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Memorandum

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Subject: Drawing Appropriate Conclusions Regarding Volume Reduction in Practice- and Site-level Studies of Stormwater BMPs

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INTRODUCTION AND PURPOSE

The careful interpretation and evaluation of data is critical in reaching appropriate conclusions about volume reduction benefits of stormwater BMPs at the practice level and the site level[1]. The purpose of this technical memorandum is to recommend ways to interpret and evaluate hydrologic data obtained from monitoring studies to quantify the performance of these systems, both absolutely and in comparison to other systems. This memorandum first discusses the fundamental questions that may possibly be answered through analysis and interpretation of volumetric data. This discussion considers both site level studies and practice level studies. Methods of interpreting and evaluating hydrologic data are introduced and discussed, and best practices in data interpretation are suggested. Finally this memo discusses the extrapolation of monitoring data to long term results and the comparison of volumetric performance between different types and scales of practices.

FUNDAMENTALS OF VOLUME REDUCTION

Surface runoff volume reduction is an important component of the overall effectiveness of BMP systems. BMPs eliminate runoff volume that would otherwise discharge directly to downstream

[1] For the purpose of this memorandum, the term "practice" is used as a general term inclusive of traditional BMPs and specific low impact development (LID) practices. Practice-level studies focus on specific practices (i.e. bioretention area, swale, vegetated buffer), and make up the majority of what is currently contained in the International BMP Database. Site level studies will be supported through updates to the International BMP Database and may consist of a combination of specific practices monitored at the site scale.

drainage systems, , reducing demand on system capacity and mitigating the hydraulic/sediment entrainment and transport impacts that increased runoff volumes may cause. In addition, reduction of surface runoff volume plays an important role in reduction in pollutant loadings to surface waters.

In general, monitoring studies attempt to answer one or more of the following questions regarding runoff volume reduction:

- How much runoff volume is reduced by a practice or by a LID site on a long term average basis?
- How much runoff volume is reduced by a practice or by a LID site under conditions specified for regulatory purposes (e.g., a specific design storm)?
- What effect does a practice or LID site have on the frequency and timing of runoff leaving the site?
- How does a practice or LID site impact the overall water balance of the system on a long term average basis? (i.e., How are deeper infiltration, evapotranspiration, and runoff balances changed?)

Because these questions generally relate to long term hydrologic performance and because hydrologic conditions at any given time are usually not average, volumetric data obtained from monitoring studies must be interpreted in the context of the hydrologic conditions preceding, during and following the study. Because monitoring studies are seldom conducted over a sufficiently long period to ensure average conditions have been documented, a major goal of data interpretation should be to appropriately extrapolate measured data to a broader context.

DATA RECORDED IN THE INTERNATIONAL BMP DATABASE

Exhibit 1 shows data fields recommended to be reported in BMP/LID studies entered into the International BMP Database (Geosyntec Consultants and Wright Water Engineers, 2009) and their relevance in interpreting volumetric results.

Exhibit 1: Recommended Reported Data and Relevance in Reaching Volume Reduction Conclusions

Reported Data	Currently Reported with BMP Database Studies?	Relevance in Volume Reduction Conclusions
Watershed Location	Yes	This permits analysis of precipitation patterns characteristic of the study location.
Watershed Area	Yes	This establishes total area tributary to monitoring point, coupled with precipitation depth and watershed rainfall-runoff characteristics. This represents the “inflow” to the system for site level studies.
Watershed Imperviousness	Yes	This is an indicator of development density, related to quantity of runoff. It can be used as one of several factors to normalize runoff volume in comparison between sites.
Predominant In-situ Surface and Near Surface Soil Types (developed condition)	Yes	This is an indicator of quantity of runoff in the monitored condition and is useful in understanding the importance of runoff, evapotranspiration, and deeper infiltration patterns from pervious areas of the watershed.
Reporting Period (Start and End Date/Time)	Yes	This establishes the time scale of the study, the season of year, and various corresponding factors (e.g., vegetation status, precipitation patterns, evapotranspiration rates, frozen ground).
Precipitation Start Time	Yes	This establishes the time of day for start of precipitation and various corresponding factors (e.g., fraction of average, seasonal, or monthly evapotranspiration, temperature).
Precipitation End Time	Yes	This establishes the duration of precipitation.

Precipitation Depth	Yes	This establishes the total input to system. When coupled with watershed area, this represents the "inflow" to the system for site level studies. In above-ground practice level studies, this represents the volume added directly to a practice.
Average Precipitation Intensity (Computed from Depth and Duration)	Yes	This is an indicator of the amount of runoff likely from pervious areas of the watershed and the average loading rate of pervious areas receiving run-on from impervious areas.
Antecedent Dry Period	Future	This is an indicator of antecedent watershed conditions and potential for dry weather pollutant build up.
Description of Antecedent Watershed/Facility Conditions (narrative)	Future	A narrative description of conditions immediately prior to the start of monitoring, including key field notes, frozen ground conditions, facility storage available, high groundwater, etc
Total Inflow Volume to BMP (Practice Level Only)	Yes	For practice level studies, this provides precise quantification of discharge from watershed and inflow volume to LID practice.
Total Surface Discharge Volume (from BMP if Practice Level Study; from Watershed if Site Level Study)	Yes	This establishes the total discharge volume from monitored area, inclusive of the effects of LID practices in watershed and monitored LID practice (if present).
Observed or Estimated Drawdown Time of Total Storage from Brim Full	Yes	This establishes the time required to empty the facility and make storage available for subsequent storms. It is useful in efforts to calibrate models of the system or extrapolate limited datasets to long-term performance through rainfall analysis. This can apply to individual practices or, if designs are consistent amongst distributed controls, to multiple similar features.
Observed or Estimated Drawdown Time of Total Storage from Half Full	Yes	This provides information about the general pattern of the draw down curve and enables a more robust use of study data.

Describe Key Weather Parameters During Study Period (narrative)	Future	Weather conditions can significantly affect the water balance of LID sites. Frozen soils can reduce infiltration rates; conversely, high ET can increase evapotranspiration rates. Characterization of ET, temperature and other similar factors are important in normalizing comparisons among LID sites.
Hydrologically Available Temporary Storage in Watershed (Site level only)	Future	Describes the normalized relationship between source areas and storage areas, both in terms of routing and relative volume, for purposes of comparing LID sites. Reported to the BMP Database as detained, retained, and excess volume for a range of storm events.
Storage Recovery Rate in Watershed (Site level only)	Future	Describes time to recover hydrologically available temporary storage. Reported to the BMP Database as minimum, maximum, and average (based on seasonal factors). Reported individually for retained and detained volume.

METRICS FOR INTERPRETING VOLUMETRIC RESULTS

The type of volumetric data obtainable and its interpretation differs between practice level studies and site level studies:

- **Practice level studies** are generally able to directly measure the total inflow to the facility and/or the total discharge from the facility. In the absence of a defined inflow, a surrogate such as precipitation depth, tributary area and runoff coefficient may be used if the watershed is sufficiently well-defined (such as a roof-top or small parking lot). The intent of practice level studies is to accurately quantify the volume reduction in a specific facility during a set of monitored storm events and, generally, to extrapolate these results to long term hydrologic performance of that facility.

- **Site level studies** are generally able to measure the discharge from the system directly, but are not able to quantify the amount of surface runoff generated on-site and removed before reaching the outlet. Rather, the precipitation depth over the monitoring period represents the overall inflow to the system. The intent of site level studies is to quantify hydrologic response during a set of monitored storm events, and generally, to extrapolate these results to long term hydrologic response in comparison to other sites/watersheds.

Exhibit 2 provides a list of simple metrics than can be calculated for each event or monitoring period and analyzed in combination with storm characteristics or monitoring period total precipitation. These are described individually in the paragraphs below.

Exhibit 2: Simple Metrics for Interpreting Single-Event Volumetric Data

Metric	Application
Presence/Absence of Discharge	Practice level and site level
Absolute Volume Reduction (Out – In)	Practice level only
Relative Volume Reduction (Out – In)/In	Practice level only
Discharge Volume per Area	Practice level and site level
Discharge Volume per Impervious Area	Practice level and site level

Care must be taken to avoid spurious correlations in the analysis of volumetric data. For example, it is convenient to correlate runoff coefficient to rainfall depth, however because runoff coefficient has rainfall volume as its denominator, a spurious correlation would be expected even if no genuine correlation existed.

Care must also be taken when averaging performance metrics from individual events. In some cases, an average may have relatively little utility in describing long term conditions. For example, the average of a ratio-based metric, such as relative volume reduction [(In – Out)/In], would implicitly be biased towards events that occurred or were monitored most frequently rather than being weighted by event volume. Thus this average could not help provide an estimate of overall long term volume reduction performance. In other cases, averages may be more meaningful in theory, but limited by the representativeness of monitored events. For example the average of absolute volume reduction [In – Out] would only be expected to produce meaningful results if it was based on a monitoring period containing a representative distribution of inflow volumes.

The following methods are suggested for interpreting trends in volume reduction metrics:

- Scatter Plots
- Histograms
- Within-Storm Time Series

Examples of the use of scatter plots and histograms to visualize the simple metrics described above are provided in the sections below. Within-storm time series will not likely be available for most studies entered into the BMP Database, thus are not discussed further in this document.

Presence/Absence of Discharge (Practice- and Site level)

Presence of discharge is a simple, yet informative metric that can be used to extrapolate the ability of systems to control the frequency of discharge. If a sufficient number of storms are monitored, data may be used directly to support conclusions regarding the threshold of discharge (e.g., the smallest storm to produce discharge was X, or the largest storm to produce no discharge was Y) or a probabilistic description of discharge (e.g., 90 percent of storms greater than 1 inch produced discharge, 50 percent of storms less than 0.7 inches produced no discharge). Such conclusions implicitly account for the various antecedent conditions encountered over the monitoring period. Given appropriate consideration for data representativeness and number of samples, these results can be used to make meaningful statements about the performance of the system. As some water quality criteria have an allowable exceedance frequency, information on the frequency of discharge can be important.

For site level studies, there may be directly connected impervious areas (DCIA) downstream of the lowest storage feature but upstream of the monitoring location. This area would be expected to produce discharge in all but the smallest events; therefore the concept of a threshold of discharge may not always apply. In these cases, analysis based on presence of discharge may not yield meaningful results.

Histograms and probability plots can be effectively used to visualize frequency of discharge. Examples are shown in Exhibit 3. The bars on the chart represent the number of rainfall events and the number of runoff events, grouped into bins of rainfall depth. Bins are defined by their upper limit. For example, the bin labeled as 0.6 inches includes all events greater than 0.5 inches and less than or equal to (LTE) 0.6 inches. In the example below, 6 storm events fell into this bin and 4 of them produced runoff. The red dashed line plots the percentage of monitored events producing runoff in each bin.

Exhibit 3: Example histogram of frequency of rainfall events and discharge events for a hypothetical site level study

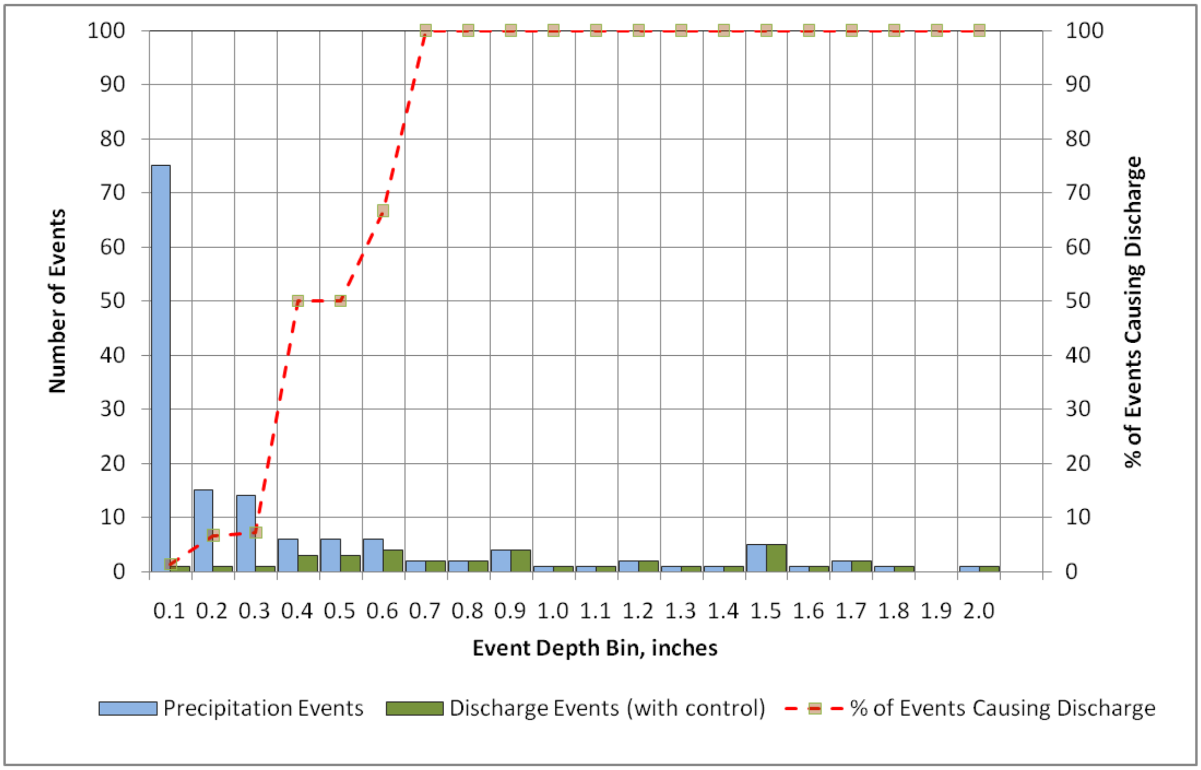


Exhibit 3 illustrates a way of visualizing the threshold of discharge from an example LID watershed as a function of depth. During the hypothetical monitoring period, no storm greater than 0.6 inches was completely retained, while at least minimal discharge occurred in one storm less than 0.1 inches. Likewise, during this monitoring period, 4 out of 6 events between 0.5 and 0.6 inches (bin labeled “0.6”) caused discharge.

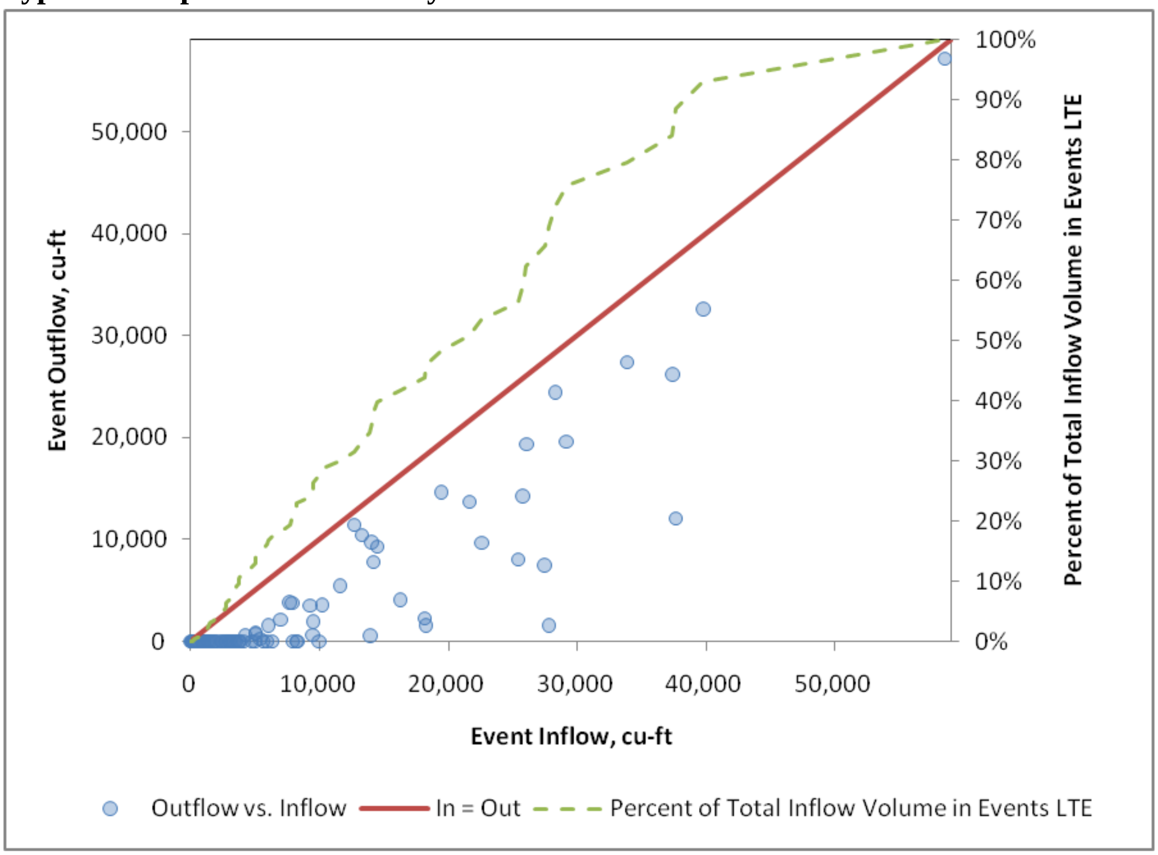
This method of analysis should not be used to estimate the cumulative volume reduction of the system, as the plot contains no information regarding the amount of volume reduced when discharge did occur.

Absolute Surface Runoff Volume Reduction (Practice level only)

Absolute surface runoff volume reduction is simply the difference between inflow and outflow runoff volume for a specific monitoring event. It is informative in describing long-term hydrologic conditions if a sufficient number of events are monitored. To estimate long term volume reduction, absolute volume reductions should be summed over a representative number of storm events and then divided by the total inflow volume to the facility over the same period of time. The method implicitly accounts for antecedent conditions, and would theoretically provide more confidence in estimates as more data are added.

A scatter plot of event inflow versus outflow can be used to visualize the performance of the facility as a function of inflow volume (Exhibit 4). In this chart, blue circles represent individual event data. The "In=Out" line represents the performance that would be expected if no volume reduction or addition occurred in the practice. Points above this line would represent monitoring events with greater outflow than inflow, which could result from saturated antecedent conditions, high groundwater, and/or measurement errors. The dashed line represents the percentage of the total inflow volume occurring in events with inflow less than or equal to the X ordinate at each point.

Exhibit 4: Example scatter plot of event outflow volume versus event inflow volume from a hypothetical practice level study

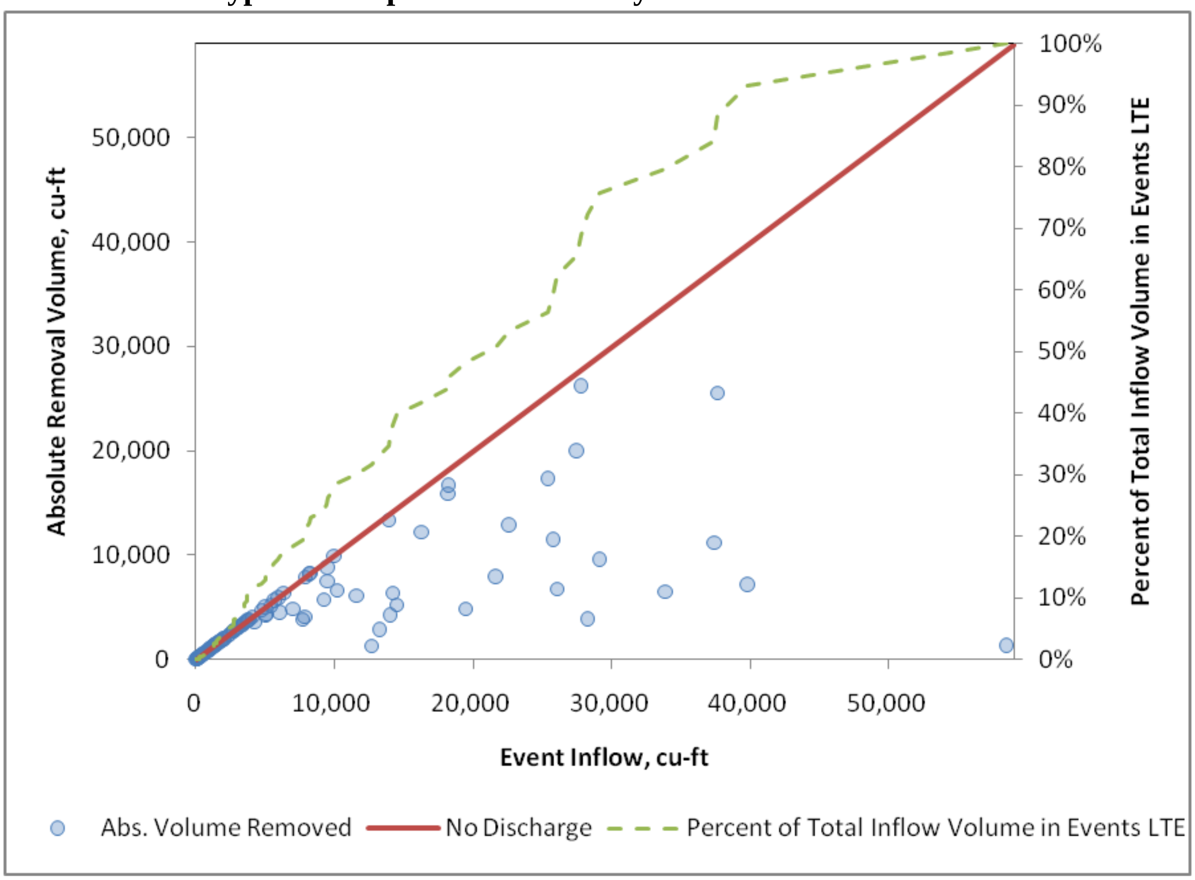


LTE = Less than or equal to (the X ordinate value)

Exhibit 4 illustrates the concept of a threshold inflow volume (in this case, approximately 6,000 cu-ft) below which discharge rarely occurs. It also illustrates a range (in this case, approximately 6,000 cu-ft to 30,000 cu-ft inflow volume) over which volume reduction ranges widely, from less than 5,000 cu-ft to more than 25,000 cu-ft. The variability of absolute volume reduction over this range of inflow volumes is explained by this range of inflow volume being similar to the storage volume of the practice. Low volume reductions could potentially be attributed to relatively short and intense storms following a previous storms (when the facility may be partly full), while higher volume reductions could potentially be attributed to longer, less intense storms occurring when the storage was at or near "empty" prior to the storm or where the inflow rates did not exceed infiltration rates or a combination.

Meaningful relationships can also be developed between absolute volume reduction and total inflow volume (Exhibit 5). In this chart, the blue circles represent paired X-Y data, where the X ordinate is the inflow volume and the Y ordinate is the absolute volume reduction [In – Out]. The solid "No Discharge" line corresponds to the performance that would be expected if all inflow was removed from surface discharge in the practice. No points are expected to be above this line. For studies with data points showing measured outflow greater than measured inflow, negative Y values would be expected. The dashed line represents the percentage of the total inflow volume occurring in events with inflow less than or equal to the X ordinate at each point.

Exhibit 5: Example scatter plot of event absolute volume reduction versus event inflow volume from a hypothetical practice level study



LTE = Less than or equal to (the X ordinate value)

Exhibit 5 represents a different way of visualizing the same dataset as Exhibit 4, and the same conclusions can be drawn regarding threshold of discharge and variability of volume reduction. Depending on the characteristics of the dataset, this method of visualization may better facilitate interpretation of these factors.

The relationship between volume reduction (blue circles) and the cumulative percentage of inflow volume relative to total inflow volume (dashed line) is informative in understanding the relative importance of different inflow volumes. For example, storms that are nearly always fully eliminated from surface discharge (<6,000 cu-ft) account for approximately 20 percent of total precipitation volume. Storms in the range over which volume reductions vary greatly (6,000 to 30,000 cu-ft) account for approximately 50 percent of total precipitation volume.

Relative Volume Reduction (Practice level only)

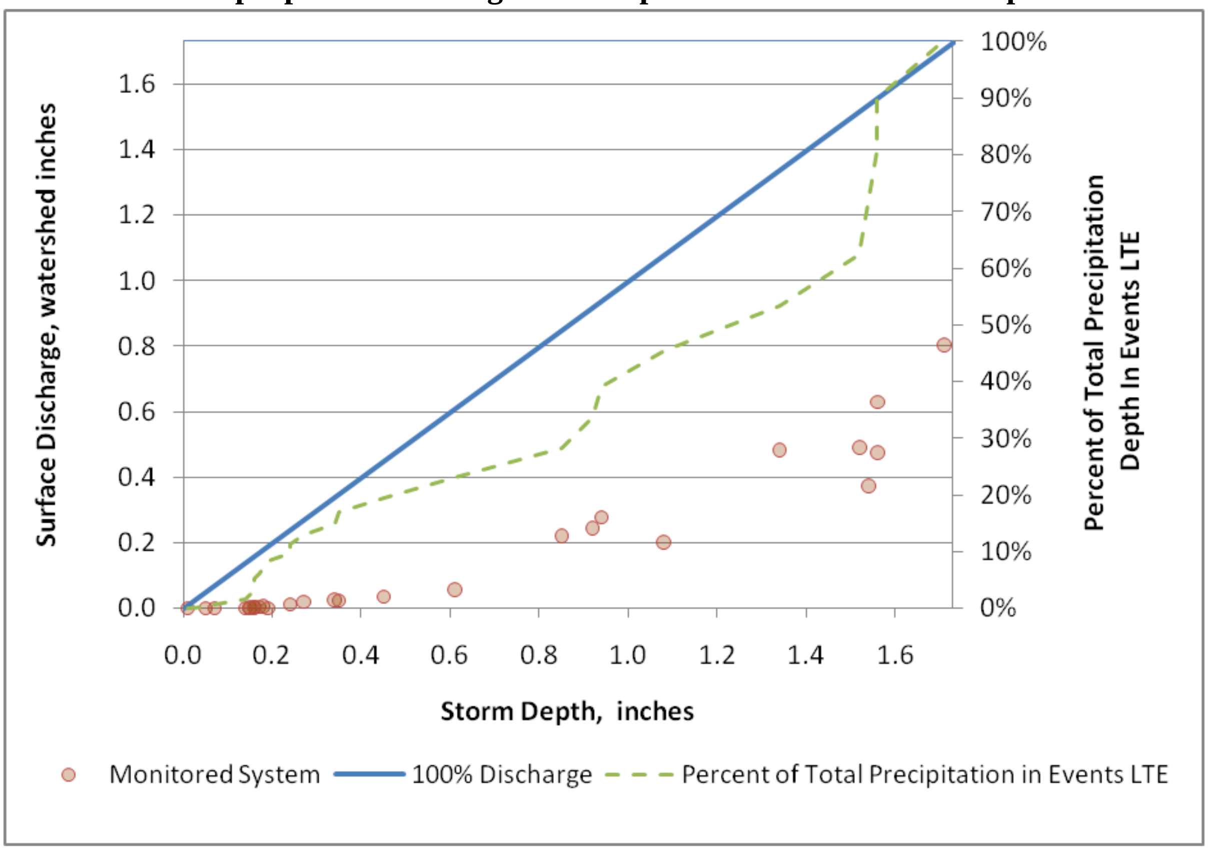
Relative volume reduction or "percent volume reduction" can be calculated for an individual storm as simply the difference between inflow and outflow divided by the inflow. This metric is informative for an individual storm event, but is prone to inappropriate interpretation if the results from individual storm events are simply averaged to yield an estimate of long term volume reduction. For example, all storms less than the facility retention volume would be recorded as 100 percent volume reduction despite the range of storm depths this could include. Likewise large storms that cause significant discharge (i.e., low percent volume reduction) would only be record as one data point despite the fact that they may account for a much larger share of the total volume. Thus, this method of interpretation has limited use in extrapolation to broader conclusions.

Discharge Volume per Area (Site level and practice level)

The discharge volume per area is calculated as the measured volume of discharge divided by the area of the tributary watershed. For one-to-one comparison to precipitation depth, the discharge volume can be expresses as "watershed inches." The ratio of discharge volume to precipitation volume is typically referred to as the runoff coefficient; however it is expected that this runoff coefficient would be different for different size storm events and antecedent conditions. The trend of discharge volume per area with precipitation depth can be useful in extrapolating the long-term discharge volume from the system. The ratio of total precipitation to total discharge can provide a direct estimate of long term runoff coefficient if monitoring data are aggregated from a representative monitoring period, however it is noted that runoff coefficient may vary significantly from year to year depending on climatic variability.

Analogous to Exhibit 4, discharge volume per area can be plotted against rainfall to facilitate interpretation of hydrologic response. A hypothetical example is provided below (Exhibit 6). In this chart, red circles represent individual event data. The "100% Discharge" line represents the performance that would be expected if 100 percent of rainfall was converted to surface runoff. Values above this line would represent monitored events with greater outflow than inflow, which could result from saturated antecedent conditions, high groundwater, and/or measurement errors. The dashed line represents the percentage of the total precipitation occurring in events with precipitation depth less than or equal to the X ordinate at each point.

Exhibit 6: Example plot of Discharge Volume per Areas versus Storm Depth



LTE = Less than or equal to (the X ordinate value)

Exhibit 6 enables the visualization of several elements of hydrologic response expected to occur in LID site level studies. First, for storm depths up to approximately 0.2 inches, no runoff occurs, representing the depression storage in the watershed (i.e., the threshold for runoff to occur, even from DCIA). From approximately 0.2 to 0.5 inches, the slope of the data is relatively shallow indicating that only a small portion of the watershed contributes to runoff, theoretically the portion of the watershed that is DCIA. Beyond the 0.5 inch storm, the slope of the data trends up again, signifying that a greater fraction of the watershed contributes to runoff in larger storms, likely as LID storage features become filled and/or infiltration rates are exceeded. While strong quantitative interpretations cannot be derived from this type of analysis, it is useful to gain better understanding of hydrologic response of a watershed.

Discharge volume per area can also be used to interpret results from practice level studies, specifically where measurement of inflow volume were not obtained. This method implicitly incorporates watershed factors external to the practice itself, thus does not permit the isolation of the performance of the practice, especially where watershed processes are complex.

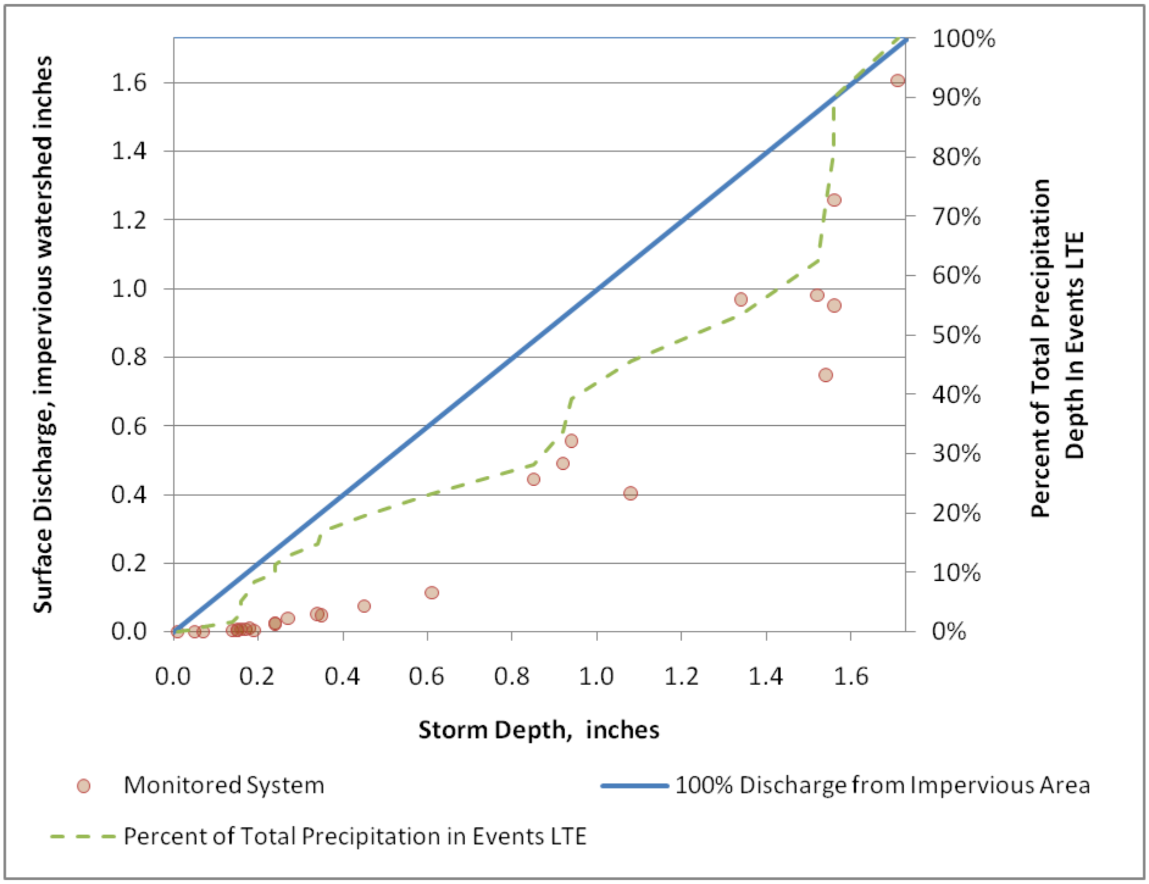
Discharge Volume per Impervious Area (Site level and practice level)

The discharge volume per impervious area is similar to the discharge volume per area described above, but is normalized to the total imperviousness of the watershed. It is calculated as the measured volume of discharge divided by the total impervious area of the tributary watershed. The discharge volume can be expresses as “impervious watershed inches.”

Normalization to impervious area has advantages and disadvantages. For ranges of storms for which runoff from pervious areas is negligible, this approach better isolates the effectiveness of LID practices on the site to mitigate runoff from impervious areas. It also allows a reasonably meaningful normalized comparison between watersheds of different densities. For example, the effectiveness of LID practices to mitigate runoff could be compared between a commercial site and a residential site despite their differences in imperviousness. Without control, the sites would be expected to discharge significantly different volumes of water per total site area, but would be expected to discharge similar volumes of water per impervious area. However, this approach relies on the implicit assumption that runoff from pervious areas is negligible in both cases, which is not generally the case in larger storms or in the case of pervious areas with little interception storage and lower infiltration rates. Thus, this metric should be carefully applied.

The same example dataset used in Exhibit 6 is plotted as impervious watershed inches of runoff versus storm depth (Exhibit 7). The same trends are noted. In this chart, red circles represent individual event data. The “100% Discharge from Impervious Area” line represents the performance that would be expected if 100 percent of rainfall over impervious area was converted to surface runoff and no runoff occurred from pervious areas. The dashed line represents the percentage of the total precipitation occurring in events with precipitation depth less than or equal to the X ordinate at each point.

Exhibit 7: Example scatter plot of discharge volume per impervious area versus storm depth



LTE = Less than or equal to (the X ordinate value)

CONSIDERATION OF MEASUREMENT ERROR IN INTERPRETATION METHODS

In interpreting volumetric data, consideration should be given for the precision and accuracy of system inflow and outflow volume measurements. Random measurement errors associated with the resolution of monitoring equipment can be magnified in the evaluation of volume reductions, particularly for practices that achieve relatively little volume reduction, or for which limited number of data points are available. For example, if inflow volume measurements have a precision of +/- 10% and outflow measurements have the same precision, unless the volume reduction is fairly large, the calculated variability in volume reduction may be more a function of uncertainty in measurements than the performance of the practice. The impacts of measurement precision on conclusions can be reduced by using methods that aggregate long term inflow and outflow volumes (e.g., comparison of total inflow to total outflow volume, or total rainfall to total site discharge). Methods of interpretation that rely on the visualization of individual event data are inherently sensitive to measurement errors, however recognition of the potential for and potential magnitude of errors as well as larger sample sizes are expected to improve the strength of conclusions that can be drawn from these observations. Analyses of relative volume reduction or "percent volume reduction" on a storm-by-storm basis are especially sensitive to the effects of measurement precision.

The accuracy of volumetric measurement can be diminished by a variety of factors, including improper calibration of equipment and omission of important factors. Of specific relevance to volume reduction studies is accounting for all inflows and outflows to/from the system. Unmeasured volumes may include the volume of direct precipitation on the practice, the volume of groundwater seepage, volume that is evapotranspirated, and others which are not reflected in inflow and outflow volumes measured at discrete monitoring points. The magnitudes of these volumes should be estimated where possible and factored into event totals and/or long term totals as appropriate.

COMPARING PERFORMANCE TO DESIGN OBJECTIVES AND CRITERIA

An underlying goal of monitoring is often to compare performance to design objectives or performance criteria. Design objectives and performance criteria applicable to practices and sites can take a number of forms. Practices are most commonly designed to capture the runoff from a specific design storm or intensity. Capture may include retaining water on-site, or detaining and discharging treated water. In either case, the time over which storage capacity should be recovered (i.e. the time it takes the facility to empty) is usually specified as an accompanying design objective.

Practices may also be designed with the direct intent of capturing a specified percentage of average annual (i.e., long term) runoff or reducing discharge volume to a specified level on a long term basis.[2] In this case, design criteria are typically developed through analysis of precipitation records using continuous hydrologic simulation. Methods of sizing may implicitly or explicitly incorporate the emptying time of the facility (i.e. the time it takes to recover storage capacity for subsequent storms). For example, long term hydrologic simulation might show that a design volume of 0.8 watershed inches would be required to capture 80 percent of average annual runoff for a bioretention practice that was designed to empty in 24 hours, while a design volume of only 0.5 watershed inches might be required if the same facility was designed to empty in 12 hours.

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[2] A typical goal is to match the "pre-development" discharge volume, however it is noted that matching overall discharge volumes does not necessarily ensure matching of pre-development peak discharge rates, frequencies or durations, or overall water balance.

The design objectives or performance criteria applicable to the study provide guidance for how volumetric performance data should be evaluated. In the first case described above (design storm-based objective), relatively few monitored events may be necessary to confirm that the facility is meeting its performance objectives (performance under a given design condition). For example, the design objectives of the facility could be evaluated by monitoring and analyzing data from a subset of events similar to the design event, with a range of antecedent conditions, and monitoring the emptying times of the facility under different seasonal conditions. If overall monitored performance is reasonably consistent with design objectives, it could be reasonably concluded that the facility meets the design objectives and the performance criteria implied by those objectives. However, this is not likely a common case. If the design objectives are not confirmed through comparison of design storm performance to design storm objectives, if performance criteria are based on long term performance, or if study objectives include the explicit quantification of long term performance, the study must either continue for a long period of time or other methods must be employed to extrapolate the performance of the system.

In the case of LID sites, specific volumetric design objectives, such as design storm methods, are less common than for other types of practices, thus it is more common that extrapolation of long term performance will be required to meet study objectives.

EXTRAPOLATING STUDY RESULTS TO LONG TERM VOLUME REDUCTION PERFORMANCE

Extrapolating a limited monitoring dataset to long term volume reduction performance may be critical in meeting study objectives and evaluating practice or site performance against established criteria. The following sections introduce two common ways of extrapolating these results to broader conclusions.

Precipitation analysis:

Monitoring data sets may permit the development of average relationships between precipitation and system performance. These relationships could potentially be probabilistic in nature, for example, the average discharge volume in events between 0.4 and 0.5 inches is 32,400 cu-ft and the standard deviation is 15,500 cu-ft. If similar relationships could be developed for each rainfall "bin", a statistical sampling routine could be implemented in combination with storm events extracted from long term rainfall records to estimate total discharge. Alternatively, a moving average of response could be developed and applied directly to each event. For example, a moving average of watershed discharge per area versus event depth could be applied to a long term cumulative distribution of storm depths to estimate total long term discharge. The critical elements of this approach lie in the strength of the relationships that can be developed between precipitation records and practice performance or site response, and the availability of long term precipitation records representative of the location.

Continuous simulation models

Continuous simulation models represent a potentially valuable tool for extrapolating a relatively small number of monitored events to long term performance. Guidance on effective and appropriate use of models is beyond the scope of this technical memorandum, however the user should consider data needed to calibrate and validate hydrologic models in developing a study design. Hydrologic models can facilitate highly detailed analysis of system performance over a long time scale. Critical to this approach is minimizing model-induced errors and using a model within the limits of its applicability.

COMPARISON BETWEEN DIFFERENT TYPES OF PRACTICES

Fundamentally, volume reduction processes can be considered in the framework of a normalized storage volume and a storage recovery rate (i.e. time for the facility to empty its storage volume), regardless of BMP type or scale. Every system can be thought of to have a retained storage volume and a rate of recovery of this volume. While magnitudes of storage and recovery rates will vary between different types of practices, this overall framework provides a basis for comparison between studies in the same category, as well as across categories. Watershed characterization efforts and monitoring results can be used to help quantify these processes. Studies with comparable tributary watersheds, comparable study design, and comparable climate may facilitate further comparisons such as frequency of discharge, frequency distribution of concentration and temporal pattern of loading.

REFERENCES

Geosyntec Consultants and Wright Water Engineers (2009). *Urban Stormwater BMP Performance Monitoring*. Prepared under Support from U.S. Environmental Protection Agency, Water Environment Research Foundation, Federal Highway Administration, Environmental and Water Resources Institute of the American Society of Civil Engineers. In draft.