Measuring Stormwater Treatment Success

Performance Monitoring
For Naturalized Stormwater Treatment Systems

Prepared By:
Applied Ecological Services, Inc.

Applied Ecological Services, Inc.™

Measuring Stormwater Treatment Success

Performance Monitoring
For Naturalized Stormwater Treatment Systems

Prepared By:
Applied Ecological Services, Inc.

Funding Provided By:
Great Lakes Protection Fund

November 20, 2009

Table Of Contents

Introduction **4**
Purpose Of This Manual **4**
Stormwater Treatment Systems: Traditional and Naturalized Systems **5**
Challenges Associated with Monitoring Naturalized Systems **9**

1.0 Defining Monitoring Objectives **12**

2.0 Developing Protocols **17**
2.1 Monitoring Locations **17**
2.2 Storm Criteria and Sample Timing **21**
2.3 Sampling Effort **23**
2.4 Selecting Relevant Pollutant Parameters to Monitor **25**
2.5 Recommended technologies available to assess parameters **30**
2.5.1 Rainfall **30**
2.5.2 Flow Measurements **32**
2.5.3 Water Quality Monitoring **35**
2.6 Quality Assurance and Quality Control **42**
2.7 Budgeting **43**

3.0 Implementing the Monitoring Plan **45**
3.1 Field Notes and Data Management **45**
3.2 Monitoring Training **45**
3.3 Permission Acquisition **46**
3.4 Deploying Automated Instruments **47**
3.5 Manual Sampling **48**

4.0 Analyzing the Study Results **49**
4.1 Data Validation **49**
4.2 Water Quantity Analysis **50**
4.3 Recommended Metrics for Reporting **51**
4.4 Statistical Analysis **52**
4.5 Compare Results to Monitoring Objectives **53**
4.6 Share Results **53**

5.0 Assessing Public Perception **55**
5.1 Public Perception **55**
5.2 Public Perception Assessments **56**
5.3 Visual Preference Surveys **57**
5.4 Visual Preference Studies **59**
5.5 Benefits of a Public Perception Analysis **60**

References **62**

Appendix **68**

Purpose of This Manual

The practice of stormwater management has evolved substantially over the last several decades and it continues to evolve today. A driver behind this evolution has been the changing objectives of stormwater management. Original engineered stormwater management was single minded in purpose – to move water quickly away from humans and their developments. Today objectives are numerous and complex including floodwater detention, groundwater infiltration, water quality improvement, natural water cycle preservation, and wildlife habitat provision. This increasing complexity of objectives has been accompanied by increasing complexity of the stormwater systems designed to satisfy them.

Given the required investment of resources devoted to stormwater management, there is great interest in assuring that those resources are well spent. In short, there is a need to assess the performance of the stormwater systems. Fortunately, the art and science of monitoring performance of stormwater systems have also continued to improve, and many tools have been developed to assist in this important task, from refined instruments to exhaustive monitoring methods texts.

For the uninitiated, the literature and equipment options may be too exhaustive. For somebody who is interested in assessing stormwater system performance but doesn't know how to begin, scratching the surface of the information available may be sufficiently intimidating that he or she often either boldly starts monitoring without a good plan or hands the entire process over to a consultant. However, there is great value in broad participation in the plan development and being knowledgeable enough to focus a consultant to ensure that the right objectives are set and resources are spent judiciously to meet those objectives.

The purpose of this manual is to provide access to the basic information needed to communicate effectively with and oversee the work of a consultant or researcher about a monitoring project that they are tasked with designing and implementing. It also is an entry point for individuals or organizations that may wish to design and implement a project on their own and are beginning to research the requirements of an effective, defensible monitoring project. The manual offers digestible descriptions of the steps required to plan and implement a monitoring project and directs readers to more detailed information. The manual incorporates information and guidance from a number of excellent references described in the reference section, as well as guidance based on first hand experience of the authors.

There is emphasis in this manual on the unique challenges associated with assessing performance of naturalized stormwater treatment systems, or low-impact development sites. The concepts presented, planning steps proposed, and techniques available to monitor various parameters are also relevant to traditional systems which may only include one

treatment element at the end of a network of storm sewer pipes.

There is also information offered in this manual pertaining to assessment of public perception. Although monitoring public attitudes toward stormwater features is not often covered in texts on performance monitoring, it is critically important. If local residents are not provided the opportunity to understand and appreciate the value of naturalized stormwater management features, particularly the native vegetation that is so critical to the success of these systems, key components of the systems may be removed. In some cases, residents have demanded replacing native communities that they think look weedy, due to poor design or maintenance, with turf grass that is not as suitable for most stormwater management functions. Therefore, staying in touch with local perceptions of stormwater features through monitoring is important to ensure long term success of the system.

This manual is broken into sections and subsections that correspond to steps in the monitoring project planning process. As such, it can be followed sequentially as a project team develops its plan. To help illustrate the concepts presented, an example is provided that runs through the planning section and offers a summary of the thinking that goes into each step in the planning process. Brief discussions of implementation and analysis of data are also provided because they affect planning decisions. An exhaustive discussion of data analysis is beyond the scope of the manual.

Stormwater Treatment Systems: Traditional and Naturalized Systems

The historic conversion of land from forests, prairies, and wetlands to agricultural lands and then to suburban and urban uses has dramatically fractured the natural processes that created and maintained healthy streams and lakes. The native ecological communities were capable of capturing, filtering, infiltrating, and slowly delivering stormwater into waters downstream. Conversion of the forests and prairies to cropland eliminated the deep dense root systems that facilitated water infiltration. Draining wetlands for agricultural purposes eliminated the capture, storage, and treatment functions of those wetlands. Loss of organic content in the soil over years of farming reduced the soil capacity to absorb rainwater.

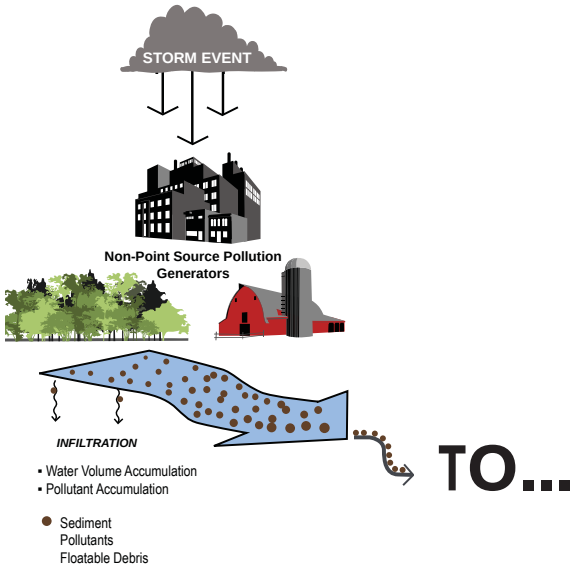
As more people have moved off the farm and into cities, the conversion of native lands and agricultural lands to urban and suburban uses, further decreased the land's ability to hold and infiltrate water by creating substantial areas that are totally impervious to water, including rooftops, parking lots, roads, and sidewalks, and reduced infiltration capacity in the pervious areas by compacting soil. Add to this the early development philosophy of removing water from developed areas as quickly as possible, and the hydrology of the developed areas were completely transformed – from a system that slowly fed water to streams and lakes over extended streams. The negative impacts on the downstream

water resources, including channel scouring and subsequent siltation, were dramatic, and downstream human communities began to experience more frequent and intensified flooding.

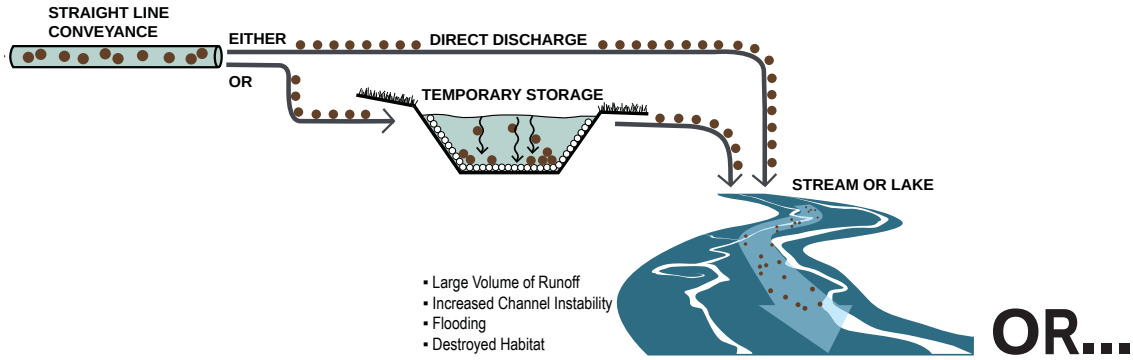
Figure 1. Deep-rooted native vegetation is critical to increase water infiltration and evapotranspiration © AES, Inc.

This flooding and channel erosion prompted a new objective that has been widely adopted in stormwater management – detention of runoff from large storm events. The long held goal of removing water from developed areas was maintained, but at the end of the storm sewer pipes, detention ponds were installed to capture and release the floodwaters at slower rates. As additional stream impairments associated with stormwater runoff were identified, additional objectives have been added to stormwater management, including sediment capture. However, the stormwater management approach has generally remained reductionist, in that communities continue to identify individual problems associated with stormwater and identify specific means of addressing the latest problem.

An alternative approach, that is increasingly gaining acceptance and support, is to mimic the natural systems that so capably managed stormwater before humans altered the landscape. The approach of reconstructing naturalized stormwater management systems is embedded in the broader conservation development concept. This naturalized approach begins by managing rain water close to where it falls in small, dispersed elements throughout the landscape, rather than collecting a considerable volume and trying to manage all of it in a single large, centralized system. The management systems are patterned after natural systems such as upland prairies, wet prairies, and treatment wetlands, with appropriate native vegetation that increases infiltration, storage, detention, and evapotranspiration (Figure 1). Impervious surfaces are minimized and "disconnected" by routing water off of impervious areas to pervious vegetated systems rather than routing water through pipes (Figures 2-3).



1. Conventional System



2. Naturalized System

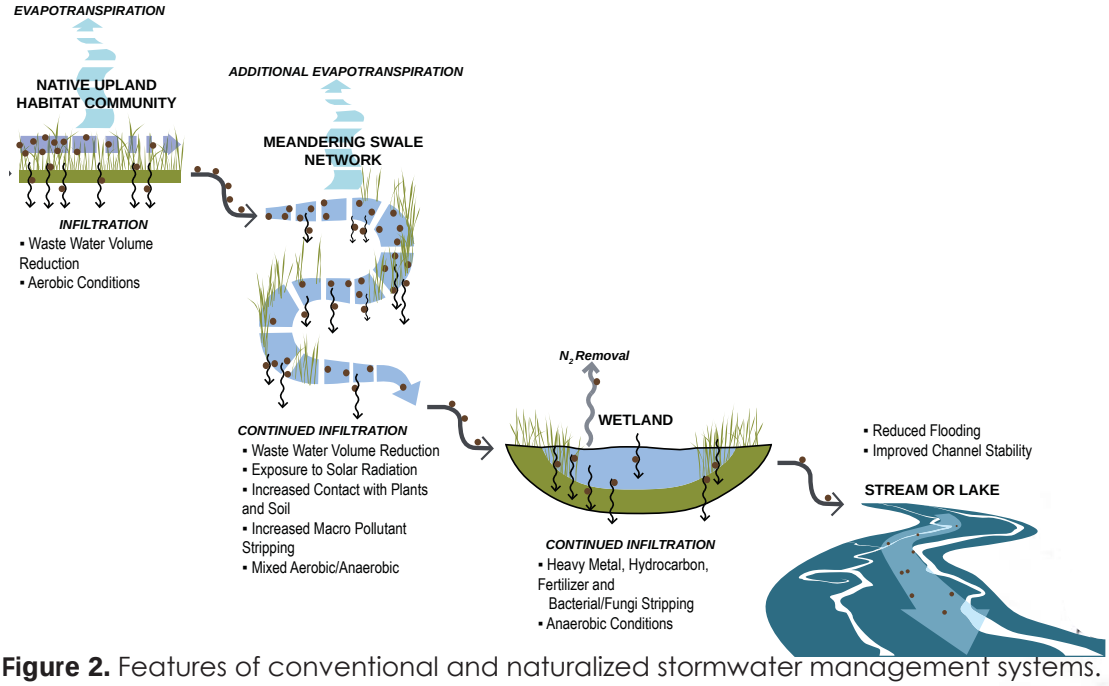


Figure 2. Features of conventional and naturalized stormwater management systems.
© AES, Inc.

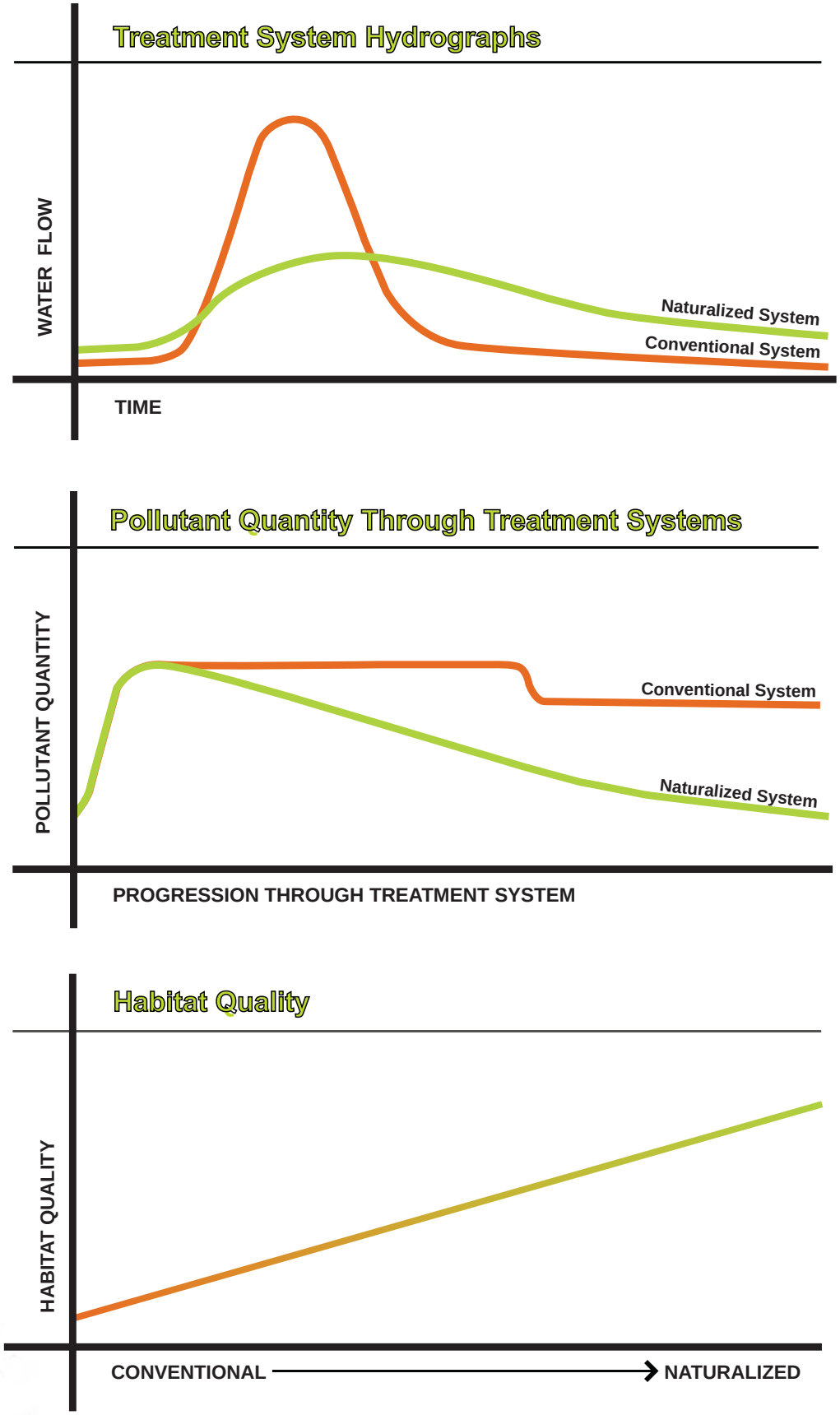


Figure 3. Relative performance and value of conventional and naturalized stormwater management systems.

This naturalized stormwater treatment system has most often been applied to suburban residential and mixed use developments, but opportunities also exist for incorporating many of the natural processes into urban areas (Figure 4).

Figure 4. Urban landscape with naturalized stormwater management features. © AES, Inc.

The benefits of naturalized stormwater treatment systems go beyond the stormwater treatment processes to include improving wildlife habitat, reducing the high urban temperatures associated with impervious and unvegetated areas, and providing aesthetic value.

Challenges Associated with Monitoring Naturalized Systems

Due to the complexity of stormwater systems that mimic native ecological communities and processes, monitoring the performance of them introduces additional challenges. Traditional systems tend to have discreet inflow and outflow points to discreet stormwater management elements. This design is very conducive to assessing performance of the treatment element by monitoring the inflow and outflow quantity and quality directly. Naturalized systems are designed to produce sheet flow across vegetated surfaces throughout the development in a way that is difficult to identify and monitor inflows and outflows. The treatment elements are also numerous, and monitoring inflow and outflow from each could quickly become prohibitively expensive. It is easiest to address these challenges if

the project team members clarify their objectives by deciding if they need to assess the performance of the site as a whole, if they need to assess performance of individual elements on the site, or if they need both.

Monitoring Individual Stormwater Management Elements

Monitoring individual treatment elements within a naturalized system is similar to monitoring traditional systems with one or two treatment elements at the end of the storm sewer pipe. This type of monitoring is valuable for determining the effectiveness of single elements within the system. The data gathered provides designers and regulators with information necessary to better design and prescribe stormwater systems that are comprised of multiple elements. For example if inflow and outflow data for a treatment wetland indicate that this element removes nitrogen extremely well, partially removes phosphorus, but does not promote infiltration, the designer knows that additional treatment elements must be paired with the treatment wetland to provide additional phosphorus removal and infiltration. As more data becomes available on the performance of each of these elements under different conditions and as part of different systems, designers can more confidently identify the required series of elements in the system and define dimensions required for those elements.

The limitation of monitoring individual elements that are part of complex systems is that the data does not provide insight into how well the elements perform together to achieve the overall objectives of the system, including protection of streams and lakes. Challenges associated with monitoring individual elements in a complex system include requirements to monitor sheet flow across vegetated surfaces and the need to monitor multiple inflows to determine total inflow quantity and quality.

Monitoring Whole Systems

The goal of monitoring an entire stormwater system is to assess its total performance with respect to meeting design objectives. The data obtained reflects the integrated performance of the entire site, including not only the stormwater elements, but also conservation design decisions such as reduced impervious area associated with use of narrow streets, and operation decisions such as reduced use of lawn fertilizers.

The limitation of whole system monitoring is that it does not provide data suitable for determining which features of the system are most important for achieving specific objectives. For example, it does not indicate which elements in the system are most effective at ensuring that the total suspended solids removal objective is met.

The biggest challenge in monitoring a whole system is establishing a good reference point for comparing to the outflow quantity and quality. When monitoring the effectiveness of an entire naturalized stormwater system, it is exceedingly difficult to estimate inflow quality

to the treatment system because the treatment system effectively begins all over the site very soon after the rain hits the ground. To address this challenge, most investigators use a paired watershed study approach, described further in Section 3 of this manual, in which the outflow characteristics of the evaluated watershed are compared to the outflow characteristics of a different "reference" watershed. Typically the reference watershed is undeveloped or developed in a different way.

Of course, one could conduct individual element monitoring and whole system monitoring at the same site, if sufficient funding were available. Regardless, it is good to keep these options in mind when deciding on monitoring objectives in the initial step of the project planning process. These and other specific considerations are discussed further in the sections that follow.

1.0 Defining Monitoring Objectives

One of the most important and often underemphasized steps in developing an effective monitoring plan is establishing study objectives. It may seem unnecessary to discuss or record monitoring objectives because they seem obvious to the investigator. These obvious, implicit objectives are often too vague to serve as the basis for a clear monitoring plan that can produce statistically significant results. For example, an investigator could set out to determine if a stormwater system "is working" without spending additional time thinking about what it means to be "working". Without thinking further about what hydrologic and water quality functions the system is supposed to perform and what to use as a baseline for comparison in determining the extent to which those functions are performed, the investigator may waste resources testing for the wrong parameters or testing at the wrong locations or wrong time.

The more specificity that is incorporated into the objectives, the easier it will be to develop a plan to satisfy those objectives within the budget available. It is useful to think about the potential impacts that the system is designed to minimize. It is also worth understanding potential water quality and hydrologic concerns for downstream waters as well as any particular stormwater system design decisions that were made to address those concerns.

Burton and Pitt (2002) divide objectives into two general categories – characterizations and comparisons. A characterization simply answers questions such as, how much water is discharged, or how much phosphorus is discharged? A comparison, on the other hand, answers the questions such as, is the quantity of phosphorus discharged significantly different from the quantity of phosphorus that enters a stormwater treatment system? Is the amount of surface water discharged from a particular conservation development with dispersed, integrated stormwater management significantly different from the amount of surface water discharged from a particular conventional development over a given period of time? To assess performance of stormwater treatment systems, comparison objectives are more likely to be relevant, but they also are more complicated, and frequently more expensive.

Objective Categories

Characterizations answer questions like:
- How much phosphorus is discharged?
- How much water is discharged?

Comparisons answer questions like:
- Is the quantity of phosphorus discharged less than the quantity that entered the system?
- Is the amount of water discharged from a particular conservation development less than that of a particular conventional development?

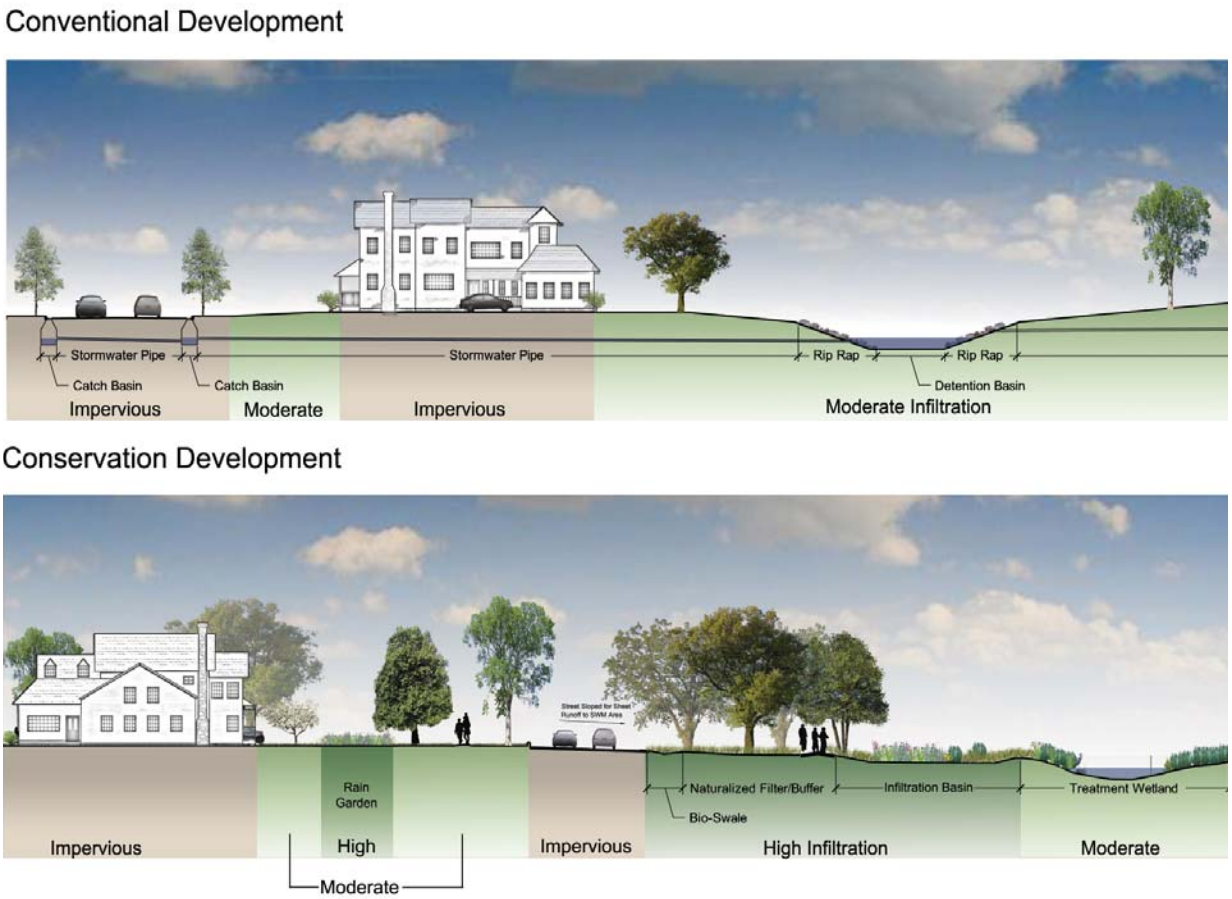


Figure 5. Monitoring objectives might include determination of runoff quantity differences between a conventional development with small infiltration areas and a conservation development with larger infiltration areas. © AES, Inc.

Setting objectives and developing a monitoring plan to meet those objectives will be an iterative process, particularly if the initial ambitions would require funding that exceeds the desired budget. For example, confidently assessing the performance of a large complex stormwater treatment system with respect to an exhaustive list of pollutant and hydrologic parameters is very expensive. After the initial objectives are developed, the specific monitoring requirements to meet those objectives should be developed along with the estimated costs of implementing the plan. If the estimated costs exceed the project budget, the objectives need to be scaled back, either by reducing the number of locations to monitor, reducing the number of parameters monitored, or both. After new objectives have been set, the plan and estimated costs should be reassessed to ensure they fall within the desired project budget. If they do not, this exercise needs to be repeated. Objectives should be scaled back further, and the project and fees should be reassessed, until a plan is developed that fits within the project budget. It is great to dream big in the beginning, but be realistic and avoid promising anybody more than can be delivered given budget constraints.

Example Monitoring Objectives:

- Determine the amount of surface water runoff that leaves a development subwatershed resulting from rain events.
- Determine the quantity of total suspended solids that leaves a development subwatershed through surface water runoff resulting from rain events.
- Determine if the quantity of phosphorus discharged from a stormwater treatment system is less than the quantity of phosphorus that enters that system.
- Determine whether the surface water runoff from a particular development is significantly less than the surface water runoff from a different development for given storm events.
- Determine whether the quantity of total suspended solids in the surface water runoff from a particular development is significantly less than the quantity of total suspended solids in the surface water runoff from the surface water runoff from a different development for given storm events.

Note that the example objectives discussed above are all related to performance of a treatment system associated with storm events. Before collecting samples that are not associated with rain events, an investigator should consider if and how non-storm event samples will be relevant to satisfying the established monitoring objectives.

EXAMPLE

A conservation development was completed in the upper Midwestern US a couple of years ago (Figure 6). None of the stormwater was routed through storm sewer pipe. Instead it flowed away from the streets, through side yards, raingardens, vegetated swales, infiltration basins, stormwater wetlands and ultimately to a stream. All of the vegetation installed in the stormwater system is native to the local area and selected to thrive in soils, available light, and the modeled hydrologic regime for each portion of the site. The stream historically provided high quality habitat and water quality that supported a diverse assemblage of aquatic life, but development pressures in the watershed had begun to decrease the quality of the system. In particular, the stream had begun experiencing greater water fluctuations following storms that have increased bank erosion; the water has become more turbid; algae production has increased; and higher concentrations of chloride have been observed due to road salt application. The city strongly encouraged the developer to use conservation development techniques to improve stormwater management, and it has established a stormwater monitoring project team to determine if those practices are working.

EXAMPLE CONT.

Monitoring Objectives

Due to the problems the stream is beginning to experience with respect to flow modification, the project team is confident that assessing the runoff quantity is important. The team would also like to assess the performance of the system with respect to the pollutants that are contributing to the turbidity and algae problems. Consultation with the state watershed assessment program staff has indicated that phosphorus is the limiting nutrient for algae growth in the stream, and that the turbidity is caused by suspended solids. The project team is also interested in understanding the removal of these pollutants in each of the various stormwater elements in the system.

Figure 6. The conservation development containing the watershed that the project team plans to evaluate. © AES, Inc.

Although the project team understands that in the long term, the stormwater treatment elements will not capture chloride, it is interested in understanding the effect that the conservation developments' narrower streets has on the road salt application and resulting chloride delivery to the stream. It is also considering testing an alternative de-icing material in the future and would like to develop baseline information for chloride runoff from a developed watershed.

EXAMPLE CONT.

With these goals in mind, the project team developed the following draft list of potential monitoring objectives for the study:

1. Determine if the total stormwater runoff from the conservation development is significantly different from the runoff from an undeveloped watershed in good condition for several storm events.
2. Determine if the peak runoff flow from the conservation development and the undeveloped watershed in good condition is significantly different.
3. Determine if the total phosphorus load from the conservation development is significantly different from the total phosphorus load from the undeveloped watershed for a range of storm events.
4. Determine if the total suspended solids load from the conservation development is significantly different from the total suspended solids load from the undeveloped watershed for a range of storm events.
5. Determine if the chloride load from the conservation development is significantly different from the chloride load from a conventionally developed watershed with larger streets for a range of storm events and seasons.
6. Determine the chloride concentration and load over the course of the entire study period for potential comparison to other datasets in the literature or future studies.
7. Determine the inflow and outflow event mean concentrations for each of the stormwater elements on the site, including the raingardens, swales, infiltration basins and wetlands.

The team developed a rough cost estimate for the monitoring study and began an exhaustive proposal writing process to find additional funding for the entire study. Unfortunately, they were unable to fully fund the entire study, so they revisited their objectives and prioritized to identify the set of questions they wanted to answer first. They decided to pursue objectives 1, 2, 3, 4, and 6. Instead of monitoring all three of the subwatersheds, they decided to use one "representative" subwatershed of the development. They further agreed to approach the homeowners associations from the conservation development and a nearby conventional development to see if they might be interested in collecting some screening level data that might ultimately help address objective 5.

2.0 Developing the Monitoring Plan Protocols

After clear objectives have been established, the details associated with the monitoring program can be developed. As a starting point, it is recommended that the investigator develop a conceptual idea of the monitoring plan by quickly estimating the project needs with respect to the following elements, which are described in detail in the sections that follow:

- Monitoring locations
- Storm criteria and sample timing
- Number of samples
- Instrumentation

An estimate of the cost associated with that plan can then be developed to determine if the objectives have been set too ambitiously and need to be modified to meet budget constraints. If the cost estimate is appropriate for the project budget, these elements of the plan should be further refined.

2.1 Monitoring Locations

The locations selected for monitoring are directly dependent on the monitoring objectives, project budget, safety, logistics, complexity of the land use patterns in the watershed, and complexity of the stormwater treatment system. If the primary monitoring objective is simply to characterize the discharge from a stormwater treatment system, it is easy to conclude that the critical location for monitoring will be the point where the water leaves the system. However, in the more likely scenario that the objective is to compare the discharge to either the inflow or runoff from a different watershed, the complexity and consequent resource requirements increase substantially.

One common means of assessing performance of a stormwater BMP is by determining the impact that the BMP has on runoff pollutant quantities or water quantities. The clearest answer to this question lies in monitoring the flow into the BMP and the flow out of the BMP and analyzing the differences between those streams, referred to by some as "practice level monitoring" (ASCE and USEPA, 2009) This is relatively straightforward when considering one BMP with one inlet and one outlet. However, for a dispersed stormwater treatment system that begins with disconnecting downspouts from conventional storm sewers and treating stormwater close to where the raindrops land, it is difficult to identify a location that represents the "inflow" to the treatment system. Most of the "inflows" will occur as sheet flow across a lawn or paved surface which introduces challenges associated with trying to collect representative samples and installing equipment capable of measuring sheet flow and/or the pollutants contained in the flow.

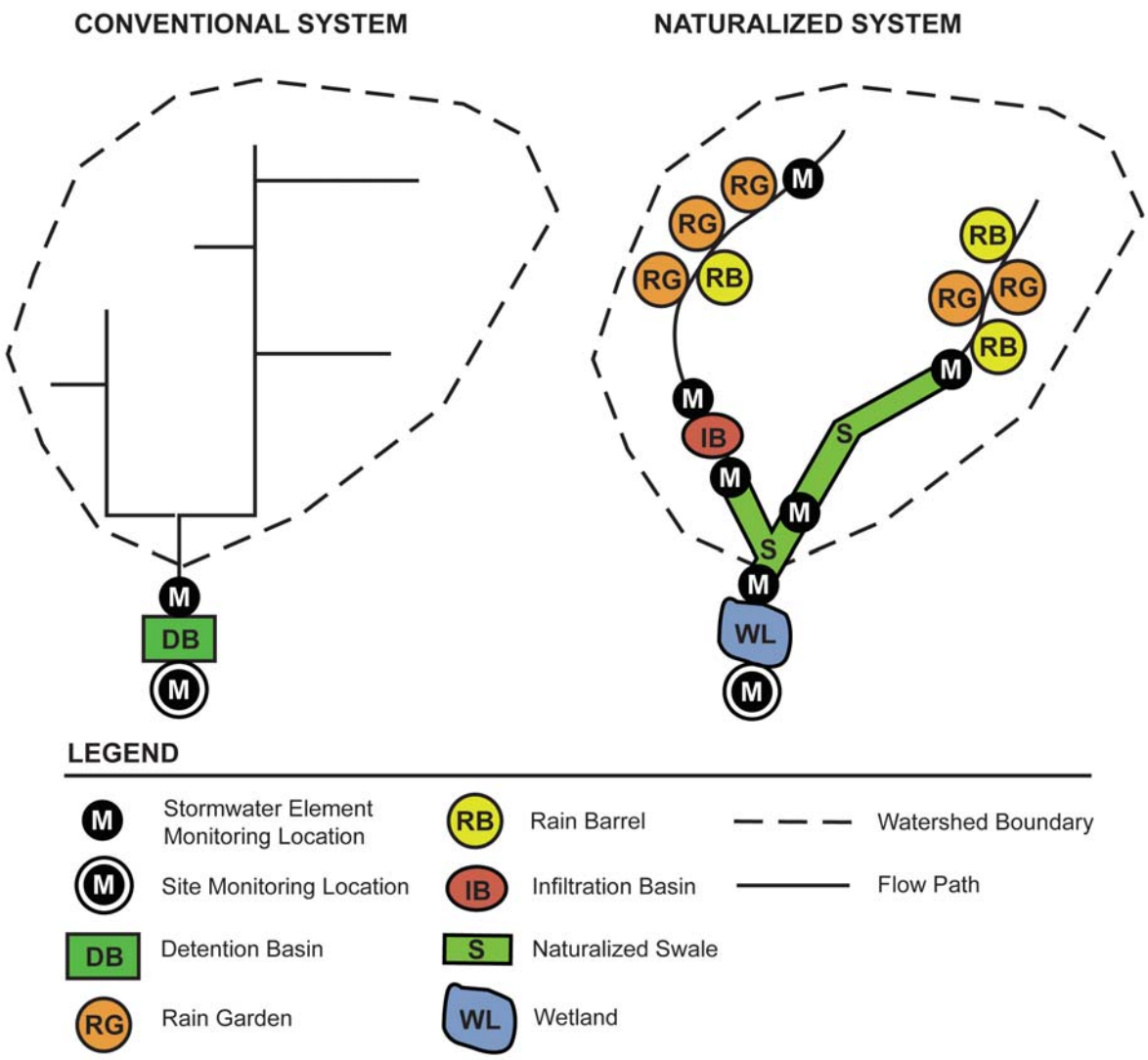


Figure 7. Individual element monitoring and site level monitoring locations for conventional and naturalized stormwater management systems. © AES, Inc.

Another approach used to assess relative performance of stormwater systems is comparing outflow characteristics of the system to outflow characteristics of a different watershed, either a watershed developed in a different manner or an undeveloped watershed. ASCE and USEPA (2009) refer to this as "site level monitoring." (Figure 7). While this approach alleviates the problem of adequately monitoring the inflow location of a dispersed system, it also introduces a lot of variables that are difficult to adequately factor into the analysis. In comparing two stormwater systems whose watersheds were developed in different ways, the investigator would ideally find two developments that had identical soils, slopes, previous land use, current landowner practices (such as fertilizer use, pet care practices, etc.), and rainfall patterns. After finding no such perfect twins, the investigator would try to select sites that were at least similar with respect to these variables and would need to document these variables for each site so they can be considered when analyzing the results of the paired study.

Another strategy is to attempt to sample inflow and outflow locations for multiple sites to attempt to account for differences between the watersheds, and assess more precisely, the relative effectiveness of the two treatment systems. Of course, this does not avoid the challenge of monitoring sheet runoff inflow to dispersed systems and requires approximately twice the monitoring locations and associated extra resources which the project budget may not allow, depending on the number of samples desired.

At some point in the planning, the investigator will need to address the trade off between sampling at more locations fewer times and sampling at fewer locations during more storms. If the project objectives emphasize capturing spatial variation, it will be important to monitor many locations. If, however, it is more important to capture variability among different storm events, sampling fewer locations during more events will be a better strategy. For example, when attempting to characterize inflows to a dispersed stormwater treatment system, if there is a mix of land uses (lawns, parking lots, agricultural fields, etc.) that drain to the system, it may be necessary to monitor runoff from each land use to capture the spatial variability. If it is all suburban style development, data collected at a few locations may be sufficient to predict the inflow characteristics. Similarly, if an objective of the monitoring program is to assess the performance of individual treatment elements in a treatment train, it will be necessary to include monitoring points located throughout the system to capture inflow and outflow from each element.

In selecting any location, it is good to keep several factors in mind. All sites must be safely accessible for all monitoring activities planned. Frustration and unplanned expenses will be reduced a great deal if the investigator can minimize the risk of vandalism of any equipment that is deployed at the site for several days without supervision. Be sure that the extent of the watershed is well known. This is not a problem for watersheds that are strictly surface drained, but sometimes subsurface storm sewers cross the topographic subwatershed boundaries. If storm sewers drain to the monitored treatment system, confirm with the local municipal public works department to ensure that the drainage system is correctly documented in the monitoring plan.

Monitoring locations should:

- Be safely accessible
- Allow protection of instruments from vandalism
- Receive water from known areas
- Enable data collection that satisfies monitoring objectives

Location of Rain Gauge

In analyzing the performance of a stormwater treatment system,

rainfall characteristics are important variables to consider. As discussed in section 2.3, it will be critical to characterize the rainfall patterns to which a watershed is subject prior to the sampling event. Rainfall from a storm system can vary significantly across even small geographic areas. Therefore, it will be important that a rain gauge is located close to the watershed that will be monitored. If somebody operates a weather station near the project site, it may be feasible to utilize that data to approximate rainfall distributions at the site. However, it is recommended that a rain gauge be installed at the site. See manufacturer's instructions for more detailed guidance regarding how to more precisely locate the rain gauge on site to avoid interferences.

EXAMPLE

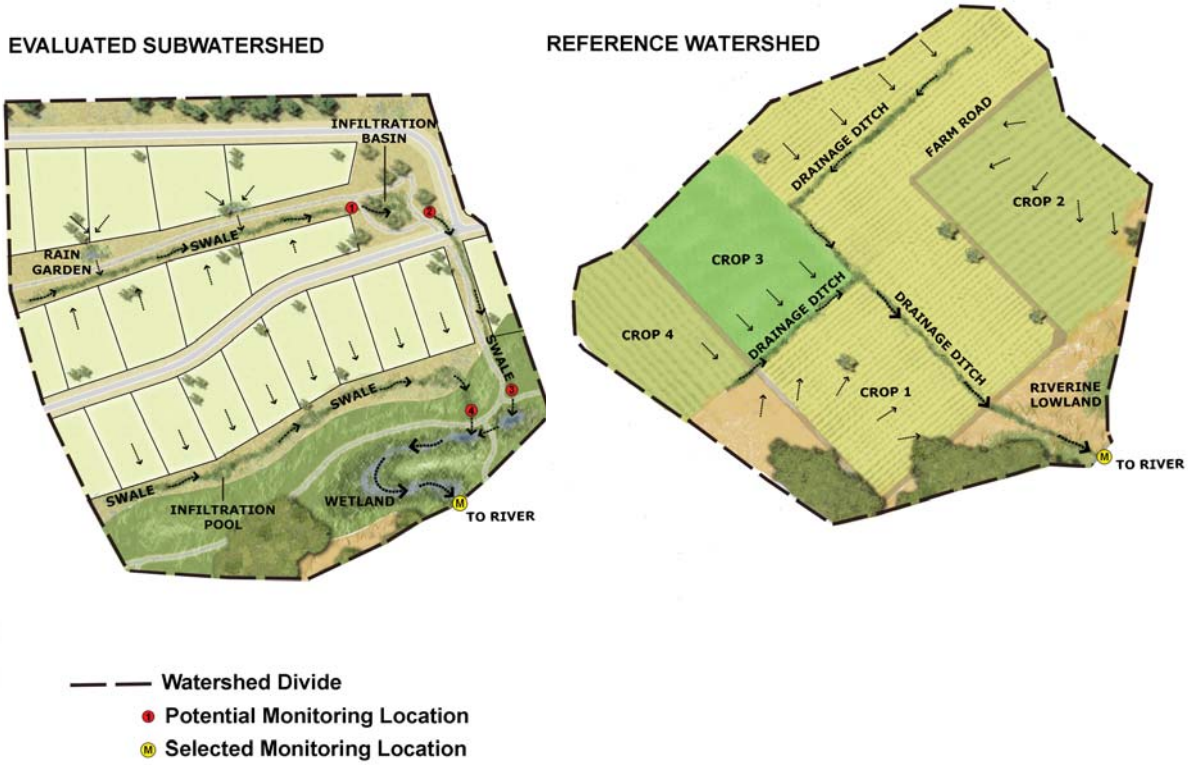


Figure 8. Watersheds and monitoring locations for a paired watershed study. © AES, Inc.

Monitoring Locations

In identifying a reference watershed to use as an undeveloped watershed in good condition, the project team had hoped to find an undisturbed site that was still in its pre-settlement condition. However, most of the watersheds that were similar in size to the subwatershed selected in the development were at least partially agricultural. Therefore, the city selected a reference watershed adjacent to the development that contained agricultural fields on which several conservation measures were employed. When considering evaluating the performance of each stormwater element in the system, several potential monitoring locations were identified.

EXAMPLE CONT.

However, when this objective was eliminated due to funding constraints, the monitoring locations selected to achieve the remaining objectives are at the outflow from each watershed as shown in Figure 8. The project planning team visited both sites to confirm that monitoring equipment could safely and securely be installed at each of these locations.

2.2 Storm Criteria and Sample Timing

Discharges from stormwater treatment systems should only consist of stormwater runoff that results from rain events, unless there are other sources of wastewater that are improperly discharging through the stormwater system. If wastewater and stormwater are combined, it may be worth collecting samples during dry periods. Otherwise, the most useful information about the performance of stormwater treatment systems will be data gathered while stormwater is passing through the system, typically during and within a couple of days after the event. Before collecting samples that are not associated with rain events, an investigator should carefully consider if and how non-storm event samples will be relevant to satisfying the established monitoring objectives. It is tempting to collect samples from pools within the treatment system or in downstream receiving waters between storms because sampling trips can be scheduled in advance without having to watch the weather and drop everything to run out for the storm sample. However, if such sampling does not contribute to meeting project objectives, it is not time and budget well spent.

The nature of runoff from a watershed and the performance of a stormwater treatment system will be very dependent on the nature of the storm event that produces the runoff. Very small rain events may produce little to no runoff because all of the rainfall is intercepted by small depressions on the site and, where possible, infiltrated into soils. Slightly larger events may produce runoff, but if there are infiltration BMPs in the treatment system or if there is available storage volume below the outfall elevation, this runoff will not be discharged. The thresholds for an event to produce runoff and discharge will depend on the nature of the site and the treatment system.

Due to the variability of runoff characteristics for different storm events, it will be important to collect data during a range of storm events. However, with increasing variability in the nature of the storm events sampled, variability of the results will also increase. For this reason, some researchers and agencies have suggested that investigators focus on sampling storm events that would be expected to produce the lowest runoff water quality. These events would be those that have high magnitude, high intensity, and long periods of time with no precipitation (antecedent dry period)

prior to the start of the storm. ASCE and USEPA (2002) have suggested using a 0.1 inch threshold as a starting point for the minimum quantity of rainfall to trigger a sampling event, but if the site being sampled contains permeable soils, dispersed stormwater management, and/or infiltration basins, a larger threshold may be necessary to sample discharge from the treatment system. ASCE and USEPA (2002) have also suggested a preferable antecedent dry period of 72 hours to reflect "worst case" conditions and a minimum antecedent dry period of 24 hours. Limits on the duration of the storms were not established in the ASCE and USEPA (2002) guidelines, but it was noted that a typical range is 6 to 24 hours.

Each monitored storm should be fully characterized with respect to:

- Quantity of rainfall
- Intensity of rainfall
- Duration of the rainfall
- Antecedent dry period

When reviewing and analyzing the data collected for the storms, it may be worth breaking the data into groups for which rainfall characteristics are similar. This may reduce the scatter in the data, allowing greater confidence in the performance characteristics associated with particular storm types.

Adding to the challenges of predicting whether a pending storm will meet the criteria set and responding quickly enough to arrive at the site in time to sample runoff from storm event, is the challenge of collecting a "representative" sample during those events. Flow rates and pollutant concentrations in the runoff can vary dramatically during and after a storm event. Particularly where there are hard surfaces, a disproportionate amount of the pollutant load resulting from a storm event may wash off the ground and run off the site during the initial period of runoff, often referred to as the "first flush". If an investigator collects one sample during this first flush at one site and collects a sample after the first flush has passed at a different site, these samples would not be comparable. To avoid comparing samples collected at different points in the runoff hydrograph and better characterize the entire runoff, the recommended approach is to collect multiple samples over the course of the entire runoff event. This is often most efficiently accomplished by using automatic samplers as described in Section 2.5.3.

The data obtained by collecting and analyzing several samples during a runoff event can be used to plot the concentration of the pollutant vs. time over the course of the runoff hydrograph for comparison between two different sample sites and for evaluation of peak runoff concentrations. If flow data is also collected, the event mean concentration (EMC) and the total pollutant load for the storm event can also be computed. These computations are described in Section 4.3, but it is important to consider which types of values are desired for reporting early in the planning process to ensure that the right data is collected to allow for those computations.

EXAMPLE

The developer's engineers designed the conservation development site to capture and infiltrate all stormwater that would result from a 0.5 inch rain event that occurred over a 24 hour time period. The project team is interested in the water quality and quantity associated with all runoff events that produce enough water to leave the site as surface flow. Therefore, they initially set 0.6 inch as the minimum rain event to qualify for monitoring. They decided to document duration of the storm events that produce runoff for each event monitored, but they did not set minimum or maximum rainfall duration criteria for sampling. The minimum antecedent dry period was established as 24 hours and the team agreed that it would be important to document the antecedent dry period for each storm to assist in understanding the results from different storms.

2.3 Sampling Effort

A very common error in analyzing monitoring data is to boldly draw conclusions regarding trends or performance when there is insufficient data to show that the apparent differences in two data sets are statistically significant. Given the number of uncontrollable variables in monitoring stormwater treatment system performance, there is a lot of variability in the data collected. With higher variability comes higher level of uncertainty that the average of the data points obtained reflect the actual average of all runoff over a long period of time. To increase confidence that results reflect the true mean of conditions at a site, the investigator needs to increase the number of samples.

Excellent discussions of determining sample size to increase likelihood of obtaining statistically significant results in several publications (Burton and Pitt, 2002, ASCE and USEPA, 2002, and CWP, 2008). However, some of the details can be daunting for somebody who does not typically work with statistics. The method will be simplified slightly here by utilizing graphical representations of the computations involved and using typical values for type 1 and type 2 error risks. To estimate the number of samples needed, the investigator will need to estimate the mean and coefficient of variation (COV), which is equal to the standard deviation of a data set divided by the mean of the data set. Since that information obviously will not be available until after monitoring begins, it will be important to do some background research to find out means and COV of data sets collected for other similar studies. Good sources of such information include the International Stormwater BMP Database (www.bmpdatabase.org) and the National Stormwater Quality Database (http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/Mainms4paper.html). Although there currently is not a lot of data available regarding performance of "treatment trains" or BMPs in series, there are a few

such studies currently listed in the database. After making an educated guess for the mean and standard deviation for your sample set(s), Figure 9 can be used to estimate the number of samples per site needed to obtain statistically significant characterization for a given allowable error expressed as a fraction of the mean, assuming 95% degree of confidence (alpha = 0.05) and 80% power (beta = 0.20), which are typical values of these statistical parameters. If a different degree of confidence or power is desired, refer to Burton and Pitt (2002).

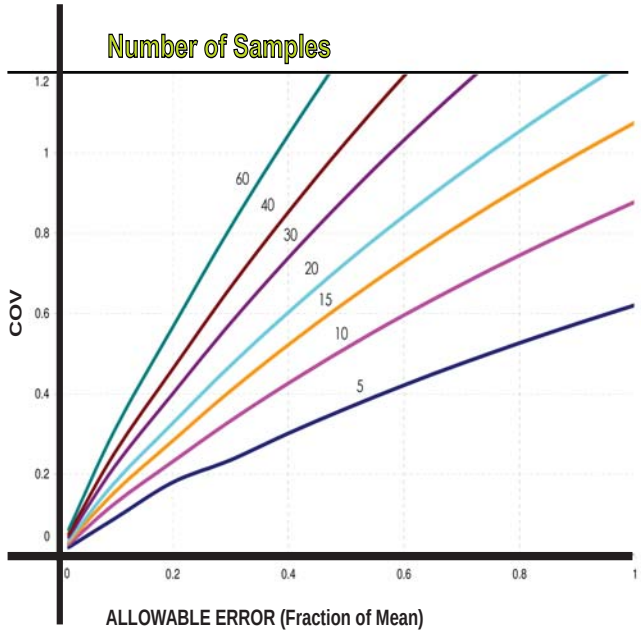


Figure 9. Number of samples required to characterize conditions based on equations from Burton and Pitt (2002) and personal communications with Bob Pitt (2009).

To demonstrate statistically significant differences between two data sets, as in a comparison of discharges from two different treatment systems, or comparison of inflow and outflow, the number of samples per site needed can be determined from Figure 10, assuming 95% degree of confidence and 80% power. As noted above, if a different degree of confidence or power is desired, refer to Burton and Pitt (2002).

The graph for comparing two data sets assumes that the standard deviation is the same for both sets, which is not necessarily true. Both graphs assume that the data sets will be normally distributed, which is not exactly correct either. However, for estimating the number of samples needed, they are reasonable approximations.

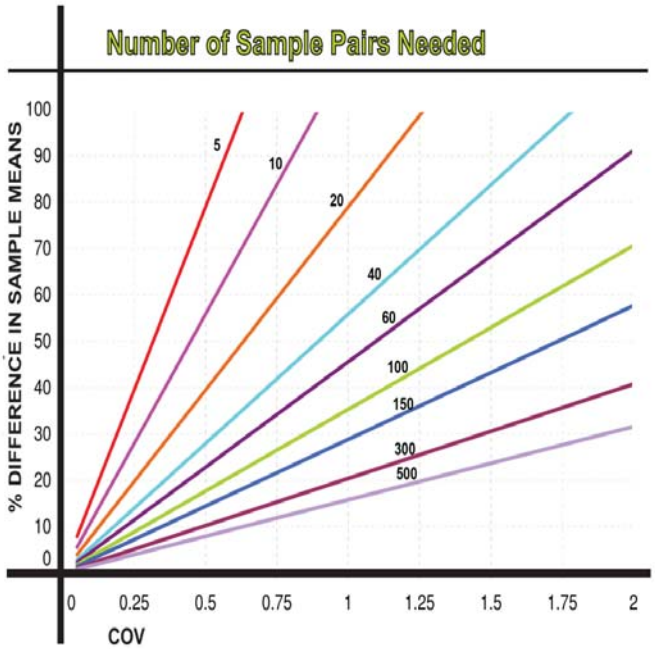


Figure 10. Number of sample pairs needed to establish statistically significant differences between two data sets.

Completing this quick estimate can be a sobering experience as the number of samples needed may require more time and resources than originally anticipated. With larger differences in the means of the data sets (ie. a more pronounced difference in quality) and smaller standard deviation (ie. less variability in quality in each set), the number of samples required decreases. Given that these values are estimated from other studies at this stage, the investigator may want to determine sample size needed for a range of realistic values before determining if objectives and schedules need to be modified.

EXAMPLE

The project team decided to estimate the number of storm events that would need to be sampled in order to obtain statistically significant results. They decided to use data available in the literature to predict rough estimates for the mean and standard deviation of total phosphorus from developed areas with multiple stormwater treatment devices and agricultural fields. A study they found of total phosphorus runoff from cropland with similar management practices and soils to those at their chosen reference site found mean concentrations of 0.11 mg/L and coefficient of variation (COV) of 0.4. Another study they identified contained data for total phosphorus runoff concentrations in stormwater from a few developments with multiple stormwater treatment elements determined average concentrations of 0.08 mg/L and COV of 0.5. They used Figure 10 with a 37% difference in sample means and COV of 0.5 to estimate that they would need at least 25 samples to detect that difference between the two sites.

The team reviewed historic rainfall data for the area and found that in recent years there were between 7 and 12 rain events per year that met the rainfall criteria that they established. Given that it was not likely that they would monitor each of the rain events that met their criteria, they estimated that it may take four or five years to monitor enough rain events to detect a 37% difference in the sample set means if the COV of the data sets are 0.5 or less. If the difference is greater and COV is smaller, less time and resources will be required. If the difference is smaller and/or the COV is larger, more time and resources will be required.

2.4 Selecting Relevant Pollutant Parameters to Monitor

Water Quality

Pollutants that may be present in stormwater runoff are numerous, from sediment particles and macronutrients to trace metals to synthetic pesticides. The costs associated with monitoring every possible pollutant in every sample are generally prohibitive. Therefore, the investigator will need to sit down with the monitoring objectives,

project budget, and estimated sample number requirements to whittle down the list of parameters to monitor. In making this selected list of parameters, there are several factors to consider.

One of the most important factors to consider in selecting parameters to monitor is land use in the watershed. Land use will have a huge impact on the pollutants that will be present in runoff. If the watershed has significant agricultural activities, one would expect the significant pollutants to reflect the regular soil disturbance associated with plowing, the application of fertilizers and pesticides, and potentially the presence of farm animal waste. Therefore the anticipated pollutants of concern would be suspended and dissolved solids, phosphorus, nitrogen, enteric bacteria, and pesticides. If the watershed is predominately residential development, the pollutants in the stormwater runoff should reflect the use of lawn chemicals, pet waste, as well typical urban features including roadways and other development surfaces. The specific pollutants may include solids, phosphorus, nitrogen, bacteria, pesticides, de-icing salts (if the watershed is in a cold climate region), oil, grease, and metals, such as cadmium, copper, zinc, and lead. Finally, if the watershed is very urban, the investigator would expect fewer lawn chemicals but higher levels of metals, de-icing salts, oil and grease. Keep in mind that past land uses may still be relevant even if the land use has changed. If a formerly agricultural area, particularly an animal operation, was developed as a residential subdivision, the nutrients and chemicals that built up in the soil may contribute to runoff that is much higher in these pollutants than is typically expected in residential developments.

In selecting parameters to monitor, the investigator should also consider downstream water quality and concerns. Data collected in the receiving waters downstream of the proposed project may reflect the pollutants of concern that are leaving the project area. Even if impairments indicated by the data are not caused solely by the area that will be monitored, it may be useful to know the extent to which the monitored area contributes to that impairment.

It will also be important to know the relative costs associated with sample collection and analysis for the parameters being considered. If there is interest in monitoring a particular pollutant for which there is not an inexpensive method, it may be appropriate to modify the project objectives slightly to monitor a pollutant for which it is easier and cheaper to obtain data, particularly if the primary pollutant of concern is associated with the substitute parameter. For example, many pollutants are transported in runoff by becoming attached to a soil particle (Figure 11). For this reason, total suspended solids can be a good proxy pollutant to indicate potential pollution from other typical stormwater pollutants. Similarly, multi-parameter probes are useful for obtaining continuous data for metrics such as dissolved oxygen, pH, and conductivity. While none of these parameters are pollutants per se, dissolved oxygen and pH are good overall indicators of stream health and the diurnal cycles of these metrics are good

indicators of algal and biological decay activities. Conductivity is a good proxy for dissolved solids, including de-icing salts.

Another decision that needs to be made for many pollutants is the form of the pollutant that should be measured. Most pollutants may be dissolved in the water or may be attached to other materials, depending on several factors, including pH. The reactivity of the pollutant is typically greater in dissolved form. For example, metals that are present in dissolved form are generally more toxic to aquatic organisms. However, metals that are not currently dissolved may become so at some point downstream, so the total amount of the metal may be important. Obtaining data on dissolved metals may also require additional sample preparation in the field, such as filtration of the sample. This additional processing adds time and/or expense to the sample collection and analysis procedures. Similarly, a water sample may be analyzed for different forms of phosphorus and nitrogen, but given the nutrient cycling that occurs in the stream, it may be most important to understand the total quantity of these nutrients present. Therefore, if budget constraints demand that only one form of each nutrient be monitored, ASCE and USEPA recommend monitoring for total phosphorus and total nitrogen (ASCE and USEPA, 2009).

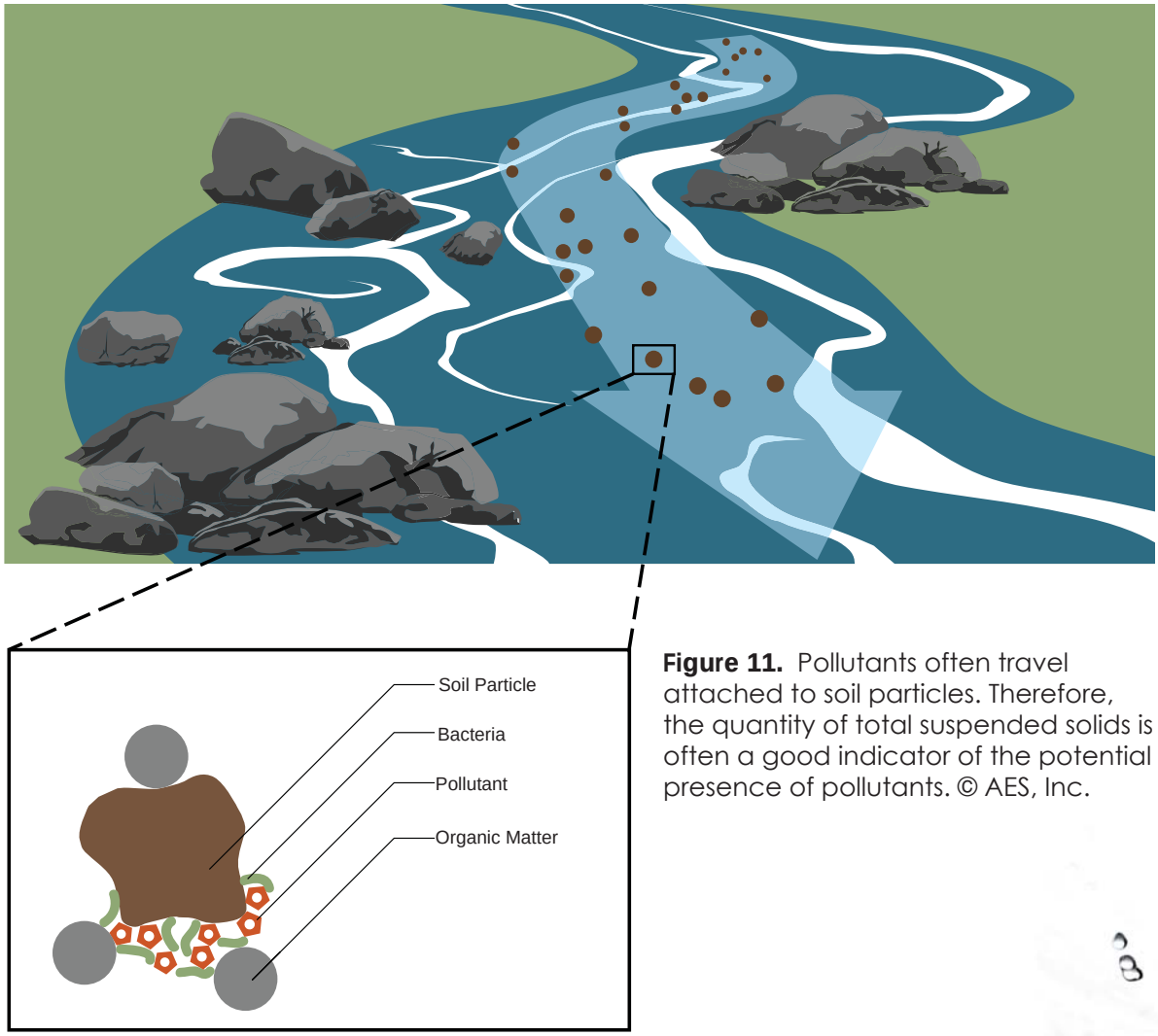


Figure 11. Pollutants often travel attached to soil particles. Therefore, the quantity of total suspended solids is often a good indicator of the potential presence of pollutants. © AES, Inc.

If it is difficult to narrow down the selection of pollutants to monitor, another option is to conduct initial screening tests in which stormwater from the site is tested for a large number of pollutants but only for a few storms. The results of these screening tests may help the investigator identify which pollutants are most significant for the particular site.

PARAMETER	UNITS	TARGET DETECTION LIMIT
Conventional		
pH	pH	N/A
Turbidity	mg/L	4
Total Suspended Solids	mg/L	4
Total Hardness	mg/L	5
Chloride	mg/L	1
Bacteria		
Fecal Coliform	MPN/100ml	2
Total Coliform	MPN/100ml	2
Enterococci	MPN/100ml	2
Nutrients		
Orthophosphate	mg/L	.05
Phosphorus- Total	mg/L	.05
Total Kjeldahl Nitrogen (TKN)	mg/L	.3
Nitrate- N	mg/L	.1
Metals- Total Recoverable		
Total Recoverable Digestion	µg/L	.02
Cadmium	µg/L	1
Copper	µg/L	1
Lead	µg/L	5
Zinc		
Metals- Dissolved		
Filtration/ Digestion	µg/L	.02
Cadmium	µg/L	1
Copper	µg/L	1
Lead	µg/L	5
Zinc		
Organics		
Organophosphate Pesticides	µg/L	.05-.2

Table 1. Parameters identified by ASCE and USEPA as typical pollutants for urban runoff monitoring programs.

It also is useful to know what other agencies and researchers have identified as key pollutants to monitor. Table 1 shows the parameters that ASCE and USEPA have identified as typical pollutants for urban

runoff monitoring programs (ASCE and USEPA, 2002). The International Stormwater BMP Database and the National Stormwater Quality Database give good ideas regarding what other researchers are monitoring.

Water Quantity

In addition to water quality measurements, it is likely that the monitoring objectives will necessitate evaluation of water quantity. Because increased impervious area associated with development tends to reduce infiltration of water and increase the volume and peak flow rates of surface runoff, stormwater systems should be designed to minimize these impacts. If the monitoring objective is to assess the extent to which the system meets that objective, it will be important to monitor the flow at some locations. Indeed, ASCE and USEPA (2009) went so far as to say that low impact development studies without appropriate hydrologic and hydraulic monitoring components are of little value.

If assessment of hydrologic performance of the system is not an objective, it still may be worthwhile to collect flow data. Because pollutant measurements will only give you concentrations of the pollutant, estimates of flow are needed to determine the total amount of the pollutant passing by the monitoring location for that event. Measurements of the flow rates will provide the most accurate assessment of the total pollutant load, though some investigators estimate flows through use of hydrologic and hydraulic models.

Monitoring objectives may also require that other components of the water balance be quantified for a site, including evapotranspiration and infiltration. These may be important if the monitoring objectives demand details on these components of the hydrologic cycle or if the investigator needs to verify the accuracy of the surface flow determined by conducting a full water balance analysis. However, since these parameters are not commonly monitored, they will not be further described here. Information on estimating infiltration and evapotranspiration directly is included in several references (ASCE and USEPA, 2009 and Burton and Pitt, 2002).

EXAMPLE

As mentioned previously, the stormwater runoff characteristics that were selected as most relevant were flow, total suspended solids (TSS), total phosphorus and chloride. To minimize laboratory costs and to obtain semi-continuous data using an unattended probe with a datalogger, turbidity was selected as a potential surrogate for TSS and conductivity was selected as a potential surrogate for chloride. In selecting these surrogate parameters, the project team hoped that with laboratory analysis of some of the samples for chloride and total suspended solids, it might be able to derive defensible relationships between the surrogate parameters and the laboratory results. This would allow them to estimate chloride and TSS

EXAMPLE CONT.

from the conductivity and turbidity data, respectively, for runoff when samples were not collected. Finally, because dissolved oxygen, temperature, and pH are good general indicators of water quality and biologic activity that can be monitored fairly easily and continuously using unattended probes, the project team decided to monitor those parameters as well.

The final list of parameters to be monitored at each site was:

1. flow
2. total phosphorus
3. turbidity
4. conductivity
5. dissolved oxygen
6. temperature
7. pH
8. total suspended solids (for select samples to calibrate the turbidity estimate)
9. chloride (for select samples to calibrate the turbidity estimate)

Additionally, rainfall monitoring was identified as important because there was not a reliable weather monitoring station sufficiently close to the site. Because the reference watershed and the evaluated watershed were adjacent, only one rainfall monitoring location was required and it was placed approximately midway between the two outfalls locations.

2.5 Recommended Technologies Available to Assess Parameters

After selecting the parameters that are most critical for meeting the program objectives, the investigator will need to select the methods of obtaining the data desired. The choice of the specific methods used will depend on the precision necessary to meet the monitoring objectives, available budget, and personnel available to do the work.

2.5.1 Rainfall

As part of any hydrologic performance study, accurate rainfall data is necessary for the watershed being monitored. It is highly recommended that a rain gauge be operated within the watershed being monitored, though if the budget is small and there is a rain gauge nearby, that may be sufficient. There are a few different pieces of equipment to consider for collecting rainfall records.

The most commonly used types are tipping bucket gauges (Figure 13) and simple manual gauges (Figure 12). Manual gauges range from the inexpensive hardware store variety to standard rain gauges with greater capacity, precision, and durability. The primary disadvantage to all manual gauges is that, due to the need to read them manually, they are not very conducive to obtaining hourly or more frequent rainfall data. Also, rainfall amounts should be recorded as soon after a storm as possible (daily readings at a minimum) to avoid losses due to evaporation. Because hourly distribution of rainfall is important information when assessing the performance of a system, these types of gauges are best used in conjunction with hourly data obtained at a nearby station. The total volume of the rainfall collected within the manual rain gauge can be compared with the total volume of rainfall measured at the hourly station to determine if the watershed near the manual gauge experienced a similar storm to the one measured at the hourly station. There is no guarantee that the distribution was the same but at least the Investigator can be confident that the total magnitudes were comparable.

Figure 12. Manual rain gauge. Photo courtesy: LaMotte Company.

For determining more detailed rainfall distribution data than is practical using a manual gauge, the most commonly used instrument is a tipping bucket gauge with a datalogger. The tipping bucket functions by allowing a tiny "bucket" fill with rain. When full to the set volume, typically 0.01 inches, it tips. The datalogger records the time of each tip, thereby obtaining a complete distribution of the storm. A disadvantage of tipping bucket gauges is that they have a tendency to underestimate very intense storms, due to the mechanics by which they function. A second disadvantage is that they do not work well in freezing conditions. To ensure that any problems in the function of the gauge are identified, it is best to install a manual gauge near the tipping bucket gauge to verify that the total rainfall for a period as determined by the tipping bucket gauge is the same as the total rainfall collected in the manual gauge.

Figure 13. Tipping bucket rain gauge. © Global Water Instrumentation, Inc – A Nova Analytics Company.

Less commonly used instruments for stormwater monitoring rainfall data collection are weighing rain gauges and optical rain gauges. Weighing

rain gauges measure rainfall by periodically weighing the water that has been collected in a bucket. They do not have the tendency to underestimate intense rainfall amounts and can be operated in freezing conditions, but they typically are more expensive than the tipping buckets. The optical rain gauge is a newer device, which uses a laser and measurement of light scatter when rain passes through the laser beam.

Regardless of the rain gauge chosen, manufacturer's instructions must be carefully followed to ensure the highest possible data quality.

DEVICE	TYPICAL USE
Manual rain gauge	In conjunction with off-site continuous rainfall data instrument to verify results closer to monitoring location
Tipping bucket rain gauge	For continuous rainfall distribution record where freezing is not a concern
Weighing rain gauge	Continuous rainfall distribution record
Optical rain gauge	Continuous rainfall distribution record

2.5.2 Flow Measurements

As mentioned previously, flow rate analysis is important for assessing the impact that a stormwater system has on the hydrologic regime of the site and for calculating total pollutant loads from the concentration data gathered. There are a number of ways in which flow is monitored in stormwater, but the most common methods measure water depth and use a derived stage-discharge relationship to determine the flow.

The most precise methods of determining flow from depth data for flow quantities typical in stormwater treatment systems is by passing the flow through a flume (Figure 14) or over a weir (Figure 15), measuring the depth of flow, and using a calibrated stage-discharge relationship to determine the flow. For flumes that are designed for flow monitoring, the manufacturer provides the stage discharge relationship. Each flume is rated for a limited range of flows, so the investigator needs to determine the anticipated range of flows that the device will need to convey.

For weirs, the depth-flow relationship may be available from the manufacturer or may be calculated from standard weir flow equations as presented in any hydraulics text. However, in using a weir to determine flow, it is critical that water falls freely over the weir and is not backed up on the downstream side of the weir. Use of a weir to determine flow is particularly convenient when it has been installed as an outlet control device from a stormwater treatment element. Even if a separate weir needs to be installed for flow measurement, weirs are typically less expensive than flumes. However, flumes are reported to require less maintenance and less loss in elevation to avoid backwater effects (ASCE and USEPA, 2009).

Figure 14. Flume. © Global Water Instrumentation, Inc – A Nova Analytics Company.

Figure 15. Weir. © AES, Inc.

If the monitoring location is a channel, swale, or pipe where it is not practical to install a flume or weir, it is possible to estimate flow using standard hydraulic relationships, such as Manning's equation. This method requires data on cross section shape, channel slope, channel material, and depth of flow and is described in hydraulics texts. However, simple hydraulic relationships are only applicable when flows do not vary much over time and the depth does not vary along the channel reach that is assessed. Such conditions are not consistently satisfied for storm flows through channels, but the flow predicted by this method may provide a reasonable estimate if there are no backwater effects and the channel is straight with a consistent slope and cross section for long distance. Some have suggested as a rule of thumb that this distance be a minimum of 20 channel diameters (ASCE and USEPA, 2009). This is the least accurate method of the techniques presented here. Therefore, it is very important that calibration studies be conducted when classic hydraulic relationships are used for channel flow measurements. To ensure that an appropriate relationship is used, it is best to seek the advice of a hydrologist or water resources engineer if using this method.

For all of the methods discussed above, flow is determined as a function of the water depth, which must be determined by at least one of several methods. Depth can be determined manually using a rod placed either temporarily or permanently in the water. Because most studies require frequent readings over long periods of time, this method is often not practical as the primary depth measuring device. More often an automated meter with a data logger is installed to record continuous depth data. Several such instruments are available that utilize different mechanisms for determining depth. The most commonly used are bubbler flow meters, pressure transducers, and ultrasonic sensors. Several of the multi-parameter probes discussed in Section 2.5.3, can include depth sensors that allow calculation of flow.

Some of the meters available also measure velocity, allowing for a direct calculation of flow as the product of the cross sectional area and velocity without use of a flume or weir. If a velocity meter is used, the only data necessary for the monitoring location is the relationship between depth and cross sectional area of the flow.

It is important to periodically calibrate all instruments according to the manufacturer's instructions. In addition, it is a good idea to run a flow calibration test at the monitoring site. The most recommended method of doing so is by conducting a tracer study. In a tracer study, a harmless but detectable and distinguishable solution is injected into the flow. Downstream samples are collected and analyzed at prescribed intervals to determine the tracer concentration in the stream over time. The flow rate is then determined using dilution relationships. A number of different tracers are available, but not all are well suited for surface water investigations due to degradation by sunlight. Tracers that are stable in sunlight include Rhodamine B and Rhodamine WT, with the latter being superior due to the tendency for Rhodamine B to leave the water column by adsorbing to sediments that settle. Samples collected downstream of the injection may either be taken to a laboratory for analysis or may be analyzed in the field. While field analytical units are relatively expensive to purchase, particularly given that they are only periodically used for calibration, the instruments may also be rented. Additionally, many of the multiparameter probes available have optional sensors for Rhodamine that would allow for relatively easy flow calibration if a multiparameter probe is proposed for the monitoring study.

DEVICE	TYPICAL USE
Weir	For flow determination in conjunction with depth monitoring device
Flume	For flow determination in conjunction with depth monitoring device; smaller elevation drop typically required than for weir
Depth meter with data logger	Used in conjunction with an established depth – flow relationship obtained using either a weir, flume or Manning's equation
Depth and velocity meter with data logger	Used without flume or weir for direct calculation of flow
Tracer detection meter	For flow calibration tests with specified tracer solution

For larger flows in a channel, it may also be feasible to run calibration tests using a velocity meter. However, since most site level analyses will not have large enough flows to monitor using this method, it is not further discussed here. For more discussion on use of flow meters to monitor and calibrate stream flows see Burton and Pitt (2002).

Note that all of the flow measuring methods described require a concentrated flow stream. None of the methods address the situation

prevalent in many conservation oriented developments where stormwater treatment is dispersed and sheet flow across buffer strips is common. To measure such flows, it would be necessary to collect sheet flow at the base of the buffer strip and concentrate the flows in a swale. If this is not desirable, the investigator may need to estimate flows at that point in the treatment system through modeling methods rather than direct measuring.

2.5.3 Water Quality Monitoring

Many stormwater monitoring objectives address pollutants associated with stormwater runoff. If pollutant parameters or proxy parameters for these pollutants have been selected for monitoring, there are several options for collecting and analyzing them.

Probes

Several probes are available that can rapidly provide in-situ water quality data in the field by simply placing the probe in the water and taking a reading. Due to the efficiency of the probes, the cost of these instruments is considerably less than the cost associated with obtaining similar data through laboratory analysis of individual samples. Probes are currently available that can measure dissolved oxygen, pH, temperature, depth, conductivity, oxidation/reduction potential, turbidity, salinity, nitrate, ammonia, chloride, blue green algae, chlorophyll, and Rhodamine. Simple hand held probes are available to measure single parameters. More complex instruments have been developed (Figure 16) with multiple probes (Figure 17) and have data logging capacities built into the unit that allows nearly continuous, unattended monitoring of multiple parameters. The efficiency associated with these instruments makes them very useful and has inspired continual advancements in the technology available. However, some of the ion selective electrodes, such as those used for nitrate, ammonia, and chloride have been given mixed reviews at best, and probably should not be relied upon for extended unattended deployment.

Figure 16. Professional Plus handheld multi-parameter instrument. Photo courtesy: YSI, Inc.

Remote communication systems are also available for these units that allow investigators to download the data collected anytime from any computer, without the need to go out to the site. This can be quite

beneficial when the project site is located far from the office. It is also helpful in ensuring that any problems in the operation of the device are identified and addressed quickly before too much time has elapsed without gathering good data. For example, if a critter decides to take up residence inside the protective casing for the instrument and gets past all of the security measures designed to keep it out, its living arrangements could send the readings outside of the normal ranges and result in data that is not reflective of the flow that should be monitored. If the investigator is checking on the instrument remotely in between maintenance trips, she or he would see this abrupt change in the parameter readings and would know to go out to the site and address the problem.

Figure 17. Quatro Cable, multi-parameter probe. Photo courtesy: YSI, Inc.

Many of the parameters for which probes are available are not pollutants, but rather indicator or proxy parameters. Therefore, without additional information about pollutants, other watershed influences on water quality, and a deep understanding of the biological and chemical processes that affect water quality the data obtained from these units may be difficult to interpret. However, published ranges of the values for these parameters in natural waters are available and can be used as a starting point for data interpretation.

DEVICE	TYPICAL USE
Single parameter hand held probe	Manual nearly instant assessment of a variety of pollutant parameters
Multi-parameter probe with datalogger	Automatic, unattended, semi-continuous data collection and storage

Sample Collection

For pollutant parameters for which probes do not exist, more labor intensive means are required for collecting and analyzing the samples. Samples can be collected either manually or using an automated sampler. They may be collected to represent a single point in time or they may be composited to represent conditions over a given duration.

A "grab" sample is a sample that is collected nearly instantaneously at a single location. Due to this collection method, the quality of that sample is representative of the quality of the water sampled only at that single time and place. Grab samples are easy to collect and often require no special equipment other than the sample bottle. Data obtained from grab samples can be important for assessing potential acute toxicity,

particularly if the timing of the sample collection coincides with the peak concentration of runoff. However, it is important to keep in mind that water quality in flowing water can change quickly, so grab samples typically are not representative of water quality over an entire storm and certainly are not representative of the quality of water that is discharged between weekly or monthly samples.

To better represent average water quality over the course of a storm, "composite" samples can be obtained. Composite samples are made by mixing small portions of sample water collected over the duration of the runoff event to create one sample.

The amount of each sample to be added to the mixed composite is determined based on either a time-weighted or flow-weighted approach. For the time-weighted approach, an equal amount of sample is added for each equal interval of time that passes between each sample collection. As an example, if the investigator sampled a 12 hr runoff event by collecting one sample at the same time of every hour, say at 2:14, 3:14, 4:14, 5:14, etc., the time-weighted composite would be made by taking an equal amount from each of those samples, say 100 mL, and combining them all into one container, for a total of 1200 mL.

For the flow-weighted approach, the amount of each sample added to the composite is determined in proportion to the flow rate at the time of collection. As an example, if the investigator collected samples each hour during a 5 hour runoff event, and the flow at the times the samples were collected were 1 cfs, 3 cfs, 7 cfs, 5 cfs, and 2 cfs respectively, a flow weighted composite could be made by combining 100 mL of the first sample, 300 mL of the second sample, 700 mL from the third sample, 500 mL from the fourth sample and 200 mL from that last sample for a total composite sample of 1800 mL. Although the flow-weighted approach can be more challenging to implement, it gives the best estimate of the average quality over the course of the storm event. Automatic sampling equipment (Figure 18) is very useful in collecting composite samples and some instruments can be synchronized with depth measuring devices to automate the flow-weighted composite. See ASCE and USEPA (2009) for a more detailed discussion of time-weighted and flow weighted compositing approaches.

Figure 18. Automatic sampler installed near outlet pipe. © AES, Inc.

For parameters that are volatile (such as volatile organic compounds and residual chlorine) or for parameters that may stick to the sampling

container (such as oil and grease), mixing a composite sample is not advised. If an average concentration of any of these parameters is desired over the duration of a storm runoff event, it is recommended that a series of samples be collected at recorded times and each sample be analyzed separately. The average concentration and/or pollutant load over the entire storm can be calculated from the individual sample concentrations and the flows during the time each sample was collected.

As mentioned above, instruments are available that automatically collect samples at a given time interval and or when triggered by various flow rates (Figure 19). These devices are quite useful for collecting multiple samples over the course of an event, as may be necessary if the monitoring objective include assessing average and/or peak pollutant concentrations during a storm event or characterizing pollutant concentration changes during an event. Automatic samplers are also very useful in any situation in which the investigator may not be able to run out to the site based on a weather forecast and wait for the storm runoff to begin and end.

Figure 19. Automatic flow sampling system. © Global Water Instrumentation, Inc – A Nova Analytics Company.

The alternative to using automatic samplers is collecting samples manually, which has lower capital costs than use of an automatic sampler, but typically has higher labor costs, particularly when multiple samples are collected over the course of the storm event. To sample a reasonable number of storm runoff events in a season, extreme flexibility is required on the part of the sampler to get out to the site before runoff begins and stay on the site long enough to collect enough samples to adequately characterize the runoff event. If such flexibility is possible, an advantage to manual sampling is assurance that the samples were collected. Some investigators have reported problems with the automatic flow trigger devices that resulted in missed samples. Additionally, the automation does not remove the manual operation entirely. An investigator will still need to visit the site soon after each event to ensure that samples are adequately preserved and delivered to the laboratory within the acceptable time frame. Some of the samplers are available with refrigeration, and ice can be added to other samplers, to temporarily preserve the samples. However, even on ice, the hold time is limited, and requires quick response time to deliver to the laboratory.

A final constraint regarding automatic samplers is that most of them can not adequately collect samples to be analyzed for volatile pollutants, due to the disturbance of the sample that occurs when pumping and filling sample bottles. Therefore, if volatile organic compounds (VOCs) or residual chlorine monitoring is desired, these samples may need to be collected by hand. There is at least one automatic sampler available that utilizes different pumping techniques that do allow for volatile compound analysis.

Collection of samples of sheet flow can be particularly challenging, either manually or with an automatic sampler, due to the very shallow water associated with sheet flow. For sheet flows across paved surfaces, water may be deep enough to collect a sample using a hand pump, but sheet flow across lawns and buffer strips typically are not amenable to such collection methods. For sampling flows across lawns or buffers strips, researchers have developed creative systems that capture water in a container. One such system, described by Bannerman, et al. (2003), includes pipes that can intercept flow along a slope using piping materials and direct this runoff water to a central container placed in a hole. There is also a commercially available product from Vortox that collects sheet flow runoff samples.

EXAMPLE

The project team needed to identify equipment necessary to monitor the parameters identified previously. To measure rainfall, one tipping bucket gauge was selected for placement approximately midway between the two monitoring locations. To monitor flow, the project team decided it would develop a stage discharge relationship for the existing outlet control device at the treatment wetland outlet and install a calibrated flume near the end of the drainage way at the reference watershed. Each of these devices would be paired with a depth sensor and data logger. To calibrate the stage discharge relationship for the weir, the team decided to conduct a few tracer tests using Rhodamine WT and a field detection unit. To monitor total phosphorus for all events and TSS and chloride for a portion of the events, they decided to install a programmable automatic sampler at each location that can collect flow weighted samples.

To continuously monitor turbidity, conductivity, dissolved oxygen, temperature and pH, multi-parameter probes with data logging capacity were selected for installation at each of the outfall locations. The team was aware that some of the membranes on these probes would need to remain moist. During the planning stage, they developed ideas for meeting that installation challenge, and decided to install the probe for the developed watershed in the final wetland cell very close to the outlet structure. For the reference water, they anticipated needing to construct a small pooled area that would hold water in between runoff events.

Sample Analysis

After the sample has been collected, there are a few options regarding analysis of the sample. The samples can either be preserved and transported to a laboratory or they can be analyzed in the field using one of the field measurement devices available.

Laboratory analysis offers several advantages and disadvantages. In laboratories, use of very sensitive instruments results in detection of lower levels of pollutants with greater accuracy and precision than is often possible with field tests. Also, laboratories typically follow well documented QA/QC protocols that satisfy stringent data quality objectives. However, the need to properly preserve and deliver samples to the laboratory quickly enough to satisfy handling requirements can be inconvenient. There are delays associated with receiving results of the analysis, and the costs of laboratory analysis can become excessive when data for large numbers of samples and or analytes is needed. If the investigator does decide to use laboratory analysis, it is important to coordinate closely with the laboratory well in advance of sample collection to ensure that the proper sample bottles and preservation techniques are utilized, to ensure that the proper chain of custody forms are obtained and completed correctly, and to ensure that the laboratory will have personnel available to receive the samples at the time when the investigator drops them off.

Although less accuracy is possible with most field analysis methods, the convenience of obtaining results instantly and the ability to resample and rerun the test if results are questionable make field analytical procedures useful

Figure 20. Test papers. Photo courtesy: LaMotte Company.

Figure 21. SMART 2 multi-test colorimeter. Photo courtesy: LaMotte Company.

for some purposes. They are particularly useful for screening level data collection.

Field tests range in complexity from simple visual color comparison tests, such as using pH paper (Figure 20)or adding prescribed reagents to a sample and comparing the resulting color to a color wheel, to analyses that utilize similar procedures and instruments to those used in laboratories, such as spectrophotometers. The most simple color comparison tests typically do not require any electronic equipment, or major capital investments. Individual parameter kits that include reagents necessary for a specified number of tests (typically 100 – 300 tests) are available from companies including LaMotte and Hach and typically cost less than a couple of dollars per test. Many of these tests have low precision, but can be useful as screening tools. Better precision is available with the purchase of a colorimeter (Figure 21), which more accurately measures the color intensity that results from similar reagent additions as those used in the color wheel comparisons. Other non-colorimetric test kits are available for other parameters including organic compounds and bacteria.

Figure 22. PhotoLab portable spectrophotometer. © WTW – A Nova Analytics Company.

At the complex end of the field test range, portable spectrophotometers are available that are essentially small versions of the equipment utilized in the laboratory. With the correct reagents, this instrument can be used to analyze a wide variety of parameters including organics, metals, and macro-nutrients. When deciding whether to invest in a sophisticated field monitoring instrument, such as a portable spectrophotometer (Figure 22), it is important to consider labor costs, in addition to the capital investment of the instrument and operating costs. Testing individual samples in the field is much more labor intensive than at a laboratory because in a laboratory, tests are done on batches of samples at one time which dramatically increases efficiency.

Before purchasing any field test kits confirm that the expected concentration of the pollutant parameter in your monitoring study is within the sensitivity range of the test. Some of the tests are more appropriate for measuring concentration of wastewater, so concentrations in surface waters may be too small to determine with any precision. For example, if choosing between a phosphorus test with a range of 1.0 to 100 mg/L and one with a range of 0.05 to 5 mg/L, the latter should be more effective for stormwater monitoring. Further, if you are out in the field monitoring and you find that the sample has a higher concentration of the pollutant than the

test range can determine, it is possible to dilute the sample with deionized water such that it is within the range of the test.
Another important consideration when choosing a field kit is any special handling requirements associated with the reagents used in the test. Some of the reagents used for some tests are hazardous, so it is important to review the reagents and any handling and disposal requirements in assessing the extent to which the method is logistically feasible and cost effective.

Emerging Technologies

The state of the science in water quality monitoring is continuously evolving. Instruments are upgraded with improvements over previous models regularly, and new technologies are always in development. With cellular technology, more remote communication is possible with unattended devices than ever before. These new advances can dramatically change the time and costs associated with particular monitoring approaches. Therefore, it is worth reading reviews of new instruments as they are unveiled and improved. Some of the most exciting developments for stormwater monitoring are with in situ continuous probes. When the ion selective probes currently available are further improved, they will offer exciting opportunities to collect continuous data regarding several important pollutants. Due to the efficiency of such tools, and their unmatched ability to collect semi-continuous data, there is also interest and research into developing in situ probes that can take readings on heavy metals, which are significant concerns in urban stormwater. Another pollutant of great interest for which no continuous monitoring device exists is phosphorus. Development of better technologies for monitoring this pollutant will be an important milestone in stormwater monitoring science.

2.6 Quality Assurance and Quality Control

Before beginning to collect stormwater monitoring data, it is very useful to spend time thinking about and drafting a clear quality assurance and quality control (QA/QC) plan. Developing and discussing a QA/QC plan with the whole project team can save a lot of time and money by ensuring that all data collected is usable for the purposes desired. The plan should include background general information, including a project description and project goals and objectives, as well as more detailed information regarding the criteria for storms to be sampled, specific sample collection methods, analytical methods, calibration techniques and requirements for each monitoring method, and training required for personnel involved.

It is very useful to identify the many ways in which error can be introduced into the monitoring data collection and analysis procedures and specify steps that will be taken to minimize the risk and severity of such errors. There are many common errors that should be considered, including failure to collect a representative sample or sample contamination, particularly during very low flows, improper calibration of instruments, improper use of field test kits, failure to properly preserve and deliver samples to laboratory

on time, failure to take good notes during the sample collection and analysis, and improper data entry into the data storage and analysis process. In developing the project QA/QC plan, these and other potential error sources should be addressed. For more information on QA/QC plans, see ASCE and USEPA (2002) and CWP (2008).

2.7 Budgeting

The final step in the monitoring plan development is double checking to ensure that the plan can be implemented within the budget constraints of the project. In performing this check, the investigator should identify all purchase or rental costs for each piece of equipment proposed, as well as the cost of any solutions required to calibrate, operate and maintain the equipment. Estimates of some of these equipment costs are summarized in Appendix A. Costs associated with securing and protecting any instruments from vandalism need to be determined for any equipment that is deployed and left unattended. Laboratory analytical costs should be identified and included in the estimate.

Perhaps the most difficult component of the budget to estimate is the labor costs associated with planning, training, calibrating and maintaining instruments, collecting samples, and analyzing them or delivering them to the laboratory. In the implementation of the plan, many things will not go according to plan, regardless of how carefully the plan was developed. There will be several times when the field sampling team is mobilized in anticipation of a storm event, but ultimately the storm is not significant to satisfy the storm criteria identified in the plan. Therefore, the time spent results in no useful data. The extent to which this occurs depends on the stringency of the storm criteria. Some researchers have recommended planning to collect twice as many samples as are needed to meet monitoring objectives when establishing the project budget (CWP, 2008). Likewise, it is important to consider staff changes over the course of the project that would increase the time and expense required for training. Unless conservative estimates are used, the time associated with implementation is often underestimated.

EXAMPLE

The project team estimated the following equipment, laboratory, and labor costs for the study described (Table 2):

DEVICE	UNIT COST	NUMBER	COST
Multi-parameter probe with data logger, cables, and calibration solutions	$8500	2	$17,000
Automatic sampler	$6500	2	$13,000
Flume	$1500	1	$1500
Depth sensor with data logger	$2000	2	$4000
Rain gauge with data logger	$800	1	$800
Construction materials for security features	$400	N/A	$400
Flow tracer study solutions and detection unit rental	$2500/mo	1	$2500
Laboratory analyses - phosphorus	$50	50 samples	$2500
Laboratory analyses – TSS and chloride	$40	20 samples	$800
Labor	$80/hr	800hrs	$64,000
TOTAL			**$106,500**

Table 2. Example cost table.

3.0 Implementing the Monitoring Plan

If the monitoring plan has been well thought through, implementing that plan should be relatively straightforward. Of course, not everything will go according to plan, but having thought through as many of the potential snags as possible during the planning process will certainly help. The implementation guidance provided here is relevant to individual element monitoring as well as complex site monitoring.

3.1 Field Notes and Data Management

It is important to obtain a field notebook that will be used exclusively for the monitoring study. Diligent notes should be taken that document all site conditions as well as the conditions at each monitoring location observed during each site visit. It is common practice for separate field books to be maintained for each separate instrument used, particularly if the instrument lasts longer than one study. If this is the case, instrument calibration data should be included in the instrument book, and the notebook used for the particular study must contain sufficient data to be able to easily find the calibration data. Weather conditions, time of day, water observations including relative clarity, color, depth and/or odor, instrument status, changes in watershed land use or activities, challenges or ease associated with sample collection and instrument maintenance should be noted for each visit. Photos should also be taken to document conditions. The more observant and detailed in note taking that the investigator is, the easier it will be to understand the results of the analyses and/or any outlying data later. When monitoring locations are established on the site, each location should be photographed, described and located with a global positioning system (GPS) where appropriate (Figure 23).

Figure 23. GPS and photo documenting the monitoring location. © AES, Inc.

3.2 Monitoring Training

The first step in implementing the stormwater monitoring program is to provide training for all individuals involved. Each person that is expected to participate in the program should be given a copy of

the monitoring plan, and a health and safety plan that includes safety guidelines for the monitoring activities as well as directions to the emergency medical facilities nearest the project site. Individuals that will be utilizing instruments in the field need to be provided training on proper calibration, maintenance and use of those instruments, as well as the protocol for properly documenting instrument use in the field notebook. If laboratory analysis is proposed, sample collectors need to be provided explicit instruction on the proper methods for collecting, labeling, preserving, and delivering samples. These instructions can be obtained from the laboratory that will be conducting the analysis. All procedures that will be performed in the field as part of the study should be performed in advance with instructors present. If possible, it is best to conduct this field training on an actual site that will be monitored to make the training as relevant as possible.

Figure 24. Field Training. © AES, Inc.

3.3 Permission Acquisition

Prior to collecting any samples or installing any equipment, the individuals that will be on site need to ensure that they have permission to access all of the sampling locations and permission to cross any lands necessary to reach those locations. Permission should also be obtained for any equipment that is installed and left unattended. Copies of the written permission forms should be on hand whenever a member of the field team is on the site. If securing instruments in the field requires placement of materials in waters regulated by the federal or state agencies, it is important to consult with the US Army Corps of Engineers as well as state natural resource agencies to ensure that all federal, state and local requirements are satisfied.

Figure 25. State and federal agencies have regulatory authority over most water bodies, including wetlands. © AES, Inc.

3.4 Deploying Automatic Instruments

Automatic probes that are deployed and left unattended in the field should be installed at least a few weeks before the project data collection is required. Installation of equipment prior to initiating the monitoring study allows the investigator to test for equipment failures, make placement adjustments as necessary, or detect errors associated with installation technique. Some of the membranes used in probes must remain moist, and therefore, the investigator will need to ensure that the probe remains submerged, even during periods of no rain. This can be a challenge at some sites and may require creating artificial pools that will hold water between rain events. Such artificial conditions should be considered when reviewing and interpreting data collected during periods of low or no flow.

All instruments should be installed and calibrated according to the manufacturers' instructions. Before leaving the office to deploy these instruments, it is important to go through the installation and calibration instructions to ensure that all necessary reagents, accessories, and tools are on hand in the field to properly install them. After deployment, these instruments should be inspected and maintained regularly according to the manufacturers' suggestions. In the beginning, it is recommended that inspections be made more frequently to ensure that errors associated with installation or choice of monitoring location are corrected quickly.

If automatic sample collection devices are being utilized, it is important to install them at least a few storm events prior to the first anticipated monitored event. This will provide the opportunity to ensure that the automatic trigger is set properly, is sensitive enough to begin collecting samples at the beginning of the runoff event, and continues to collect samples through the runoff event according to the protocol developed. When sampling begins, be sure to follow both the manufacturers' instructions and the laboratory instructions to ensure that the proper bottles are used, samples are preserved, and samples are delivered on time. Before delivering samples to the laboratory, confirm that the rain gauge shows that the storm event satisfied the criteria established and that the samples were collected at times that encompass the full runoff event as intended. If the storm event does not meet the criteria or the samples do not cover the duration of the runoff event, any sample bottles that were filled should be emptied and replaced with clean bottles. The contaminated bottles must be cleaned before they can be reused.

3.5 Manual Sampling

Implementing the manual sampling components of the stormwater monitoring program requires diligent weather watching and flexibility to mobilize quickly. There is judgment and risk involved in predicting whether or not an approaching storm system will result in a sufficiently significant storm to warrant monitoring runoff from it. If the project demands quick results and/or has a more generous budget, the investigator may need to

err on the side of mobilizing for more storms and expecting that more of those efforts will be fruitless due to storm systems that will not produce enough rainfall and runoff to satisfy the minimum criteria. If on the other hand, the project has more time flexibility but a tighter budget, the investigator will want to avoid mobilizing unless there is a very high probability that the storm will be substantial. Of course if the project has a demanding schedule and a tight budget, it may be necessary to revisit the objectives and monitoring plan to determine what needs to change.

If the investigator does decide to mobilize the monitoring team to collect storm samples, it will be important to arrive at the monitoring locations before runoff begins to capture the full range of runoff conditions. If manual sampling is proposed at multiple locations that are more than a few minutes of travel time apart, it will be necessary to have multiple individuals to collect samples at the designated intervals at each location. The laboratory that has been identified to receive and analyze the samples should be contacted when mobilizing to collect the samples to arrange for delivery.

Figure 26. Manual sampling from a canoe. © AES, Inc.

As mentioned in Section 2.1, it is important to have a rain gauge on site to collect accurate rainfall distribution data. If an off site gauge is determined to be close enough to provide accurate distributions, the investigator should have at least a simple manual gauge at the site to confirm that the total quantity of rainfall measured for a storm event by the off site gauge is very close to that measured at the site. To confirm this for each storm event, it is critical that the rain gauge on site be emptied after each event. Therefore, when using a manual rain gauge to confirm values of off site gauges, it is important to visit the site after each event to empty the gauge.

4.0 Analyzing the Study Results

It is sometimes tempting to leave all data review and analysis until the end of the study or at least until the first interim report is due, and it is true that there is significant efficiency associated with focusing on the complete body of data and crunching all numbers at once. However, it is often helpful to begin reviewing and analyzing data early. This can help illuminate any problems that may have been incorporated into the monitoring program design that are best addressed as soon as possible. It can help identify additional parameters that should be monitored or parameters that may be revealed to be less significant and can be eliminated from further study. Therefore, it is best to provide at least a cursory review of the data early and often throughout the study. Regular interim reports are recommended.

4.1 Data Validation

Before entering data into the data management system and analyzing the data, the investigator should review it carefully to ensure that all QA/QC parameters indicate that the data is reliable. All data collected using automated probes should be reviewed with the calibration notes to ensure that the instruments were properly calibrated prior to data collection and that calibration conducted after data collection indicates that the instrument continued to accurately measure the parameter of interest through the extended deployment period. The data should also be reviewed to make sure that all measurements are within the possible range for the instrument and for the water body that is measured. It is common to observe diurnal, or daily, cycles in natural waters for many parameters including dissolved oxygen, pH, and redox potential, particularly when water is relatively calm. This is due to algal and macrophytic processes of photosynthesis during daylight hours and respiration during dark hours.

In validating the flow data gathered using a depth sensor and a weir or flume, the investigator should check to make sure that all depth data falls within the range of calibrated depths for the weir or flume. Any depth data outside that range should be qualified as appropriate based on the different degree of certainty of the stage-discharge relationship outside of the range.

Results of all samples analyzed at a laboratory should be reviewed to ensure that the quality assurance measures undertaken at the laboratory confirm that the results are valid. Specifically, confirm that the duplicate analyses, the method blanks, and the spiked samples all indicate that accuracy and precision are all adequate. If it is unclear what some of these components of the laboratory report mean, contact the laboratory for further explanation and/or review information contained in several documents (ASCE and USEPA, 2002, Burton and Pitt, 2002) regarding laboratory QA/QC protocols.

4.2 Water Quantity Analysis

Many studies have monitoring objectives related to water quantity. In assessing the effects that the stormwater system has on water quantity, it is helpful to plot rainfall distribution and stormwater flow hydrographs on a single graph (Figure 27). If inflow and outflow to a treatment system are both monitored, those flows should both be shown.

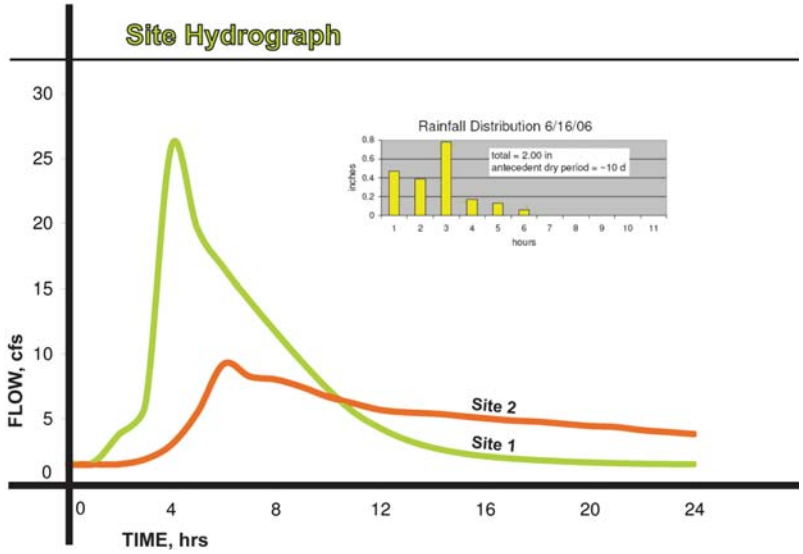


Figure 27. Site Hydrographs

If the system is working properly there should be some reduction in the total area under the outflow hydrograph compared to the inflow hydrograph, representing an overall reduction in total surface runoff and corresponding increase in capture and infiltration. The graph should also illustrate a reduction in the peak of the outflow hydrograph compared to the inflow hydrograph, representing a reduction in the maximum flow rate leaving the site and corresponding reduction in the erosive capacity of the peak flow. The centroid of the outflow hydrograph should also show a shift to the right when compared to that of the inflow hydrograph, and it should have a wider base, indicating that water has been detained and released slowly.

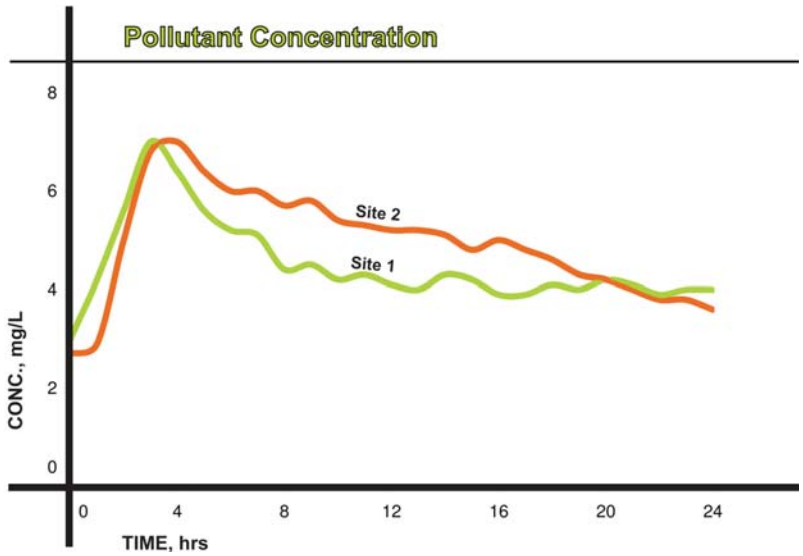


Figure 28. Concentration

If the budget and/or geographic constraints prohibited inflow quantity measurements, it may be worth simulating the runoff hydrograph using standard hydrologic equations, such as those presented in the Natural Resources Conservation Service's TR-55 method and comparing the resulting synthetic hydrograph to those measured at the outlet. Likewise, if the study was designed to compare two different treatment systems' performance for the same rain events, outflow hydrographs

for each system for the same rain event should be plotted together for comparison.

4.3 Recommended Metrics for Reporting

As mentioned in Section 2.2, results of the analysis of samples collected over the course of an individual runoff event can be shown graphically as a plot of the concentration vs. time. This is fairly straightforward, and provides a useful depiction, particularly when graphs of the paired sites are both plotted on the same graph (Figure 28).

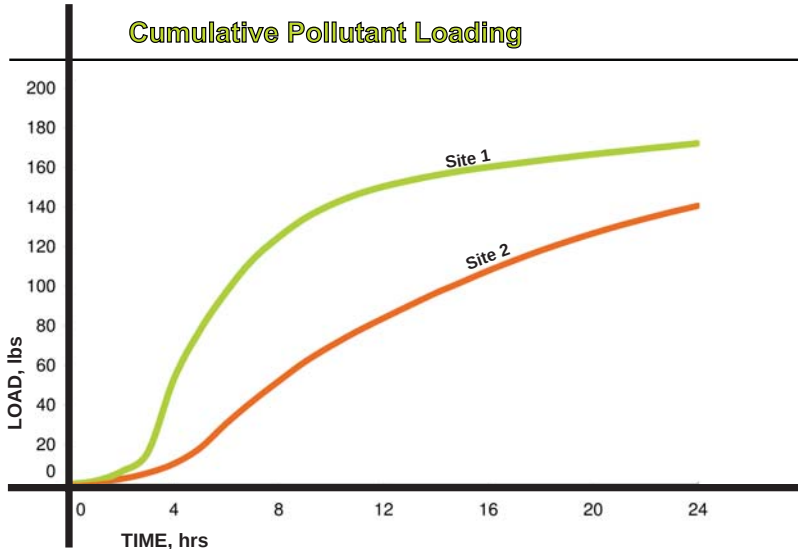


Figure 29. Cumulative Pollutant Loading

This also provides very clear information regarding the peak concentration, which may be important if there are toxicity concerns or other water quality implications for waters immediately downstream of the monitoring location.

The analyst should keep in mind that pollutant concentration and pollutant load are not directly proportional; much more pollution is captured by systems that have significant infiltration than is reflected only by concentration. Figure 29 shows cumulative pollutant load for the same data set as used in Figure 28 and the hydrographs shown in Figure 27.

To evaluate performance over a longer term than a single storm, it is best to compute the event mean concentration (EMC) and/or the pollutant load for each storm. As mentioned previously, flow data is required for both of these analyses. The total pollutant load for a storm event is the mass of the pollutant during a given period of time and is calculated as:

load= ∑ (concentration of sample)*(flow rate at time of sample)*(time interval associated with the sample)

The EMC is a flow weighted average of the concentrations measured over the course of the storm event and is calculated as the total load divided by the total flow volume:

$$EMC = \frac{\text{load}}{\sum \text{(flow rate at time of sample)*(time interval associated with the sample)}}$$

Another parameter that is sometimes reported is the percent removal of a particular pollutant by the treatment system, calculated as the difference between the outlet and inlet concentrations divided by the inlet concentration. However, this metric can be very deceptive. Many reports of high percent removal of a pollutant occur when the inlet concentration is very high (ASCE and USEPA, 2002). The outlet concentration is often comparable but slightly higher than that measured during events with more typical inlet concentrations. A high percent removal value often is more reflective of poor inlet water quality than of performance of the treatment systems; therefore, this metric is not recommended for use in evaluating performance.

4.4 Statistical Analysis

One of the tendencies in analyzing data and reporting study results is to make claims that are not clarified with statistical analysis of the data. For example, somebody might collect a few samples at a developed site with a naturalized stormwater system and at a developed site with a conventional stormwater system, find that the average outlet EMC values were 4 mg/L for the naturalized system and 6 mg/L for the conventional system, and declare that the naturalized system is 33% more effective. However, without providing additional information regarding the sample size, it is not clear how likely it was that the average conditions that were measured reflect the average conditions at all times during each storm, including those that were not sampled. If the average concentrations were based on samples collected during three storms, there is more potential that the calculated average was skewed by an anomalous sample than if 30 storms were sampled. Therefore, it is important to conduct statistical analysis or at a minimum provide enough information in the reporting to allow others to statistically qualify the results. The primary metrics needed to conduct the statistical analysis are the mean, sample size, and standard deviation of the EMC values. These variables are defined as:

sample size = n = total number of storms sampled and validated

EMC mean = $\bar{x} = \frac{\sum_{i=1}^{n} EMC_i}{n}$ **standard deviation** =s = $\sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$ **coefficient of variation** = COV = $s/\bar{x}$

Unless the investigator is well versed in statistics, he or she may become overwhelmed by statistical manipulations, but many of the computations are fairly straightforward, and simple spreadsheet

software (such as Microsoft Excel®) can assist with many of them. Other software packages that specifically perform statistical analyses are also available. A good review of the available software is provided by Burton and Pitt (2002).

If the analyst is not comfortable performing many statistical analyses, at a minimum, he or she should estimate the 95% confidence interval. When the sample set has at least 20 values and the distribution of the data is roughly normal, the 95% confidence interval is approximately the mean plus and minus twice the standard deviation. For example, if the mean effluent concentration of total phosphorus from a treatment system is 0.30 mg/L and the standard deviation is 0.08 mg/L. The 95% confidence interval would be (0.30 – 2*0.08) to (0.30 + 2*0.08) or 0.14 – 0.46 mg/L.

As mentioned previously, if the scatter of the data, as reflected in the standard deviation, is large it may be worth breaking the data into subsets based on the storm characteristics discussed in Section 2.2.

4.5 Compare Results to Monitoring Objectives

The final step in evaluating the results of the monitoring study is revisiting the monitoring objectives identified at the beginning of the study. The statistical analysis performed on the data sets should be used to answer the questions posed. For example, if the objective was to determine whether the quantity of total phosphorus leaving a particular stormwater system was less than that entering system, the paired pollutant load values for inflow and outflow for each storm can be plotted to provide a visual assessment of the performance. The mean and confidence intervals should also be closely examined. If the 95% confidence intervals do not overlap, there is 95% confidence that the difference between the data sets is significant. It is useful to more specifically characterize the level of significance with statistical analysis with appropriate understanding and software. If there is overlap between the confidence intervals, the monitoring team needs to perform additional monitoring and/or additional statistical analysis before making justifiable statements regarding the performance of the system.

4.6 Share Results

To ensure that stormwater management design continues to evolve and improve protection of the public's waters, it is important to share the results of well designed and implemented studies with other engineers, scientists, developers, and designers. Of course, one way to share results is by publishing papers in peer reviewed journals. An easier way to do this is by following protocols of and submitting results to the International Stormwater BMP Database (www.bmpdatabase.org). The International Stormwater BMP Database is an exciting project sponsored by several governmental agencies and professional organizations which began in 1996 as a clearinghouse for monitoring guidance and data. At the time of

publication of this manual, the database contained information on over 300 stormwater management studies. Most of the studies were conducted for single stormwater treatment elements, but there were a few studies that included multiple elements in series. The project partners had also begun establishing guidelines for standardizing data collected to assess low impact development (LID) sites, which will be relevant to the naturalized stormwater systems emphasized in this manual. There are specific data submittal requirements to ensure that the data submitted meets the data quality objectives of the database project. These data requirements should be reviewed during monitoring plan development if submittal to this project is desired.

5.0 Assessing Public Perception

In addition to measuring the performance of a stormwater treatment system in terms of its hydrologic and water quality functions, there is also value in assessing the degree to which the local community embraces the design. The long term viability of a treatment system is sometimes dependent on acceptance by the local residents. If public perception of the stormwater treatment system's functionality and aesthetic is negative, the permanence of such an installation is likely to be jeopardized. Some naturalized stormwater systems might be perceived as "weedy" if careful attention is not paid to plant species selection, and this negative perception can ultimately lead to replacement with a non-native monoculture that may not be as effective at achieving the stormwater and habitat functions desired. It is therefore critical that use of naturalized treatment systems be accompanied by a public education program that emphasizes the values of these systems. It is also important to gauge the public's general like or dislike of the installed system and to assess whether modifications to the stormwater plant species may be necessary.

There are a couple of visual preference assessments that can be carried out to assess public perception. These studies are an especially powerful tool when used prior to designing the system, as they can steer the design in a direction that is compatible with the public's preferences, thereby reducing public discontent with the installation once it is in place. However, they are also a useful tool when used post-design, as they can measure the aesthetic success of the design, determine the amount and type of maintenance needed, and assess whether changes to the public education program are necessary. Because this manual focuses on post-implementation monitoring, post-design public perception studies are likely to be of most relevance to the reader. It is important to note, however, that such studies usually prove most beneficial when used both before and after the design and implementation.

Uses of visual preference assessments:

PRE-DESIGN:
- Can steer the design to meet public expectations and preferences
- Can help define the amount and type of maintenance that will be needed

POST-DESIGN:
- Can reveal the aesthetic success of the design
- Can evaluate the current maintenance measures
- Can assess the efficacy of the current public education programs

5.1 Public Perception

One way we make sense of what we see is by reading and interpreting

the visual data we observe. These data are made up of form, content, and organization (Kaplan, 1989). Precedent studies describing the aesthetic impacts of naturalized systems on the public's perception of system's healthiness or design intent are well known (Gobster, 1993; Nassauer, 1992). Stormwater systems are often viewed more favorably, particularly regarding cleanliness, durability, and scientific justification, when the engineering components or man-madeness are readily observed or known (Achiam, 2002). Naturalized systems, in contrast are often perceived as unattractive, uncontrolled, and/or unreliable. This perception seems to have little to do with ecological function or efficiency and appears to be rooted strictly in the system's aesthetic appearance.

Aesthetic value is based on how easily we can interpret the intent, pattern, and content of a system. Interpretation is influenced by our level of familiarity, by what we know intrinsically and extrinsically, and can be further differentiated by experiences as well as inadvertent or directed learning.

Figure 30. Conventional, manicured detention basin. © AES, Inc.

Figure 31. Naturalized detention basin. © AES, Inc.

The design, installation, and maintenance of naturalized stormwater strategies, as well as the level of education of the public regarding such strategies, directly contribute to public acceptance of the system. Poorly interpreted systems, which might be achieving the desired water quantity and water quality objectives wonderfully, can still fail if poor public perception and understanding of the strategy results in its removal or redesign to a more 'engineered' or acceptable aesthetic. Educating the public on the benefits of using naturalized systems can have a significant impact on the acceptance of such strategies. A person is more likely to accept and positively perceive the aesthetics of a naturalized system if that person is aware of all of the benefits associated with that system. Public education is therefore a powerful tool that can be used to positively impact the results of qualitative surveys.

5.2 Public Perception Assessments

Visual preference surveys and studies are a popular way to solicit public involvement and feedback. Though sometimes used interchangeably the terms describe distinct methodologies; a Visual Preference Survey

collects a different suite of data than a Visual Preference Study. Selecting the appropriate qualitative study begins by identifying objectives. If the objective is to answer questions such as, 'Does the public like this or that?' and 'If so how much do they like it?', then the Visual Preference Survey is the appropriate qualitative analysis. If however, the objective is to determine in greater depth the reasons why a particular scene is attractive by answering questions such as, "what is liked about it?" or "why is it liked?", then the Visual Preference Study is the appropriate qualitative analysis. A detailed description of both methodologies is found below.

5.3 Visual Preference Surveys

Visual Preference Surveys (VPSu) were developed and trademarked by Anton Nelessen, an urban designer (Ewing, 2005) in the late nineteen seventies, but grew in popularity and practice throughout the nineties. The practice became part of the design process in the field of New Urbanist and Traditional Neighborhood Development planning. Nelessen developed the VPSu as a fast and efficient way to poll the public's preference for different design imagery. The VPSu is typically done in one of two ways. The first way is to provide cameras and predesigned score cards to a determined sample population, often volunteers are solicited. Participants are asked to photograph desirable and undesirable scenes within the project study area, and record their preference for the scene on the score card. Typically participants score cards provide space to indicate the photo number, numbered sequentially, and preference score. Scores can be binary (like or dislike) or rated on a scale, such as from 1 to 5. Participants might be asked to go out and photograph scenes that day, over the course of a week, or over a longer period, such as a month or more. When complete the participant returns the camera, with the undeveloped images and score card.

Circle the number that corresponds most closely with your preference of the scene to the left.

Do you:

1 Strongly Dislike
2 Dislike
3 Neither Like or Dislike
4 Like
5 Strongly Like

Figure 32: Sample VPSu scene scoring. © AES, Inc.

The second way a VPSu can be conducted is to expose a sample population to scenes, such as in a slide show presentation, and ask them to rate their preference for each individual scene on a scaled score card as it is presented. At the end of the presentation the score cards are collected, tallied, and analyzed. In the second method scenes presented are better controlled than when participants are asked to photograph their own preferred scenes. The surveyor can select which specific scenes get rated, and has control over the photo's variables, including perspective, time of day and season when it is photographed.

The weaknesses in both common types of VPSu's is that there is an inherent bias in the scoring of scenes, namely that various, unrelated images are scored on preference. The survey measures the public's acceptability of a scene or image (Nelessen et al., 1995) but isn't designed to measure the public's evaluation of scene components. A VPSu is supposed to answer two questions: 'Do you like the scene?' and 'How much do you like the scene?' It does little to answer the questions, 'What do you like in the scene?' and 'Why do you like the scene?' There are also logistical and material needs, particularly with the first technique, that must be coordinated for the survey to be successful.

The strength of the VPSu is that it is relatively simple and easy to gauge the 'pulse' of public interest or desire. The statistical analysis is easily performed with a simple spreadsheet application found on most computers, and the results are easily understood by the casual reviewer. Scenes can be easily arranged after scoring from highest to lowest rated and scenes that had uncertain or middle of the road scores can be quickly eliminated. A typical VPSu of either the first or second type might range in cost from $8,000–20,000 depending on the number of scenes, if equipment (such as disposable cameras) is purchased, and the hourly rate of the consultant conducting the analysis.

Visual Preference Surveys
are meant to answer two questions:

1. Is the scene liked?
2. How much is it liked?

VPSu's can be used to identify BMP types that are preferred visually before designing and linking the BMP's in a larger stormwater strategy. VPSu can also be used to rate two aesthetically different BMP's with similar functions, such as a mown swale or native plant bioswale. Participant photography can be used to solicit opinions regarding the aesthetic character of existing BMP's, as can a presentation-based survey. The VPSu can also be used to adjust maintenance techniques to reflect aesthetic preferences for in-ground strategies. Descriptive statistical analysis might reveal that 45% of participants liked a particular dry detention basin scene with mowed side banks, 50% of participants liked a wetland with native vegetation, and 30% of participants liked an open water detention pond. However, this data does not indicate why participants

preferred these scenes; it does not offer insight regarding whether their preference was due to the intrinsic nature of these different type of BMP's or due to extrinsic variables in the scenes. This technique doesn't discriminate between BMP types, it simply describes the public's preference for the aesthetic of a BMP as shown in the scene. If 'what' or 'why' doesn't need to be known the VPSu is the qualitative analysis that should be used.

5.4 Visual Preference Studies

Shortly after Nelessen described the VPSu, allied professionals began using a similar but more analytical method known as Visual Preference Studies (VPSt), which examine a scene's qualities and components that contribute to preference. This type of qualitative analysis is less concerned with if a scene is liked or not and more concerned with what is liked about the scene or why the scene is liked.

Visual Preference Studies are meant to answer two questions:

1. What is liked about the scene?
2. Why is it liked?

The VPSt is a presentation-based analysis; independent collection of images is not possible with this technique. Scenes are often presented in pairs or blocks with very few variable changes. A series of detention basin side slope images might illustrate four different treatments: mown, stone, concrete, and naturalized planting. Participants are provided a score card that corresponds with the presentation and asked to score the block of images against each other and not against any other scenes. Scoring is done by rating images on a scale, such as a scale from 1 to 5, or ranking a series of scenes in order of preference. For example, participants may be asked to rank the scenes 1 through 4 in order of preference with 1 being the least preferred and 4 being the most preferred, or participants may be asked to score each image in the block on a scale of 1 to 5, 1 being strongly disliked and 5 being strongly liked.

It is critical that the scenes themselves are closely controlled to ensure that only one characteristic of the photo is changed through a series of images. For example, if one was presenting three slides illustrating three different detention basin side slope treatments the scenes would be almost identical, with only the side slope treatments varying. Any variables that may induce an image bias, such as the presence of children in the background for example, must be either present or lacking in all three slides being compared to ensure a fair and balanced comparison. By ensuring that all other parts of the image are more or less equal, the surveyor can assure that the scores reflect the relative preference for the variable being tested. Scenes from different locations can be used as long the variables can be controlled; photographic visualizations and drawings can also be used, but it is best to compare drawings with other drawings and photos with other photos or computer generated photo realistic visualizations.

Because the statistical analysis is inferential this type of perception analysis is best performed with a sample population between 25 and 250 individuals and evaluating 5 to 100 scenes (Ewing, 2005).

Like the VPSu this method can be used before design of the stormwater strategy to determine public preference of valued qualities or after the strategy is in the ground to determine the parts of the strategy that are valued. Because this type of analysis focuses on the specific qualities that contribute to preference, one is able to analyze the 'why's and 'what's that contribute to aesthetic preference. If the VPSt revealed that an in-ground bioswale scored highest when wildflowers were prominently in bloom in the scene one would know to manage the BMP to maximize the wildflower abundance and duration of blooming.

The cost of a VPSt analysis can be comparable to the VPSu; the statistical analysis is more difficult and more time consuming. In addition, one may desire to prepare detailed and often expensive professional visualizations.

Figure 33. The two images that might occur in a paired VPSt. Preparation of the images required an artist to 'digitally' paint the vegetation in the second scene. © AES, Inc.

5.5 Benefits of a Public Perception Analysis

As can be seen above, perception assessments are no more difficult to execute than some types of hydrologic or water quality assessments. Though sometimes overlooked, these analyses can be just as important in ensuring that the stormwater system is successful. These assessments can be labor intensive requiring someone to identify an appropriate sample population, coordinate the collection of images, tally score cards, and report findings. They may also require specialized consulting or design to run the data analysis or prepare stylized scenes, such as illustrated above (Figure 33). None of these concerns are insurmountable, and, when coordinated properly, the process can effectively and enjoyably be paired with other public participation events such as charrettes, public meetings, presentations, or public tours. In fact, the survey can frame or contribute to ancillary public outreach programs such as public education or citizen science programs.

Incorporating public feedback and preferences before and after a stormwater management strategy is implemented is critical for public acceptance of the strategy techniques. The surveyed group should include key stakeholders for the particular project, as well as those whose buy-in is desired, such as neighbors, elected officials, and users of the site.

Figure 34. Public education session. © AES, Inc.

Aesthetic value is real, though nuanced and sometimes difficult to determine. The extent to which people understand and accept the aesthetic character of a naturalized stormwater system will often determine the long term success of that system. Therefore, there is tremendous value in monitoring public perception.

References

There are several excellent textbooks, guidance manuals, and journal articles that were instrumental in the development of this manual and are good sources for greater depth on the concepts, methods, and equipment summarized. Those references that were most useful in preparation of this manual are listed below with a short statement regarding the nature of the publication or study. The first three references provide very thorough guidance in all aspects of stormwater monitoring design.

American Society of Civil Engineers (ASCE) and United States Environmental Protection Agency (USEPA). 2002 (revised 2009). Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements. EPA-821-B-02-001.

The ASCE and USEPA documents are particularly important if a project team is interested in sharing its results through the International BMP Database. In October 2009, when this manual was being completed, a revised version of the ASCE and USEPA document was released that contains additional information on low-impact development.

Burton, G. A.; and Pitt, R. E. (2002) Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers. CRC Press: Boca Raton, Florida.

The Burton and Pitt document is a definitive text that provides excellent guidance and very thorough discussion on all components of monitoring study design.

Center for Watershed Protection. 2008. Monitoring to Demonstrate Environmental Results: Guidance to Develop Local Stormwater Monitoring Studies Using Six Example Study Designs.

The Center for Watershed Protection publication provides a good overview of the elements of stormwater design and illustrates the process through use of several very different specific studies.

The following papers offer good examples of actual stormwater monitoring studies that were conducted, the equipment utilized and the results obtained from them.

Barraud, S., Gibert, J., Winiarski, T., and Krajewski, J.-L.B. 2002. Implementation of a Monitoring System to Measure Impact of Stormwater Runoff Infiltration. Water Science and Technology, 45(3):203-210.

Barraud, et al. describes the design of a long term monitoring project for an infiltration basin, particularly the impacts to soil and groundwater.

Dietz, M.E. 2007. Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions. Water Air Soil Pollution, 186:351-363.

Dietz provides an overview of the research conducted associated with components of low-impact development design, including bioretention areas, green roofs, permeable pavement, and large scale LID studies.

Dietz, M.E., and Clausen, J.C. 2008. Stormwater Runoff and Export Changes with Development in a Traditional and Low Impact Subdivision. Journal of Environmental Management, 87: 560 – 566.

Dietz and Clausen describe their study that provides a comparison of flow quantity, total phosphorus, and nitrogen in runoff from traditional and low impact development sites during construction phase through 1-2 years after construction was complete.

Farrell, A.C. and Scheckenberger, R.B. 2003. An Assessment of Long-Term Monitoring Data for Constructed Wetlands for Urban Highway Runoff Control. Water Quality Research Journal of Canada, 38(2):283-315.

Farrell and Scheckenberger studied three wetlands in series in a highway interchange in a cold climate.

Hood, M.J., Clausen, J.C., and Warner, G.S. 2007. Comparison of stormwater lag times for low impact and traditional residential development. Journal of the American Water Resources Association, 43(4):1036 – 1046.

Hood, et al. developed and evaluated hydrographs for runoff events from traditional and low impact development sites.

Roseen, R.M., Ballestero, T.P., Houle, J.J., Avelleneda, P., Wildey, R., and Briggs, J. 2006. Storm Water Low-Impact Development, Conventional Structural, and Manufactured Treatment Strategies for Parking Lot Runoff. Transportation Research Record, 1984:135 – 147.

Roseen, et al. evaluated performance of 11 different stormwater management elements by splitting runoff from a parking lot to parallel flow paths.

Selbig, W.R. and Bannerman, R.T. 2008. A Comparison of Runoff Quantity and Quality from Two Small Basins Undergoing Implementation of Conventional- and Low-Impact-Development (LID) Strategies: Cross Plains, Wisconsin, water years 1999–2005: U.S. Geological Survey Scientific Investigations Report 2008–5008, 57 p.

Selbig and Bannerman compared flow, total solids, total suspended solids, total phosphorus, and temperature of runoff from a low impact development site and a traditional site.

The following papers include studies that provide useful guidance regarding some of the advantages, limitations, and cautionary information regarding devices and methods available for stormwater monitoring.

Blom, L.B., Morrison, G.M., Kingston, J., Mills, G.A., Greenwood, R., Pettersson, T.J.R., and Rauch, S. 2002. Performance of an In Situ Passive Sampling System for Metals in Stormwater. Journal of Environmental Monitoring, 4: 258-262.

Blom et al. evaluate the performance of a metal sampling system that collects metals on a membrane, rather than in a water sample bottle, for laboratory analysis.

Burton, G.A., Pitt, R., and Clark, S. 2000. The Role of Traditional and Novel Toxicity Test Methods in Assessing Stormwater and Sediment Contamination. Critical Reviews in Environmental Science and Technology, 30(4):413-447.

Burton et al. discuss the uses and limitations of whole effluent toxicity testing and use of in situ toxicity testing.

Clark, S.E., Sui, C.Y.S, Pitt, R., Roenning, C.D., and Treese, D.P. 2009. Peristaltic Pump Autosamplers for Solids Measurement in Stormwater Runoff. Water Environment Research, 81(2):192 – 200.

Clark et al. evaluated the effectiveness of peristaltic pump autosamplers in capturing all particle sizes in a stormwater flow stream.

Ma, J., Kang, J., Kayhanian, M., and Stenstrom, M.K. 2009. Sampling Issues in Urban Runoff Monitoring Programs: Composite versus Grab. Journal of Environmental Engineering, 135(3):118 – 127.

Ma et al. examined the accuracy of event mean concentrations and mass first flush samples calculated from a number of grab samples and compared results to a flow weighted automatic samples.

Selbig, W.R., Bannerman, R., and Bowman, G. 2007. Improving the Accuracy of Sediment-Associated Constituent Concentrations in Whole Storm Water Samples by Wet-Sieving. Journal of Environmental Quality, 36:226 – 232.

Selbig et al. identify problems associated with accurately splitting samples for multiple analyses when larger solids that settle in sampling bottles are present and propose separating solids and analyzing them separately.

The following papers provide additional information regarding analysis and reporting of stormwater monitoring data and programs.

Fletcher, T.D., and Deletic, A. 2007. Statistical Evaluation and Optimization of Stormwater Quality Monitoring Programmes. Water Science and Technology, 56:12:1-9.

Fletcher and Deletic provide a statistical review of water quality monitoring programs aimed at estimated long term pollutant loads discharged from waterways that drain larger watersheds, including use of turbidity as a surrogate for TSS, recommended intervals between grab samples, and use of autosamplers.

Urbonas, B.R. 1995. Recommended Parameters to Report with BMP Monitoring Data. Journal of Water Resources Planning and Management, 121:1:23-34

Urbonas proposes a standard list of minimum parameters for reporting performance of stormwater treatment elements, including physical dimensions of the elements and parameters associated with rainfall distribution and runoff volume.

The following papers offer additional guidance regarding monitoring design in general.

Lee, H., Swamikannu, X., Radulescu, D., Kim, S., and Stenstrom, M.K. 2007. Design of Stormwater Monitoring Programs. Water Research, 41: 4186-4196

Lee et al. evaluate several stormwater monitoring programs to identify ways of increasing the likelihood of identification of high-risk dischargers and increasing data reliability for assisting in the development of defensible results through the regulatory total maximum daily load program.

Leecaster, M.K., Schiff, K., and Tiefenthaler, L.L. 2001. Assessment of Efficient Sampling Designs for Urban Stormwater Monitoring. 2002. Water Research, 36:1556-1564.

Leecaster et al. analyzed 15 min data to determine the number of samples and flow compositing methods that most efficiently and effectively characterize single storms and determine long term loadings.

Moustafa, M.Z., and Havens, K.E. 2001. Identification of an Optimal Sampling Strategy for a Constructed Wetland. Journal of the American Water Resources Association. 37(4): 1015-1029.

Moustafa and Havens determined the effect of sampling frequency and type on the estimates of monthly nutrient loads and flow-weighted concentrations in large scale constructed wetland in the south Florida.

Strecker, E.W., Quigley, M.M., Urbonas, B.R., Jones, J.E., and Clary, J.K. 2001. Determining Urban Storm Water BMP Effectiveness. Journal of Water Resources Planning and Management, 127(3):144-149.

Strecker et al. describe comparability problems between different stormwater management effectiveness studies and identify considerations that affect data transferability and statistical significance.

Thomson, N.R., McBean, E.A., Snodgrass, W., and Mostrenko, I. 1997. Sample Size Needs for Characterizing Pollutant Concentrations in Highway Runoff. Journal of Environmental Engineering, 123(10): 1061 – 1065.

Thomson et al. analyzed random samples from databases to determine number of samples required to achieve stable confidence bands for that data set.

The following papers offer additional guidance regarding visual preference and public perception.

Achiam, C. M. (2002). Linking Visual Preferences to Planning Sustainably: Using stormwater management in a rural community as a case study. The University of British Columbia, School of Community and Regional Planning.

Achiam's master thesis review visual preference methodologies for stormwater systems.

Ewing, R., M. R. King, S. Raudenbush, and O. J. Clemente. (2005). Turning highways into main streets. Journal of the American Planning Association. Vol. 71. No. 3. 269-283.

Ewing et al differentiates between the visual preference survey and the visual preference study.

Gobster, P. H. (1993). Managing urban open spaces for naturalness: Preferences of Chicago Housing Authority children. G. A. Vander Stoep (Ed.), Proceedings of the 1993 Northeastern Recreational Research Symposium. pp. 64-67. Randor, PA. US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Kaplan, R. and S. Kaplan. (1989). The experience of nature – a psychological perspective. New York: Cambridge University Press.

Kaplan & Kaplan discusses the impacts of aesthetics on our cultural understanding of place.

Nasar, J. L. (1988). Environmental aesthetics: Theory, research, and application. Cambridge, UK: Cambridge University Press.

Nassar discusses the impacts of aesthetics on our cultural understanding of place.

Nassauer, J. I. (1992). The appearance of ecological systems as a matter of policy.
Landscape Ecology, 6, 239-250.

Ross, R. W., Jr. (1979). The Bureau of Land Management and Visual Resource Management: An overview. 1979. Presented at the National Conference on Applied Techniques for Analysis and Management of the Visual Resource. Incline Village, NV. 666-670.

An introduction to the Bureau of Land Management's visual resource management process.

Sanoff, H. (1991). Visual research methods in design. New York: Van Nostrand Reinhold.

Sanoff outlines methodologies for visual preference assessment.

Stamps, A. E. (2000). Psychology and the aesthetics of the built environment. Netherlands: Kluwer Publishers.

Appendix

Monitoring Equipment Pricing

The following equipment pricing estimates are provided to assist in preliminary planning and budget analysis for monitoring project. The prices shown reflect the estimates for purchase of new equipment as reported in 2009. Additional chemical solutions and maintenance equipment is required for some of the devices that are not all included in the price shown. Estimates of shipping and handling are also not included in the prices shown. The cost estimates are not specific to particular brands but reflect a range of prices available for similar devices from multiple manufacturers. This table is provided as an initial screening tool; prior to finalizing any budget, direct quotes should be obtained from local distributors. Opportunities to purchase equipment used can also be explored to reduce project costs.

Equipment	Parameter	Approximate Price (2009)
Parshall flume	Flow	$570 - $3560 (0.2 cfs – 20 cfs flow)
H flume	Flow	$340 - $1020 (0.1 cfs – 11 cfs flow)
Palmer Bowles flume	Flow	$450 - $1270 (0.15 cfs – 3.5 cfs flow)
Volumetric Weirs	Flow	$200 - $400 ; can also be constructed at site for cost of materials
Pressure transducer (depth meter)	Flow	$1570 without remote logger; $1850 with datalogger
Tracer test detection unit	Flow calibration	>$8000 purchase , $2000 / month to rent, plus $125/gal-lon of water safe dye
Tipping bucket rain gauge	Rainfall	$170 - $450 plus $330 for datalogger
Stormwater flow sampler	Sheet runoff sampler	$800 per unit (in-ground installation required)
Automatic sampler	Concentrated flow sampler	$6000-$7000 for refrigerated sampler plus supplies/setup equipment; $3000-4000 for non-refrigerated sampler; $450 /month to rent

Multi-parameter probe (hand-held)	Multiple parameters (DO, temperature, pH, conductivity, nitrate, ammonia, salinity, chloride, total dissolved solids, oxidation reduction potential)	$2200 - $3200 for complete setup with probes, all cables, supplies (depending on number of parameters)
Multi-parameter probe (with datalogger for unattended deployment)	Multiple parameters (DO, temperature, conductivity, pH, oxidation reduction potential, salinity, chlorides, and nitrate)	$7000 for a unit with six parameter capability (additional parameters available at additional cost)
DO probe	DO	$170
pH probe	pH	$280
Conductivity probe	Conductivity	$300
Nitrate probe	Nitrate	$330
Chloride probe	Chloride	$330
ORP probe	ORP	$230
Ammonia probe	Ammonia	$330
Colorimeter	Many Parameters	$600 - $1200 plus reagents for specific tests
Portable Spectrophotometer	Many Parameters	$3200 plus reagents for specific tests
Individual parameter test strips with visual comparisons	Several Parameters	$8-20 per 50 test strips for each parameter
Bacteria test kit	Bacteria (fecal coliform)	$5 - $10 per test
Hydrocarbon test kit	Hydrocarbons (BTEX, PAH)	$600 for reader plus $30 per sample

© Applied Ecological Services, Inc.

Applied Ecological Services, Inc.™

17921 Smith Road
P.O. Box 256
Brodhead, WI 53520