Monitoring of Stormwater Treatment Practices

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Abstract

Monitoring, the most comprehensive level of assessment, is achieved by collecting and analyzing influent and effluent runoff samples and/or measuring influent and effluent flow rates as a function of time over the course of one or more natural runoff events. Monitoring, which is not limited by the size of the stormwater treatment practice, can be used to assess the performance of a practice with regard to reduction in contaminant load or concentration and reduction of runoff volume. This chapter discusses and explains the techniques of monitoring and how to carry out a monitoring program for various stormwater treatment practices. It also provides guidance about which stormwater treatment practices are best suited for monitoring and which are not. It ends with a case study of a monitoring effort on a dry detention pond.

8.1 What Is Monitoring?

If capacity testing (level 2a) and synthetic runoff testing (level 2b) are not feasible assessment approaches for a specific location or do not achieve the goals of the assessment program, monitoring should be considered. Monitoring is the most comprehensive assessment technique and can be used to assess water volume reduction, peak flow reduction, and pollutant removal efficiency for most stormwater treatment practices. Monitoring is accomplished during natural runoff events by measuring all influent and effluent flow rates over the entire runoff event and, if pollutant removal is to be assessed, collecting influent and effluent samples to determine pollutant concentrations. To assess runoff volume reduction, peak flow reduction, or both by monitoring a stormwater treatment practice, the inflow(s) and outflow(s) must be measured or estimated according to the techniques described in Chap. 9. The peak influent and effluent flow rates can be compared to determine the peak flow reduction and the total volume of influent can be compared to the total volume of effluent to determine the runoff volume reduction. Additional information

about monitoring stormwater treatment practices is available in the report "Urban Stormwater BMP Performance Monitoring" (US EPA 2002).

As stated above, pollutant removal efficiency can also be determined by monitoring if, in addition to measuring inflow and outflow discharges, all inflow and outflow locations are sampled according to the techniques described in Chap. 10. Pollutant removal efficiency can then be determined as the difference between the influent and effluent pollutant mass loads or event mean concentrations (EMCs), as defined and described in Chap. 12.

Natural runoff events vary in discharge and duration, so they require continuous flow measurement (or estimation). Pollutant removal assessment also requires sampling of all flows entering and exiting a stormwater treatment practice. For accurate estimates of performance, monitoring takes more time to complete (typically 14 or more continuous months), more equipment, and more labor. It, therefore requires larger expenditures than the first two levels of assessment. Monitoring is the only method that accurately measures the quantity and quality of runoff from a specific watershed, and the response of a stormwater treatment practice to that runoff. Capacity testing (level 2a) and synthetic runoff testing (level 2b) measure the ability of a stormwater treatment practice to perform specific processes (e.g., infiltration, sediment retention). These data can be used in models to estimate how a stormwater treatment practice would perform in a given watershed during natural runoff events.

Monitoring has more potential for uncollected or erroneous data as compared to synthetic runoff tests for the following reasons:

1. Weather is unpredictable and can produce various runoff volumes of various durations with varying pollutant concentrations at various times. In order for a storm event to be monitored correctly and accurately, all the monitoring equipment must be operating correctly and the runoff event parameters (water depth, etc.) must be within the limit ranges of the equipment
2. Equipment malfunction due to routine wear or vandalism is more likely. Without consistent inspection and maintenance, storm events may be measured or sampled incorrectly or not at all

As with any field work, safety is an important concern and should be addressed when conducting monitoring.

8.2   Monitoring Sedimentation Practices

Some sedimentation practices may be too large for synthetic runoff testing (i.e., a sufficient water supply is not available) and therefore may require monitoring (level 3) to achieve the assessment goals. To successfully monitor a stormwater treatment practice, it is necessary to follow appropriate procedures for Water Budget Measurement, Water Sampling Methods, and Analysis of Water and Soils in Chaps. 9, 10, and 11, respectively. In addition, there are some monitoring considerations specific to dry ponds, wet ponds, and underground sedimentation practices provided in the following sections.

8.2.1 Dry Ponds

With monitoring, one can assess a dry pond's peak flow reduction, runoff volume reduction, and pollutant removal efficiency. Measuring and comparing inflow and outflow hydrographs for a dry pond can give an estimate of the reduction in peak flow for a given runoff event and, therefore, an estimate of the hydraulic effectiveness of the stormwater treatment practice. Dry ponds are not typically designed to, and often do not, infiltrate a significant fraction of the runoff volume. The data collected when monitoring a dry pond, however, can be used to determine how much, if any, of the influent runoff volume is infiltrated. Because dry ponds are typically designed to drain within 2 days, the fraction of water lost to evapotranspiration is negligible and can be ignored. Thus, with no other mechanism available for water to leave the pond, the difference between the total volume of influent and effluent is the volume lost to infiltration.

To assess pollutant removal efficiency, influent and effluent samples must be collected and analyzed for the concentration of the target contaminant. Pollutant removal effectiveness is typically reported as the reduction in the total mass load between the influent and effluent locations or the percent difference between the influent event mean concentration (EMC) and effluent EMC. See Chap. 12, for guidance on analyzing data collected from monitoring studies.

8.2.2 Wet Ponds

Monitoring of wet ponds (also known as wet detention basins) is well documented (Wu et al. 1996; Comings et al. 2000; Koob 2002; Mallin et al. 2002). Monitoring of wet ponds is accomplished in the same manner as with dry ponds (see previous section). Short-circuiting within a wet pond can be estimated by monitoring the movement of a naturally occurring conservative tracer, such as chloride, as it moves through a wet pond if a sufficient pulse in concentration has occurred at the inlet. Plotting the inflow and outflow tracer concentrations as a function of time and comparing the two curves can determine if, and to what extent, short-circuiting may be occurring (see Example 7.2).

8.2.3 Underground Sedimentation Devices

Monitoring wet vaults and underground sedimentation devices for hydraulic performance or water quality treatment is not recommended because wet vaults and underground sedimentation devices are typically designed for small subwatersheds in urban areas and are located underground with limited access. Monitoring equipment should be kept in an environmental cabinet for protection from extreme weather, vandalism, and theft. Finding a semipermanent place for the equipment cabinet in an urban area such as a busy parking lot or intersection can be difficult, and if a cabinet were located in such a place it would be an easy target for vandals.

Also, sampling tubes must often run from the sampling location to the cabinet where the samples are stored, and these tubes are sometimes protected by metal or plastic piping. Such tubes and pipes crossing sidewalks and streets in an urban area would not only present a challenge, but would also create a liability. Furthermore, sampling tubes need to exit the underground device, meaning that catch basin covers would need to be removed during the monitoring period or modified to allow passage of the sampling lines. Because underground sedimentation devices are generally small, at least two cabinets and sampling lines (one each for inlet and outlet monitoring) would be in close proximity to each other, further complicating the matter.

In some situations, however, monitoring of an underground sedimentation device may be feasible and beneficial. In these situations, monitoring can be accomplished in a manner similar to that of monitoring dry ponds.

8.3   Monitoring Filtration Practices

Monitoring (level 3) is the most comprehensive method for assessing filtration practices. Monitoring can assess how well a filter reduces runoff peak flow, reduces runoff volume (by infiltration into the surrounding soil), and captures pollutants.

The perforated pipe collection systems that collect stormwater after it passes through a filtration practice are typically 4–8 in. (10–20 cm) in diameter. The small pipe diameter can present a significant challenge to measuring and sampling the effluent. If using a weir to measure flow from a perforated pipe, it is important to design the weir crest (i.e., invert) elevations such that the water level in the perforated pipe will always be below the level of the perforations in the pipe. This is because back pressure in the perforated pipe can prevent filtered water from entering the pipe. Sometimes, the perforated pipe collection system is connected to a catch basin that has other inflows; in these situations, it could be difficult to separate the outflow from the filtration practice from the other flows entering the catch basin. Thus, it is important to sample and measure flow from the perforated pipe system before it combines with any other surface runoff or conduit flow to ensure an accurate comparison between outflow and inflow for the filtration practice.

Infiltration into the native soil may occur in filtration practices that do not have impermeable liners or other barriers such as concrete walls. If infiltration is possible, infiltration rates should be measured or estimated to complete the water budget. The amount and rate of infiltration will depend on the stormwater filter design and saturated hydraulic conductivity of the underlying soils. Discussion and recommendations for estimating such infiltration as part of a water budget are included in Chap. 9.

Evaporation and transpiration (also discussed in Chap. 9) will likely account for an insignificant ($< 5\%$) portion of the water budget because they are slow processes and water typically does not remain in properly functioning filtration practices for more than 48 h. Additionally, vegetation, which can increase infiltration and evapotranspiration, is often limited in filtration practices to ensure adequate filtration by the filter media and to facilitate maintenance of the filter surface.

8.4   Monitoring Infiltration Practices

Some infiltration practices may be too large for synthetic runoff testing (i.e., a sufficient water supply is not available) and therefore may require monitoring (level 3) to achieve the assessment goals. To successfully monitor a stormwater treatment practice, it is necessary to follow appropriate procedures for Water Budget Measurement, Water Sampling Methods, and Analysis of Water and Soils in Chaps. 9, 10, and 11, respectively. In addition, there are some monitoring considerations specific to infiltration basins, trenches, and permeable pavements provided in the following sections.

8.4.1   Infiltration Basins

If the size of an infiltration basin precludes the use of synthetic runoff testing, monitoring can be used to assess the overall effective saturated hydraulic conductivity and infiltration capacity of the basin. In this case, the major difference between synthetic runoff testing and monitoring is that in monitoring, a natural runoff event is used to fill the basin rather than a fire hydrant or water truck. Once the basin is filled and the water surface elevation begins to drop, the procedures are identical and data analysis is the same in both scenarios. For details on this method, see Chap. 7.

8.4.2   Infiltration Trenches

Monitoring can be used to determine the ability of an infiltration trench to infiltrate runoff by determining the time required to infiltrate the WQV. Infiltration trenches function by storing water within the trench and allowing the stored water to infiltrate through the sides and bottom of the trench. If the trench receives the WQV of runoff, monitoring the water surface elevation within the trench will determine the time required to infiltrate this volume, which is the design volume.

Once the trench is filled with stormwater, data collection and analysis are performed in an identical manner to that of synthetic runoff testing. See Chap. 7 for a detailed discussion of the procedure.

Because water in the trench disperses as it infiltrates into the surrounding soil and does not have a well-defined location at which it exits the practice, obtaining representative effluent samples is extremely difficult. Thus, it is difficult to use monitoring to accurately assess the pollutant removal effectiveness of infiltration trenches.

Monitoring an infiltration trench can be made easier by installing sampling locations underneath the trench during construction. Sampling locations should be located below the bottom of the trench at a distance that ensures the samples represent water that has been fully treated by the soil. Sampling locations should not be located such that water not treated by the trench (e.g., groundwater) is sampled.

8.4.3   Permeable Pavements

It is possible to use monitoring to assess the infiltration capability of permeable pavements, although unique challenges usually exist. If monitoring can be accomplished, however, results do not yield a value of saturated hydraulic conductivity for the pavement. Instead, only an indication of the volume or fraction of runoff that can be infiltrated will be obtained.

Monitoring permeable pavements is challenging because of difficulties in accurately measuring inflows to and outflows from the permeable pavement surface. These measurements, as discussed in Chap. 9, must be obtained in order to successfully complete an assessment. Outflows are difficult to measure because runoff from a permeable pavement typically does not occur at one or two locations where the flow rate can be measured. For example, runoff from a permeable parking lot may flow as sheet or shallow concentrated flow out the driveway, into the gutter, and down the street, making flow measurement extremely difficult.

Inflows, which also must be measured over time, can also present a challenge. For example, runoff may be generated from adjacent permeable surfaces (e.g., grassed yards) and impermeable surfaces (e.g., buildings and impermeable pavements). This runoff can flow on to the permeable pavement over a widespread area, again making it difficult to accurately measure the total flow rate. In other situations it can be difficult to isolate the permeable pavement. For example, some parking lots have permeable pavement in the parking stalls but not in the driving lanes. If all inflows and outflows on the permeable pavement surface can be accurately measured, completing a water budget on the pavement will determine the volume of water that has infiltrated. This volume can be compared to the total volume of influent to indicate the fraction of runoff that can be infiltrated for the rainfall event. The volume infiltrated divided by the area available for infiltration and divided by the time over which infiltration occurs results in an average infiltration rate, which is dependent on but not equal to the saturated hydraulic conductivity.

Significant water depth (i.e., 6 in. (15 cm) or more) on top of permeable pavement is typically not obtainable; therefore, water surface elevation measurements are not made during monitoring. As a result, monitoring efforts on permeable pavements do not yield a value for the overall effective saturated hydraulic conductivity.

8.5   Monitoring Biologically Enhanced Practices

For most biologically enhanced practices, monitoring may be possible but not cost-effective or necessary. In fact, only constructed wetlands and swales may require monitoring. Bioretention practices are often relatively small in size, and assessment may be achieved in a much more cost-effective manner through capacity testing (level 2a) or synthetic runoff testing (level 2b). For example, bioretention practices that are located in residential areas on private property (i.e., resident's front yards) can range from 500 square feet (46.5 m^2) down to 20 square feet (1.86 m^2), and may

occur on 50% or more of the properties on a given street. Monitoring each bioretention practice in this area would be costly in both equipment and labor. Monitoring may be appropriate, however, to investigate the overall impact of a number of bioretention practices in a subwatershed or drainage basin. Constructed wetlands and swales are large by comparison, and their design typically facilitates monitoring.

8.5.1   Bioretention Practices (Rain Gardens)

If an adequate water supply is available, synthetic runoff testing (level 2b) is preferred to monitoring because monitoring can be cost intensive and result in minimal conclusive data. Monitoring, however, can provide information regarding the watershed that synthetic runoff testing cannot, such as characteristics of watershed runoff coefficients and pollutant loads.

   If monitoring is to be performed, the procedures are identical to those for infiltration basins, which are discussed previously in this chapter. Monitoring bioretention practices is easier if the practice has a subsurface pipe collection system to allow for effluent measurement and sampling. Effluent measurement allows for a water budget to be completed on the practice, which allows for the volume reduction to be determined. Effluent sampling allows for pollutant removal rates to be estimated when compared to influent sampling. Monitoring bioretention practices without subsurface collection systems for pollutant capture can be cost-prohibitive and result in minimal conclusive data (Tornes 2005). See Chaps. 9, 10, 11, and 12 for details on water budget measurement, sampling, sample analysis, and data analysis.

8.5.2   Constructed Wetlands and Swales

Numerous studies have been published concerning the assessment of constructed wetlands and swales with monitoring (Maehlum et al. 1995; Kadlec and Knight 1996; Oberts 1999; Barrett, et al. 1998; Carleton et al. 2000; Laber 2000; Yu et al. 2001; Bulc and Slak 2003; Farahbakhshazad and Morrison 2003; Farrell 2003; Deletic and Fletcher 2006). Monitoring is the most comprehensive assessment technique for measuring the hydraulic and pollutant removal effectiveness of a constructed wetland. Runoff volume reduction (by evapotranspiration) can be estimated by comparing the total influent water volume to the total effluent water volume in the water budget for the constructed wetland. It is important to recognize that constructed wetlands typically do not infiltrate stormwater runoff and may receive substantial ($> 5\%$) inflow from direct rainfall due to their large surface areas (see Chap. 9 for more information). Monitoring constructed wetlands for pollutant removal effectiveness requires that the volume and water quality of all stormwater inputs and outputs are measured. Refer to Chap. 9 for guidance on flow measurement, Chap. 10 for guidance on sampling techniques for gathering stormwater samples, and Chap. 11 for analysis techniques and recommendations. Data from monitoring should be analyzed according to methods described in Chap. 12.

8.5.3 Filter Strips

Filter strips typically lack the inlet and outlet flow structures that would allow for discharge measurement or pollutant sampling. In this case, it is not recommended that filter strips be monitored for water quality or hydraulic performance.

8.6   Case Study: Monitoring a Dry Detention Pond with Underdrains

A dry detention pond with underdrains was evaluated using monitoring. It drains a watershed that encompasses the corner of the local public works facility site, consisting of 45 acres (18.2 ha) with impervious area on the site of 10.2 acres (4.1 ha). Future construction of the facilities may occur on the remainder of the site.

The dry detention pond is approximately three acres with a slope of 1% from inlet to outlet. It is designed to provide storage for up to a 100 year—24 h rainfall event. Stormwater runoff is directed through grass waterways to a small pretreatment pond (forebay) before it enters the main detention pond. After entering the detention pond, the stormwater runoff infiltrates through the soil media. A series of rock-filled trenches holding perforated drain tile acts as an underdrain for the pond, into which most of the stormwater runoff drains. As shown with the circle labeled "Dry Infiltration Basin" in Fig. 8.1, the drain tile system consists of an 8-in. (20.3 cm) diameter, 140-ft (42.7 m) long, perforated polyethylene pipe running down the near middle of the basin. At eight locations on the 8-in. (20.3 cm) pipe, a set of two, 8-in. (10.1 cm) diameter, perforated polyethylene underdrain laterals are attached; one to each side of the main pipe. Each lateral extends outward away from the main pipe at a 45° angle for 30 ft (9.1 m). Thus, in addition to the 140-ft (42.7 m) of 8-in. (20.3 cm) diameter central drain tile, there is a total of 480 ft (146.3 m) of the 4-in. (10.1 cm) diameter laterals.

A cross section of the underdrain system is shown in Fig. 8.2. The underdrain pipe was surrounded by a mixture of soil and ASTM C33 fine sand, which was used as the filter media. A filter fabric was used to separate the soil-sand filter media and underdrain pipe from the surrounding existing soil. A layer of 6 in. (15 cm) of native soils (typically tighter clays for local area) was used to bury the filter fabric so it was not exposed at the surface. The underdrains collect the infiltrated storm water and drain it to the outlet structure. The outlet structure is 5 ft (1.5 m) in diameter and receives infiltrated runoff through an 8-in. (20.3 cm) underdrain pipe as shown in Fig. 8.3. The outlet structure acts as an overflow spillway so that runoff in excess of the design storage volume will bypass filtration and be discharged downstream. An 18-in. (46 cm) diameter reinforced concrete pipe collects runoff from the outlet structure and discharges it to the downstream watershed. Native plants were planted on the site, including the grass waterways (ditches) and areas around the parking lot.
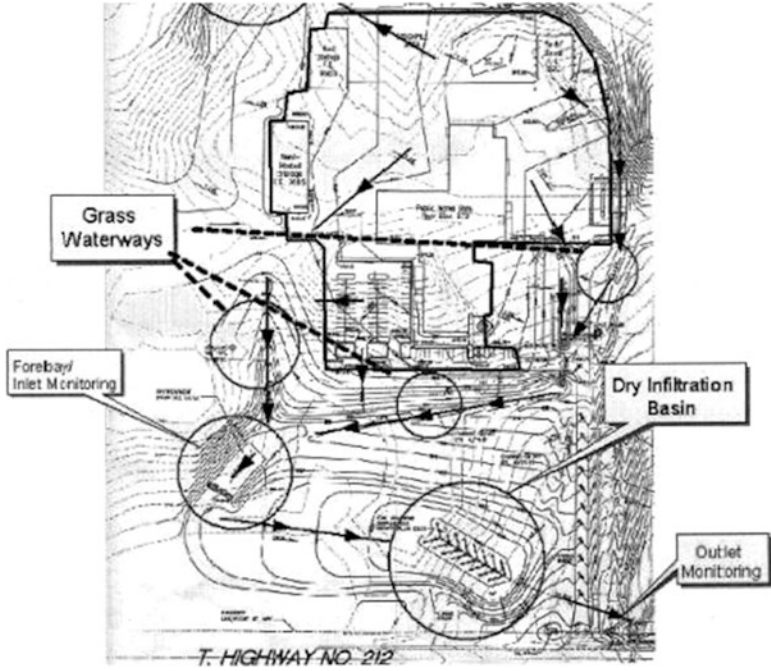
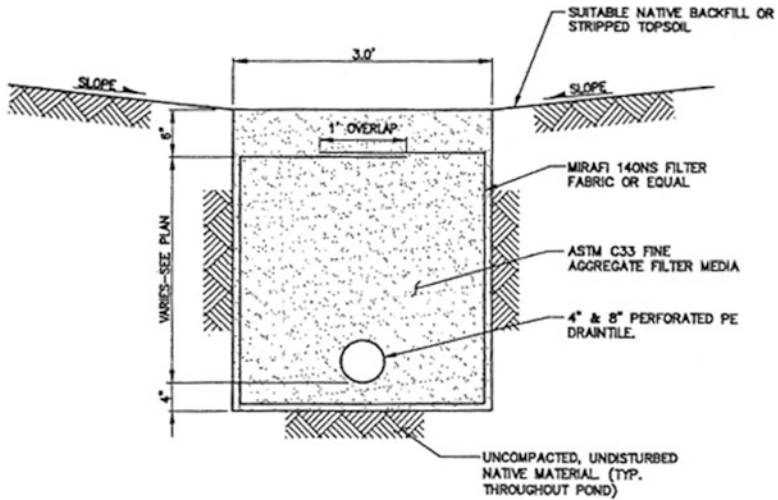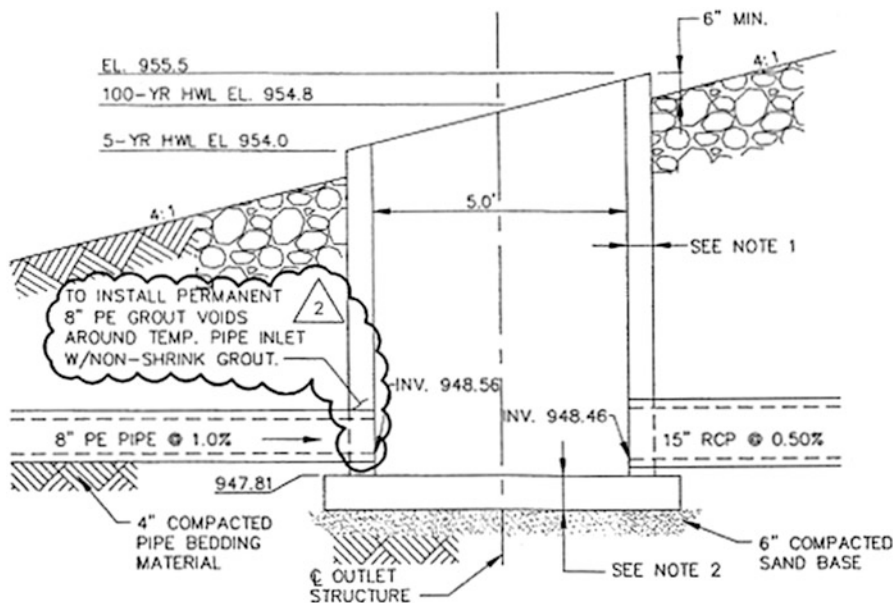**Fig. 8.1** Plan view of dry detention pond

Fig. 8.2 Cross section of pond under-drain system

Fig. 8.3 Outlet structure of dry detention pond

8.6.1   Assessment Goals

The goals of this assessment were to (1) assess runoff volume reduction and (2) assess pollutant retention performance of total suspended solids, volatile suspended solids, total phosphorus, and particulate phosphorus. This pond was designed to drain within 48 h after a runoff event by filtering the stormwater through the sand trenches. In addition to filtration, a primary treatment process of dry detention ponds with underdrains is sedimentation, which occurs while the runoff is pooled in the pond.

8.6.2   Assessment Techniques

To meet the assessment goals, both inflow and outflow had to be measured and sampled. The pond was chosen for monitoring because it has one influent and one effluent location and limited overland inflow. Thus, only two flow measurement and sampling stations were needed.

A portable water quality sampler, which contained a complete set of 24, 1 L wedge-shaped bottles, was installed at the inlet of the pond. The unit was programmed to collect flow-weighted samples and to record the depth, velocity, and discharge at 10-min intervals. A tipping bucket rain gauge was also installed near the inlet of the pond to collect data on the total rainfall amount, antecedent dry days, and rainfall intensity for each storm event.

Fig. 8.4 Rectangular weir at the inlet of the pond, which was later modified

Initially, a 5-ft (1.5 m) wide rectangular, sharp-crested weir was installed at the inlet of the pond, as shown in Fig. 8.4, with an ultrasonic flow sensor. The sensor was installed over the water surface just upstream of the weir to measure depth behind the weir. The equipment continuously monitored and recorded the rainfall and water level, which was used to calculate the corresponding flow rate.

Results from preliminary monitoring showed that the rectangular weir did not provide accurate estimates of discharge at the relatively low discharge rates that were most common at the site. Therefore, the 5-ft (1.5 m) wide rectangular weir was modified by cutting a 3-in. (7.6 cm) deep, 90° V-notch into the middle of the rectangular weir such that the result was a sharp-crested compound weir which would more accurately measure low discharges.

At the outlet, another portable automatic sampler was programmed to collect flow-weighted samples. Using a flexible circular spring ring, an Acoustic Doppler Velocimeter (ADV) was installed on the bottom of the outlet culvert. This type of sensor uses Doppler technology to measure average velocities at locations across the flow cross section. A pressure transducer contained within the sensor measured water depths and calculated flow areas based on conduit geometry. The automatic sampler calculated the total discharge by summing the products of all recorded average velocities and their corresponding flow areas.

Initial monitoring revealed that the ADV sensor did not accurately measure flow velocities when water depth was less than approximately 2 in. (5 cm). A 3-in. (7.6 cm) tall plastic circular weir, as shown in Fig. 8.5, was installed to ensure that the area velocity sensor used at the outlet had at least 2 in. (5 cm) or more of water depth needed to accurately measure the velocity profile. The area velocity sensor was located inside of the pipe, 6 in. (15 cm) upstream of the circular weir.

Subsequent monitoring revealed that the circulating flow caused by installing the weir resulted in significant error with the ADV sensor measurement. The sensor appeared to sum the forward and backward velocity caused by the weir, resulting in significantly larger flow velocity than the actual net forward velocity. The depth

Fig. 8.5 Circular weir installed in the outlet pipe of the pond

measurement, however, reported by the probe was correct, and these values were used to calculate the head over the weir. After the weir was properly calibrated, the head measurements could be used to calculate the discharge over the weir and thus the flow in the outlet pipe.

The monitoring systems at both the inlet and outlet of the pond were powered by heavy duty deep-cycle marine batteries and solar powered battery chargers. Although the samplers and data loggers are watertight, corrosion resistant, and can be installed without additional protection, all the monitoring equipment was enclosed in lockable wooden environmental cabinets. A laptop PC with corresponding software was used to retrieve the data from the automatic samplers.

8.6.3   Assessment Results

Data and samples were collected for twelve runoff events over two years. Due to the extra variables and uncertainties introduced when monitoring, this time frame is not uncommon to obtain meaningful results. The results are presented in Tables 8.1, 8.2, and 8.3. The data presented in Tables 8.1 and 8.2 were used to estimate the performance of the pond for volume reduction and pollutant retention as listed in Table 8.3. There was significant infiltration in the pond. Values ranged from 1/3 of the total influent volume at high discharges to greater than 2/3 of the total volume at lower discharges.

Overall, load-based efficiencies are preferred for total load studies. Total load is determined by subtracting the sum of the outflow from the sum of the inflow and dividing by the sum of the inflow (see Chap. 12). The overall load-based efficiencies for the twelve monitored storms were 88% for total suspended solids,

Table 8.1 Rainfall amount, measured, direct, and total influent, measured effluent, and infiltration volume for the pond (1 in. = 2.54 cm, 1 ft^3 = 0.028 m^3)

	Total rainfall (in)	Measured influent volume (ft^3)	Direct rainfall volume (ft^3)	Total influent volume (ft^3)	Measured effluent volume (ft^3)	Total infiltration volume (ft^3)
SE 1	4.1	76,182	44,649	120,831	70,062	50,769 (42.0%)
SE 2	2.23	15,586	24,285	39,871	24,744	15,127 (37.9%)
SE 3	0.7	12,138	7,623	19,761	3,837	15,924 (80.6%)
SE 4	2.25	39,752	24,503	64,255	32,281	31,974 (49.8%)
SE 5	1.58	31,075	17,206	48,281	8,796	39,485 (81.8%)
SE 6	1.39	11,312	15,137	26,449	18,967	7,482 (28.3%)
SE 7	1.67	39,181	18,186	57,367	30,420	26,947 (47.0%)
SE 8	0.41	9,280	4,465	13,745	5,184	8,561 (62.3%)
SE 9	1.16	25,574	12,632	38,206	32,470	5,736 (15.0%)
SE 10	0.4	4,980	4,356	9,336	2,158	7,178 (76.9%)
SE 11	0.51	8,630	5,554	14,184	6,926	7,258 (51.2%)
SE 12	0.18	1,247	1,960	3,207	220	2,987 (93.1%)

81% for volatile suspended solids, 58% for total phosphorus, and 52% for dissolved phosphorus (see Chap. 12). These load-based efficiencies incorporate infiltration as a treatment mechanism and are therefore less comparable between sites.

The average concentration-based retention efficiencies for the twelve storms at dry detention pond with underdrains were 78% for total suspended solids, 64% for total volatile solids, 13% for particulate phosphorus, and 7% for total phosphorus (see Chap. 12). Retention efficiencies for dissolved phosphorus varied significantly and ranged from negative 60% to positive 28%. Dry detention ponds are focused on removing sediment and the associated pollutant concentration, such as particulate phosphorus. The primary retention mechanisms are not designed to retain dissolved phosphorus; thus, dissolved phosphorus retention is minimal.

8.6.4   Conclusions and Recommendations

The dry detention pond with underdrains was selected and monitored from May 2004 to November 2004 and May 2005 to August 2005 to assess its pollutant removal performance. Performance was estimated by comparing the influent and effluent pollutant loads and concentrations. From the results obtained in this study, the following specific conclusions were reached.

The measured concentrations of most parameters in stormwater runoff that entered at the dry detention pond with underdrains were substantially lower than concentrations typically mentioned in other studies throughout the nation, which influenced the pollutant retention efficiency of the pond. The lower values found at this site are thought to be related to pretreatment provided by the small pond near

Table 8.2 Total influent and effluent pollutant load and concentration of TSS, VSS, TP, and DP for the pond (all loads are in kg, all concentration are in mg/L)

Storm event	Total suspended solids				Volatile suspended solids			
	Load in	Load out	Conc. in	Conc. out	Load in	Load out	Conc. in	Conc. out
SE 1	194	19.8	57.6	10	18.2	5.36	5.4	2.7
SE 2	873	76.2	791	109	107	10.9	96.7	15.6
SE 3	10.6	0.98	19.2	9	4.3	0.47	7.8	4.3
SE 4	117	24.9	64.8	27.2	23.8	6.03	13.2	6.6
SE 5	15.6	1.32	11.5	5.3	8.81	0.95	6.5	3.8
SE 6	4.04	1.29	5.6	2.4	2.09	0.75	2.9	1.4
SE 7	29.9	21.7	18.4	25.2	8.45	6.97	5.2	8.1
SE 8	6.32	0.69	16.2	4.7	2	0.29	5.1	2
SE 9	9.66	8.1	8.9	8.8	2.41	1.86	2.2	2
SE 10	2.42	0.5	9.1	8.1	1.21	0.22	4.6	3.5
SE 11	4.28	2.28	10.6	11.6	1.83	1.06	4.6	5.4
SE 12	0.25	0.01	2.7	1.8	0.13	0.01	1.4	0.8
Storm event	Total phosphorus				Dissolved phosphorus			
	Load in	Load out	Conc. in	Conc. out	Load in	Load out	Conc. in	Conc. out
SE 1	0.547	0.175	0.162	0.088	0.209	0.101	0.062	0.051
SE 2	0.273	0.106	0.247	0.151	0.041	0.028	0.037	0.041
SE 3	0.058	0.009	0.105	0.082	0.038	0.006	0.069	0.059
SE 4	0.418	0.19	0.232	0.208	0.254	0.117	0.141	0.128
SE 5	0.359	0.046	0.265	0.183	0.226	0.03	0.167	0.12
SE 6	0.123	0.083	0.171	0.155	0.07	0.048	0.097	0.09
SE 7	0.278	0.194	0.171	0.225	0.175	0.109	0.108	0.127
SE 8	0.078	0.018	0.201	0.125	0.033	0.01	0.084	0.065
SE 9	0.285	0.218	0.263	0.237	0.179	0.15	0.165	0.163
SE 10	0.041	0.008	0.157	0.236	0.026	0.005	0.099	0.08
SE 11	0.065	0.028	0.162	0.142	0.033	0.015	0.082	0.078
SE 12	0.007	0.001	0.077	0.086	0.004	0.0004	0.048	0.077

the inlet and also by the two grassy ditches/swales used to transport stormwater runoff to the detention pond.

The use of a primary device (e.g., V-notch, rectangular or circular weirs, flumes) for flow measurement is strongly recommended, especially in outlet underdrain pipes. These devices are easy to install and can be used to provide continuous flow hydrographs using measurements of water surface level. The study revealed that an AV sensor cannot measure any velocity unless there is at least 2.5–3 in. (6.4–7.6 cm) of water over it, which does not often occur in underdrain outlets.

This research study confirmed that dry detention ponds with underdrains are an effective option for water quality control. The pond provided moderate stormwater treatment and reduced the concentrations of total suspended solids, volatile suspended solids, particulate phosphorus, and total phosphorus, even with small influent concentrations.

Results from the dry detention pond with underdrains indicate that influent pollutant concentrations influenced the pollutant retention efficiencies.

Table 8.3 Load-based and concentration-based removal efficiencies for the pond

	Load-based removal efficiencies				Concentration-based removal efficiencies			
	TSS (%)	VSS (%)	TP (%)	DP (%)	TSS (%)	VSS (%)	TP (%)	DP (%)
SE 1	90%	71%	68%	52%	83%	50%	46%	18%
SE 2	91%	90%	61%	32%	86%	84%	39%	−11%
SE 3	91%	89%	84%	84%	53%	45%	22%	14%
SE 4	79%	75%	55%	54%	58%	50%	10%	9%
SE 5	92%	89%	87%	87%	54%	42%	31%	28%
SE 6	68%	64%	33%	31%	57%	52%	9%	7%
SE 7	27%	18%	30%	38%	−37%	−56%	−32%	−18%
SE 8	89%	85%	77%	70%	71%	61%	38%	23%
SE 9	16%	23%	24%	16%	1%	9%	10%	1%
SE 10	80%	82%	80%	81%	11%	24%	−50%	19%
SE 11	47%	42%	57%	55%	−9%	−17%	12%	5%
SE 12	96%	96%	86%	90%	33%	43%	−12%	−60%

Larger total suspended and volatile solids influent concentrations for Storm Event 2 resulted in greater total suspended and volatile solids retention. Similarly, dissolved phosphorus retention efficiencies were greater for large influent concentrations and less for small influent concentrations. However, the trend between influent pollutant concentrations and retention efficiencies was not consistent for all twelve monitored storms at pond.

The filter underdrain system at the pond exhibited poor hydraulic performance and failed to keep the pond dry between the storm events. The runoff residence time in the pond for the twelve storm events monitored ranged from 2 days to 17 days, with an average of 5 days. The filter system requires continual maintenance to ensure that it is functioning properly. Field maintenance activities to maintain the hydraulic performance of the filter media may include replacing the filter media or replacing only a few inches from the top of the filter media.

8.7   Scheduling Maintenance

While not its primary function, monitoring can be used to schedule maintenance. Monitoring requires frequent visits to the site to check equipment and collect samples, resulting in impromptu visual inspections. During these visits, items needing maintenance can be observed and maintenance can be scheduled.

Scheduling maintenance from monitoring is similar to scheduling maintenance from synthetic runoff testing results. If a stormwater treatment practice is not performing as expected, review the monitoring data to determine if other aspects of the practice are functioning properly such as infiltration, filtration, stormwater storage, and sedimentation. Check the practice for the possibility of short-circuiting, excessive sediment deposition resulting in very little storage volume, and erosion within the practice.