitted to provide batch treatment rather than flow through treatment of stormwater runoff. The retrofitted batch treatment detention basin had TSS removal efficiencies of 91 percent, whereas the likely TSS removal for a traditional extended detention basin is closer to 60 or 70 percent (Middleton and Barrett 2008). In addition the retrofitted detention basin showed statistically significant reductions in total copper, lead, and zinc, chemical oxygen demand, total phosphorus, nitrate and nitrite, and total Kjeldahl nitrogen (Middleton and Barrett 2008).

2.1.3 Question: Once installed, do model predicted quantities of stormwater controls in a basin reduce stormwater impacts enough to support the receiving water's designated beneficial uses?

Several studies included in the literature database used models to evaluate the effectiveness of BMPs at reducing pollutant loads or pollutant concentrations. However, only one study was found that looked at how closely the model predicted stormwater controls matched the effectiveness of those BMPs once installed in the field. There were no studies found within the effectiveness study literature database that looked at the effectiveness of retrofit BMPs and providing flow control.

One study conducted at two sites in Australia focused on the sediment removal effectiveness of grass swales and filter strips and verifying the TRAVA, which is a model of sediment behavior in grass. The difference between the predicted and measured sediment loading rates from the two sites was +/- 25 percent and +/- 50 percent for the filter strip, and +/- 17 percent and +/- 11 percent for the grass swales (Deletic and Fletcher 2005). Overall, the study determined that TRAVA is a reliable tool to predict the performance of filter strips and swales at removing sediments from stormwater runoff. The study did state that most models of grass filter performance have been developed for agricultural and forested environments and relatively few field studies have been completed on grass filter performance in an urban environment.

A study conducted by Ackerman and Stein (2008) used a model to assess how well two types of BMPs reduced pollutant runoff from a generic one-acre land parcel. The BMP types included a retention facility and a flow through swale and the model looked at removal of solids and total copper in terms of concentration, load reduction, and frequency of exceedance of the California Toxics Rule (CTR). The model predicted copper and solids reductions of over 60 percent for both BMPs; however, the effectiveness was reduced during larger storms or during wet years (Ackerman and Stein 2008). Both BMPs all reduced the frequency of the effluent event mean concentration exceeding the CTR (Ackerman and Stein 2008).

As outlined in Section 2.1, another study conducted in Boston used the WinSLAMM model to evaluate the potential reductions of phosphorus loading by retrofitting two developed sites with various arrangements of wet detention ponds and biofiltration cells (Hurley and Forman 2011). The sites drained to the Charles River which has a phosphorus TMDL that was issued in 2007. The TMDL requires a 65 percent reduction in phosphorus loading from industrial, commercial, institutional, and high density residential land uses in the watershed (Hurley and Forman 2011). The model indicated that the 65 percent reduction goal could be met for the developed sites of they were retrofitted with a detention pond or biofilter than covered five percent of the site's area and received 100 percent of the runoff (Hurley and Forman 2011).

As noted above, there was only one study found in the literature database that compared how well model predicted BMP effectiveness matched BMP effectiveness once installed in the field. And the study noted that few models have been developed that specifically look at BMP effectiveness in urban environments. However, assessing the accuracy of model predicted BMP effectiveness, both for stormwater quality and quantity issues, seems to be an important topic that would be beneficial to investigate more thoroughly.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Stormwater often contains oil, chemicals, and toxic metals and unmanaged stormwater can have devastating effects on the quality of lakes, streams and other water bodies. In Washington State stormwater is the leading contributor to water quality pollution in urban waterways. BMPs are regularly incorporated and often required with new developments, however, existing developments with traditional BMPs are a major contributor to stormwater pollution and often do not have adequate stormwater control or treatment measures (WERF 2009). Retrofitting these existing developments by installing BMPs is one way municipalities are looking to address issues with stormwater pollution.

Retrofitting existing developed areas to include BMPs can be difficult to accomplish due to a variety of factors including cost, lack of space and existing drainage or site conditions. In addition, despite the relatively widespread use of BMPs and their known effectiveness on site-specific installations, there is still some uncertainty over their effectiveness over a range of applications and circumstances (Ackerman and Stein 2008). This is due to the fact that BMPs are typically monitored in the field under certain settings, which can make it difficult to generalize or extrapolate the findings. BMP effectiveness models are one tool that can be used to predict BMP effectiveness under varying environmental conditions. These models can be valuable in helping to assess effectiveness as well as the cost versus benefit of various types and sizes of BMPs that may be appropriate for retrofits.

Based on a review and summarization of the articles included in the literature database it is recommended that additional studies be completed to further investigate the benefits of retrofitted BMPs and BMP effectiveness models. A few of these recommendations include:

1. Perform field studies on existing urban retrofitted BMPs within western Washington to assess their effectiveness at removing a variety of pollutants.
2. Survey local municipalities to assess the feasibility of adding BMPs to existing developed areas. Investigate what sort of incentives landowners would need to take part in a program.
3. Conduct a more extensive literature search on which retrofitted BMPs, or combination of retrofit BMPs, are most effective at removing specific pollutants of interest.
4. Conduct field studies or more extensive literature search on studies that compare model predicted BMP effectiveness to field verified BMP effectiveness.
5. The majority of BMP effectiveness models were developed for agricultural and forested environments. Improve the models by incorporating more urban stormwater runoff data that will provide predicted results that are more practical for use by the stormwater management industry.

4.0 REFERENCES

Ackerman, Drew and Eric D. Stein. 2008. Evaluating the Effectiveness of Best Management Practices Using Dynamic Modeling. Journal of Environmental Engineering. Vol. 134, No. 8: pp 628-639.

Barrett, Michael E. 2003. Performance, Cost, and Maintenance Requirements of Austin Sand Filters. Journal of Water Resources Planning and Management. Vol. 129, No. 3: pp 234-242.

Deletic, Ana and Tim D. Fletcher. 2005. Performance of Grass Filters used for Stormwater Treatment – A Field and Modelling Study. Department of Civil Engineering. Monash University. Melbourne, Australia.

Hurley, Stephanie E. and Richard T.T. Forman. 2011. Stormwater ponds and biofilters for large urban areas: Modeled arrangements that achieve the phosphorus reduction target for Boston's Charles River, USA. Ecological Engineering. Vol. 37, No. 6: pp 850-863.

King County Department of Natural Resources and Parks, Washington State Department of Ecology, City of Kirkland, Washington State Department of Transportation. 2012. Stormwater Retrofit Analysis and Recommendations for the Juanita Creek Basin in the Lake Washington Watershed.

King County Stormwater Services Section (King County). 2010. Stormwater runoff pollution and how to reduce it. 2010. Web. http://www.kingcounty.gov/environment/waterandland/stormwater/introduction/stormwater-runoff.aspx

Middleton, John R. and Michael E. Barrett. 2008. Water Quality Performance of a Batch-Type Stormwater Detention Basin. Water Environment Research, Volume 80, Number 2.

Sample, D.J., J.P. Heaney, L.T. Wright, C.Y. Fan, F.H. Lai, and R. Field. 2003. "Costs of best management practices and associated land for urban stormwater control." Journal of Water Resources Planning and Management. 129(1), 59-68.

Shamma, Y. Zhu, D.Z,. Gyurek, L.L., and Labatiuk, C.W. 2002. Effectiveness of Dry Ponds for Stormwater Total Suspended Solids Removal. Canadian Journal of Civil Engineering, 29, 316-324. 2002.

United States Environmental Protection agency (USEPA). 2011. Stormwater Retrofit Techniques for Restoring Urban Drainages in Massachusetts and New Hampshire. Small MS4 Permit Technical Support Document. April 2011.

Washington State Department of Ecology (Ecology) 2011a. Washington State Department of Ecology. Effectiveness Study Selection. Stormwater Work Group Published online. https://sites.google.com/site/pugetsoundstormwaterworkgroup/home/selection-of-effectiveness-studies.

Washington State Department of Ecology (Ecology) 2011b. Stormwater Work Group. Recommended Effectiveness Study Topics and Questions. Published online. https://sites.google.com/site/pugetsoundstormwaterworkgroup/home/selection-of-effectiveness-studies/recommended-effectiveness-study-topics-and-questions.

Washington State Department of Transportation. 2012. Stormwater Management Manual for Western Washington. Publication Number 12-10-030. August 2012.

Water Environment Research Foundation (WERF).2009. Stormwater BMP Concepts and Policies. 2009. Web. February 1 2012.