FINAL

WHITE PAPER
for
Stormwater Management Program Effectiveness Literature Review

Traditional BMPs
Filter Strips

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EXECUTIVE SUMMARY

Vegetative filter strips (VFS) are best management practices (BMPs) that are designed to treat sheet flow and are often used along roads and highways. They are effective at reducing total suspended solids (TSS) as well as concentrations of particulate pollutants (Schmitt et al. 1999) and are an approved BMP by the Washington State Department of Ecology (Ecology) for the treatment of TSS (WSDOT 2011). The effectiveness of VFS is dependent on several factors, including width, slope, vegetated cover, flow rate and whether there is an equal flow distribution across the length of the VFS.

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 Hypothesis relating to how the VFS width and other design aspects affect its ability to remove sediments and other pollutants.

Hypothesis: Reducing the size of a filter strip does not alter its effectiveness at reducing pollutant concentrations.

A number of studies have been conducted that look at how the size, particularly the width, of a VFS affects its effectiveness at reducing pollutant concentrations. These studies show varied sediment and pollutant removal results at different widths, slopes, and grass types. However, most of the studies indicate the width of the filter strip is a significant factor affecting its ability to remove pollutants and reducing the size of a filter strip can alter its effectiveness at reducing pollutant concentrations. In addition, based on the available studies the filter strips that showed good removal of sediments were at a minimum five meters (16.4 feet) wide.

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

1. Performance of filter strips generally decreases with increasing flow rates (Magette et al. 1989). Conduct effectiveness studies of filter strips in Western Washington where light to moderate rainfall and flow intensities may show increased effectiveness of narrower filter strips.
2. Conduct a literature search that is specific to western Washington to assess current widths and effectiveness of filter strips employed in Western Washington.
3. Perform local field studies on filter strips of varying widths, slopes, and vegetation to determine if there is an optimal combination.
4. Construct and perform field studies on a filter strip that is narrower than eight feet Washington State Department of Transportation (WSDOT) minimum to determine if it meets Ecology's guidelines for basic treatment of TSS.

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ABBREVIATIONS AND ACRONYMS

VFS	vegetative filter strips
BMPs	Best Management Practices
TSS	total suspended solids
µm	micrometers
Ecology	Washington State Department of Ecology
NPDES	National Pollutant Discharge Elimination System
WSDOT	Washington Department of Transportation
SWMP	Stormwater Management Plan

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 white paper aims to summarize the publications within the effectiveness study literature database (Ecology 2011a) that related to the ranked effectiveness study and Storm Water Management Plan topic #12: Traditional BMPs. The paper specifically addresses the following Null Hypothesis relating to how size may affect the effectiveness of vegetative filter strips.

Null Hypothesis: Reducing the size of a filter strip does not alter its effectiveness at reducing pollutant concentrations.

- Are existing sizing criteria for vegetative filter strips (based on bioswales) overly conservative?
- Which combinations of length, width, slope, soil types and vegetation types result in greatest removal of sediment by vegetative filter strips?

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

1.2 PROBLEM STATEMENT

During the 2004 National Water Quality Inventory it was determined that eight percent of streams, seven percent of lakes, and 12 percent of estuaries in the United States were impaired by urban storm water (USEPA 2009). In the National Water Quality Inventory 1990 Report to Congress it was estimated that roughly 30 percent of identified cases of water quality impairment were attributable to urban storm water runoff.

Vegetative filter strips (VFS) are best management practices (BMPs) that are designed to treat storm water that sheet flows directly off of pavement. They are gently sloping and densely vegetated and remove pollutants from runoff by filtering, slowing, and providing some infiltration of stormwater (USEPA 2012). They are widely used in the United States to treat runoff in urban areas (Gharabaghi et al. 2006), especially along roads and highways. They are effective at reducing total suspended solids as well as concentrations of particulate pollutants, but are less effective at reducing soluble pollutants (Schmitt et al. 1999). In Washington State, filter strips are approved for “basic treatment” which is the designation used for BMPs that are able to

achieve a goal of 80 percent removal of total suspended solids (TSS) (WSDOT 2011). They can also be used as part of a treatment train for removal of phosphorus and dissolved metals.

The Washington State Department of Transportation (WSDOT) Highway Runoff Manual (2011) outlines the following sizing requirements for vegetative filter strips:

- The greatest flow path from the contributing area delivering sheet flow to the vegetated filter strip should not exceed 150 feet in length.
- The slope of the filter strip should be between 2 and 33 percent.
- The width[1] of the vegetated filter strip is determined by the residence time of the flow though the vegetated filter strip. A nine-minute residence time is used to calculate vegetated filter strip width. A minimum width of eight feet is recommended in order to ensure long term effectiveness of the vegetated filter strip will occur.
- Filter strips may be planted with a combination of grass and native vegetation such as small shrubs. Grasses should be selected that can withstand relatively high-velocity flows as well as wet and dry periods. The addition of native shrubs can provide soil stability and more effective runoff treatment.

[1] Width of the filter strip refers to the dimension parallel to the flow path.

2.0 LITERATURE SUMMARY AND TALKING POINTS

The Traditional BMP null hypotheses and ranked questions for Topic #12 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 12 (Ecology 2011b)

Rank[1]	Null Hypothesis	Questions
12	Reducing the size of a filter strip does not alter its effectiveness at reducing pollutant concentrations.	• Are existing sizing criteria for vegetative filter strips (based on bioswales) overly conservative?
		• Which combinations of length, width, slope, soil types and vegetation types result in greatest removal of sediment by vegetative filter strips?

Notes:

1 Rank assigned by the SWG.

2.1 DOES REDUCING THE SIZE OF A FILTER STRIP ALTER ITS EFFECTIVENESS AT REDUCING POLLUTANT CONCENTRATIONS?

A number of studies included in the literature database have looked at the effect of size of VFS on their ability to reduce pollutant concentrations in runoff. One study conducted by Barrett et al. (1998) looked at two grassed medians between divided highways that had different length, width, slope, drainage area, vegetation cover, and highway traffic load. The water quality results showed similar reductions in pollutants between the two medians. However, most studies found the size of a VFS, particularly its width, does have an effect on its pollutant removal ability.

One field study was conducted on vegetated filter strips in Aberdeen, Scotland and Brisbane Australia. The study saw an exponential decrease of TSS along the width of the filter strip (Deletic and Fletcher 2005).

Another study compared two pairs of level spreader vegetated filter strips in North Carolina. Two filter strips that were 7.6 meters (25 feet) wide were paired with two filter strips that were 15.2 meters (50 feet) wide. The study showed that all of the filter strips reduced TSS concentrations significantly and substantially; however, both of the 15.2 meter filter strips had greater TSS reductions than the 7.6 meter filter strips (Winston et al. 2011). The 15.2 meter wide filter strips had 75 percent and 67 percent TSS reductions while the 7.6 meter wide filter strips had TSS reductions of 51 and 65 percent, with one of the 15.2 meter wide filter strips having significantly lower TSS concentrations than its paired 7.6 meter wide filter strip (Winston et al. 2011).

A series of field experiments conducted in Ontario saw similar results. A total of 10 VFS plots with widths ranging from 2.5 to 20 meters were constructed at three locations. The results showed that TSS removal increased from 50 to 98 percent as the width of the filter strip increased from 2.5 meters to 20 meters (Gharabaghi et al. 2006). In addition the study indicated the width of the filter strip is a significant factor affecting the ability of the filter strip to remove TSS (Gharabaghi et al. 2006).

Lastly a study completed by Schmitt et al. (1999) concluded that filter strips of 7.5 and 15 meters in width can reduce sediments by 76 and 93 percent, respectively, and Abu-Zreig et al. (2003) found that the ability of a vegetated filter strip to remove sediments varied directly with the width of the filter strip. In general the articles included within the literature database indicate reducing the size of a filter strip is likely to alter its effectiveness at reducing pollutant concentrations.

The subsections below summarize the publications within the effectiveness literature database that related to the Traditional BMP Ranked List of Effectiveness Topic #12 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 VFS and how their design can impact their effectiveness. In general, it was found that filter strips greater than 5 meters in width have better pollutant removal results.

2.1.1 Question: Are existing sizing criteria for vegetative filter strips (based on bioswales) overly conservative?

According to the WSDOT Highway Runoff Manual (2011) the width of a filter strip should be designed using a function of:

- Slope,
- Length of the contributing area,
- Design flow rate,
- Design flow velocity, and
- Residence time of the flow through the filter strip.

A nine-minute residence time is used when calculating the width. At a minimum, a filter strip width of eight feet is recommended in order to ensure long term effectiveness (WSDOT 2011).

As outlined in Section 2.1, a number of studies included in the literature database have looked at the how the size of a filter strip may affect its ability to reduce pollutant concentrations in runoff. A series of field experiments conducted in Ontario, Canada looked at 10 VFS plots with widths ranging from 2.5 to 20 meters. The results showed that about 50 percent of sediments were removed within the first 2.5 meters, with an additional 25 to 45 percent within the next 2.5 meters (Gharabaghi 2006). Almost all of the large sediment particles (larger than 40 micrometers [µm]) were captured within the first 5 meters; however, the remaining smaller particles were very difficult to remove. Overall, Gharabaghi et al.(2006) found that the first five meters (16.4 feet) are critical to the removal of suspended sediments.

Other studies suggest wider filter strips may be needed if trying to meet the 80 percent removal goal set by Ecology for Basic Treatment BMPs. A study of two pairs of level spreader VFS in North Carolina found that filter strips 7.6 meters wide removed 51 and 65 percent of TSS concentrations while filter strips 15.2 meters wide removed 75 and 67 percent of TSS concentrations (Winston et al. 2011). Chaubey et al. (1994) saw a 66 percent removal rate for TSS and 27 percent removal rate for total phosphorus with a 4.6 meter wide filter strip and Line and Hunt (2009) found that a 7.3 meter wide filter strip removed 83 percent of TSS and 48 percent of total phosphorous.

Since the WSDOT sizing criteria uses a series of calculations to determine the width of a filter strip, it is difficult to know the average size of filter strips in Washington and determine if this criterion is overly conservative. However, based on the available studies, the WSDOT filter strip minimum width of eight feet does not seem to be overly conservative since the filter strips that showed good removal of sediments were five meters (16.4 feet) or wider. It should be noted, however, that the performance of a filter strip tends to decrease as flow rates increase (Magette et al. 1989). None of the studies within the literature database were conducted in western Washington, so narrower filter strips may perform better here where rainfall and associated stormwater runoff is typically light to moderate intensity. Additionally, as noted by Winston et al. (2011) few studies have documented the effectiveness of filter strips at removing pollutants from urban runoff. Most studies have instead looked at agricultural runoff. Local field studies should be conducted to more accurately determine if the current sizing criteria are overly conservative.

2.1.2 Question: Which combination of length, width, slope, soil types and vegetation types result in the greatest removal of sediment by vegetative filter strips?

Several studies included in the literature database looked at how width, slope, and vegetation types affect the ability of a filter to remove sediments and other pollutants. However, these studies looked at these factors independently and did not examine what combination were the most effective at removing sediment or other pollutants.

No studies were obtained through the literature database that looked at how different lengths or soil types affect the pollutant removal ability; however, the *Vegetated Filter Strip Low Impact Development Fact Sheet* (Godwin et al. 2011) put out by the Oregon Sea Grant Extensions found online did provide some recommendations for soil type.

Length

No studies found in the literature database discussed how the length of the filter strip may affect its pollutant removal ability.

Width

A number of studies have looked at whether the width (flow path length) of a filter strip affects how effective it is at removing suspended sediments and other pollutants. Gharabaghi et al. (2006) observed that the first five meters (16.4 feet) of a filter strip plays a large role in removal of suspended sediments, capturing more than 95 percent of particles larger than 40 µm. Other studies indicate wider filter strips may be needed to achieve desired pollutant removals. A study completed by Schmitt et al. (1999) concluded that filter strips of 7.5 and 15 meters in width can reduce sediments by 76 and 93 percent, respectively while a study of two pairs of level spreader VFS in North Carolina found that filter strips 7.6 meters wide removed 51 and 65 percent of TSS concentrations while filter strips 15.2 meters wide removed 75 and 67 percent of TSS concentrations (Winston et al. 2011).

Slope

A study conducted by Correll (1996) suggests filter strips will not work effectively if the slope is greater than 5 percent; however, results from a study done by Bren et al. (1997) showed excellent removal of TSS in filter strips with slopes of up to 23 percent as long as there was

uniform flow distribution. Arnold et al. (1993) and Field et al. (2007) found that the ideal slope for filter strips are five percent or less, and slopes up to 15 percent are acceptable but should not be encouraged.

A study done more recently at Washington State University (WSU) (Navickis-Brasch 2011) looked at 45 sites in Eastern Washington. This study found that VFS with a slope up to 33 percent still allow for dispersed flow and meet the treatment and flow control goals, depending vegetative cover and soil characteristics (Navickis-Brasch 2011). The slope of the VFS alone was not found to be statistically significant to concentrated flows and erosion, rather low vegetation coverage and a high sand content in the soil were found to have the strongest correlation to the severity of embankment erosion (Navickis-Brash 2011). The WSDOT Highway Runoff Manual (2011) recently increased their maximum slope criteria from 15 to 33 percent and calls for filter strips to have a slope between 2 and 33 percent.

Soil Type

As with the filter strip length, no studies were found in the literature database that discussed optimal soil type. A study conducted at WSU did find that soils with a high percentage of sand had greater erosion severity on steeper slopes (Navickis-Brasch 2011). In addition, a Vegetated Filter Strip Low Impact Development Fact Sheet put out by the Oregon Sea Grant Extension listed some recommendations. The fact sheet indicated the top 18 inches of soil should be amended with an ideal infiltration rate of between ½ inch and 12 inches per hour (Godwin et al. 2011). In addition, it recommended a soil mix of 60 percent sandy loam and 40 percent compost (Godwin et al. 2011).

Vegetation Type

In general, filter strips with denser vegetation have been found to be better at reducing embankment erosion and more efficient at removing sediments and pollutants from runoff. The WSDOT Highway Runoff Manual (2011) states filter strips in Washington should be designed to include grass that can withstand relatively high velocity flows as well as both extended wet and dry periods. The addition of native vegetation such as small shrubs may help with pollutant removal effectiveness by providing root penetration into the subsoil and increasing infiltration.

One study conducted by Gharabaghi et al. (2006) looked at how various grass mixes affected the effectiveness of filter strips in Ontario, Canada. The filter strips were planted with one of three types of mixtures: Type A—an equal mixture of Perennial Ryegrass, Kentucky Bluegrass and Reed Canary grass; Type B—a mixture of Birdsfoot Trefoil and Creeping Red Fescue; and Type C—existing native vegetation, undisturbed for many years, consisting of native species including wild oat, quack, tall fescue grass and dandelions. The study found that Type B significantly increased the concentration based removal rate when compared to Type A and Type C.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Vegetated filter strips have proven to be an effective BMP at removing suspended sediments from stormwater runoff. However, studies show the level of effectiveness varies depending on the width, slope, vegetated cover, and flow rate. A uniform or equal distribution of flow across the filter strip is also critical to its effectiveness no matter the size or design.

While a number of studies have been conducted that look at how various design aspects affect the pollutant removal ability of filter strips, there were no articles found in the literature database that looked at the optimal combination of filter strip length, width, slope, and vegetation. Additionally, as noted by Winston et al. (2011) few studies have documented the effectiveness of filter strips at removing pollutants from urban runoff. Most studies have instead looked at agricultural runoff. Therefore, it is recommended that additional studies be considered to better understand how different design combinations may affect the ability of a filter strip to treat urban runoff. A few of these recommendations include:

1. Performance of filter strips generally decreases with increasing flow rates (Magette et al. 1989). Conduct effectiveness studies of filter strips in western Washington where light to moderate rainfall and associated runoff intensities may show increased effectiveness of narrower filter strips.
2. Conduct a literature search that is specific to Western Washington to assess current widths and effectiveness of filter strips employed in Western Washington.
3. Perform local field studies on filter strips of varying widths, slopes, and vegetation to determine if there is an optimal combination.
4. Construct and perform field studies on a filter strip that is narrower than 8 foot WSDOT minimum to determine if it meets Ecology's guidelines for basic treatment of TSS.

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