Article 112

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Performance and Condition of Biofilters in the Pacific Northwest

What exactly is a biofilter? Some would say it is a grassed swale with class. More technically, it a swale that is explicitly designed to treat stormwater rather than just conveying it along. In the last few years, our knowledge about biofilters has increased as a result of research from the Pacific Northwest.

Local governments in the Puget Sound region of Washington have turned to biofilters as cost-effective methods to treat urban stormwater runoff. They are passive, technically simple, and flexible methods of treating runoff in developing areas. Biofiltration is a process where stormwater is treated by contact with vegetation and soil surfaces along a long and broad grass swale. A cooperative team of researchers from several cities and universities has investigated the performance of biofilters over the last few years. In addition, the researchers have gathered field data to define some of the most critical variables for the design of biofilters.

The biofilter design process relies on an adaptation of Manning's formula of open channel flow for the six month, 24-hour design storm, using an iterative process constrained by a specified maximum velocity and slope. Manning's formula for open channel flow expresses the relationship among all of the principal biofilter design variables, with the exception of biofilter length. It is frequently expressed as follows:

$$Q = (1.49/n) * A * R^{0.67} * s^{0.5}, \text{ where}$$

Q = the volumetric flow rate, ft^3/s

n = Manning's coefficient, accounting for boundary friction

A = cross-sectional area, ft^2

R = hydraulic radius, the ratio of cross-sectional area to wetted perimeter, ft

s = channel slope (ft vertical/ft horizontal)

Horner *et al*. (1988) have developed an iterative biofilter design procedure based on the capacity of the biofilter during the water quality design event and the stability (erosion potential) of the biofilter during more extreme events. Key design variables in Horner's procedure include the Manning's *n* value, swale shape, maximum flow velocity for the design storm, and residence time in the biofilter (Seattle Metro, 1992).

To determine the pollutant removal performance of a typical biofilter, the City of Mountlake Terrace (Washington) constructed a test 200-foot long biofilter. The geometry of the trapezoidal biofilter was as follows: 4% average slope, five-foot bottom width, and 3:1 (h:v) sideslopes. Average residence time for runoff within the biofilter was computed to be just under ten minutes. The biofilter was about two years old, and was mowed twice a year. The biofilter served a comparatively large 15.5 acre watershed, consisting of single family and multi-family residential homes, parks, and a major arterial road. Total imperviousness in the contributing watershed was approximately 47%.

During the second phase of the study, the upper 100 feet of the test biofilter was piped, thereby effectively reducing its length by half. This modification enabled the researchers to test the performance of biofilters designed for a shorter length and corresponding residence times (about five minutes).

Runoff inflow and outflow from the 200-foot configuration was monitored during six storm events in the summer and fall of 1991. An additional six flow-weighted composite samples were collected from the shorter 100-foot biofilter in the Fall and Winter of 1992. Removal rates were computed based on the change in pollutant concentration occurring between the inflow and outflow from the biofilter. Consequently, the sampling method did not measure the possible reduction in pollutant loads due to runoff infiltration within the biofilter itself. Infiltration, however, was very minor. The swale was on a glacial till not far below the surface, and the upper soil layer was observed to saturate rapidly (<1 hour) after the onset of a storm.

The 200 foot long biofilter was found to be reasonably effective in removing many pollutants contained in urban stormwater (Table 1). In general, high rates of removal were reported for sediment, hydrocarbons, and particulate trace metals, but nutrient removal was very modest. Less than 30% of the total phosphorus entering the biofilter was removed, and the biofilter actually was a net exporter of nitrate. More encouraging removal rates were observed for biologically available phosphorus forms. Surprisingly, the biofilter tended to increase the level of fecal coliform bacteria as runoff passed through it. This increase was thought to be due to pet droppings and possible bacterial multiplication within the biofilter itself.

Table 1: Pollutant Removal Performance of 100- and 200-Foot Biofilters, N=6 (METRO Seattle, 1992)

Pollutant	100 foot biofilter (%)	200 foot biofilter (%)
Suspended Sediment	60	83
Turbidity	60	65
TPH (Hydrocarbons)	49	75
Total Zinc	16	63
Dissolved Zinc	negative	30
Total Lead	15	67
Total Aluminum	16	63
Total Copper	2	46
Total Phosphorus	45	29
Bioavailable P	72	40
Nitrate-N	negative	negative
Bacteria	negative	negative

Table 2: Field Survey of the Condition of Biofilters, N=44 (Horner, 1988)

Characteristics	Percent of biofilters sampled
Vegetative type	
Natural grass	27
Grass seed mix	41
Emergent wetlands	30
Vegetative cover	
Full	59
Some bare spots	30
Poor	11
Dry weather flow	
Dry	36
Standing water	38
Running water	17
Inlet Type	
Curb cut	18
Culvert pipe	63
Unchannelled	18
Soil infiltration rate high	18
200 feet or longer	66
Slope less than 2%	86
Had check dams	6
Sideslopes	
Gentle	30
Steep	70
Had been regularly mowed	41
Had been maintained	50
Cross-sectional shape	
Trapezoidal	33
Parabolic	50

As might be expected, the 100-foot long biofilter did not perform as well the longer version, although clear statistical differences were only noted for two pollutants. Removal rates for the shorter biofilter were also more inconsistent (higher standard deviation). The one exception to this pattern was the moderate to high removal observed for various forms of phosphorus. This result, however, may be a sampling artifact, as the greater removal rates occurred during storms that produced very low phosphorus concentrations at the inflow point.

Based on the monitoring study, the research team concluded that a five to 10 minute residence time in a minimum 100-foot long biofilter would ensure reliable pollutant removal, particularly for storms with significant rainfall peaks.

The project site also allowed the researchers to compute detailed measurements of actual Manning's *n* values under typical biofilter conditions. Three independent methods were used to measure velocity of flow, and a range of *n* values were computed for the biofilter (from 0.192 to 0.198, when it had been mowed to a height of six inches). Generally, the value of *n* did not vary with small changes in slope, but did vary with flow rate. The research team recommended a standard Manning's *n* value of at least 0.20 for stormwater biofilter design. Unmowed, taller grasses were computed to have higher Manning's *n* values during high flow events (approximately 0.24).

One of the frequently cited concerns about biofilters involves how well they are constructed and maintained in the field. Horner and his colleagues (1988) surveyed the condition of 44 biofilters in the field. The study indicated that there clearly was plenty of room to improve in both areas (Table 2). For example, about four in 10 biofilters did not have the dense grass cover necessary to achieve effective filtration. Similarly, only 40% of all biofilters were dry during the summer months—the remainder had standing or running water. A high proportion of the biofilters could be referred to as "biocanyons," as they had sideslopes in excess of 3:1 (h:v). Nearly all the biofilters that received runoff from curb cuts had significant sediment deposition at the edge of the biofilter that could impede the entry of runoff into the system. Most significantly, less than half of all biofilters had ever been maintained after they were constructed. Periodic grass mowing was the maintenance activity performed most often (41%).

Based on both the monitoring and field experience, the research team has suggested refined design criteria to improve the performance of biofilters, which are summarized in Table 3. The biofilter does appear to be a promising technique to treat the quality of urban stormwater, but will require future improvements in design, maintenance and landscaping One particular design improvement would be to place more biofilters off-line. In this event, they would only treat runoff from the water quality design storm, but would bypass larger storm events that produce greater runoff depths, are more erosive and could possibly mobilize pollutants trapped in biofilter soils.

References

Horner, R. *et al.* 1988. *Biofiltration Systems for Storm Runoff Water Quality Control.* Washington Dept. of Ecology. 84 pp.

Seattle Metro and Washington Ecology. 1992. *Biofiltration Swale Performance: Recommendations, and Design Considerations*. Publication No. 657. Washington Dept. of Ecology. 220 pp.

Table 3: Key Biofilter Design Criteria

- *Geometry*
  Preferred geometry minimizes sharp corners and has gentle slopes, parabolic or trapezoidal shapes, with sideslopes no greater than 3:1 (h:v)
- *Longitudinal slope*
  Should be in the range of 2 to 4%. Checkdams should be installed if slopes exceed 4% and underdrains installed if slopes are less than 2%.
- *Swale width*
  Should be limited to no more than 8 feet, unless structural measures are used to ensure uniform spread of flow.
- *Maximum residence time*
  Try to achieve a hydraulic residence time for the 6 month 24 hour storm of about 9 or 10 minutes.
- *Maximum runoff velocity*
  No more than 0.9 fps for 6 month, 24 hour storm, and no more than 1.5 fps for 2 year storm event.
- *Mannings n value*
  Recommend the use of a 0.20 value in design
- *Mowing*
  Routine mowing is used to keep grass in active growth phase, and to maintain dense cover.
- *Grass height*
  Normal grass height should be at least two inches above design flow depth.
- *Biofilter Soils*
  A sandy loam topsoil layer, with an organic matter content of 10 to 20%, and no more than 20% clay. If soil test indicates that the current soil does not meet these criteria, a surface layer topsoil amendment may be used.
- *Water table*
  Designer should check to determine the level of the seasonally high water table. If it is within a foot of the bottom of the biofilter, it may be advisable to select wetland species.
- *Plant selection*
  Select grass species that produces a uniform cover of fine-hardy vegetation that can withstand the prevailing moisture condition. Wetland adapted species such as *Juncus* and *Scirpus* may be utilized if drainage is poor.
- *Landscaping*
  Other plant material can be integrated into a biofilter; but care should be taken to prevent shading or leaffall into swale.
- *Construction*
  Use of manure mulching or high fertilizer hydroseeding to establish ground cover should be avoided during construction, as these can result in nutrient export.