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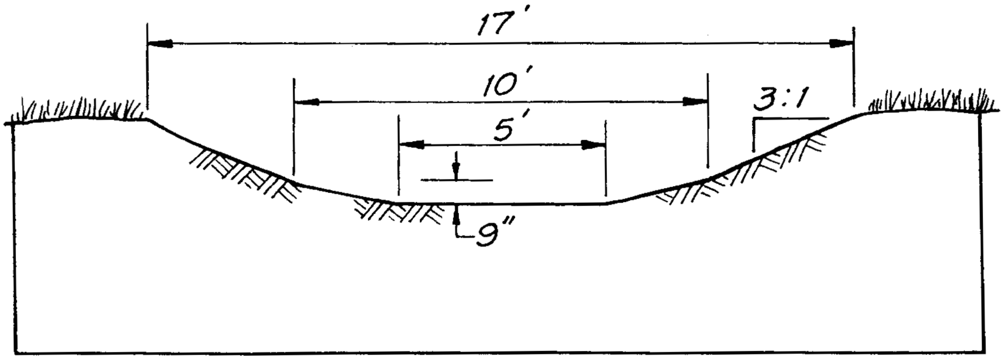
Performance of Dry and Wet Biofilters Investigated in Seattle

Biofilters are grass channels designed to treat stormwater runoff instead of merely conveying it downstream. To remove pollutants, biofilters employ greater swale lengths, broad bottoms, gentle slopes, and dense grass turf. Together, these factors increase the residence time of runoff throughout the channel, allowing time for adsorption, uptake, settling and filtering and infiltration of stormwater pollutants. A monitoring study by Seattle METRO indicated that a 200-foot long biofilter showed promise in removing many pollutants found in urban stormwater.

Biofilters are easy to design and construct and are extremely cost-effective in comparison to other practices. For these reasons, the concept is gaining popularity in the Northwest although the practice is not yet commonplace. As more biofilters are being constructed, some nagging questions remain. First, the pollutant removal capability of biofilters is derived from a single monitoring study. If more biofilters are monitored, will they confirm the pollutant removal capability of the first study or show it to be a sampling fluke? Second, field inspections have consistently shown that most biofilters are not constructed and maintained under the ideal test conditions that were followed in the first monitoring study. Does pollutant removal performance decline in biofilters that are in fair or poor condition, and by how much?

Two recent studies from the greater Seattle area explore these questions in some detail. In the first study, Jennifer Goldberg investigated the performance of a biofilter retrofit known as the "Dayton Avenue Swale." The original channel was a 600-foot long drainage ditch located in the right-of-way separating the backyards of a residential area. It was converted into a biofilter by reshaping the dimensions of the channel, adding top soil over the glacial till soils, and re-planting a dense cover of grass. The new dimensions of the biofilter were a length of 570 feet, a base width of five feet and an average longitudinal slope of 1%. Figure 1 shows a cross-section of the new and broader channel, with other site and design data provided in Table 1.

Goldberg sampled eight storm events at Dayton swale during 1991 to 1993. Sample collection was limited by "lost flows" (i.e., analysis of the biofilter revealed that as much as 30 to 80% of all incoming runoff infiltrated into the soil and never reached the downstream end). Goldberg noted that downstream runoff was seldom observed unless the biofilter soils were already saturated, and the rainstorm had at least moderate intensity and long duration. In addition, incoming sediment often dropped out in the first 50 feet of the biofilter, forming a small "hump" that impeded the flow of stormwater and caused minor ponding. In general, the investigators found it difficult to maintain a constant grade along the entire length of the biofilter. Investigators also discovered possible internal sources of pollution within the biofilter, including a colony of mountain beavers that made their burrows in the side slopes, pets that routinely used the biofilter to defecate, and adjacent trees that dropped rotting fruit into the swale.



A biofilter has much broader and longer dimensions than a typical grass channel.

Figure 1: Schematic of the Cross-Section of the Dayton Biofilter

Table 1: Comparison of Two Biofilter Performance Studies

Design characteristic	Dayton Avenue	Uplands Swale
Drainage area	90 acres, 20% Imperv.	17 acres
Length	570 feet	350 feet
Slope	1%	1.1%
Base width	5 feet	6.8 feet
Cross-section shape	Parabolic	Trapezoidal
Vegetative condition	Full grass cover	Dense wetland cover, with some subchannels formed
Design criteria for two year 24 hour storm event	Maximum Velocity: 1.5ft/sec Max Runoff Depth: 9 inches Manning's 'n' : 0.07	Conveyance only
Maintenance	Mowed several times/year, clippings removed	Never mowed, trees growing on lower side-slopes
Application	Retrofit of conveyance channel	New development
No. of Storms Sampled	8 events	17 events
Pollutant removal method	Change in upstream downstream concentration	Flow weighted change in concentration

Despite these limitations, performance monitoring revealed that the Dayton biofilter was reasonably effective (Table 2). Suspended sediment concentrations were reduced by 68%, and turbidity dropped by a smaller amount (41%). While removal of total phosphorus was negligible (5%), the biofilter was able to remove 30 to 35% of soluble or biologically-available phosphorus. In contrast to other monitored biofilters, the Dayton swale showed a modest capability to remove nitrate (31%). The biofilter reduced concentrations of total aluminum, copper and lead by 40 to 60%, but was only able to reduce soluble copper levels by 20%. Concentrations of oil/grease in the biofilter's outflow were always below detection limits. The biofilter, however, did a very poor job in reducing fecal coliform bacteria. Bacterial concentrations from the Dayton biofilter were about three times higher in the outflow than the inflow, which is not surprising given the potential internal bacterial sources observed (e.g. pets and beaver). Overall, the performance of the Dayton Avenue biofilter was generally comparable to that of the original Montlake Terrace biofilter site. Removal rates for both sites may be conservative since pollutants entrained in the "lost flow" through the biofilter could not be accounted for in the pollutant removal calculations. While losing flow to infiltration makes monitoring a challenge, infiltration can be a major pollutant removal pathway for biofilters and indicates the practice is functioning properly.

The Upland Swale

The second study conducted in Kings County involved a swale that could be termed an "accidental biofilter." Although the Uplands Swale was originally designed as a conveyance channel, it was constructed to dimensions that were very similar to a biofilter. Its 350-foot long channel had trapezoidal shape, a base width of 6.8 feet, and a longitudinal slope of 1% (see Table 1 for more site and design data). The channel had been excavated to near or below the water table, and consequently, the swale had standing water and dense wetland vegetation. Clumps of soft rush (*Juncus effusus*) dominated the wetland plant community, although some dense stands of cattail (*Typha latifolia*) were also present. Flow tended to channelize around the clumps of soft rush, but spread more uniformly as it passed through cattail stands.

Although infiltration clearly was not a factor in this wet swale, it did appear to store some runoff from minor storms (less than 0.3 inches of rainfall) and, as a consequence, runoff was seldom measured at the swale outflow during minor storms. Like many biofilters, the Uplands Swale had been neglected prior to monitoring. Poor past construction practices deposited perhaps as much as a foot of sediment on the floor of the swale. And even though the upper slopes of the biofilter were mowed about once a year, a dense growth of young alders and willows had become fully established along the lower side-slopes, and were starting to shade the channel.

The Uplands Swale was selected for monitoring for a simple reason: it was characteristic of many biofilters actually installed in the field—soggy, poorly maintained, and with wetland plants replacing grass cover. As part of the study, King County staff also inspected the field condition of 32 other biofilters. Field inspections found only 27% of biofilters in good condition with uniform grass cover and no channelization, with an additional 40% of biofilters reported to be in fair condition (some bare patches, minor channelization and soggy conditions impairing performance). The remaining 33% of biofilters were classified as "poor" and were presumed to have little, if any, pollutant removal capability (i.e., vegetation was absent and channelization was conspicuous). Major factors cited for poor biofilter condition were, in rank order, poor initial vegetative establishment, soil saturation or ponding, channelization, shading by overhanging trees and sediment deposition from construction activity.

All of these factors were present to some extent at the Uplands Swale. Because prior monitoring had involved biofilters operating under relatively ideal conditions (Dayton and Montlake Terrace), the King County study focused on biofilters in fair condition. Seventeen storm events were sampled in the Uplands Swale from 1994 to 1995. Pollutant removal was calculated on the basis of upstream and downstream changes in flow-weighted event mean concentrations (EMCs).

As might be expected, the pollutant removal performance of this wet swale was mixed (Table 3). On the positive side, the Uplands Swale reduced suspended sediment concentrations by 67%, which is comparable to the performance of a biofilter in good condition (i.e., Dayton). Reduction in total phosphorus concentrations through the wet swale was also notable (39%). On the other hand, the wet swale tended to increase the concentration of soluble and biologically active phosphorus, indicating that the swale's soils or vegetation was releasing these phosphorus forms. The greatest release occurred during the non-growing season, whereas removal was often positive in the late spring and early summer when wetland plant growth was most vigorous. A similar phosphorus removal pattern was observed in an earlier study of a Florida wet swale.

A minor reduction in nitrate (9%) and ammonia (16%) was noted in the wet swale, which may have been due to plant uptake or microbial action. Monitoring generally indicated that metal concentrations were largely unaffected during their transit through the swale, although detection limit problems and quality control complicated the analysis. Little change was noted for total lead (6%) and total zinc (–3%), and a net release of total copper was computed. The effect of the wet swale on dissolved metals was even more equivocal, with virtually no concentration change recorded during most storm events, and more importantly, very little change with respect to aquatic toxicity thresholds.

Table 2: Estimated Pollutant Removal of the Dayton Avenue Biofilter

Pollutant	Removal Rate (%)	Inflow Conc. (mg/l)
Suspended Sediment	67.8	47
Turbidity	44.1	31
Total Phosphorus	4.5	0.228
Soluble Reactive Phosphorus	35.3	0.136
Bio-active Phosphorus	31.9	0.133
Nitrate-Nitrogen	31.4	1.24
Total Lead	62.1	0.037
Total Copper	41.7	0.011
Dissolved Copper	20.9	0.006
Fecal Coliform Bacteria	-264	3,725 org/100 ml
Oil/Grease	not detected	not detected (below 0.5)

Table 3: Estimated Pollutant Removal of the Uplands "Wet Biofilter" Pollutant

Pollutant	Removal Rate (%)	Inflow Conc. (mg/l)
Suspended Sediment	67	30.3
Total Phosphorus	39	0.13
Sol. Reactive Phosphorus	(-45)	0.04
Bio-active Phosphorus	(-31)	0.06
Nitrate-Nitrogen	9	0.345
Ammonia-Nitrogen	16	0.352
Total Copper	(-35)	0.0066
Total Lead	6	0.0023
Total Zinc	(-3)	0.025

Although the pollutant removal capability of the Dayton Avenue and Uplands swales were not as great as other stormwater practices, they do appear to play an important role in groundwater recharge.

The Biofilter Gap

When considering biofilters, watershed managers need to close the gap between the potential shown at test sites and their real world implementation. As biofilters become more popular, it appears that the gap may actually be widening rather than closing. When the 1995 King County field survey is compared to an earlier 1987 survey by Horner, it is evident that the field condition of biofilters has actually worsened. For example, Horner reported that 59% of biofilters that he surveyed were in “good” condition in contrast to the most recent survey, which found that only 27% could be so classified. King County’s study concluded that in a typical subwatershed, the poor design, construction and maintenance of biofilters cuts potential downstream pollutant reduction potential by half.

Clearly, biofilter performance can only be improved if more effort is placed on construction inspection and maintenance enforcement. Given the poor experience with biofilter implementation, it seems reasonable to require performance bonds for biofilters to ensure that they are correctly installed, vegetated, and protected from construction sediment. As good practice, the performance bond would be released after a satisfactory field inspection two years after initial construction. In most cases, reinforcement plantings, sediment removal, regrading and other spot repairs would be needed before final acceptance.

Soil testing is another useful requirement to confirm soil permeability and fertility and the distance to the water table. Such data should be submitted prior to actual design to determine whether the biofilter will ultimately be dry or wet, and consequently, what specific construction methods and vegetative stabilization techniques are needed. Lastly, maintenance agreements should clearly assign the right of inspection and corrective maintenance to local governments, so that they have an enforcement mechanism to compel routine maintenance.

Basic biofilter design criteria are continually evolving. Based on recent monitoring studies and field experience, several additional design refinements seem appropriate:

- Limit biofilter length to no more than 200 feet for individual units (although designers need to consider local conditions such as rainfall and various intended uses of the biofilter).
- Require a pool or other form of pretreatment at the upper end of a biofilter if it receives concentrated inflows (to prevent a sediment buildup at the top of the swale).
- Limit longitudinal slopes to 1% or greater, unless it is intentionally designed as a “wet” biofilter.
- Develop more specific design criteria for “wet” biofilters that govern ponding, wetland stabilization, check dams and other criteria.
- Require more stringent geo-technical testing prior to design and construction.
- Lastly, as Arnold (1997) notes, it is essential to properly train public works crews on the best techniques for maintaining the long-term performance of biofilters.

—TRS

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