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Water Resources Consulting L.L.C.
Peter Willing, Ph D.

July 18, 2001

Washington State Department of Ecology
3190 160th Ave. S.E.
Bellevue, Washington 98008-5452
ATTENTION: Ann Kenny

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USACE
REGULATORY BRANCH

U.S. Army Corps of Engineers
Regulatory Branch
P.O. Box 3755
Seattle, Washington 98124-2255
ATTENTION: Muffy Walker, Gail Terzi

RE: Supplemental Information, Department of the Army Section 404 Permit Application, SeaTac Airport. USACE Reference 1996-4-02325

Dear Ms. Kenny, Walker, and Terzi:

My comments in the meeting on July 10th between Airport Communities Coalition representatives and the Department of Ecology elicited some questions from Ms. Kenny about the performance record of stormwater Best Management Practices (BMP's). This letter provides clarifying detail and documentation in response to these questions. It also provides elaboration of previous comments on stored stormwater for flow augmentation.

The first question concerned bacteria loading associated with biofiltration swales. Results compiled from a range of BMP performance monitoring efforts (Claytor et al., excerpt enclosed) conclude that bioswales or open grassed channels have either low or negative removal efficiencies for fecal coliform. Both the enclosed EPA 1999 compilation and the work by Adolfson (1999, excerpt enclosed) concur in these results. Negative removal efficiency means that more bacteria were measured in the discharge than were measured in the inflow to the BMP in question. This result was observed in the 1992 Metro study on which the Port relies, as well as numerous others. These results have not been rigorously accounted for, but one opinion is that bioswales can exhibit bacterial growth and behave as a source of bacteria themselves.

Strecker et al. (enclosed) developed recommended parameters for assessing BMP performance. The Department of Ecology and Corps of Engineers should require the Port of Seattle to provide the recommended information on the BMP's that it is proposing at SeaTac, and rigorously review them, before accepting claims that the BMP's will effectively treat airport stormwater.

As I mentioned in the meeting, there is a serious concern about the suitability of the stored stormwater proposed by the Port of Seattle as a flow augmentation source for the creeks around SeaTac airport. The Port proposes to capture and store 8.9 acre feet in the Miller Creek Basin and 7.1 acre-feet in the Des Moines Creek basin. The December 2000 Stormwater Management Plan

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Exhibit 352
Date 2/15/02
Witness Willing
Diane Mills, Court Reporter

(Appendix D, figures C139, C150, C151) has not been changed in this particular; it shows 7.2 acre feet of carry over storage in two vaults in the Miller Creek basin, but there is no indication of where the remaining 1.7acre-feet will be stored. The plans show 1.8 acre-feet in the SDS4 vault on Des Moines Creek, but do not account for the remaining 5.3 acre feet of required storage in that basin. The drawings show a dead storage discharge line in the bottom of the vault. If built as shown the first discharge to the receiving Class AA streams, which would already be under stressed low flow conditions, would be an anoxic slug of sediment laden water carrying a six-month accumulation of pollutant load. The Port argues that pollutant species will be bound by adsorption to soil particles and rendered biologically inactive. Under anaerobic conditions, which the Port concedes will occur, many bound inorganic compounds will go back into solution and become biologically available again. Other than sporadic references to reaeration of the stormwater, the Port has not proposed any treatment to bring it up to a standard appropriate for release to Class AA receiving waters. It is noteworthy that the Port's plans for maintenance of stormwater detention vaults (HNTB, 2001) show no consideration or mention of flow augmentation.

To contemplate inappropriate use of Best Management Practices, and release of stored stormwater without treatment into local streams, falls considerably short of the required reasonable assurance that the Port's projects will meet water quality standards.

Sincerely,

Peter Willing, Ph. D.
Attachment

REFERENCES

Adolfson Associates, 1995. Pilot Evaluation, Subsurface Stormwater Disposal Facilities, Clover/Chambers Creek Basin. Final Report to Tacoma-Pierce County Health Department.

Claytor, R.A and T.R. Schueler, 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection, Silver Spring, MD. Supplemental funding by USEPA Region 5.

EPA, 1999. Preliminary Data Summary of Urban Stormwater Best Management Practices. EPA-821-R-99-012.

HNTB. 2001. Memorandum from Alan Black to Michael Cheyne, April 26, 2001. Yellow D6 version.

Strecker, E., Quigley, M.M., and Urbonas, B.R.. Undated. Determining Urban Stormwater BMP Effectiveness. URS Greiner Woodward Clyde, Portland, Oregon.

Design
of
Stormwater Filtering Systems

Prepared by

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The Center for Watershed Protection
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U.S. Environmental Protection Agency, Region 5

December 1996

Printed on Recycled Paper

Table 3.2 also compares how each filtering design rates with respect to *maintenance burden* and other important feasibility factors.

3.1C Comparative Pollutant Removal Capability

How effective are the filtering designs at removing the key pollutants of concern in a watershed? As part of the preparation of this manual, some thirty published and unpublished monitoring studies were consulted on the pollutant removal performance of stormwater filtering systems. Estimated average removal rates for each of the eleven stormwater filter designs are indicated in Table 3.3. The matrix also shows the number of actual performance monitoring studies that were available to assess a given design. Three filtering designs (underground sand filters, pocket sand filters and bioretention) have yet to be monitored, and their potential performance is inferred from monitoring of similar designs, infiltration rates, modeling and other analysis provided in Chapter 4.

Despite their many differences in design, stormwater filters have some similarities with respect to performance. For example, all typically report removal rates of *suspended sediment* in excess of 80%. Although monitoring data for *hydrocarbons* is more limited, removal rates typically ranged from 65% to 90%.

Some differences were seen in the comparative ability to remove *total phosphorus*. The best performers were the surface and perimeter sand filter, dry swale and gravel filter, all of which showed at least a 50% removal. Grass channels, wet swales, filter strips and possibly organic sand filters were less reliable, at 10 to 40% average removal.

Stormwater filtering systems exhibit only a modest capacity to remove *total nitrogen*. only one design was found to remove more than 50% of total nitrogen (gravel filter), and most ranged from 30 to 45%. The bulk of the observed removal was for organic forms of nitrogen; eight of eleven filtering designs had zero or even negative removal rates for soluble nitrate-nitrogen. The latter phenomena reflects the fact that while nitrification is prevalent in the mainly aerobic environment of most filter beds, denitrification is limited (leading to buildup of nitrate in the effluent). Only the gravel filter, dry swale, and wet swale showed a capability to remove nitrate.

While all filtering designs showed at least moderate capacity to remove *trace metals* such as copper, lead, and zinc, most of the removed metals were already attached to particles. Designs that showed promise in removing dissolved metals include the organic sand filter, gravel filter and dry swale.

TABLE 3.3: ESTIMATED POLLUTANT REMOVAL CAPABILITY OF DIFFERENT STORMWATER FILTER SYSTEMS (AVERAGES OF REPORTED MONITORING DATA)

Filtering System	*Monitoring Data?*	*TSS*	*TP*	*TN*	*NO³*	*Other Pollutants/Comments*
Surface Sand Filter	Yes, 6	85%	55%	35%	Neg	Bacteria: 40-80% Metals: 35-90%
Underground Sand Filter	No Data	Presumed to Comparable to Surface Sand Filter				
Perimeter Sand Filter	Yes, 3	80%	65%	45%	Neg	Hydrocarbons 80%
Organic Sand Filter	Yes, 1	95%	40%	35%	Neg	Hydrocarbons: 90% Sol. P Negatives Metals: 85%+
Pocket Sand Filter	No Data	Presumed to be Comparable to Surface Sand Filter				
Drainage Channel	Yes, 10	30%	10%	Zero	Zero	Bacteria: Negative
Grass Channel = biofilter	Yes, 1	65%	25%	15%	Neg	Hydrocarbons: 65% Metals 20-50% Bacteria: Negative
Dry Swale	Yes, 3	90%	65%	50%	80%	Metals 80-90%
Wet Swale	Yes, 2	80%	20%	40%	50%	Metals: 40-70%
Bioretention	No Data	Presumed to be Comparable to Dry Swale				
Filter Strip	Yes, 1	70%	10%	30%	Zero	Metals 40-50%
Gravel Filter	Yes, 2	80%	80%	65%	75%	Hydrocarbons 85% Metals: 50-75%

Control of *fecal coliform bacteria* is important in shellfish areas, beaches and drinking water supplies. The filter designs that showed the best ability to remove bacteria included surface sand filters and gravel filters; drainage channels and grass channels had no effect on bacterial levels, and the remaining practices have yet to be monitored for this important parameter.

It should be noted that pollutant removal rates and mechanisms rely on processes in a generally aerobic environment, as opposed to anaerobic environment. Filters which go anaerobic tend to release previously captured phosphorous as iron phosphates break down.

3.1D COMPARATIVE DESIGN CRITERIA

The sizing criteria for each of the eleven filtering designs are summarized in Table 3.4. Each type of filter design is compared based on the sizing criteria for each of its four standard design components:

- the quantity and method used for flow regulation
- the quantity and method used for pretreatment
- the depth and nature of the filter media and the area of the filter bed, expressed as the percentage of contributing impervious area
- the quantity and method used for overflow

4.2B OPEN VEGETATED CHANNELS

Few best management practices exhibit such a great variability in pollutant removal performance as open grass channels. Sixteen historical performance monitoring studies of "grass swales" were re-analyzed based on the open channel classification presented earlier to try to explain this variability. Ten of the open channels could be classified as "drainage channels" based on two criteria—they were designed only to be non-erosive for the two year storm, and their particular combination of soil and slope did not allow significant infiltration of runoff into the soil profile. Site data and pollutant removal data for these drainage channels are shown in Table 4.8. The poor performance of drainage channels is due to the fact that they do not act as an effective filter (i.e., very little runoff actually filters through the soil media). Since the soil filter is not used, drainage channels can only rely on sedimentation and adsorption pathways for removal. During most storms, runoff passes through the channel in just a few minutes, thereby greatly reducing the effectiveness of those removal pathways.

One open channel was explicitly designed as a grassed channel (Seattle METRO, 1992). The 200 foot long grass channel, termed a biofilter, was found to be reasonably effective in removing many pollutants contained in urban stormwater. The performance monitoring data for the biofilter is summarized in Table 4.9. In general, high rates of removal were reported for sediment, hydrocarbons, and particulate trace metals. Nutrient removal was much more mixed.

Five open channels were either explicitly designed as a dry or wet swale, or had a combination of soils, slope and water table so that they effectively functioned like one (Table 4.10). Given the small number of open channels that met these criteria, they were lumped together as a single group. The swales demonstrated a much greater and more consistent capability to remove pollutants conveyed in urban stormwater. In nearly every case, most of the mass removal could be accounted for by the infiltration or retention of runoff into the soil profile during storms (i.e., actual pollutant concentration did not change appreciably as they passed through the channel). As a group, the swales showed excellent removal of suspended sediment, nitrogen, organic carbon and trace metals.

Table 4.8
Pollutant Removal Performance of Ten Drainage Channels

n	Reference	State	YR	N	M	S	L	A	SOIL	TSS	TOC	TP	SP	TN	NO3	Cu	Pb	Zn	Other
1	OWML	VA	83	33	M	1.8	260	9.5	SL	NEG	NEG	NEG	-	NEG	-	-	NEG	NEG	-
2	DWML	MD	83	50	M	4.1	445	19.0	SL	NEG	NEG	NEG	-	NEG		-	NEG	NEG	
3	OWML	MD	83	8	M	5.1	425	12.0	SL	31	NEG	NEG	-	37	-	-	33	NEG	-
4	DORMAN	VA	89	9	M	4.7	185	1.3	SL	85	76	41	-	-	11	28	48	49	TKN=17
5	DORMAN	MD	89	4	M	3.2	193	1.3	SL	NEG	23	12	-	-	NEG	14	55	9	TKN=9
6	YU	VA	89	4	M	5A	200	1.5		68	-	60		-			-	74	-
7	YOUSEF	FL	85	6	C	1.0	550	-	Sa	-	-	8	26	13	11	14	27	29	TKN (-20)
8	OAKLAND	NH	83	11	C	>2%	100	-		33	-	NEG	NEG	-	-	48	67	50	COLI = NSD
9	WELBORN	TX	87	19	C	-	200	2.9	-	NSD	NEG	NEG	NEG	NEG	NEG	NSD	NSD	NSD	COLI = NSD
10	PITT	ONT	86	50	C			-		NSD			-	NSD	-	NSD	NSD	NSD	COLI = NSD

Notes. N=number of samples, M=mass or concentration method, S=slope, L=length, A=contributing area (acres), SOIL (SL=silt loan, Sa=sandy), COLI=fecal coliforms, NEG=negative removal efficiency reported, NSD=no statistically different concentration between control (usually pipe flow)

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TABLE 4.9: POLLUTANT REMOVAL PERFORMANCE OF A GRASS CHANNEL (BIOFILTER) OF TWO LENGTHS IN WASHINGTON (SOURCE: SEATTLE METRO, 1992)

Pollutant	*100 Foot Biofilter*	*200 Foot Biofilter*
Suspended Sediment	60%	83%
TPH (Hydrocarbons)	49%	75%
Total Zinc	16%	63%
Dissolved Zinc	negative	30%
Total Lead	15%	67%
Total Copper	2%	46%
Total Phosphorus	45%	29%
Bioavailable P	72%	40%
Nitrate-N	negative	negative
Bacteria	negative	negative

TSS

Only four out of nine drainage channels had a positive removal rate for suspended sediment, suggesting that neither settling, filtration or infiltration occurred to any great degree as it passed through the channels. By contrast, sediment removal rates for dry swales, wet swales and the grass channel all exceeded 80%.

ORGANIC CARBON

Drainage channels showed little ability to remove organic carbon, with four of six tested showing negative removal rates. Both dry swales and wet swales on the other hand, had carbon removal rates in excess of 50%. While no data was available for grass channels it would appear reasonable that settling and filtration pathways would be effective for this primarily particulate pollutant.

Table 4.10
Pollutant Removal Performance of Six Water Quality Swales

No.	Reference	State	YR	N	M	S	L	A	SOIL	TSS	TOC	TP	SP	TN	NO3	Cu	Pb	Zn	Other
1	DORMAN	FL	89	8	M	1.0	185	0.6	Sa	98	64	18	-	-	45	65	81	81	TKN=48
2	HARPER	FL	88	16	M	1.0	210	0.8	Sa	87	69	83	-	84	80	69	90	90	
3	HARPER	FL	88	11	M	1.8	210	1.2	WET	81	48	17	-	40	52	56	50	69	-
4	KERCHER	FL	83	13	M	>2.0	-	14.0	Sa	99	99	99	-	99	99	-	99	99	
5	METRO	WA	92	6	C	4.0	200	16.0	till	83	-	29	72	-	NEG	46	67	73	HC=75 COLI=NEG
6	WANG	WA	81	8	M	-	200	-		80	-	-	-			70	80	60	

Notes. N=number of samples, M=mass or concentration method, S=slope, L=length, A=contributing area (acres), SOIL (SL=silt loam, Sa=sandy).
HC=hydrocarbons, COLI=fecal coliforms, NEG=negative removal efficiency reported, NSD=no statistically different concentration between control (usually pipe flow)

NUTRIENTS

Drainage channels provided negligible removal of nutrients. In most sites, nitrogen and phosphorus removal was either consistently low or non-existent. Nutrient removal in the grassed channel, in contrast, was somewhat higher, with about 30% of total phosphorus and 70% of soluble phosphorus effectively removed (Seattle METRO, 1992). The grass channel was also a net exporter of nitrate.

Dry and wet swales showed better ability to remove nitrogen, with the mass removal rates ranging from 40 to 99%. Phosphorus removal was more variable, with the two swales experiencing the most infiltration recording phosphorus removal rates greater than 80%, and three reporting with minor infiltration capability showing removal rates of 30% or less. Phosphorus removal may be limited in any open channel system. Monitoring has shown that open channels have high phosphorus levels stored in the thatch and surface soil layer. Some of the stored phosphorus may recycle back into the water column, or be eroded during larger storms. In addition, the high phosphorus levels in channel soils may be too high to allow meaningful adsorption.

TRACE METALS

While some drainage channels did exhibit a moderate ability to remove trace metals attached to particles (i.e. lead and zinc), an equal number showed no metal removal capability whatsoever. By contrast, trace metal removal rates for grass channels, dry swales and wet swales were uniformly high. It should be noted that most metal removal is due to settling and filtering of metals attached to particles. Removal of soluble metals, however, was only 20 to 50% (Yousef et al., 1985).

Most monitoring studies only report removal of total trace metals, and do not independently measure the fraction of metals found in soluble form. This can be significant as soluble metals usually exert the greatest impact or toxicity to aquatic life. Many trace metals are primarily found in soluble forms (cadmium, copper and zinc), while others are mostly attached to sediment particles (iron and lead). Yousef et al. (1985) found that swales were not very effective at adsorbing soluble metal species Adsorption requires that a metal be present in runoff as a positively charged cation that can be adsorbed to a negatively charged particle in the soil or organic layer. Metals, however, can be found in a complex number of ion species depending on the prevailing acidity (pH) of runoff. Some metals such as zinc readily adsorb to soil at pH levels typical of stormwater runoff 6.5 to 8.0, but many others (aluminum, cadmium, copper, chromium and lead) show little tendency to adsorb to soils within this pH range. Consequently, the ability of swale soils to remove many soluble trace metals tends to be rather low.

BACTERIA

The three studies that examined the ability of drainage channels to remove fecal coliform bacteria found no significant change in the counts of this key human health indicator after channel treatment. Oakland (1983), Welborn and Veenhuis (1987), Pitt and McLean (1986) all reported that drainage channels had no effect in reducing bacterial concentrations as they traversed through the swale. Seattle METRO (1992) also reported that a grass channel actually tended to increase the level of fecal coliform bacteria as runoff passed through it. This increase was thought to be due pet droppings and possible bacterial multiplication within the biofilter itself.

PETROLEUM HYDROCARBONS

The only study that examined hydrocarbon removal in grass channels found they were very effective at removing both hydrocarbons and oil and grease (Seattle METRO, 1992)

CHLORIDES

Open channels appear to have no capability to trap soluble chlorides (Harper, 1988, Demers and Sage, 1990).

METAL AND NUTRIENT ACCUMULATION IN SOILS

A number of researchers have found that both metals and nutrients tend to be higher in surface soils of open channels than adjacent upland soils. (Wiggington et al. 1983, Dorman et al. 1989, Harper 1988, WCC 1994, Lind and Karro 1995). A summary of the average concentration of metals and nutrients in twelve open channel systems in the U.S. can be found in Table 4.11. The higher levels appear to suggest that swales are accumulating metals and nutrients. One interpretation from the data might be that open channels are trapping and retaining these pollutants, but it can also be argued that swales are simply a better depositional environment. Since swales are a depression in the landscape, they represent an excellent depositional site for aerosols and dust generated by vehicles on adjacent roads, and this factor may well explain the higher levels.

Another interesting aspect of Table 4.11 is the surprising consistency in phosphorus, organic nitrogen, copper and zinc levels in surface soils among the many geographically diverse sites. The only pollutant that exhibits great variability is lead. The lead variability may be due to the declining rates of lead deposition in recent years associated with the gradual introduction of unleaded gasoline, and localized differences in airborne lead deposition due to traffic factors.

According to Lind and Karro (1995), soil type is very important factor for metal accumulation in open channels. Those that have a high content of clay or organic matter in surface soils are able to adsorb metals better.

4.3 COMPARATIVE POLLUTANT REMOVAL CAPABILITY

Several generalizations can be made about the overall performance of stormwater filtering systems. In general, they exhibit a high capability to remove suspended sediments, organic carbon and hydrocarbons, a moderate ability to remove total phosphorus and nitrogen (although low or negative with respect to soluble nutrient forms, and a moderate to high ability to remove trace metals pollutants (although, again, some designs are less effective at removing soluble forms). The one stormwater pollutant whose performance cannot easily be generalized is fecal coliform with some designs showing a high capability to remove bacteria, and others showing none. The average reported removal rates for the eleven stormwater filtering designs are compared in Table 3.5 in the last chapter.

How do the different stormwater filtering designs compare with respect to pollutant removal capability? Table 4.18 provides a general comparison of expected pollutant removal rates, based on monitoring data, theory and best professional judgement. As can be seen, most filtering designs have a high capability to remove sediment and hydrocarbons. Phosphorus removal rates range more widely, with the highest rates reported for gravel filters, dry swales and perimeter sand filters, and the lower rates for grass channels, wet swales and filter strips. Nitrogen removal typically ranges from 30 to 50%. Most filtering systems; however, have a zero or negative removal rate for soluble nitrate (with the exception of dry swales, wet swales and gravel filters). Most filtering systems have a high capability to remove bacteria, with the exception of open channel options such as drainage channels and grass channels. Metal removal rates are variable, but most designs appear capable of removing 50 to 75% of the total metal load delivered to them.

How does the performance of filtering systems, as a group, compare to other BMP systems, such as stormwater ponds, wetlands and infiltration systems? Table 4.19 presents a very generalized comparison of the comparative pollutant removal capability of these four groups of BMPs (important caveat: actual removal rates for a particular design within a BMP group, however, may be higher or lower than those shown in the Table, and are presented only for rough technology comparison).

When the four groups of BMP systems are compared, it is evident that there is not a great deal of difference in their capability to remove sediment, hydrocarbons or total phosphorus. Greater differences in pollutant removal are noted for nitrogen (especially nitrate), organic carbon, and trace metals. There is not enough data available to assess if their are any differences in bacteria removal among the four groups of BMPs. It should also be noted that the removal rates indicated for infiltration BMPs are projections only, since very few of these systems have actually been monitored. In summary, it appears that the removal capability of most BMP systems is similar for most pollutants of concern, *when they are designed and maintained properly and incoming pollutant levels are higher than the irreducible concentration.*

TABLE 4.18: ESTIMATED POLLUTANT REMOVAL CAPABILITY OF DIFFERENT STORMWATER FILTER SYSTEMS (AVERAGES OF REPORTED MONITORING DATA)

Filtering System	*Monitoring Data?*	*TSS*	*TP*	*TN*	NO_3	*Other Pollutants/Comments*
Surface Sand Filter	Yes, 6	85%	55%	35%	Neg	Bacteria: 40-80% Metals: 35-90%
Underground Sand Filter	No Data	Presumed to Comparable to Surface Sand Filter				
Perimeter Sand Filter	Yes, 3	80%	65%	45%	Neg	Hydrocarbons: 80%
Organic Sand Filter	Yes, 1	95%	40%	35%	Neg	Hydrocarbons: 90% Sol. P Negatives Metals: 85%+
Pocket Sand Filter	No Data	Presumed to be Comparable to Surface Sand Filter				
Drainage Channel	Yes, 10	30%	10%	Zero	Zero	Bacteria: Negative
Grass Channel = biofilter	Yes, 1	65%	25%	15%	Neg	Hydrocarbons: 65% Metals: 20-50% Bacteria. Negative
Dry Swale	Yes, 3	90%	65%	50%	80%	Metals: 80-90%
Wet Swale	Yes, 2	80%	20%	40%	50%	Metals: 40-70%
Bioretention	No Data	Presumed to be Comparable to Dry Swale				
Filter Strip	Yes, 1	70%	10%	30%	Zero	Metals: 40-50%
Gravel Filter	Yes, 2	80%	80%	65%	75%	Hydrocarbons: 85% Metals: 50-75%

TABLE 4.19
COMPARATIVE POLLUTANT REMOVAL CAPABILITY OF FOUR TYPES OF BMP SYSTEMS

Stormwater Pollutant	*Pond Systems**	*Wetland Systems*	*Infiltration Systems*	*Filtering Systems*
Suspended Sediment	80	75	90**	85
Organic Carbon	65	15	90**	50
Total Nitrogen	35	25	50**	35
Nitrate-N	60	60	50**	Negative
Total P	65	50	60**	60
Ortho-P	70	40	50**	50
Copper	50	30	60**	45
Lead	85	75	90**	85
Zinc	65	50	90**	75
Bacteria	1-2 Log	1-2 Log	1-2 Log**	2 Log
Hydrocarbons	80**	80**	?	85

Notes: * Does not include dry extended detention ponds
** Projected
The removal rates shown are for comparison purpose only
Actual removal for each system can vary widely depending on design
Sources: Current Assessment of Urban BMPs, Design of Stormwater Wetlands

4.4 DESIGN FACTORS TO ENHANCE FILTERING SYSTEM PERFORMANCE

In this section, practical design techniques are presented to consistently enhance the pollutant removal performance of stormwater filtering systems. These key design principles have been incorporated into the engineering methods presented in succeeding design chapters. Some general design principles that apply to all filtering systems include:

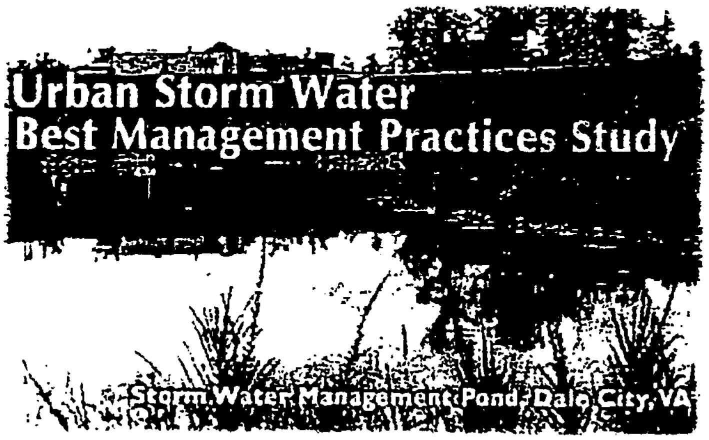
4.4A TYPE AND VOLUME OF PRETREATMENT

A pretreatment cell is not only needed to protect a filter from clogging, but also to temporarily store diverted runoff for subsequent treatment. Consequently, the

EPA United States Environmental Protection Agency
Office of Water

EFFLUENT GUIDELINES

Download Report - National Storm Water BMP Database - Storm Water Links



Preliminary Data Summary of Urban Stormwater Best Management Practices

EPA-821-R-99-012, August 1999

EPA conducted a study of urban storm water discharges in 1997-98 to explore how the Effluent Guidelines program can contribute to the Agency's efforts in implementing the national storm water program requirements under Section 402(p) of the Clean Water Act. The study is intended to complement the ongoing implementation of the National Pollutant Discharge Elimination System (NPDES) Storm Water permit program.

The study is based largely on existing literature and data on best management practices (BMPs) that are used to control urban storm water runoff. Topics covered include: BMP performance measures and measurable goals, availability of measurement methods, design criteria, monitoring issues, costs and cost minimization opportunities, and the benefits and economic impacts of constructing and operating BMPs.

The discussion of BMP performance includes structural BMPs such as infiltration devices, ponds, filters and constructed wetlands; and the effectiveness of non-structural BMPs, low impact development practices and management measures such as maintenance practices, street sweeping, public education and outreach programs. Literature sources include BMP performance studies compiled for the new National Storm Water BMP Database and BMP design manuals and guidance prepared by EPA and other Federal agencies, states and local governments.

In early 1999, shortly after completion of this report, EPA began development of Effluent Guidelines for the Construction and Development Industry, focusing on storm water discharges.

Download the Report

- Part A (PDF*, 19 pages, 483K)
  Table of Contents
  Chapter 1: Summary
  Chapter 2: Introduction and Scope
  Chapter 3: Existing Storm Water Regulations and Permits

- Part B (PDF*, 49 pages, 442K)

Table 5-7. Structural BMP Expected Pollutant Removal Efficiency

BMP Type	Typical Pollutant Removal (percent)				
	Suspended Solids	Nitrogen	Phosphorus	Pathogens	Metals
Dry Detention Basins	30 - 65	15 - 45	15 - 45	< 30	15 - 45
Retention Basins	50 - 80	30 - 65	30 - 65	< 30	50 - 80
Constructed Wetlands	50 - 80	< 30	15 - 45	< 30	50 - 80
Infiltration Basins	50 - 80	50 - 80	50 - 80	65 - 100	50 - 80
Infiltration Trenches/ Dry Wells	50 - 80	50 - 80	15 - 45	65 - 100	50 - 80
Porous Pavement	65 - 100	65 - 100	30 - 65	65 - 100	65 - 100
Grassed Swales	30 - 65	15 - 45	15 - 45	< 30	15 - 45
Vegetated Filter Strips	50 - 80	50 - 80	50 - 80	< 30	30 - 65
Surface Sand Filters	50 - 80	< 30	50 - 80	< 30	50 - 80
Other Media Filters	65 - 100	15 - 45	< 30	< 30	50 - 80

Source: Adapted from US EPA, 1993c.

Infiltration Systems

Infiltration systems can be considered 100 percent effective at removing pollutants in the fraction of water that is infiltrated, since the pollutants found in this volume are not discharged directly to surface waters. Quantifying the removal efficiency of infiltration systems, therefore, can perhaps best be determined by calculating the percent of the average annual runoff volume that is infiltrated, and assuming 100 percent removal of the pollutants found in that runoff volume. Since collecting samples of runoff once it has been infiltrated can be very difficult, little field data exist on the efficiency of infiltration for treatment of storm water. Since infiltrated water does not leave the BMP as a discrete flow, there is no representative way of collecting a true outflow sample. Infiltration systems can be monitored by installing a series of wells around the perimeter of the BMP for collecting samples. However, this can add significant costs to any monitoring effort. Table 5-8 summarizes the available field data on the efficiency of infiltration practices in treating storm water. Reported removal efficiencies are based on the results of three studies that evaluated the performance of infiltration trenches and two studies that evaluated the efficiency of porous pavement systems.

Open Channel Vegetated Systems

Open channel vegetated systems are used widely for storm water quality control. However, these systems can be difficult to monitor, especially systems that intercept runoff as sheet flow such as grass filter strips. As a result, data on these types of systems are not as prevalent as other more readily monitored BMP types such as ponds and constructed wetlands. Table 5-16 summarizes the pollutant removal efficiency of open channel vegetated systems. Removal efficiencies are based on data collected from 20 monitoring studies.

Table 5-16. Pollutant Removal Efficiency of Open Channel Vegetated Systems

Parameter	Average or Median Removal Efficiency (percent)	Range of Removals (percent)		Number of Observations
		Low	High	
Soluble Phosphorus	11	-45	72	8
Total Phosphorus	15	-100	99	18
Ammonia-Nitrogen	3	-19	78	4
Nitrate	11	-100	99	13
Organic Nitrogen	39	11	86	3
Total Nitrogen	11	-100	99	10
Suspended Solids	66	-100	99	18
Bacteria	-25	-100	0	5
Organic Carbon	23	-100	99	11
Cadmium	49	20	80	6
Chromium	47	14	88	5
Copper	41	-35	89	15
Lead	50	-100	99	19
Zinc	49	-100	99	19

Source: Brown and Schueler, 1997a

Evaluation of available data does not provide a good indication as to the actual performance of these systems. The above data indicate that a wide range in pollutant removal efficiency is reported in the literature for open channel vegetated systems. Since there are a variety of system designs lumped into the above summary, arriving at efficiency estimates for a particular system type given available data is difficult. In general, these types of BMPs should be effective at removing suspended solids and associated pollutants from runoff by sedimentation and by filtration by vegetation, and are certainly effective at slowing the velocity of storm water runoff and for providing detention of runoff if check dams or other structures are incorporated to provide ponding of runoff. However, dense vegetation must be maintained in order to assure proper functioning. In addition, negative removals are frequently reported for sediment and nutrients. If open channel vegetated systems are not properly maintained, significant export of sediments and associated pollutants such as metals and nutrients can occur from eroded soil. In addition, standing water in these systems can be a significant source of bacteria and can provide the conditions necessary for mosquito breeding. Additional data gathering is needed in order to support these assumptions and to quantify the efficiency of these systems.

Open channel vegetated systems can be used as pretreatment devices for other BMPs, or can be used in a "treatment train" approach. For example, grass filter strips are commonly used to accept sheet flow from parking lots in order to pre-treat runoff prior to being treated by a bioretention facility or a filter. Vegetated swales can be used to convey runoff to BMPs such as ponds or constructed wetlands, providing pretreatment of the runoff volume. When used in combination with other BMPs, the overall quality of the treated runoff can be improved and the total runoff volume can be reduced due to infiltration that occurs in the open channel vegetated systems.

Miscellaneous and Vendor-Supplied Systems

Little data exist in the published literature on the efficiency of vendor-supplied systems. Data is frequently available from the vendors, and as more of these systems are installed it is expected that more data will become available. An evaluation of the efficiency of these systems has not been included in this report. The EvTEC program (see section 5.2.1.8) and other evaluation programs should provide useful information that indicates the efficiency of these systems in removing pollutants from runoff.

5.5.3 Controlling Flow Impacts

The removal of pollutants from storm water runoff is an important function of storm water BMPs. However, in many cases receiving water problems are not due to the pollutants contained in storm water, but rather can be attributed to the large flow rates that result in receiving streams that receive storm water discharges. Therefore, in some cases, controlling the volume and flow rate of storm water discharges is as important, if not more important, than removing pollutants prior to discharge. Site-specific parameters will dictate the importance of flow control in preventing degradation of receiving waters.

Evaluating the effectiveness of BMPs in controlling flow impacts is not an easy task. Site-specific variations such as slope, soil types, ground cover, and watershed-imperviousness can greatly impact the hydraulic response of a watershed to rainfall. In addition, receiving water

Pilot Evaluation

Subsurface Stormwater Disposal Facilities

Clover/Chambers Creek Basin

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Tacoma-Pierce County Health Department

Pierce County
Public Works
Surface Water Management

Adolfson Associates, Inc.
and Associated Firms

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Similar to results obtained for the other two facilities, total lead concentrations in the influent and treated stormwater, as well as the shallow ground water system, varied considerably from 80 to 1,470 µg/l. With the exception of zinc, influent stormwater concentrations were comparable to those measured at the two other monitoring sites. Zinc concentrations at this site were the highest of the three sites, but within the range typically measured in heavily urbanized areas.

Table 12 summarizes the mean concentrations of constituents monitored at the facility over the four-year period. Nineteen events were monitored. Removals of total metals were consistently between approximately 45% and 80% throughout the course of the study. Mean concentrations of copper were reduced by 47%; lead concentrations were reduced by 79% and zinc concentrations were reduced by 50%.

Infiltration of stormwater through the vegetation layer and upper 6-inches of topsoil appears to be the major pollutant removal mechanism. There was not significant difference in removal rates at the different sampling locations along the length of the swale. One sampler (2DP) was located at approximately 14-inches below the surface; results compared with the sampler 6-inches below the surface did not indicate increased removal with increased depth. Soil depth was approximately 8-inches, with underlying coarse gravels.

Mean concentrations of lead and zinc in the shallow ground water system underlying the swale were lower than those in the influent stormwater, but higher for total copper and arsenic. Arsenic was present in the background water quality sample obtained prior to implementing the facility, indicating a source of arsenic other than the Type 3 SDF.

Relatively high concentrations of total metals in the shallow ground water system were recorded for all parameters as shown in Table 11. As previously described, relatively high concentrations of total metals have regularly been measured in the shallow ground water system in Lakewood. These concentrations indicate the ability of particulates to migrate through the gravelly soils in the unsaturated zone and enter the uppermost ground water system. Concentrations measured in the shallow ground water system prior to implementation of the infiltration facility were the highest measured during the study, indicating high background loading of total metals.

Dissolved Metals

Dissolved metals concentrations in influent stormwater were relatively low except for zinc. The percentage of dissolved metals by weight varied depending on whether the sample was untreated stormwater, treated stormwater, or ground water. Table 13 summarizes the relative percentages of dissolved metals by weight, compared to total metals.

Table 13. Relative Percentages of Dissolved Metals by Weight, Type 3 SDF

	Cu	Pb	Zn
Influent Stormwater	38%	13%	47%
Treated Stormwater	85%	35%	86%
Ground Water	17%	13%	15%

As indicated in the table, the relative percentage of dissolved metals increases considerably in the treated samples. This indicates that much of the pollutant removal accomplished in the facility is related to particulate removal. Concentrations of dissolved metals in ground water, however, are relatively low, indicating much of this loading is related to the particulate phase.

pH

pH values varied from 6.5 to 9.4. There was generally minimal variation in pH as stormwater moved through the facility. There was less variability in ground water, although peak pH readings in ground water samples coincided with peak stormwater values. pH values are shown in Table 14

Conductivity

Conductivity values varied widely in stormwater samples and to a lesser extent in the ground water samples. A single, highly conductive sample in March 1993, was dampened by moving through the swale. Conductivity values are shown in Table 14.

Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD), was relatively low compared to samples collected from the two other facilities. Elevated levels of COD correspond to elevated levels of TPH and metals. indicating a link with petroleum and automobile by-products. Mean COD concentrations were reduced by 63% in treated stormwater; ground water levels were less than 15% of the measured levels in influent stormwater.

Total Petroleum Hydrocarbons (TPH)

The total petroleum hydrocarbon (TPH) concentrations were consistently reduced by the facility. Mean TPH concentrations were reduced by 83% in the facility. Influent stormwater concentrations were lower than those measured at the other two sites, reflecting the residential character of the drainage area. TPH was generally not detected in the shallow ground water system; TPH was detected in only two of nineteen samples.

Nitrate

Nitrate concentrations in ground water were higher than concentrations detected in influent stormwater entering the facility. Concentrations in the shallow ground water system are concluded to reflect background loading from decades of intensive septic tank utilization; although septic tanks are no longer utilized in the area, increased levels of nitrate remain in the shallow ground water system.

Detected nitrate concentrations in the treatment facility varied between 0.2 and 0.5 mg/L, comparable to samples from other sites in the area. The swale did not appear to provide appreciable removal of nitrate concentrations, however, nitrate concentrations in the recharged stormwater are significantly lower than concentrations in the shallow ground water system.

Fecal Coliform Bacteria

Fecal coliform were variable within the shallow ground water system with counts ranging from 7 to greater than 16 org/100 mL. Samples collected from the catch basin and swale had relatively consistent fecal coliform concentrations of greater than 16 org/100 mL.

The swale appeared to provide no significant removal of fecal coliform. Bacteria were present in the ground water system at levels exceeding the Maximum Contaminant Levels.

Relationship to Washington Ground Water Quality Standards

Prior to implementing the Type 3 SDF, background ground water sampling indicated concentrations of arsenic, lead, and fecal coliform in excess of state ground water quality criteria. The treated stormwater from the facility did not result in a mean concentration of lead and arsenic below the state criteria.

Regarding the three tests outlined for evaluating compliance with the antidegradation policy (described for SDF Type 1 above), the following evaluation is offered.

Concerning test number 1 (AKART), SDF Type 3 offered the highest degree of treatment of the three facilities tested and is comparable to, or exceeds treatment facilities outlined in the Puget Sound Basin Stormwater Management Manual.

The facility reduces the concentration of contaminants in stormwater entering the ground water system. The facility also provides a significant source of recharge to ground water, which promotes long-term availability of the resource. Additional monitoring is required to determine the long-term effectiveness, but the facility appears to be improving water quality for numerous parameters. The parameter of concern related to compliance test number 2 is coliform bacteria, because concentrations in the treated stormwater have frequently exceeded the criteria. Fecal coliform bacteria were detected in the shallow ground water system prior to implementing the Type 3 facility, and have frequently been detected in the local shallow ground water system (Adolfson Associates, Inc., 1989).

According to compliance test number 3, the introduced stormwater must not contaminate the "natural" levels present in the ground water system. Based upon the data available, the infiltrating stormwater has lower concentrations of total metals than the uppermost aquifer. Based upon review of data collected, the Type 3 SDF provides the most consistent removal of pollutants of the three facilities tested and meets the AKART criteria.

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of arsenic in the sediment was significantly lower than the other metals, as would be expected as the sources of arsenic are less widespread.

Type 2 Facility

Sediment accumulations measured in this facility ranged from 8 to 10 inches. Concentrations of copper, lead, zinc, and TPH were several times higher than that found in the other two facilities. This is likely due to the surrounding land use at this site (i.e., auto repair facility) and/or the vandalism that has occurred at the site. Arsenic concentrations were similar to those found at the other two sites.

Type 3 Facility (grass lined swale)

Sediment accumulations measured at this site ranged from 5 to 14 inches. Concentrations of metals and TPH measured at this site are similar to that found at the Type 1 facility, with the concentrations of TPH being slightly higher. This is likely due to the larger commercial area draining to this facility.

SUMMARY OF MAJOR CONCLUSIONS

Following is a summary of the major conclusions, based on the review of the analytical data and field findings collected from up to 19 storm events over nearly a 4-year sampling period.

Some of the conclusions differ from preliminary conclusions drawn in the 1991 Interim Report, which amplifies the importance of long-term monitoring efforts. Several initial trends were altered as the study progressed.

Type 1 SDF

Concentrations of total metals and bacteria found in the shallow ground water system prior to implementing the facility, indicate the potential for these constituents to migrate through the vadose zone from surface sources. The uppermost aquifer appears to have a concentrated layer of suspended particulates, high in metals. There is no immediately apparent source for these constituents other than overlying land use activities.

The Type 1 stormwater disposal facility did not provide significant or consistent removal of dissolved or particulate constituents in the stormwater runoff sampled. This facility is not recommended for implementation in areas where pollutant removal is a priority.

Type 2 SDF

This facility did not provide consistent pollutant removal. Initial results indicated potentially considerable removals of total metals and TPH, however, as the study proceeded, the facility's effectiveness declined. Sediments deposited in the facility appeared to be flushed out during moderate to heavy storm events, resulting in high concentrations of total metals. This facility was located in a worst-case situation in terms of loading from petroleum by-products and total metals. Based upon the monitoring results, the Type 2 SDF as currently configured, should not be installed in an area with projected high loadings. Modifications to the facility, including providing a more effective filter media, would likely improve treatment effectiveness.

Type 3 SDF

The Type 3 facility provided consistent removal of total metals, COD, and TPH. The predominant removal mechanism is infiltration through the vegetated soil column. Clearly, removal rates of total metals, TPH, and COD are significantly higher following infiltration through a vegetated soil column than through sandy media. A soil depth of six inches appears to provide removals of particulates ranging from 50% to 80%. Neither dissolved constituents nor bacteria were removed by the facility.

Type 1, 2, and 3 Facilities

The current data collected do not indicate that consistent or significant removal of fecal coliform bacteria is occurring within any of the three facilities tested.

Nitrate-nitrogen concentrations were not significantly reduced by any of the three facilities tested, however, the concentration of nitrate in recharged stormwater appears to be significantly lower than nitrate concentrations in the shallow ground water observed during this evaluation.

Background concentrations of total lead in the shallow ground water system observed during this evaluation exceeded the Washington Department of Health Maximum Contaminant Levels (WAC 246-290, 1991). These concentrations appear to be associated largely with particulates, and are suspended in the top 15 to 20 feet of the shallow aquifer. Elevated lead concentrations in stormwater runoff and the shallow ground water system are a persistent problem in the Lakewood area. These levels may be due to a relatively high utilization of leaded fuels in older-model vehicles, army vehicles, and large trucks.

The performance effectiveness of the Stormwater Disposal Facilities is determined in large part by consistency with the Washington State Ground Water Quality Standards, Chapter 173-200 Washington Administrative Code. Based upon the limited data collected, SDF Type 3 provides the greatest degree of consistency with the criteria for primary and secondary contaminants.

Maintenance Considerations

Maintenance of facilities, particularly the Type 3 facility, the grass-lined swale, is critical to the effective operation of the facility.

Determining Urban Stormwater BMP Effectiveness

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Abstract

The overall purpose this US EPA funded cooperative research program with the American Society of Civil Engineers (ASCE) is to develop a more useful set of data on the effectiveness of individual best management practices (BMPs) used to reduce pollutant discharges from urban development. BMP performance data gathered at a particular site should not only be useful for that site, but also be useful for comparing studies of similar and different types of BMPs in other locations. Almost all BMP effectiveness studies in the past have provided very limited data that is useful for comparing BMP design and selection among individual BMP types (e.g. sand filters). This paper overviews some of the problems of past BMP effectiveness studies from the perspective of comparability between studies. It suggests some of the ways that data should be collected to make it more useful for assessing factors (such as settling characteristics of inflow solids and physical features of the BMP) that might have led to the performance levels achieved. It briefly presents the database that has been developed by this project, which not only serves as a tool for storing data from existing studies, but as a tool for entering and storing data collected from future studies. Discussed are considerations that affect data transferability, such as effectiveness estimations, statistical testing, etc. It overviews the efforts to establish and analyze the data base for existing studies and overviews proposed analyses for the future, when more studies that have followed the protocols are available. The database has specifically pointed out the need for additional BMP performance studies, as the current data is very sparse in terms of studies that have recorded enough information to be useful in assessing BMP type performance.

Introduction

Many studies have assessed the ability of stormwater treatment BMPs (e.g., wet ponds, grass swales, stormwater wetlands, sand filters, dry detention, etc.) to reduce pollutant concentrations and loadings in stormwater. However, in reviewing and summarizing the information gathered from these individual BMP evaluations, it is apparent that inconsistent study methods and reporting make wider-scale assessments difficult, if not impossible. For example, individual studies often included the analysis of different constituents and utilized different methods for data collection and analysis, as well as varying degrees of information on BMP design and inflow characteristics. Just the differences in monitoring strategies and data evaluation alone contribute significantly to the range of BMP "effectiveness"that has been reported. These differences make combining these individual studies almost impossible to assess what design factors may have contributed to the variation in performance (Strecker et al., 1992). Urbonas (1994 and 1995) and Strecker (1994) summarized information that should be recorded regarding the physical, climatic, and geological parameters that likely affect the performance of a BMP and considerations regarding sampling and analysis methods.

Efficiency, Effectivness, and Performance

In order to better clarify the terminology used to describe the level of treatment achieved and how well a device, system, or practice meets its goals, definitions of some terms often used loosely in the literature are provided here. These terms help to better specify the scope of monitoring studies and related analyses·

The database specifies a chosen set of reporting information, but does not guide users on how to develop such information. For example, it does not specify in detail what a flow-weighted composite sample is and how it should be collected. The next step beyond the EPA protocols and database effort should be a guidance document on monitoring data collection strategies and techniques to improve their consistency and ultimate transferability. A few of the issues related to proper guidance are discussed in the next two sections. It should be recognized that, with the development of the database and the protocols, it will be a number of years (5 to 10) before a significant number of new studies on BMPs are conducted utilizing the protocols. Therefore, a rigorous evaluation of BMP selection and design factors will need to take place in the long-term future.

Recommended Parameters for Assessing BMP Performance

In developing a method for quantifying BMP performance, it is helpful to look at the objectives of previous studies seeking such a goal. BMP performance studies usually are conducted to obtain information regarding one or more of the following objectives:

- What degree of pollution control does the BMP provide under typical operating conditions?
- How does performance vary from pollutant to pollutant?
- How does performance vary with various input concentrations?
- How does performance vary with large or small storm events?
- How does performance vary with rainfall intensity?
- How do design variables affect performance?
- How does performance vary with different operational and/or maintenance approaches?
- Does performance improve, decay, or remain the stable over time?
- How does the BMP's performance compare relative to other BMPs?
- Does the BMP reduce toxicity to acceptable levels?
- Does the BMP cause an improvement in downstream biotic communities?
- Does the BMP have potential downstream negative impacts?

The monitoring efforts implemented most typically seek to answer a subset of the above questions. This often leaves larger questions about the performance of the BMP, and the relationship between design and performance, unanswered. Standardization of BMP data collection and evaluation methods (i.e., guidance and the ASCE/EPA database) allows this broader set of questions to be examined.

There has been a very wide variety of pollutants analyzed in BMP and characterization studies. The protocols established under the EPA-funded cooperative research program recommend a standard set of constituents for BMP testing programs. Table 2 presents the recommended constituents developed from the review of previous studies with an understanding of costs and likelihood of providing meaningful results. A discussion of how these constituents were selected and a detailed description of each can be found in Strecker (1994).

There are some practical and technical considerations regarding data reporting which would facilitate data usefulness, including consistent formatting of data, the clear indication of QA/QC results, standard comparisons to water quality criteria, reporting of tributary watershed characteristics, and BMP design information. The last two items are considered critical for evaluation of what contributed to BMP effectiveness in one location over another.

Data Reporting. It is recommended that all constituent concentration data be reported as event mean concentrations (EMCs). These statistics should be based on use of the lognormal distribution. The NURP and FHWA studies (EPA,