Appendix H: Performance assessment of biofiltration systems using simulated rain events

CRC for Water Sensitive Cities

Australian Government
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Business Cooperative Research Centres Programme

Condition assessment and performance evaluation of biofiltration systems

Practice note 2: Performance assessment of biofiltration systems using simulated rain events

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The Facility for Advancing Water Biofiltration (FAWB) aims to deliver its research findings in a variety of forms in order to facilitate widespread and successful implementation of biofiltration technologies. This Practice Note for Performance Assessment of Biofiltration Systems using Simulated Rain Events is part of a series of Practice Notes being developed to assist practitioners with the assessment of construction and operation of biofiltration systems.

1. Scope of document

This Practice Note for Performance Assessment of Biofiltration Systems using Simulated Rain Events is designed to provide practitioners with a hydrologic and treatment performance assessment tool where a more detailed assessment than collecting the occasional water quality sample is required, but where continuous flow and water quality monitoring is not feasible. From a practical viewpoint, this approach is limited to small-scale systems as the volume of stormwater required to evaluate large-scale systems is too onerous. This approach is also limited to sites where the outlet can be easily accessed in order to measure flow and collect water quality samples.

2. Rain event simulation

The hydrologic and treatment performance of biofiltration systems can be assessed by simulating a rain event. A pre-determined volume of semi-synthetic water (usually equivalent to that of the design storm) is prepared and delivered to the biofiltration system. Normally this is done via a tanker truck and a mixing tank. The outflow rate is measured and water quality samples are collected at regular intervals until outflow ceases.

Simulating a rain event is a full-day exercise and initially requires a minimum number of four people; the busiest stage is preparing and delivering the semi-synthetic stormwater to the biofilter. Once this stage has finished, two people can manage the flow monitoring and water quality sample collection at the outflow.

Caution: Appropriate safety protocols and precautions should be followed. For example, if the biofiltration system to be monitored is beside a road, traffic control may be required. While the risk of microbiological and virological hazards in stormwater is likely to be low, gloves should be worn. Personnel should also have received necessary vaccinations; consult a general practitioner or health advisor for further information.

Note: A rain event simulation cannot be carried out in wet weather as any unquantified inflows will interfere with mass balance calculations with respect to runoff volumes and pollutant loads. Further, there must also be no residual outflow from a previous rain event. The simulation should be carried out on a day when it is not predicted to rain before outflows from the simulation cease (i.e., at least 24 hours after the beginning of the simulation), and when there is no outflow from an existing event.

2.1 Determination of rain event simulation volume

In general, a rain event simulation should be based on the design storm for that biofiltration system, as this will enable evaluation of the upper performance limit. For example, if a biofiltration system was designed to treat up to a 15-minute rain event with an average recurrence interval (ARI) of three months, the simulation volume should be equivalent to the volume of runoff produced during this rain event, and over a time as close as possible to the design storm duration (see further commentary on this in Section 2.5).

2.2 Determination of water quality sampling intervals

Outflow concentrations of some pollutants have been shown to vary dramatically with flow rate or time, therefore water quality samples need to be collected at regular intervals in order to obtain a representative water quality assessment of the entire rain event. These water quality samples can then be analysed individually or combined; the latter option will cost significantly less, but will give less information about the performance of the system. 12 – 15 water quality samples collected over the entire duration of outflow will suffice. Calculate the sampling interval by dividing the event volume by the number of samples to be collected:

$$\text{interval} = \frac{\text{event volume} \times 0.7}{\text{no. samples}}$$

e.g. $$\text{interval} = \frac{3000\ \text{L} \times 0.7}{14} = 150\ \text{L}$$

The 0.7 multiplier allows for a fraction of the inflow to be retained by the system, which has been demonstrated to be in the order of 30% (Hatt et al., 2009). The total number of samples collected would be 15, including at the start of outflow.

2.3 Selection of water quality parameters

The pollutants that should be monitored will be determined by the system objectives and the type of receiving water. In general, the following parameters should be measured as a minimum:

- Total suspended solids (TSS);
- Total nitrogen (TN);
- Total phosphorus (TP); and
- Heavy metals – copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn).

Physical parameters such as pH, electrical conductivity (EC, as a measure of salinity), temperature, and dissolved oxygen (DO) are relatively cheap and easy to measure using a field probe and chould also be considered. The following water quality parameters might also be required:

- Nutrient species – ammonium (NH4+), oxidised nitrogen (NOx), organic nitrogen (ON), and orthophosphate (PO43-, commonly referred to as dissolved reactive phosphorus, FRP); and
- Other metals – aluminium (Al), chromium (Cr), iron (Fe), manganese (Mn), and nickel (Ni).

Consult with the analytical laboratory as to the sample volume required to carry out the analyses.

2.4 Apparatus

The following is required:

- Semi-synthetic stormwater – volume as determined in Section 2.1 and prepared according to Practice Note 2: Preparation of Semi-Synthetic Stormwater (available at http://www.monash.edu.au/fawb/products/index.html) – Note: This will most likely need to be prepared on-site
- Stirrer
- Means of delivering the water (e.g. tanker truck)
- Tank with removable lid and off-take point (with tap) at bottom of tank
- Stopwatch x 2
- 10 L bucket x 2
- Scales –battery operated, capacity to weigh 5+ kg, precision to 2 decimal places, water resistant
- Water quality sample bottles as required (see Table 1)
- 0.45 μm quick-fit filters (allow at least two filters per sample)
- 2 x 25 mL syringes
- Gloves
- 2 x permanent marker pens
- Rubber boots
- Cool box and ice
- Portable computer and long-life battery (or several standard batteries)

Table 1. Handling and preservation procedures for typical water quality parameters (Australian/New Zealand Standard, 1998).

Pollutant	Container	Filter	Preservation
Total Suspended Solids	plastic bottle, general washed	n/a	refrigerate
Total Nitrogen/Total Phosphorus	plastic bottle, general washed	n/a	refrigerate or freeze
Nutrient species • Dissolved Organic Nitrogen • Nitrate/Nitrite • Ammonia • Filterable Reactive Phosphorus	plastic bottle, general washed	0.2 µm	filter on site (0.45 µm cellulose acetate membrane filter) and refrigerate or freeze
Metals	plastic bottle, acid washed	n/a	acidify with nitric acid to pH 1 to 2

2.5 Procedure

a. Place tank just upstream of the inlet to the biofiltration system.

b. Prepare semi-synthetic stormwater in tank, continuously stirring.

   Note: Depending on the size of the tank, it may not be possible to prepare the entire volume of semi-synthetic stormwater required in one batch. If this is the case, it is entirely fine to prepare the stormwater in batches, however the total number of batches should be minimised to reduce variability and maximise repeatability of the experiment.

c. Collect water quality samples from the tank into the appropriate containers, process and store as required.

   Note: To avoid sample contamination, rinse sample collection vessels and bottles with a small amount of sample before filling and ensure hands do not contact the sample, filters, inside of bottles, lids, etc. Samples that require filtering should be filtered as soon as possible, preferably immediately, and samples that require refrigeration should be stored on ice.

   Note: If the semi-synthetic stormwater is prepared in batches, water quality samples should be collected from each batch and equal volumes from each batch combined for an average inflow concentration.

d. Continue stirring, open tap to allow semi-synthetic stormwater to flow into biofilter, start one stopwatch.

   Note: This stopwatch is the timer for the whole simulation and should not be stopped until the final flow and water quality measurements are taken.

e. If preparing semi-synthetic stormwater in batches, begin preparing next batch as soon as the tank is empty. Repeat Steps b - d (except for starting the stopwatch) until all the semi-synthetic stormwater has been delivered to the biofilter.

   Note: It is not possible to replicate a typical hydrograph using this approach, however the aim is to deliver the entire volume in the same timeframe as the design storm. For example, for a 15-minute design storm, the stormwater should be prepared and delivered to the biofilter in approximately 25 minutes (allowing for some flow attenuation in the catchment).

f. Check the outlet at regular intervals. At the first appearance of flow, measure the flow rate using a bucket and the other stopwatch and collect a water quality sample.

g. Measure the flow rate at two-minute intervals. Enter this data into a spreadsheet to keep track of the cumulative outflow volume (an example spreadsheet is provided with the case study described in Section 4).

h. Continue to monitor the flow rate and cumulative outflow volume, collecting water quality samples at the appropriate intervals. The flow rate will change rapidly at first and reach a peak before decreasing.
The rate of change will also decrease, at which point flow measurements intervals can be increased to every five minutes, and even longer as flow slows.

i. Flow monitoring and water quality sample collection should continue until the time between samples is deemed too high (see case study as a guide); this is the end point, however consider also taking a final flow measurement and water quality sample the following day (i.e., 24 hours after the start of the simulation).

j. Water quality samples should be analysed by a NATA-accredited laboratory.

2.5.1 Quality control

It is important to collect quality control samples to validate results and eliminate the possibility of sample contamination. At least one of each of the following should be collected per simulation:

- Field blank
- Transport blank
- Replicate sample

For further details, see the Australian standard for design of water quality sampling programs (Australian/New Zealand Standard, 1998).

3. Interpretation of results

It is very easy for data to be defective, therefore it is essential that data is checked for errors prior to evaluating results. Possible problems include noise, missing values, outliers. However, outliers should not be removed without reason or justification.

3.1 Pollutant load calculations

Pollutant loads can be calculated by combining the flow and water quality data.

$$l_{in} = v_{in} c_{in}$$

where: lin = inflow load (mg)

vin = total inflow volume (L)

cin = inflow pollutant concentration (mg/L)

$$l_{out} = \sum_{i=1}^{N} v_{i,out} c_{i,out}$$

where: lout = outflow load (mg)

vi,out = volume between samples i and i-1

ci,out = pollutant concentration at sampling interval i

N = total number of samples taken during simulation

The load reduction is simply the difference between the inflow and outflow load expressed as a percentage of the inflow load.

3.2 Performance targets

A number of state, territories, regions and municipalities stipulate performance targets for WSUD, which often include biofiltration systems (e.g. Clause 56.07 of the Victoria Planning Provisions prescribes target pollutant load reductions of 80, 45, and 45% for TSS, TN, and TP, respectively). Where these exist, monitoring data should be compared against these targets.

In the absence of stipulated performance targets, outflow pollutant concentrations could be compared to the ANZECC Guidelines for Fresh and Marine Water Quality; these guidelines provide water quality targets for protection of aquatic ecosystems – the targets to use should be selected according to the location of the biofilter and the state of the receiving water (e.g. slightly disturbed, etc.). However, the reality is that, even using the best available technology, biofiltration systems will not necessarily always be able to comply with these relatively strict guidelines. The local authority may in this instance choose to rely on the national Load Reduction Targets provided in Chapter 7 of Australian Runoff Quality (Wong, 2006).

Note: Comparison of simulation results to performance should be treated with caution. While this methodology enables a more detailed assessment than occasional grab samples, it still provides only a "snapshot" and doesn't give detailed information about the overall performance of the biofiltration system for the whole range of rain events it is subjected to.

4. Case study: Saturn cresent, Brisbane

The methodology for simulating a rain event was originally developed in order to monitor the performance of a small biofiltration basin in McDowall, Queensland (Figure 1). This system was retrofitted into the streetscape of a residential area in 2006 to treat road and roof runoff. The 20 m^2 treatment area (2% of the impervious catchment area) contains a 400 mm deep sandy loam filter media and a dense growth of Carex appressa and various Dianella species. The system has a maximum ponding depth of 200 mm. Two perforated 100 mm diameter PVC underdrain pipes in the underlying drainage layer (100 mm sand plus 200 mm gravel) convey the treated water to a side-entry pit, which is connected to the existing storm drainage system.

This design storm for this system is a 3-month ARI with a duration of 15 minutes, which equates to a volume of 3000 L. Semi-synthetic stormwater is prepared in five 600 L batches using mains water supplied by a tanker, slurry and chemicals (Figure 2a, b and c, and see Practice Note 2 for further details on semi-synthetic stormwater preparation). The target pollutant concentrations match typical stormwater quality for Brisbane (Table 2). The semi-synthetic stormwater is stirred in the tank using a kayak paddle during preparation and as the water is discharged to the biofilter (Figure 2d and e). It takes approximately 25 minutes to prepare and discharge the five batches to the biofilter (Figure 2f and g). Outflow appears 20 – 25 minutes after the beginning of the simulation (i.e., when the first batch of semi-synthetic stormwater is discharged to the biofilter). Flow is measured every two minutes until the peak has passed (Figure 3). Water quality samples are collected every 150 L (Figure 3). This equates to samples being collected every five minutes or so at the peak of the hydrograph, and extending to 50 minutes between samples by the 14th sample. At this point, the simulation is finished for the day, however the stopwatch is left running as one final flow measurement and water quality sample is collected on the following day (approximately 24 hours after the start of the simulation, Figure 3).

Figure 1. Biofiltration basin at Saturn Crescent, October 2006.

Water quality samples are collected from each of the five batches of semi-synthetic stormwater and combined in equal portions to create a composite sample. The 15 outflow water quality samples are analysed individually. Parameters that are analysed for include: TSS, TN, NOx, NH3, DON, PON, TP, FRP, Cu, Cd, Pb and Zn. The following volumes are collected for each sample: 1 L for TSS, 250 mL for TN/TP, 100 mL filtered for nutrient species and 100 mL for metals. The samples for nutrient species are filtered immediately, and all samples are stored on ice until they can be delivered to the analytical laboratory.

Table 2. Target pollutant concentrations for Saturn Crescent rain event simulations.

Pollutant	Concentration (mg/L)
Total Suspended Solids (TSS)	150
Total Nitrogen (TN)	1.69
Nitrate/Nitrite (NOx)	0.59
Ammonia (NH3)	0.24
Dissolved Organic Nitrogen (DON)	0.47
Particulate Organic Nitrogen (PON)	0.39
Total Phosphorus (TP)	0.31
Copper (Cu)	0.05
Lead (Pb)	0.14
Zinc (Zn)	0.25
Cadmium (Cd)	0.0045

Figure 2. Conducting a rain event simulation at the Saturn Crescent biofiltration system.

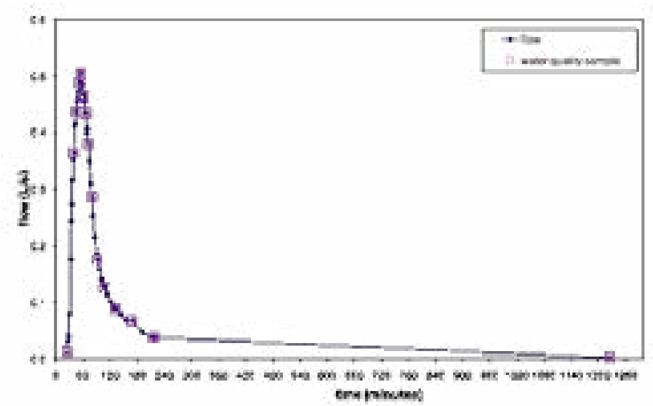

Figure 3. Typical hydrograph for a rain event simulation at the Saturn Crescent biofiltration system showing water quality sample collection times.

References

Australian/New Zealand Standard (1998). AS/NZS 5667.1:1998 Water quality - Sampling, Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. Homebush, New South Wales, Standards Australia.

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EXISTING TWIN SIDE
ENTRY PIT
IL 2.20
IL 1.70
EDGE DETAIL B
1
1
Ø300
IL 1.59
Ø375
1:5
EXISTING JUNCTION
PIT TO REMAIN
Ø525
1:5
FSL2.05m AHD
EXISTING POWER
POLE
m MIN PED ZONE
TO DRG 1432-08
DETAILS