Tahoe Stormwater and BMP Performance Database
Monitoring and Reporting Guidance Document

FINAL

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nhc

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MONITORING AND REPORTING GUIDANCE DOCUMENT

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SECTION 1. EXECUTIVE SUMMARY

Internationally recognized as a unique and valuable resource, Lake Tahoe is one of very few large lakes in the world that reflect the extraordinary beauty of its mountainous surroundings in such clear and pristine water. Urbanization in the Tahoe Basin threatens these natural qualities, so coordinated action has been taken to mitigate the effects of urban development and other human land use changes. This action is represented in the Environmental Improvement Program (EIP), developed to orchestrate lake and watershed restoration, and is guided by a Total Maximum Daily Load (TMDL) Program that provides a science-based blueprint for implementation of the EIP.

The Lake Tahoe TMDL has identified urban stormwater runoff as one of the main sources for pollutant loading of clarity-degrading nutrients and fine sediment particles into Lake Tahoe (LRWQCB and NDEP 2010). Therefore, implementation of best management practices (BMPs) to reduce pollutant sources and treat urban stormwater is seen as one of the best options for mitigating the effects of landscape development and restoring lake clarity.

The Lake Clarity Crediting Program (Crediting Program) defines a comprehensive and consistent accounting system for tracking pollutant load reductions with restoration and BMP implementation (LRWQCB and NDEP 2009). In concert with application of the Pollutant Load Reduction Model (PLRM) (nhc et al. 2009), the Crediting Program will allow project implementers and regulatory agencies to estimate the pollutant load reductions of various urban pollutant source control and treatment strategies on an urban catchment scale. Ultimately, however, these estimates must continue to be validated and improved by measurements of pollutant reductions linked to specific practices.

The purpose of the Tahoe Stormwater and BMP Database (Database) is to guide the collection of consistent and reliable information on stormwater runoff characteristics and Treatment BMP performance around the Tahoe Basin. This Database has been developed in support of the Tahoe Regional Stormwater Monitoring Program (RSWMP) to provide a centralized, internet-accessible, reliable source of stormwater data collected by different groups associated with the TMDL and RSWMP efforts. As existing information and new data are uploaded into the Database, it will support the continued development, calibration and testing of load reduction models and other stormwater management tools, and it will provide a framework needed for tracking stormwater BMP implementation, monitoring results, and maintenance activities.

In its current form the Database accepts information from monitoring at stormwater runoff sites and on a subset of Treatment BMP types identified by the PLRM and the Best Management Practice Maintenance Rapid Assessment Methodology (BMP RAM; 2NDNATURE et al. 2009). A detailed description of considerations for Treatment BMP performance evaluations and the requirements for data entry into the Database is provided in the following pages of this document. Although the current version of this Database is fully functional and will serve initial purposes of RSWMP and the TMDL, the vision for future versions will be to extend development to a web-based application. This will circumvent limitations inherent to the current desktop design. In the meantime, please review the Database User's Guide (provided as Appendix A) before proceeding with data entry. If you have suggestions or encounter problems during the use of this version of the Database, kindly contact the Database manager or the RSWMP development team to identify specific issues and develop potential solutions.

SECTION 2. TAHOE STORMWATER AND BMP PERFORMANCE DATABASE OVERVIEW

2.0 DATABASE GOAL AND OBJECTIVES

Over the last several decades, numerous Treatment BMP monitoring studies have been conducted throughout the Lake Tahoe Basin with the similar objective to evaluate and quantify the water quality benefit of a particular Treatment BMP. However, there has been no standardization in monitoring data selection, terminology, units of measurement, analytical forms of the pollutants of concern, data management techniques, data analysis methods, or data reporting strategies. In addition, there has been no clear link between the physical, geochemical, and/or biogeochemical processes that are relied upon to provide a "water quality" benefit and associated measured pollutant load reductions. This has inhibited the comparison of Treatment BMP performance and restricted the development of adaptive management strategies for resource managers tasked with improving Lake Tahoe clarity.

Standardized comparisons of Treatment BMP performance with respect to pollutant loading to the lake could be used by resource managers, researchers, stormwater engineers, and maintenance personnel alike to:

- inform and prioritize future stormwater improvement projects,
- identify stormwater quality research opportunities,
- enhance Treatment BMP design and specifications with respect to optimizing the treatment of the key pollutants of concern,
- develop more efficient and effective Treatment BMP maintenance schedules, and
- improve the scientific basis for Lake Tahoe TMDL stormwater tools, including the PLRM.

The goal of the Tahoe Stormwater and BMP Performance Database (Database) is to provide a consistent data entry and storage system that can assist in the planning and implementation of stormwater projects in the Lake Tahoe Basin. The following are objectives of the Database:

- Compile Tahoe stormwater and Treatment BMP data in a centralized, internet accessible location.
- Organize stormwater and Treatment BMP data in a consistent manner to allow for data integration and data analysis across multiple studies, locations, and Treatment BMP types.
- Provide a structure that enables evaluations of Treatment BMP performance relative to key design parameters, drainage area conditions, maintenance activities, and influent water quality over time.
- Streamline routines for data upload and retrieval.
- Build upon existing efforts by focusing on the current Lake Tahoe pollutants of concern and Treatment BMP types employed, but provide a flexible framework so additional pollutants and Treatment BMP types can be added in the future.

2.1 DEVELOPMENT PRIORITIES

The following three categories define the major pollutant load reduction elements employed in a stormwater quality improvement project:

- <u>Pollutant Source Controls (PSCs):</u> reduce the mobilization and transport of pollutants of concern at their sources. This includes sources that could be widely distributed in a catchment (e.g., land surface erosion, traction sand, fertilizer applications, animal waste) and those that are more concentrated specific sources (e.g., gully erosion). Examples of PSCs include reduced fertilizer applications, erosion control structures and street sweeping.

- Hydrologic Source Controls (HSCs): reduce runoff volumes and minimize the concentration of stormwater runoff through distributed runoff interception, infiltration, and disconnection of impervious surfaces. HSCs primarily function to increase infiltration, which routes precipitation or surface runoff to groundwater. Examples of HSCs include residential infiltration features and pervious pavement.
- Treatment BMPs: remove pollutants of concern after they have entered concentrated stormwater runoff flow paths. This might include treatment of flows to be infiltrated to groundwater as well as those to be discharged to surface waters. Examples of Treatment BMPs include dry basins, wet basins, infiltration basins, and bed filters.

The priority for developing the initial version of the Tahoe BMP Database was the incorporation of stormwater and treatment BMP performance data into the Database. Thus, the framework for pollutant and hydrologic source controls that has been developed within this initial version of the Database allows the user to enter data that characterizes the drainage attributes and the conditions of a catchment. Since preliminary focus was on Treatment BMPs and runoff characteristics, the initial version of this Database does not provide a suite of complex statistical analyses on pollutant or hydrologic source control performance. However, the Database has a flexible design such that additional fields and analysis techniques may be added in future versions without significant additional effort.

2.2 FRAMEWORK OF DATABASE

The Database produced within the scope of this project consists of a Microsoft SQL Server database backend with a graphical user interface front end (forms, reports, etc.) developed using Microsoft Visual Studio. Appendix B details the Database structure and specifications. The initial version of the Database is a downloadable, self-extracting executable that can be locally installed on any computer. Each installation of the Tahoe BMP and Stormwater Database application connects to the central MS SQL Server database through the internet, allowing individual users to access and query data contained in the Database using the application's graphical user interface. Users can also add data to the Database.

The initial version of the Database is a localized program, meaning that each installation is a standalone application installed on the user's computer but connected to the central online database. Changes made by each user are reflected in the master copy of the Database. Additional work outside the scope of this project will be necessary to develop and deploy a single web application front end to the Database on a web server to centralize the functionality of the Database. This would simplify the deployment of updates and maintenance of the application front-end since all users will essentially be using one web application as opposed to multiple applications on individual computers. The user interface has been designed with loosely coupled modules that allow parts of the program to be easily changed without modifying the underlying database or requiring an extensive amount of additional code. This approach provides greater flexibility and functionality in the design of the user interface, and results in code than can be reused for the development of an online front end to the Database that may eventually be deployed on the Tahoe Integrated Information Management System (TIIMS) server, or similar online system.

SECTION 3. MONITORING AND REPORTING GUIDANCE DOCUMENT OVERVIEW

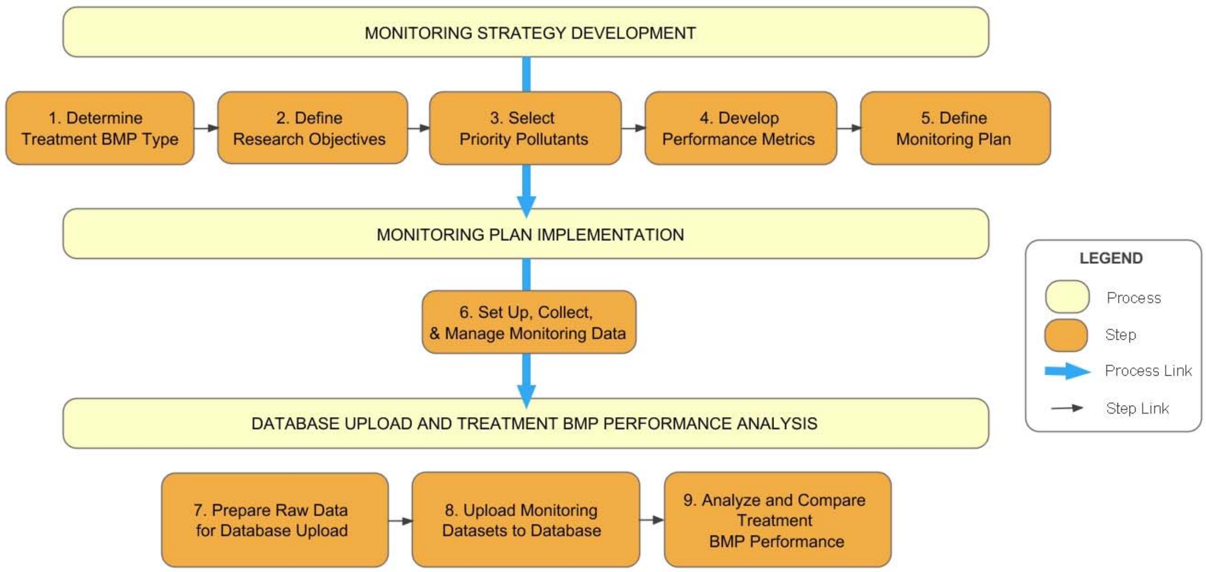
The purpose of this Monitoring and Reporting Guidance Document is to provide concise guidelines for designing a monitoring strategy to quantify the water quality treatment performance and ultimate load reductions of a Treatment BMP, while ensuring the data is obtained in a manner consistent with the data input requirements of the Database. The guidance document presents a process to create a monitoring strategy that may increase the consistency of future Treatment BMP monitoring efforts and data analyses. The process is summarized in Figure 3.1 and includes:

1. Monitoring Strategy Development – The monitoring strategy is the roadmap that justifies how the collection of specific monitoring data will quantify the load reductions for specific pollutants (i.e., treatment performance) provided by a specific Treatment BMP. The researcher[1] determines the Treatment BMP type, defines research objectives, and selects the priority pollutants of concern. A standard list of Lake Tahoe Treatment BMP types has been defined by the physical, chemical and/or biological processes relied upon to reduce the stormwater loads of the pollutants of concern (2NDNATURE et al. 2009). Based on these decisions, the researcher chooses the appropriate data calculations (performance metrics) to properly quantify the water quality performance of the Treatment BMP and the necessary data collection (monitoring plan) to perform those calculations. The development of the monitoring strategy is an iterative process and includes fiscal and policy considerations, in addition to the scientific data needs.
2. Monitoring Plan Implementation – The monitoring plan is defined during the development of the monitoring strategy and is *what, where,* and *when* data is collected and managed to evaluate Treatment BMP performance. Implementation of the monitoring plan includes all data collection efforts for the duration of the study, such as site instrumentation, continuous data downloads, event monitoring, water quality sampling, and data QA/QC.
3. Monitoring Data Upload and Performance Analysis - Following completion of the data collection and monitoring efforts, the researcher organizes and manages the raw data in preparation for Database input and uploads the dataset to the Database. The researcher can then export monitoring datasets from the Database using queries to calculate performance metrics that quantify and compare the treatment performance of selected Treatment BMPs based on catchment, design, water quality and maintenance characteristics.

Section 4 provides step-by-step guidance for the development of the monitoring strategy and includes brief guidance on implementing the monitoring plan. Section 5 includes guidance on preparing the monitoring data for Database input, successfully uploading the dataset to the Database, and querying the Database to summarize the complex water quality datasets obtained from a specific Treatment BMP in order to inform existing data gaps and improve our knowledge of Treatment BMP performance. Section 6 briefly discusses the existing limitations and next steps anticipated for the Database. Finally, Section 7 provides a glossary of terms used throughout this document.

[1]Note: The term researcher is used generally throughout this document to refer to the person or persons who are responsible for the monitoring plan design, implementation, data collection and data analysis. This can include jurisdictional implementers, agency personnel, academic researchers, consultants, etc.

Figure 3.1. Guidance Document Process. Schematic illustrates the process by which a researcher designs, collects and prepares monitoring data for the Tahoe Stormwater and BMP Performance Database. Orange boxes define the researcher steps, which are discussed in Sections 4 (Steps 1-6) and 5 (Steps 7-9) of this guidance document.



SECTION 4. TREATMENT BMP MONITORING STRATEGY

4.1 OVERVIEW

Section 4 guides the researcher through developing a monitoring strategy that will quantify the water quality benefit of a Treatment BMP, which is expressed as the volume and/or load reduction of one or more pollutants of concern. It should be noted that while the Database allows entry of data associated with stormwater sites (defined as a single monitored location that does not have an associated Treatment BMP), this guidance document focuses on the development of Treatment BMP monitoring strategies. The process described below is applicable to the evaluation of a stormwater site; however, it is assumed that development of a monitoring strategy associated with a stormwater site will be less complicated than a Treatment BMP and therefore is not explicitly discussed below.

The first step in developing an effective monitoring strategy is to clearly define the objectives of the planned performance evaluation. Once the research objectives are defined, the researcher will design an appropriate monitoring and data collection strategy to meet these objectives with a clear vision of the required data fields to populate the Database. The top portion of Figure 3.1 illustrates the 5 primary steps researchers follow to develop a rigorous treatment BMP monitoring strategy. The goal of monitoring strategy development is to identify and obtain monitoring data that is relevant to water quality performance of a Treatment BMP in a manner consistent with input requirements of the Database. Each of the 5 steps is described in detail below. A hypothetical performance evaluation for a dry basin is provided as a tangible example (Section 4.8) to illustrate the application of the monitoring strategy development process presented herein. General guidance is provided regarding implementation of the selected monitoring plan (Step 6) in Section 4.9, but detailed guidance for implementing the selected monitoring plan is outside of the scope of this document.

The following is a brief description of the steps to be completed by the researcher. Details and specific guidance on how to perform each step are provided in the rest of this section.

MONITORING STRATEGY DEVELOPMENT

Step 1. Determine Treatment BMP Type – Six Tahoe Treatment BMP types are included in the initial version of the Database. It is essential that the researcher properly identifies the Treatment BMP to be monitored to ensure compatibility with the Database and the selection of an appropriate monitoring strategy.

Step 2. Define Research Objectives – The researcher should clearly define the water quality performance hypotheses that will be tested by the data collected. Database inputs can be grouped into six research objective categories: Characterize Meteorology, Characterize Catchment Hydrology and Pollutant Sources, Quantify BMP Pollutant Load Reductions, Quantify BMP Surface Water Hydrology, Quantify BMP Influent and Effluent Concentrations, and Characterize Local Groundwater Impacts. These research objectives should be defined with an understanding of the water quality treatment processes relied upon by the respective Treatment BMP type determined in Step 1.

Step 3. Select Priority Pollutants – Data collection and monitoring should target those pollutants which address the research objectives defined in Step 2. Consideration should be given to the pollutants the Treatment BMP is designed to treat most effectively and the pollutants that may have elevated concentrations in stormwater within the catchment and thus will be targeted by the Treatment BMP.

Step 4. Identify Performance Metrics – A clear relationship between the research objectives and the data collection efforts should be established as part of the treatment performance evaluation by identifying performance metrics. Performance metrics are quantitative measures (e.g., mean total phosphorus effluent concentration, pounds of total suspended sediment removed, etc.) that facilitate data reporting communication and improve comparisons across monitoring sites and time periods. Performance metrics are applied to monitoring data to address research objectives and test hypotheses.

Step 5. Define Monitoring Plan – The monitoring plan is the data collection and management blueprint to obtain the necessary data to calculate performance metrics and address research objectives. The monitoring plan includes the identification of the specific types of data to be obtained, the locations where monitoring should occur, the frequency at which data should be collected, and the strategy for data management and subsequent analysis.

MONITORING PLAN IMPLEMENTATION

Step 6. Set Up, Collect and Manage Monitoring Data – This step is the actual data collection and monitoring of the Treatment BMP and includes instrumentation, sampling, data collection, data management, and QA/QC. Properly obtained monitoring data will both (1) quantify performance and (2) be consistent with and standardized to the Database. This document provides a general description of the decisions to be made, but does not provide specific monitoring protocols.

Please note the following about the process shown in Figure 3.1:

- It is assumed that the researcher has already identified the specific Treatment BMP to be evaluated. This document does not provide guidance for site selection for monitoring, as the considerations for Treatment BMP selection cover a wide breadth of issues (policy, regulatory, financial, technical, etc.) that are outside the scope of this guidance document.
- The completion of Steps 2-5 in Figure 3.1 is iterative. The researcher is encouraged to continually refine and adapt the monitoring strategy to strengthen the linkages between the research objectives, performance metrics and monitoring plan.
- At the end of this section, general guidance is provided on the steps and considerations to improve the quality of the specific monitoring plan, including data collection, data management and data analysis. Specific, detailed technical recommendations for equipment selection, field monitoring protocols, statistical analyses, and QA/QC protocols are essential to an effective performance evaluation, but they are not within the scope of this guidance document.

4.2 STEP 1: DETERMINE TREATMENT BMP TYPE

To ensure proper integration into the Database, the researcher must begin by identifying the type of Treatment BMP to be monitored. The Database development team has coordinated and aligned the Treatment BMP types with the Pollutant Load Reduction Model (PLRM) and the Best Management Practices Maintenance Rapid Assessment Methodology (BMP RAM) to provide consistency with these Lake Tahoe TMDL urban stormwater tools. The following six Treatment BMPs are included in the first version of the Database:

- Dry Basins
- Wet Basins
- Infiltration Basins
- Treatment Vaults
- Cartridge Media Filters
- Bed Filters

Table 4.1 lists the Treatment BMP types, other common names, primary treatment processes, and a narrative description of key characteristics to assist the researcher with proper identification of the specific Treatment BMP type. The researcher should critically examine the Treatment BMP to be evaluated based on the descriptions provided in Table 4.1 and not rely upon previous BMP type categorizations and definitions. It is critical to the standardization and usability of the Database that all monitored Treatment BMPs have been classified consistently. While the Database allows the user to define the monitored BMP type as “Other”, it is anticipated that the majority of monitoring studies will focus on one of the six Treatment BMP types listed above. If, however, the monitored BMP is not one of these six Treatment BMPs, the user should consult the broader list of 11 Tahoe Treatment BMPs identified in the BMP RAM Technical Document (Table 6.1, available at http://ndep.nv.gov/bwqp/file/bmp_ram_tech09.pdf). The user is highly encouraged to identify the Treatment BMP as one of these 11 Treatment BMP types to maintain consistency into the future with the Lake Tahoe TMDL tools. Appendix C provides the key design parameters of interest by Treatment BMP type.

Table 4.1. Tahoe Treatment BMP Types

Treatment BMP Type	Other Names	Primary Treatment Process(es)[1]	Description
Dry Basin (DB)	Dry Extended Detention Basin, Dry Basin, Dry Pond, Detention Pond	Infiltration Particle Capture	• A constructed basin with riser outlets designed to detain stormwater runoff for some minimum time to allow particle and associated pollutant settling. Outflow occurs at the top of the water column and/or through drain holes in the riser at discrete depths. • Designed to completely empty at some time after stormwater runoff ends (48-72 hours is typical). • The term "dry" implies that there is no significant permanent water pool between storm runoff events. • Water quality improvements downgradient expected as a result of (1) volume reduction via infiltration due to high hydraulic conductivity of footprint soil and (2) effluent concentration reduction due to residence time and particle capture. • Wetland and riparian vegetation species distribution is minimal to absent. Moderate distribution of grass and/or tree species likely and acceptable.

Treatment BMP Type	Other Names	Primary Treatment Process(es)[1]	Description
Wet Basin (WB)	Wet Basin, Wet Pond, Retention Pond, Wetland Swale, Wet Extended - Retention Pond, Stormwater Wetlands, Constructed Wetlands	Particle Capture Nutrient Cycling	• A constructed basin that detains runoff and has a persistent pool of surface water typically through the wet season and intermittently and/or consistently in the dry season. • A wet basin may or may not incorporate extended detention storage. The extended detention storage is an additional surcharge volume overlying the permanent pool that can be designed to attenuate peak flows. • Wet basins require a permanent source of water to maintain vegetation and biological communities. Base flows must match or exceed infiltration and evapotranspiration rates. • Wet basin detention results in flow rate reductions, increased hydraulic residence times and particle aggregation and subsequent settling. Substrate is typically fine organic matter and silt making infiltration rates relatively low. Pollutant load reductions realized by particle capture and biogeochemical processes due to high vegetation presence. Annual stormwater volume reductions occur primarily by evapotranspiration. • A high frequency of stormwater inundation increases the vegetation density. Dominant vegetation is wetland species and can be supplemented with riparian species with very high densities.
Infiltration Basin (IB)	Large-Scale Infiltration Feature	Infiltration	• Constructed basin that captures stormwater runoff and infiltrates it into the ground; an overflow weir is typically the only outlet. • Highly permeable substrate designed to rapidly infiltrate significant volumes of stormwater into unsaturated zone. Pollutant load reductions realized due to significant volume reductions. Performance primarily depends on the hydraulic properties of subsurface media (e.g. ability to infiltrate), groundwater table depth and gradient, and type of pollutants and loadings. • While vegetation can improve infiltration characteristics, its distribution may be minimal, depending upon site conditions.
Treatment Vault (TV)	Flow Separation Vault, Hydrodynamic Separators, Sedimentation Vault, Baffle Box	Particle Capture	• Flow-through confined space structure that separates sediment, debris and other particulate pollutants from the water volumes via various screening and settling techniques. • Hydrodynamic separators, or vortex separators, are one type of treatment vault designed to remove suspended sediment and attached pollutants through screening (physical separation) and centrifugal gravity separation. Baffles can be included to facilitate the removal of floatable debris and oil and grease. • These devices are often installed below ground in precast or cast-in-place concrete vaults. • Water quality improvements of stormwater continuing downgradient expected as a result of particle capture. No volume loss occurs due to impervious base, thus pollutant load reductions realized only by concentration reductions associated with particle capture. • Typically manufactured and proprietary structures.

Treatment BMP Type	Other Names	Primary Treatment Process(es)[1]	Description
Cartridge Filter (CF)	Proprietary Media Filter (e.g. Stormfilter®)	Media Filtration	• Cartridge filters are contained within a confined space similar to treatment vaults. • Following screening, primary sedimentation, and possibly skimming, a cartridge filter includes a chamber with filters, which may be filled with a variety of media, such as zeolite, perlite, peat, compost, and various sorbent materials to target specific pollutants. • The proprietary filter media type targets removal of the pollutants of concern, resulting in downgradient stormwater concentration reductions. Typically, no volume loss occurs due to impervious base.
Bed Filter (BF)	Surface Sand Filter, Underground Sand Filter, Perimeter Sand Filter, Organic Media Filter	Media Filtration	• Typically a settling/pretreatment basin followed by a filter bed (e.g., sand filter, activated alumina) with volume retention above the bed. Filtration is usually controlled by the rate of infiltration through the filter bed. However, outlet structures may also be used to control the flow rate. • The capture of particles and pollutants is achieved via filtration of stormwater through an activated alumina, sand or other media type. • Hydraulically similar to infiltration basins except the runoff is filtered through the bed, collected into an under drain, and discharged to an outlet rather than being infiltrated to the local unsaturated zone. Little to no volume loss occurs.

[1] The four treatment processes are Particle Capture, Infiltration, Media Filtration and Nutrient Cycling, and are defined in the glossary of this document. A detailed discussion of the treatment processes is provided in the BMP RAM Technical Document (Chapter 5, 2NDNATURE et al. 2009).

4.3 ORIENTATION OF MONITORING STRATEGY MATRIX

A well-designed monitoring strategy defines the objectives of data collection and clearly demonstrates how the monitoring data will be analyzed to calculate performance metrics to effectively evaluate the identified research objectives. The Database development team has created a monitoring strategy matrix (MSM) to give researchers tangible guidance as they select the appropriate data necessary to meet the desired research or monitoring objectives in a manner that is consistent with the Database format. The matrices are designed to provide a transparent tool by which researchers can develop, modify, and iterate their monitoring strategies, always with the goal of focused data collection to directly evaluate the water quality performance of the Treatment BMP for the pollutants of interest.

A separate monitoring strategy matrix has been developed for each of the six Treatment BMP types included in the Database (MSM-DB, MSM-WB, MSM-IB, MSM-TV, MSM-CF, and MSM-BF). Sections 4.4-4.7 provide the researcher with more detailed explanations and specific guidance on how to use the matrix to inform monitoring strategy development during each step of the process. Demonstration in the use of the matrix for a hypothetical Treatment BMP example is presented in Section 4.8.

MSM - DB: Dry Basin Monitoring Strategy Matrix

Monitoring Research Objectives / Performance Metrics of Treatment BMP

All Treatment BMP research objectives can be analyzed on event, seasonal, or annual time scales for each priority pollutant at each monitoring location.

Monitoring Research Objectives / Performance Metrics of Treatment BMP	General Site Information												Monitoring Data Inputs to Database by User																													
	Catchment Characteristics				Monitoring Locations							Soil Properties		Surface Water Discharge Time Series				Groundwater Discharge Time Series				Discrete Samples								Event-Specific Data												
																															Event Volumes				Event Composite Samples							
	Catchment Area	Land Use Distribution	Impervious Area	Land Use Condition	Location Type	Spatial Coordinates	Elevation	Groundwater Well Screen Interval	Groundwater Total Depth	Description	**Soil Samples**	Treatment BMP Infiltration Rate	**Meterology Time Series**	Inflow Discharge Time Series	Outflow Discharge Time Series	Change in Storage Time Series	Bypass Discharge Time Series	Local Upgradient WSE Time Series	Local Downgradient WSE Time Series	Regional Upgradient WSE Time Series	Regional Downgradient WSE Time Series	Inflow Concentration	Outflow Concentration	Treatment BMP Concentration	Bypass Concentration	Local Upgradient Groundwater Concentration	Local Downgradient Groundwater Concentration	Regional Upgradient Groundwater Concentration	Regional Downgradient Groundwater Concentration	Event Metadata (duration, type)	Event Inflow Time Series	Event Outflow Time Series	Event Change in Storage Time Series	Event Bypass Time Series	Inflow Composite	Outflow Composite	Treatment BMP Composite	Bypass Composite	Local Upgradient Groundwater Composite	Local Downgradient Groundwater Composite	Regional Upgradient Groundwater Composite	Regional Downgradient Groundwater Composite
Characterize Meterology																																										
Total Precipitation (in)																																										
Characterize Catchment Hydrology and Pollutant Sources																																										
Total Catchment Water Volume (cf)																																										
Catchment Concentration (ug/L)																																										
Catchment Load (lbs)																																										
Quantify Treatment BMP Pollutant Load Reductions																																										
Total Pollutant Load (g)																																										
Pollutant Load Reduction (lbs, %, # particles <16um)																																										
Quantify Treatment BMP Surface Water Hydrology																																										
Hydraulic Residence Time (HRT) (days)																																										
Volume Infiltrated (cf)																																										
Volume Evaporated (cf)																																										
Volume Bypassed (cf)																																										
Treated Water Volume (cf)																																										
Outflow Volume (cf)																																										
Volume Reduction (%, cf)																																										
Catchment Volume Treated by BMP (%)																																										
Duration BMP at Capacity (days)																																										
Duration BMP Inundated (days)																																										
Outflow Frequency (days, % of year)																																										
Quantify Treatment BMP Influent and Effluent Concentrations																																										
Pollutant Concentration Reduction (ug/L, %, # particles/L)																																										
Concentration Statistics (min, max, mean, median, stdev, etc)																																										
Comparison of Nutrient Ratios																																										
DIN:TN (molar)																																										
SRP:TP (molar)																																										
SRP:DIN (molar)																																										
<16um:TSS (by mass)																																										
Characterize Local Groundwater Impacts																																										
Volume Infiltrated (cf)																																										
Infiltration Concentration (ug/L)																																										
Effective Groundwater Volume (cf)																																										
Groundwater Concentration (ug/L)																																										
Groundwater Concentration Statistics (min, max, mean, etc)																																										
Comparison of Groundwater Nutrient Concentrations																																										
DIN:TN (molar)																																										
SRP:TP (molar)																																										
SRP:DIN (molar)																																										
<16um:TSS (by mass)																																										
Groundwater Discharge (cfs)																																										
Infiltrated Volume:Groundwater Volume																																										

Required
Desirable
Not Necessary

MSM - WB: Wet Basin Monitoring Strategy Matrix

(Cell values: R = Required (green), D = Desirable (orange), blank = Not Necessary (white))

	General Site Information												Monitoring Data Inputs to Database by User																													
	Catchment Characteristics				Monitoring Locations							Soil Properties		Surface Water Discharge Time Series				Groundwater Discharge Time Series				Discrete Samples								Event-Specific Data												
																															Event Volumes				Event Composite Samples							
Monitoring Research Objectives / Performance Metrics of Treatment BMP All Treatment BMP research objectives can be analyzed on event, seasonal, or annual time scales for each priority pollutant at each monitoring location.	Catchment Area	Land Use Distribution	Impervious Area	Land Use Condition	Location Type	Spatial Coordinates	Elevation	Groundwater Well Screen Interval	Groundwater Total Depth	Description	**Soil Samples**	Treatment BMP Infiltration Rate	**Meterology Time Series**	Inflow Discharge Time Series	Outflow Discharge Time Series	Change in Storage Time Series	Bypass Discharge Time Series	Local Upgradient WSE Time Series	Local Downgradient WSE Time Series	Regional Upgradient WSE Time Series	Regional Downgradient WSE Time Series	Inflow Concentration	Outflow Concentration	Treatment BMP Concentration	Bypass Concentration	Local Upgradient Groundwater Concentration	Local Downgradient Groundwater Concentration	Regional Upgradient Groundwater Concentration	Regional Downgradient Groundwater Concentration	Event Metadata (duration, type)	Event Inflow Time Series	Event Outflow Time Series	Event Change in Storage Time Series	Event Bypass Time Series	Inflow Composite	Outflow Composite	Treatment BMP Composite	Bypass Composite	Local Upgradient Groundwater Composite	Local Downgradient Groundwater Composite	Regional Upgradient Groundwater Composite	Regional Downgradient Groundwater Composite
Characterize Meterology																																										
Total Precipitation (in)	D	D	D	D	R	D	D			D			R																													
Characterize Catchment Hydrology and Pollutant Sources																																										
Total Catchment Water Volume (cf)	R	R	R	R	R	R	R			D			D	R			R																									
Catchment Concentration (ug/L)	R	R	R	R	R	R	R			D			D									R			D																	
Catchment Load (lbs)	R	R	R	R	R	R	R			D			D	R			D					R			D																	
Quantify Treatment BMP Pollutant Load Reductions																																										
Total Pollutant Load (g)	D	D	D	D	R	R	R			D	D	R	D	R	R	D	R					R	R	R	D					R	R	R	D	R	R	R	R	D				
Pollutant Load Reduction (lbs, %, # particles <16um)	D	D	D	D	R	R	R			D	D		D	R	R	D						R	R	R	D					R	R	R	D		R	R	R	D				
Quantify Treatment BMP Surface Water Hydrology																																										
Hydraulic Residence Time (HRT) (days)	D	D	D	D	R	R	R			D			D	R	D	R														R	R	D	R									
Volume Infiltrated (cf)	D	D	D	D	R	R	R			D		R	D			R														R			R									
Volume Evaporated (cf)	D	D	D	D	R	R	R			D			D			R														R			R									
Volume Bypassed (cf)	D	D	D	D	R	R	R			D			D				R													R				R								
Treated Water Volume (cf)	D	D	D	D	R	R	R			D		R	D	R	D	D														R	R	D	D									
Outflow Volume (cf)	D	D	D	D	R	R	R			D		R	D		R	D														R	R	R	D									
Volume Reduction (%, cf)	D	D	D	D	R	R	R			D			D	R	R	D	D													R	R	R	D	D								
Catchment Volume Treated by BMP (%)	D	D	D	D	R	R	R			D		R	D	R	D	D														R	R	D	D									
Duration BMP at Capacity (days)	D	D	D	D	R	R	R			D			D		D	R														R		D	R									
Duration BMP Inundated (days)	D	D	D	D	R	R	R			D			D			R														R			R									
Outflow Frequency (days, % of year)	D	D	D	D	R	R	R			D			D		R	D														R		R	D									
Quantify Treatment BMP Influent and Effluent Concentrations																																										
Pollutant Concentration Reduction (ug/L, %, # particles/L)	D	D	D	D	R	R	R			D	D		D									R	R	R	D					R					R	R	R	D				
Concentration Statistics (min, max, mean, median, stdev, etc)	D	D	D	D	R	R	R			D	D		D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
Comparison of Nutrient Ratios	D	D	D	D	R	R	R			D	D		D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
DIN:TN (molar)	D	D	D	D	R	R	R			D	D		D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
SRP:TP (molar)	D	D	D	D	R	R	R			D	D		D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
SRP:DIN (molar)	D	D	D	D	R	R	R			D	D		D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
<16um:TSS (by mass)	D	D	D	D	R	R	R			D	D		D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
Characterize Local Groundwater Impacts																																										
Volume Infiltrated (cf)	D	D	D	D	R	R	R			D	D	R	D			R														R												
Infiltration Concentration (ug/L)	D	D	D	D	R	R	R			D	D		D											R						R							R					
Effective Groundwater Volume (cf)	D	D	D	D	R	R	R	R	R	D			D					R	R	D	D																					
Groundwater Concentration (ug/L)	D	D	D	D	R	R	R	R	R	D	D		D													R	R	R	D	R									R	R	R	D
Groundwater Concentration Statistics (min, max, mean, etc)	D	D	D	D	R	R	R	R	R	D	D		D													R	R	R	D										R	R	R	D
Comparison of Groundwater Nutrient Concentrations	D	D	D	D	R	R	R	R	R	D	D		D													R	R	R	D										R	R	R	D
DIN:TN (molar)	D	D	D	D	R	R	R	R	R	D	D		D													R	R	R	D										R	R	R	D
SRP:TP (molar)	D	D	D	D	R	R	R	R	R	D	D		D													R	R	R	D										R	R	R	D
SRP:DIN (molar)	D	D	D	D	R	R	R	R	R	D	D		D													R	R	R	D										R	R	R	D
<16um:TSS (by mass)	D	D	D	D	R	R	R	R	R	D	D		D													R	R	R	D										R	R	R	D
Groundwater Discharge (cfs)	D	D	D	D	R	R	R	R	R	D			D					R	R	R	R									R												
Infiltrated Volume:Groundwater Volume	D	D	D	D	R	R	R	R	R	D		R	D			R		R	R	R	R									R												

Required
Desirable
Not Necessary

MSM - IB: Infiltration Basin Monitoring Strategy Matrix

Monitoring Research Objectives / Performance Metrics of Treatment BMP	General Site Information												Monitoring Data Inputs to Database by User																													
	Catchment Characteristics				Monitoring Locations							Soil Properties		Surface Water Discharge Time Series				Groundwater Discharge Time Series				Discrete Samples								Event-Specific Data												
																															Event Volumes				Event Composite Samples							
All Treatment BMP research objectives can be analyzed on event, seasonal, or annual time scales for each priority pollutant at each monitoring location.	Catchment Area	Land Use Distribution	Impervious Area	Land Use Condition	Location Type	Spatial Coordinates	Elevation	Groundwater Well Screen Interval	Groundwater Total Depth	Description	**Soil Samples**	Treatment BMP Infiltration Rate	**Meteorology Time Series**	Inflow Discharge Time Series	Outflow Discharge Time Series	Change in Storage Time Series	Bypass Discharge Time Series	Local Upgradient WSE Time Series	Local Downgradient WSE Time Series	Regional Upgradient WSE Time Series	Regional Downgradient WSE Time Series	Inflow Concentration	Outflow Concentration	Treatment BMP Concentration	Bypass Concentration	Local Upgradient Groundwater Concentration	Local Downgradient Groundwater Concentration	Regional Upgradient Groundwater Concentration	Regional Downgradient Groundwater Concentration	Event Metadata (duration, type)	Event Inflow Time Series	Event Outflow Time Series	Event Change in Storage Time Series	Event Bypass Time Series	Inflow Composite	Outflow Composite	Treatment BMP Composite	Bypass Composite	Local Upgradient Groundwater Composite	Local Downgradient Groundwater Composite	Regional Upgradient Groundwater Composite	Regional Downgradient Groundwater Composite
Characterize Meterology																																										
Total Precipitation (in)																																										
Characterize Catchment Hydrology and Pollutant Sources																																										
Total Catchment Water Volume (cf)																																										
Quantify Treatment BMP Pollutant Load Reductions																																										
Total Pollutant Load (g)																																										
Pollutant Load Reduction (lbs, %, # particles <16um)																																										
Quantify Treatment BMP Influent and Effluent Concentrations																																										
Hydraulic Residence Time (HRT) (days)																																										
Volume Infiltrated (cf)																																										
Volume Evaporated (cf)																																										
Volume Bypassed (cf)																																										
Treated Water Volume (cf)																																										
Volume Reduction (%, cf)																																										
Catchment Volume Treated by BMP (%)																																										
Duration BMP at Capacity (days)																																										
Duration BMP Inundated (days)																																										
Characterize Local Groundwater Impacts																																										
Volume Infiltrated (cf)																																										
Effective Groundwater Volume (cf)																																										
Groundwater Discharge (cfs)																																										
Infiltrated Volume:Groundwater Volume																																										

Required
Desirable
Not Necessary

MSM - TV: Treatment Vault Monitoring Strategy Matrix

Monitoring Research Objectives / Performance Metrics of Treatment BMP	General Site Information												Monitoring Data Inputs to Database by User																													
All Treatment BMP research objectives can be analyzed on event, seasonal, or annual time scales for each priority pollutant at each monitoring location.	Catchment Characteristics				Monitoring Locations							Soil Properties		Surface Water Discharge Time Series				Groundwater Discharge Time Series				Discrete Samples								Event-Specific Data	Event Volumes				Event Composite Samples							
	Catchment Area	Land Use Distribution	Impervious Area	Land Use Condition	Location Type	Spatial Coordinates	Elevation	Groundwater Well Screen Interval	Groundwater Total Depth	Description	**Soil Samples**	Treatment BMP Infiltration Rate	**Meteorology Time Series**	Inflow Discharge Time Series	Outflow Discharge Time Series	Change in Storage Time Series	Bypass Discharge Time Series	Local Upgradient WSE Time Series	Local Downgradient WSE Time Series	Regional Upgradient WSE Time Series	Regional Downgradient WSE Time Series	Inflow Concentration	Outflow Concentration	Treatment BMP Concentration	Bypass Concentration	Local Upgradient Groundwater Concentration	Local Downgradient Groundwater Concentration	Regional Upgradient Groundwater Concentration	Regional Downgradient Groundwater Concentration	Event Metadata (duration, type)	Event Inflow Time Series	Event Outflow Time Series	Event Change in Storage Time Series	Event Bypass Time Series	Inflow Composite	Outflow Composite	Treatment BMP Composite	Bypass Composite	Local Upgradient Groundwater Composite	Local Downgradient Groundwater Composite	Regional Upgradient Groundwater Composite	Regional Downgradient Groundwater Composite
Characterize Meterology																																										
Total Precipitation (in)	D	D	D	D	R	D	D			D			R																													
Characterize Catchment Hydrology and Pollutant Sources																																										
Total Catchment Water Volume (cf)	R	R	R	R	R	R	R			D			D	R			R																									
Catchment Concentration (ug/L)	R	R	R	R	R	R	R			D			D									R			D																	
Catchment Load (lbs)	R	R	R	R	R	R	R			D			D	R			D					R			D																	
Quantify Treatment BMP Pollutant Load Reductions																																										
Total Pollutant Load (g)	D	D	D	D	R	R	R			D			D	R	R	D	R					R	R	R	D					R	R	R	D	R	R	R	R	D				
Pollutant Load Reduction (lbs, %, # particles <11um)	D	D	D	D	R	R	R			D			D	R	R							R	R	R	D					R	R	R	D		R	R	R	D				
Quantify Treatment BMP Surface Water Hydrology																																										
Hydraulic Residence Time (HRT) (days)	D	D	D	D	R	R	R			D			D	R	D	R														R	R	D	R									
Volume Bypassed (cf)	D	D	D	D	R	R	R			D			D				R													R				R								
Treated Water Volume (cf)	D	D	D	D	R	R	R			D			D	R	D	D														R	R	D	D									
Outflow Volume (cf)	D	D	D	D	R	R	R			D			D		R	D														R		R	D									
Catchment Volume Treated by BMP (%)	D	D	D	D	R	R	R			D			D	R	D	D														R	R	D	D									
Duration BMP at Capacity (days)	D	D	D	D	R	R	R			D			D		D	R														R		D	R									
Duration BMP Inundated (days)	D	D	D	D	R	R	R			D			D			R														R			R									
Outflow Frequency (days, % of year)	D	D	D	D	R	R	R			D			D		R	D														R		R	D									
Characterize Local Groundwater Impacts																																										
Pollutant Concentration Reduction (ug/L, %, # particles/L)	D	D	D	D	R	R	R			D			D									R	R	R	D					R					R	R	R	D				
Concentration Statistics (min, max, mean, median, stdev, etc)	D	D	D	D	R	R	R			D			D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
Comparison of Nutrient Ratios	D	D	D	D	R	R	R			D			D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
DIN:TN (molar)	D	D	D	D	R	R	R			D			D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
SRP:TP (molar)	D	D	D	D	R	R	R			D			D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
SRP:DIN (molar)	D	D	D	D	R	R	R			D			D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D
<16um:TSS (by mass)	D	D	D	D	R	R	R			D			D									R	R	R	D	D	D	D	D	R					R	R	R	D	D	D	D	D

Required (R)
Desirable (D)
Not Necessary (blank)

MSM - CF: Cartridge Filter Monitoring Strategy Matrix

Monitoring Research Objectives / Performance Metrics of Treatment BMP All Treatment BMP research objectives can be analyzed on event, seasonal, or annual time scales for each priority pollutant at each monitoring location.	General Site Information: Catchment Characteristics				General Site Information: Monitoring Locations						Soil Samples	Soil Properties	Monitoring Data Inputs to Database by User	Surface Water Discharge Time Series				Groundwater Discharge Time Series				Discrete Samples								Event-Specific Data	Event Volumes				Event Composite Samples							
	Catchment Area	Land Use Distribution	Impervious Area	Land Use Condition	Location Type	Spatial Coordinates	Elevation	Groundwater Well Screen Interval	Groundwater Total Depth	Description	Soil Samples	Treatment BMP Infiltration Rate	Meteorology Time Series	Inflow Discharge Time Series	Outflow Discharge Time Series	Change in Storage Time Series	Bypass Discharge Time Series	Local Upgradient WSE Time Series	Local Downgradient WSE Time Series	Regional Upgradient WSE Time Series	Regional Downgradient WSE Time Series	Inflow Concentration	Outflow Concentration	Treatment BMP Concentration	Bypass Concentration	Local Upgradient Groundwater Concentration	Local Downgradient Groundwater Concentration	Regional Upgradient Groundwater Concentration	Regional Downgradient Groundwater Concentration	Event Metadata (duration, type)	Event Inflow Time Series	Event Outflow Time Series	Event Change in Storage Time Series	Event Bypass Time Series	Inflow Composite	Outflow Composite	Treatment BMP Composite	Bypass Composite	Local Upgradient Groundwater Composite	Local Downgradient Groundwater Composite	Regional Upgradient Groundwater Composite	Regional Downgradient Groundwater Composite
Characterize Meterology																																										
Total Precipitation (in)	Desirable	Desirable	Desirable	Desirable	Required	Desirable	Desirable			Desirable			Required																													
Characterize Catchment Hydrology and Pollutant Sources																																										
Total Catchment Water Volume (cf)	Required	Required	Required	Required	Required	Required	Required			Desirable			Desirable	Required			Required																									
Catchment Concentration (ug/L)	Required	Required	Required	Required	Required	Required	Required			Desirable			Desirable									Required			Desirable																	
Catchment Load (lbs)	Required	Required	Required	Required	Required	Required	Required			Desirable			Desirable	Required			Desirable					Required			Desirable																	
Quantify Treatment BMP Pollutant Load Reductions																																										
Total Pollutant Load (g)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable	Required	Required	Desirable	Required					Required	Required	Required	Desirable					Required	Required	Required	Desirable	Required	Required	Required	Required	Desirable				
Pollutant Load Reduction (lbs, %, # particles <16um)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable	Required	Required	Desirable						Required	Required	Required	Desirable					Required	Required	Required	Desirable		Required	Required	Required	Desirable				
Quantify Treatment BMP Surface Water Hydrology																																										
Hydraulic Residence Time (HRT) (days)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable	Required	Desirable	Required														Required	Required	Desirable	Required									
Volume Bypassed (cf)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable				Required													Required				Required								
Treated Water Volume (cf)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable	Required	Desirable	Desirable														Required	Required	Desirable	Desirable									
Outflow Volume (cf)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable	Required	Required	Desirable														Required	Required	Required	Desirable									
Catchment Volume Treated by BMP (%)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable	Required	Desirable	Desirable														Required	Required	Desirable	Desirable									
Duration BMP at Capacity (days)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable		Desirable	Required														Required		Desirable	Required									
Duration BMP Inundated (days)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable			Required														Required			Required									
Outflow Frequency (days, % of year)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable		Required	Desirable														Required		Required	Desirable									
Quantify Treatment BMP Influent and Effluent Concentrations																																										
Pollutant Concentration Reduction (ug/L, %, # particles/L)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable									Required	Required	Required	Desirable					Required					Required	Required	Required	Desirable				
Concentration Statistics (min, max, mean, median, stdev, etc)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable									Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable	Required					Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable
Comparison of Nutrient Ratios	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable									Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable	Required					Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable
DIN:TN (molar)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable									Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable	Required					Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable
SRP:TP (molar)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable									Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable	Required					Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable
SRP:DIN (molar)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Desirable									Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable	Required					Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable
<16um:TSS (by mass)	Desirable	Desirable	Desirable	Desirable	Required	Required	Required			Desirable			Required									Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable	Required					Required	Required	Required	Desirable	Desirable	Desirable	Desirable	Desirable

Required
Desirable
Not Necessary

MSM - BF: Bed Filter Monitoring Strategy Matrix

Monitoring Research Objectives / Performance Metrics of Treatment BMP	Metadata												Monitoring Data Inputs to Database by User																													
All Treatment BMP research objectives can be analyzed on event, seasonal, or annual time scales for each priority pollutant at each monitoring location.	Catchment Characteristics				Monitoring Locations							Soil Properties		Surface Water Discharge Time Series				Groundwater Discharge Time Series				Discrete Samples								Event-Specific Data												
																																		Event Volumes				Event Composite Samples							
	Catchment Area	Land Use Distribution	Impervious Area	Land Use Condition	Location Type	Spatial Coordinates	Elevation	Groundwater Well Screen Interval	Groundwater Total Depth	Description	**Soil Samples**	Treatment BMP Infiltration Rate	**Meteorology Time Series**	Inflow Discharge Time Series	Outflow Discharge Time Series	Change in Storage Time Series	Bypass Discharge Time Series	Local Upgradient WSE Time Series	Local Downgradient WSE Time Series	Regional Upgradient WSE Time Series	Regional Downgradient WSE Time Series	Inflow Concentration	Outflow Concentration	Treatment BMP Concentration	Bypass Concentration	Local Upgradient Groundwater Concentration	Local Downgradient Groundwater Concentration	Regional Upgradient Groundwater Concentration	Regional Downgradient Groundwater Concentration	Event Metadata (duration, type)	Event Inflow Time Series	Event Outflow Time Series	Event Change in Storage Time Series	Event Bypass Time Series	Inflow Composite	Outflow Composite	Treatment BMP Composite	Bypass Composite	Local Upgradient Groundwater Composite	Local Downgradient Groundwater Composite	Regional Upgradient Groundwater Composite	Regional Downgradient Groundwater Composite
Characterize Meterology																																										
Total Precipitation (in)																																										
Characterize Catchment Hydrology and Pollutant Sources																																										
Total Catchment Water Volume (cf)																																										
Catchment Concentration (ug/L)																																										
Catchment Load (lbs)																																										
Quantify Treatment BMP Pollutant Load Reductions																																										
Total Pollutant Load (g)																																										
Pollutant Load Reduction (lbs, %, # particles <16um)																																										
Quantify Treatment BMP Surface Water Hydrology																																										
Hydraulic Residence Time (HRT) (days)																																										
Volume Bypassed (cf)																																										
Treated Water Volume (cf)																																										
Outflow Volume (cf)																																										
Catchment Volume Treated by BMP (%)																																										
Duration BMP at Capacity (days)																																										
Duration BMP Inundated (days)																																										
Outflow Frequency (days, % of year)																																										
Quantify Treatment BMP Influent and Effluent Concentrations																																										
Pollutant Concentration Reduction (ug/L, %, # particles/L)																																										
Concentration Statistics (min, max, mean, median, stdev, etc)																																										
Comparison of Nutrient Ratios																																										
DIN:TN (molar)																																										
SRP:TP (molar)																																										
SRP:DIN (molar)																																										
<16um:TSS (by mass)																																										

Required
Desirable
Not Necessary

The following provides general orientation to the matrices:

- Only one Treatment BMP type is presented per monitoring strategy matrix.
- Each row of the matrix represents one performance metric.
    - A performance metric is a quantitative value that summarizes specific monitoring and/or water quality parameters and thereby facilitates data reporting communication and improves comparisons across Treatment BMPs, monitoring sites and time periods.
    - Performance metrics are grouped by the six research objective categories (Characterize Meteorology, Characterize Catchment Hydrology and Pollutant Sources, Quantify Treatment BMP Pollutant Load Reductions, Quantify Treatment BMP Surface Water Hydrology, Quantify Influent and Effluent Concentrations, and Characterize Local Groundwater Impacts).
    - Only the performance metrics relevant to the primary treatment processes utilized by the Treatment BMP type (see Table 4.1) are provided in the matrix.
    - More details on each performance metric are presented in Table 4.3.
- Each column of the matrix represents one type of Monitoring Data.
    - Monitoring data are the specific information collected by the researcher to calculate the performance metrics and evaluate the water quality treatment performance of the BMP, and are input directly into the Database.
    - More details on each type of monitoring data are presented in Table 4.4.
    - Note that the BMP design characteristics are not included as monitoring data. For more information on the key design parameters for each Treatment BMP type, see Appendix C (Treatment BMP Design Parameters).
- Each cell at the intersection of a row (Performance Metric) and column (Monitoring Data) is one of 3 colors: green, orange, or white.
    - Green cells indicate the monitoring data is required in order to calculate the respective performance metric.
    - Orange cells indicate the monitoring data is desirable for performance metric calculation.
    - White cells indicate the monitoring data is not necessary to performance metric calculation.

4.4 STEP 2: DEFINE RESEARCH OBJECTIVES

In Step 2 the researcher defines the objectives of the data collection to effectively design and implement a monitoring strategy. The researcher should clearly identify the water quality performance hypotheses that will be tested by the collected data with a clear understanding of the water quality treatment processes relied upon by the respective Treatment BMP type (see Table 4.1). As discussed in Section 4.3, this guidance document classifies the objectives into six categories that are typical of Tahoe Treatment BMP water quality performance evaluations, which are presented as the row headings in the monitoring strategy matrices for each Treatment BMP type. It should be noted, these objectives are provided for the evaluation of a single Treatment BMP; however a researcher could apply any of these objectives to several BMPs in order to compare their relative treatment performance. The six categories are described below and, where appropriate, questions are provided to further assist the researcher through the process of selecting and developing research objectives.

CHARACTERIZE METEOROLOGY

Meteorology includes all climatic data (e.g., precipitation, temperature, wind speed, relative humidity) to provide a context for specific events and for differences across water years. Most water quality monitoring efforts are performed for discrete time periods, yet the greatest future and applied value of the datasets is to extrapolate the results to other water years and different hydrologic conditions to allow comparison across studies. Meteorological data allows critical annual, seasonal and runoff event comparisons to better constrain potential variability in temporal datasets due to varying meteorological factors. Consideration of the precipitation and temperature differences between runoff events, seasons and years allows researchers to constrain meteorological variability from hydrologic and loading differences due to actual BMP treatment. Meteorological data provides context for the analysis of water quality performance data. Additionally, this data when coupled with runoff hydrology and water quality monitoring can greatly assist with validation and refinement of Treatment BMP performance modeling. The Database development team recommends that local meteorological data, particularly precipitation and temperature, are collected as part of any water quality performance monitoring effort.

CHARACTERIZE CATCHMENT HYDROLOGY AND POLLUTANT SOURCES

The water quality performance of a Treatment BMP is highly dependent upon inflowing hydrology and water quality. The characteristics of the contributing catchment will have a significant influence on both of these variables. Catchment characteristics likely to influence total runoff volumes include catchment size, the distribution and connectivity of impervious surfaces, slopes, and hydrologic routing of stormwater. While the fate and transport of different pollutants will vary greatly, catchment characteristics likely to influence the concentrations and loading of the priority pollutants may include: native soil type and distribution; land use characteristics, including type, density, and condition; and human activities, including road abrasive and fertilizer application. Researchers evaluating Treatment BMP performance should obtain data and information that will improve the understanding of catchment characteristics that are expected to influence the relative loading of priority pollutants. The researcher should use these catchment characteristics to inform the selection of the priority pollutants to be included in the research (Step 3).

Urban catchment characteristics provide additional context to assess the performance of a Treatment BMP and improve the comparison of performance across Treatment BMPs. The researcher should incorporate the characterization of catchment factors into the Treatment BMP evaluation and then use these factors to inform the selection of other research objectives. The specific catchment factors selected will depend on both the Treatment BMP type and identified priority pollutants. The Database development team recommends that catchment hydrology and pollutant source data should be included as a component of any water quality performance analysis.

QUANTIFY TREATMENT BMP POLLUTANT LOAD REDUCTIONS

The primary goal in the design and construction of the majority of Lake Tahoe Treatment BMPs is to reduce loading of the primary pollutants of concern affecting lake clarity. By definition, performance evaluations intend to quantify the load reduction of key pollutants as a result of the presence of the Treatment BMP of interest. Hence, paired estimates of total influent and total effluent loads are needed to compute load reductions. With these data the researcher may then explore the effectiveness of load reductions relative to overall loading from the catchment or the differences in pollutant loading due to runoff event characteristics (type, magnitude, duration, etc.). Both stormwater hydrology (volume) and water quality concentrations (mass/volume) monitored at the influent and effluent of a Treatment BMP are required to properly calculate loads and load reductions.

QUANTIFY TREATMENT BMP SURFACE WATER HYDROLOGY

The performance of some Treatment BMPs is dependent upon their ability to reduce stormwater runoff volumes and attenuate peak flow rates. Researchers should consider the design characteristics (Appendix C of this document includes the key Treatment BMP design parameters) and current condition of the Treatment BMP to determine if the Treatment BMP is likely to result in a reduction of stormwater volumes. Key Treatment BMP design attributes will target increased stormwater volume detention, increased hydraulic residence times, decreased flow velocities, and/or increased infiltration to the subsurface.

Below are examples of questions researchers should consider in determining if the quantification of Treatment BMP surface water hydrology may be an appropriate research objective for the BMP.

- Is the Treatment BMP designed to induce infiltration of surface water volumes to the subsurface?
- Is the Treatment BMP designed to retain surface water volumes and reduce discharge rates?
- What is the anticipated percent of inflowing surface water that will be treated on an average annual basis (e.g., 80% of the average annual runoff volume)?
- What is the anticipated hydraulic residence time?

The formulation of specific research objectives should be developed considering (1) key Treatment BMP design attributes that target stormwater runoff volumes and flow rates (see Appendix C), (2) meteorological considerations, including seasonal and event type variability in performance, and (3) catchment hydrology. For example, the researcher may consider how the presence of the Treatment BMP has changed the stormwater hydrograph, or what the actual hydraulic residence time is for an event, or what the water quality treatment volume is relative to the volume bypassing treatment. These types of research objectives can inform the observed hydrologic behavior of the Treatment BMP relative to sizing assumptions made during design.

The quantification of surface water hydrology is a necessary component of any water quality performance analysis that includes the quantification of pollutant load reductions. Continuous inflow and outflow monitoring, as well as water level measurements will help facilitate quantification of volume losses, flow rate reductions, treated volumes (if both treated and bypass outflows are monitored), and hydraulic residence times.

QUANTIFY TREATMENT BMP INFLUENT AND EFFLUENT CONCENTRATIONS

Many Treatment BMPs are designed to reduce pollutant concentrations through particle capture, media filtration, and nutrient cycling (see Appendix C). Below are examples of questions researchers should consider in determining if BMP concentration objectives are appropriate for the monitoring strategy:

- Is the Treatment BMP designed to physically settle, trap, or capture particulate pollutants?
- Does the Treatment BMP use active media filtration to specifically adsorb dissolved pollutants?
- Are wetland and/or riparian vegetation species present to promote biological uptake or transformation of dissolved pollutants?

The formulation of specific research questions should be developed considering (1) key Treatment BMP design attributes that target pollutant removal (see Appendix C), (2) meteorological considerations, including seasonal and event type variability in performance, and (3) catchment pollutant sources and expected loads. For example, the researcher may compare seasonal vegetation growth to removal of biologically available nutrients or compare the effluent pollutant concentration reductions of particulate and dissolved pollutants. These types of research objectives can inform the observed pollutant removal performance of the BMP relative to the treatment capability assumptions made during design.

The quantification of Treatment BMP water quality is a necessary component of any water quality performance analysis that includes the quantification of pollutant load reductions. Water quality samples (preferably flow-weighted composite samples) collected at the influent and effluent locations for a BMP are essential for evaluating water quality treatment performance.

CHARACTERIZE LOCAL GROUNDWATER IMPACTS

Many Treatment BMPs are designed to infiltrate stormwater runoff as a means to reduce stormwater volumes and pollutant concentrations (see Appendix C). One continued significant concern is the potential transfer of dissolved pollutants from stormwater to groundwater, which could reduce the rate of overland pollutant delivery to the Lake but may not reduce the overall load of conservative dissolved pollutants (e.g., nitrate) that may enter the Lake through subsurface pathways. Treatment BMP monitoring may consider the impacts of infiltration on local groundwater resources depending upon a number of possible considerations, including but not limited to:

- Is infiltration a primary process by which the Treatment BMP reduces pollutant loading?
- What are the groundwater water quality conditions upgradient, beneath and downgradient of the Treatment BMP?
- Are the primary dissolved pollutants of concern conservative or non-conservative in the subsurface environment?
- Is the proximity of the Treatment BMP to the Lake a concern with respect to potential geochemical treatment capabilities in the subsurface environment? In other words, might seasonal groundwater elevations prevent effective infiltration and associated treatment during wet months? Or might the effective unsaturated soil volumes be too small to consistently retain and degrade the pollutants of concern prior to the lake or stream interface?

4.5 STEP 3: SELECT PRIORITY POLLUTANTS

Step 3 in developing the monitoring strategy is the identification of the specific pollutants of concern. This is a critical step towards ensuring that data collection efforts directly meet the research objectives. There are two key components to proper selection of the research priority pollutants:

- Understand the pollutants most likely to be introduced and potentially treated by the Treatment BMP. The selection of research objectives in Step 2 should provide the researcher with an improved understanding of the treatment capabilities of the BMP. For example, a treatment vault is designed to treat stormwater through physical settling and separation of particles and, thus, the priority pollutants for a vault monitoring study may be particulate pollutants. Review the Treatment BMP type descriptions in Table 4.1 and the key design parameters in Appendix C, as well as the descriptions of the pollutants below, in order to identify the priority pollutants for the Treatment BMP to be evaluated.
- Fine sediment particles (FSP) and nutrients have been identified as the primary pollutants impairing Lake Tahoe clarity. While other pollutants may be interesting from a research perspective and concentration data for any type of pollutant can certainly be added to the Database, this guidance document focuses on the analysis of FSP and nutrients due to the high priority of these constituents with regard to protecting Lake Tahoe.

SEDIMENT

Suspended sediment in Lake Tahoe can be characterized by three different analytic species: total suspended sediment (TSS), suspended sediment concentrations (SSC), and fine sediment particles (FSP; <16 µm). Both TSS and SSC represent the measured mass of sediment contained in a known volume of water, and stormwater samples analyzed for TSS or SSC can be used to quantify the suspended sediment loads transported in runoff. FSP refers to the amount of suspended sediment particles that are 16µm or smaller, generally calculated as a percentage of TSS by mass (see Figure 4.1).

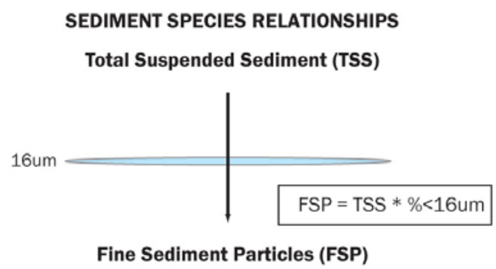


Figure 4.1 Sediment Species Relationship. Pollutants of concern recommended for the Database are in bold.

Research for the Tahoe TMDL (LRWQCB and NDEP 2010) suggests nearly two-thirds of the total annual contribution of fine sediment particles to the lake is generated from urban stormwater runoff, including erosion of native material, anthropogenic application of road abrasives, and road and tire breakdown. Sediment particles are typically treated though physical trapping and/or settling due to flow attenuation or media filtration. Decreasing lateral flow velocity limits the particle transport capacity of stormwater, allowing particle settling and retention within the Treatment BMP. Engineered flow-through systems can physically trap, separate, and/or sieve particulates. Recent event-based monitoring of Tahoe Treatment BMPs (2NDNATURE 2008, 2010) suggests that Treatment BMPs can achieve FSP load reductions both through volume reductions, as well as concentration reductions.

NUTRIENTS

The primary nutrient species contributing to the decline in Lake Tahoe's clarity include nitrogen (N) and phosphorous (P). Figure 4.2 presents schematics of the P species and N species. Nutrient analytes are either particulates or dissolved (i.e., pass through a 0.45µm filter) and either organic or inorganic. It is assumed that when nutrient compounds adhere to organic particles and/or are sorbed or precipitated with inorganic particles larger than 0.45µm, photosynthetic organisms cannot easily utilize them for photosynthesis. Only dissolved inorganic nutrients are considered readily biologically available and consequently can stimulate photosynthetic growth. Table 4.2 presents the different analytical species for both N and P.

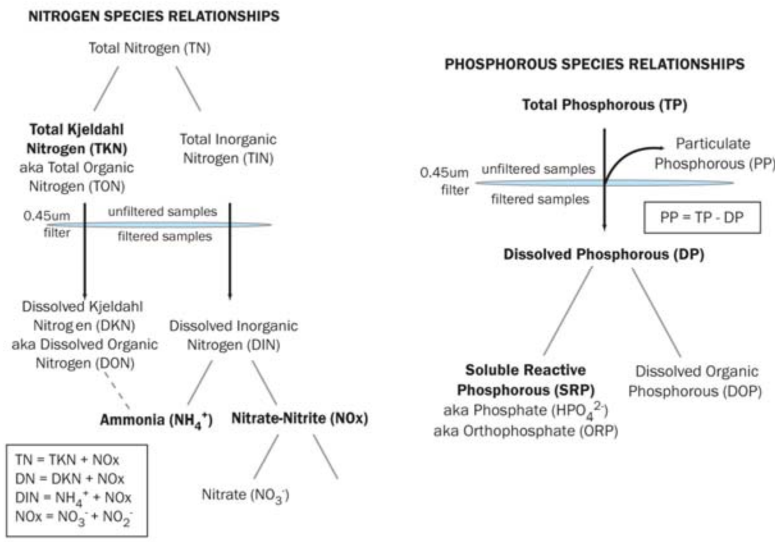


Figure 4.2 Nitrogen (left) and Phosphorous (right) Species Relationships. Pollutants of Concern recommended for the Database are in bold.

Table 4.2. Nutrient Analytical Species. Pollutants of concern recommended for the Database are listed in bold.

	Nitrogen (N)		Phosphorous (P)	
	Organic	**Inorganic**	**Organic**	**Inorganic**
Total	Total Nitrogen (TN)		**Total Phosphorous (TP)**	
Particulate	**Total Kjeldahl Nitrogen (TKN; total organic nitrogen)[1]**	Total Inorganic Nitrogen (TIN)	Particulate Phosphorous (PP)	
Dissolved	Dissolved Kjeldahl Nitrogen (DKN; dissolved organic nitrogen)	**Nitrate-Nitrite (NO_X), Ammonia (NH_4^+)[2]**	**Dissolved Phosphorous (DP)**	
			Dissolved Organic Phosphorous (DOP)	**Soluble Reactive Phosphorous (SRP; phosphate, orthophosphate)**

[1] TKN is defined as total organic nitrogen plus ammonia; however, ammonia typically represents a very small fraction of TKN and therefore TKN can be considered a particulate analyte.
[2] NO_x = Nitrate (NO_3^-) + Nitrite (NO_2^-); Dissolved Inorganic Nitrogen (DIN) = NO_x + NH_4^+

Urban land uses and activities can be significant sources of nutrients. Nitrogen pollution can be generated from leaky septic and/or sewer systems, fertilizer applications, automobile exhaust, fires, and industrial activities. Atmospheric deposition of nitrate on impervious surfaces in urban areas as a result of fires and automobile exhaust has also been identified as a significant source (USDA 2000). Phosphorous sources include weathering of P-rich volcanic and granitic rocks, leaky septic and/or sewer systems, detergents, agricultural runoff, and fertilizer applications.

Nutrients physically transported in surface water include both dissolved and particulate forms adhered to inorganic or organic particles. Treatment of particulate species is similar to the processes described for suspended sediment, including particle settling and capture by flow attenuation, physical capture, or infiltration. Dissolved species are typically treated through active media filtration or nutrient cycling (Figure 4.3). Engineered flow-through systems can be equipped with active media to adsorb and remove dissolved constituents. The type of media installed is dependent on which pollutant of concern is targeted. Nutrient cycling involves the reduction of biologically available nutrients due to uptake by growing vegetation during photosynthesis.

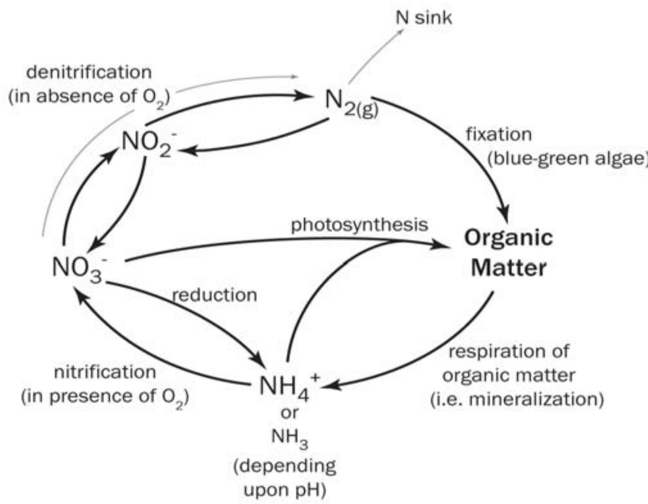


Figure 4.3 Nitrogen Cycle
(modified from Stumm and Morgan 1996)

OTHER POTENTIAL POLLUTANTS OF CONCERN

Researchers may consider the evaluation of other pollutants of concern, depending on specific, localized characteristics of the Treatment BMP and its surrounding land uses.

Hydrocarbons, including volatile organic compounds (VOCs), fuel oxygenates (e.g., methyl tert-butyl ether [MtBE]), total petroleum hydrocarbons (TPH), total extractable petroleum hydrocarbons (TEPH), and oil and grease, are associated with highly industrial and commercial urban land uses. Treatment processes can include active media filtration, particle capture or infiltration, depending on the solubility of the compound.

Sources of trace metals (e.g., cadmium, copper, lead, zinc, mercury) pollution include roads, parking lots, and dense commercial land uses. The treatability of metals is a function of the dissolved/particulate fractionation and the speciation. Lead and zinc are often highly associated with particulates, whereas cadmium and copper often have a higher dissolved fraction. Particulate-bound metals can be removed via particle capture and media filtration. Dissolved metal species can be removed by active media filtration, infiltration, and nutrient cycling processes that sequester or precipitate metal species.

Organic pesticides are primarily applied on golf courses. Treatment BMPs downstream of this land use may use media filtration or nutrient cycling and associated biogeochemical processes to reduce pollutant loads to Lake Tahoe.

4.6 STEP 4: DEVELOP PERFORMANCE METRICS

Performance metrics are quantitative values that summarize specific monitoring and/or water quality parameters and thereby facilitate data reporting communication and improve comparisons across Treatment BMPs, monitoring sites and time periods. The performance metrics are the data analysis link between the research objectives and the monitoring data to be collected. The monitoring datasets are used to calculate the performance metrics, which are then used to evaluate Treatment BMP performance. Following the completion of Steps 1-3 (Identify Treatment BMP Type, Define Research Objectives, and Select Priority Pollutants), the researcher will define in Step 4 the performance metrics that will be calculated to evaluate the performance of the Treatment

BMP using the data collected. Performance metrics should simplify data communication and facilitate quantitative analysis of the compiled dataset while preserving the robustness of the dataset. Properly defined and calculated metrics are the key to reliable and consistent Treatment BMP performance evaluations.

The following guidance is provided to assist the researcher with identifying appropriate performance metrics.

1. Locate the appropriate monitoring strategy matrix (MSM-DB, MSM-WB, MSM-IB, MSM-TV, MSM-CF, and MSM-BF) for the Treatment BMP type of interest (Step 1; Section 4.2).
2. Based on the identified Research Objectives (Step 2), review all potential performance metrics.

   Within the matrix, the performance metrics are grouped according to the 6 research objectives (Step 2; Section 4.4)
3. Refer to performance metric descriptions in Table 4.3 to assist with performance metric selection.

   Table 4.3 includes a brief description of the metric, the calculation method, suggested units of measurement, and the possible time intervals for data integration. This list has been compiled based on numerous Lake Tahoe BMP effectiveness monitoring studies and represents a wide-range of analytical techniques. This list is limited to proven metrics that focus on the stormwater treatment priorities in the Tahoe Basin, but other relevant performance metrics likely exist. Not all performance metrics listed in Table 4.3 are relevant to every Treatment BMP type. For example, cartridge filters are typically underground vaults that do not infiltrate stormwater volumes; therefore, local groundwater impact metrics are not appropriate for this type of Treatment BMP.
4. Develop a list of performance metrics based on those that best address the research objectives and will best test the research hypotheses.

   In selecting the performance metrics as part of the monitoring strategy, the researcher should continually refer to the research objectives. The key to developing an effective monitoring strategy is to link data collection and analysis efforts to the specific research hypotheses to be tested. Researchers should continually ask themselves, “Does this performance metric directly address one of the chosen research objectives?”. If the answer is no, the performance metric may not be a priority. If the answer is yes, the researcher is encouraged to define specifically how the performance metric directly addresses an objective. This will help the researcher prioritize and refine the performance metric list. Rather than choosing all performance metrics that may answer the research objectives, researchers are challenged to focus their efforts on the metrics that *best* address the objectives. By focusing on a selected subset of performance metrics, the researcher can ensure a cost-effective and efficient use of available resources.
5. As necessary, refine the monitoring strategy, including research objectives, priority pollutants, and performance metrics.

   The process of designing the monitoring strategy can be fluid and may take several iterations before the final research objectives and performance metrics are selected. As researchers begin to select performance metrics, they may decide to further refine or even change the research objectives or priority pollutants.

TABLE 4.3. Performance Metric Descriptions

Data Input	Units	Description	Calculation	Time Interval
Characterize Meteorology				
Total Precipitation	inches	Rainfall measured at site	Sum of Rainfall	Water Year, Season, Month, Event
Characterize Catchment Hydrology and Pollutant Sources				
Total Catchment Water Volume	cf	Volume of stormwater runoff emanating from catchment	BMP Inflow Volume + Bypass Volume	Water Year, Season, Month, Event
Catchment Concentration	ug/L	Pollutant concentration of stormwater runoff emanating from catchment	Average (can be time or flow weighted) from laboratory analytical results	Water Year, Season, Month, Event
Catchment Load	lbs	Pollutant load in stormwater runoff emanating from catchment	Concentration of Total Catchment Water Volume	Water Year, Season, Month, Event
Quantify Treatment BMP Pollutant Load Reductions				
Total Pollutant Load	g	Grab sample analyzed for the pollutant of concern	Sample concentration* Volume	Water Year, Season, Month, Event
Pollutant Load Reduction	lbs, %, # particles <16um	Effect of BMP on pollutant load reduction	(Inflow Load-Outflow Load)/Inflow Load	Water Year, Season, Month, Event
Quantify Treatment BMP Surface Water Hydrology				
Hydraulic Residence Time (HRT)	days	Measure of average length of time water remains in BMP	*Basin Volume/Inflow Rate*	Water Year, Season, Month, Event
Volume Infiltrated	cf	Volume of water infiltrated to subsurface through BMP substrate	Duration (hr) * Infiltration Rate (cm/s) * Basin Surface Area (ft^2)	Water Year, Season, Month, Event
Volume Evaporated	cf	Volume of water lost from BMP through evapotranspiration	Duration (hr)* Evapotranspiration Rate (in/month)* Basin Surface Area (ft^2)	Water Year, Season, Month, Event
Volume Bypassed	cf	Volume of water diverted around BMP and therefore untreated by BMP	Integration of Bypass Discharge Time Series over time interval	Water Year, Season, Month, Event
Treated Water Volume	cf	Volume of water treated by BMP	Integration of Inflow Discharge Time Series over time	Water Year, Season, Month, Event
Outflow Volume	cf	Volume of water lost from BMP through outlet	Integration of Outflow Discharge Time Series over time	Water Year, Season, Month, Event
Volume Reduction	cf, %	Runoff volume reduced through treatment by BMP	cf: Inflow Volume - Outflow Volume %: (Inflow Volume - Outflow Volume)/Inflow Volume	Water Year, Season, Month, Event
Catchment Volume Treated by BMP	%	Percent of catchment runoff treated by BMP	Treated Water Volume/Total Catchment Water Volume	Water Year, Season, Month, Event
Duration BMP at Capacity	days, % of year	Number of days water volume at (or exceeding) BMP capacity	days: Number of Days of Outflow Occurrence %: Number of Days of Outflow Occurrence/365	Water Year, Season, Month, Event
Duration BMP Inundated	days, % of year	Number of days when BMP has water in it	days: Number of Days BMP water depth > 0 %: Number of Days BMP water depth > 0/365	Water Year, Season, Month, Event
Outflow Frequency	days, % of year	Number of days outflow occurred	Number of Days of Outflow Occurrence/365	Water Year, Season, Month, Event
Quantify Treatment BMP Influent and Effluent Concentrations				
Pollutant Concentration Reduction	ug/L, %, # particles/L	Effect of BMP on pollutant concentration reduction	(Inflow Concentration-Outflow Concentration)/Inflow Concentration	Water Year, Season, Month, Event
Concentration Statistics	min, max, mean, median, stdev, etc	Pollutant of concern concentration, varied by location of sample (inlet, outlet, or bypass)	Standard methods for calculating min, max, mean, median, stdev, etc	Water Year, Season, Month, Event
Comparison of Nutrient Ratios	Ratio	Comparison of pollutants of concern	Described below	Water Year, Season, Month, Event
DIN:TN (molar)	Ratio	% of total nitrogen biologically available	[(Nitrate + Nitrite + Ammonia Concentrations)/14]/[Total Nitrogen Concentration/14]	Water Year, Season, Month, Event
SRP:TP (molar)	Ratio	% of total phosphorus biologically available	[SRP Concentration/31]/[Total Phosphorous Concentration/31]	Water Year, Season, Month, Event
SRP:DIN (molar)	Ratio	% of biologically available phosphorus relative to biologically available nitrogen	[SRP Concentration/31]/[(Nitrate + Nitrite + Ammonia Concentration)/14]	Water Year, Season, Month, Event
<16um:TSS (by mass)	g	% of fine sediment in TSS	[TSS Concentration <16um]/[TSS Concentration]	Water Year, Season, Month, Event
Characterize Local Groundwater Impacts				
Volume Infiltrated	cf	volume of water infiltrated to subsurface through basin substrate	Duration (hr) * Infiltration Rate (cm/s) * Basin Surface Area (ft^2)	Water Year, Season, Month, Event
Infiltration Concentration	ug/L	Concentration of pollutant of concern infiltrating subsurface	BMP Concentration	Water Year, Season, Month, Event
Effective Groundwater Volume	cf	Storage reservoir beneath BMP, effective for storing water	(Surface Area of Infiltrating Surface * Thickness of Effective Shallow Aquifer) * Porosity of Material	Water Year, Season, Month, Event
Groundwater Concentration	ug/L	Concentration of pollutant of concern found in groundwater	N/A	Water Year, Season, Month, Event
Groundwater Concentration Statistics	min, max, mean, median, stdev, etc	Pollutant of concern concentration, varied by location of sample (inlet, outlet, or bypass) found in groundwater	Standard methods for calculating min, max, mean, median, stdev, etc., weighted by time or volume of storm event	Water Year, Season, Month, Event
Comparison of Nutrient Ratios	Ratio	Comparison of pollutants of concern	Described below	Water Year, Season, Month, Event
DIN:TN (molar)	molar	% of total nitrogen biologically available	[(Nitrate + Nitrite + Ammonia Concentrations)/14]/[Total Nitrogen Concentration/14]	Water Year, Season, Month, Event
SRP:TP (molar)	molar	% of total phosphorus biologically available	[SRP Concentration/31]/[Total Phosphorous Concentration/31]	Water Year, Season, Month, Event
SRP:DIN (molar)	molar	% of biologically available phosphorus relative to biologically available nitrogen	[SRP Concentration/31]/[(Nitrate + Nitrite + Ammonia Concentration)/14]	Water Year, Season, Month, Event
<16um:TSS (by mass)	g	% of fine sediment in TSS	[TSS Concentration <16um]/[TSS Concentration]	Water Year, Season, Month, Event
Groundwater Discharge (cfs)	cfs	Groundwater discharge from subsurface	Q=Kadh/dl (Darcy's Law)	Water Year, Season, Month, Event
Infiltrated Volume: Groundwater Volume	Ratio	Potential impact of BMP on subsurface	Volume Infiltrated/Effective Groundwater Volume	Water Year, Season, Month, Event

4.7 STEP 5: DEFINE MONITORING PLAN

Step 5 of the monitoring strategy development is the completion of the monitoring plan. The monitoring plan includes *what, where* and *when* monitoring data will be collected at the Treatment BMP throughout the duration of the monitoring study. These specific data will be input directly into the Database (Step 8). The monitoring plan is the data collection and management blueprint and includes the identification of the specific types of data to be obtained, the general locations where monitoring should occur, and the frequency at which data should be collected. Direction on how the monitoring occurs, including monitoring protocols, data collection, data management, QA/QC, and analysis protocols, is not provided as part of this document, though guidance on the implementation of the monitoring plan is presented in Section 4.9.

The following process is provided to assist the researcher with identifying appropriate monitoring data to collect in order to calculate performance metrics and quantify the water quality treatment performance of the BMP.

1. List all required and desirable monitoring data, based on the selected monitoring strategy.
   a. Use the appropriate monitoring strategy matrix based on Treatment BMP type (Step 1; Section 4.2).
   b. Locate the matrix rows associated with each selected performance metric (Step 4; Section 4.6).
   c. Find each green cell in the row and move up the column to determine the *required* monitoring data.
   d. Find each orange cell in the row and move up the column to determine the *desired* monitoring data.
   e. Note that Treatment BMP design parameters are not included in the monitoring strategy matrices. Appendix C of this document provides the key design parameters by Treatment BMP type and it is assumed the researcher will collect this information as part of the BMP treatment performance monitoring.
2. Consult Table 4.4 for descriptions of the monitoring data.

   For each type of monitoring data, details on the recommended units, suggested methodology or instrumentation, site location, and recommended monitoring frequency are provided in Table 4.4.

   - The Database allows the researcher to choose the specific units; however, this guidance document recommends specific measurement units to maintain consistency across future Lake Tahoe water quality performance evaluations.
   - The methodology or instrumentation suggestions are based on the numerous data collection strategies that have been implemented throughout the Tahoe Basin during BMP effectiveness monitoring studies. The guidance document does not endorse specific monitoring equipment. The researcher should consider specific site logistics, technical instrument specifications and costs to determine the most appropriate monitoring equipment for the selected Treatment BMP.
   - Site locations designate the appropriate monitoring locations within and around the Treatment BMP to collect the necessary monitoring data.
   - A discussion on the selection of appropriate monitoring frequency is provided below.
3. Consider the appropriate frequency of monitoring based on the desired monitoring strategy, research requirements, available resources, etc. and refine the monitoring data list. Table 4.4 is divided into two sections: general site information and monitoring data. General site information includes those characteristics unlikely to change during the duration of the monitoring study; this information is collected one time at the beginning of the monitoring study and then again only if significant changes occur. Monitoring data is collected throughout the monitoring study and is further divided to distinguish event-based collection from monthly or near-continuous collection.

   When developing a monitoring plan it will be important for the researcher to decide whether they want to identify intra-event or storm-to-storm variability. Storm-to-storm variability is generally more

TABLE 4.4. Monitoring Data Descriptions

Monitoring Data	Units	Methods or Instrumentation Recommended for Monitoring	Location of Data Collection	Desirable Frequency of Data Collection
General Site Information				
Catchment Characteristics				
Catchment Area	acres	GIS	Catchment	Every 5 years
Land Use Distribution	acres	GIS	Catchment	Every 5 years
Impervious Area	acres	GIS	Catchment	Every 5 years
Land Use Condition[1]	N/A	RAM	Catchment	Annually
Monitoring Locations				
Location Type (inlet, outlet, other)	N/A	N/A	Variable	Every 5 years
Spatial Coordinates	N/A	GIS	Variable	Every 5 years
Elevation	ft	Survey	Variable	Every 5 years
Groundwater Well Screen Interval	ft	Bore Log	Variable	Once at time of installation
Groundwater Well Total Depth	ft	Bore Log	Variable	Once at time of installation
Description	N/A	Metadata (Company, Product Name, Model #, etc.)	Variable	Recorded at time of instrument deployment
Soil Samples				
Treatment BMP Infiltration Rate	in/hr	Soil core analysis	In Treatment BMP	Every 5 years
Monitoring Data				
Meteorology Time Series				
Surface Water Discharge Time Series				
Inflow Discharge Time Series	cfs	Flow meter or Depth gage with constrained geometry (e.g., flume) at Treatment BMP inlet	Inlet	Near continuous during instrument deployment
Outflow Discharge Time Series	cfs	Flow meter or Depth gage with constrained geometry (e.g., flume) at Treatment BMP outlet	Outlet	Near continuous during instrument deployment
Change in Storage Time Series	cfs	Depth gage within Treatment BMP and depth to volume rating curve	In Treatment BMP	Near continuous during instrument deployment
Bypass Discharge Time Series	cfs	Flow meter or Depth gage with constrained geometry (e.g., flume) at TreatmentBMP bypass	Bypass	Near continuous during instrument deployment
Groundwater Discharge Time Series				
Local Upgradient WSE Time Series	ft	Depth gage in local upgradient well(s)	Upgradient	Near continuous during instrument deployment
Local Downgradient WSE Time Series	ft	Depth gage in local downgradient well(s)	Downgradient	Near continuous during instrument deployment
Regional Upgradient WSE Time Series	ft	Depth gage in regional upgradient well(s)	Regional Upgradient	Near continuous during instrument deployment
Regional Downgradient WSE Time Series	ft	Depth gage in regional downgradient well(s)	Regional Downgradient	Near continuous during instrument deployment
Discrete Samples				
Inflow Concentration	mg/L	Automated sampler or grab samples at Treatment BMP inlet	Inlet	Monthly
Outflow Concentration	mg/L	Automated sampler or grab samples at Treatment BMP outlet	Outlet	Monthly
Treatment BMP Concentration	mg/L	Automated sampler or grab samples within Treatment BMP	In Treatment BMP	Monthly
Bypass Concentration	mg/L	Automated sampler or grab samples at Treatment BMP bypass	Bypass	Monthly
Local Upgradient Groundwater Concentration	mg/L	Grab sample from local upgradient well(s)	Upgradient	Monthly
Local Downgradient Groundwater Concentration	mg/L	Grab sample from local downgradient well(s)	Downgradient	Monthly
Regional Upgradient Groundwater Concentration	mg/L	Grab sample from regional upgradient well(s)	Regional Upgradient	Monthly
Regional Downgradient Groundwater Concentration	mg/L	Grab sample from regional downgradient well(s)	Regional Downgradient	Monthly
Event-Specific Data				
Event Metadata (duration, type)	N/A	Meteorology data	Catchment	Defined storm event by volume or time
Event Volumes				
Event Inflow Time Series	ft^3	Flow meter or Depth gage with constrained geometry (e.g., flume) at Treatment BMP inlet	Inlet	Defined storm event by volume or time
Event Outflow Time Series	ft^3	Flow meter or Depth gage with constrained geometry (e.g., flume) at Treatment BMP outlet	Outlet	Defined storm event by volume or time
Event Change in Storage Time Series	ft^3	Depth gage within Treatment BMP and depth to volume rating curve	In Treatment BMP	Defined storm event by volume or time
Event Bypass Time Series	ft^3	Flow meter or Depth gage with constrained geometry (e.g., flume) at Treatment BMP bypass	Bypass	Defined storm event by volume or time
Event Composite Samples				
Inflow Composite Samples	mg/L	Automated sampler or grab samples at Treatment BMP inlet	Inlet	Defined storm event by volume or time
Outflow Composite Samples	mg/L	Automated sampler or grab samples at Treatment BMP outlet	Outlet	Defined storm event by volume or time
Treatment BMP Composite Samples	mg/L	Automated sampler or grab samples within Treatment BMP	In Treatment BMP	Defined storm event by volume or time
Bypass Composite Samples	mg/L	Automated sampler or grab samples at Treatment BMP bypass	Bypass	Defined storm event by volume or time
Local Upgradient Groundwater Composite Samples	mg/L	Grab sample from local upgradient well(s)	Upgradient	Defined storm event by volume or time
Local Downgradient Groundwater Composite Samples	mg/L	Grab sample from local downgradient well(s)	Downgradient	Defined storm event by volume or time
Regional Upgradient Groundwater Composite Samples	mg/L	Grab sample from regional upgradient well(s)	Regional Upgradient	Defined storm event by volume or time
Regional Downgradient Groundwater Composite Samples	mg/L	Grab sample from regional downgradient well(s)	Regional Downgradient	Defined storm event by volume or time

[1] Several tools are currently in development to assess and score the relative condition of urban land uses and stormwater treatment BMPs. The Lake Tahoe Database is being developed with the intention to incorporate these tools and the resulting condition scores into Database.

important for estimating annual pollutant loadings due to laboratory analysis costs and the associated complexity of the datasets that may not improve accuracy of annual loading estimates. Typical stormwater monitoring is more likely to focus on sampling more storms rather than detailed monitoring of individual storms, unless a specific research objective focuses on event-specific pollutant distribution questions. Flow-weighted composites are the most accurate and cost-effective way to estimate event mean concentrations, which are needed to compute event loads. Unless peak concentrations or the entire pollutographs are needed, composite samples are recommended.

The monitoring necessary to evaluate Treatment BMP performance can be a resource-intensive undertaking. It is important for the researcher to select a monitoring frequency that (1) is plausible, given the resources available, and (2) will provide enough data to appropriately address the chosen research objectives. Table 4.5 provides some factors to consider when selecting the data collection and monitoring frequency for the Treatment BMP performance evaluation. Based on the monitoring strategy, the researcher may choose to monitor locations within the BMP at different frequencies. For example, winter rain events may be targeted at the BMP inlet and outlet, while monthly groundwater samples may be collected during the spring snowmelt season.

Table 4.5. Monitoring Frequency Considerations

Type	Description	Pros	Cons
Near-continuous	Instrument collects data on discrete (e.g., 5-, 10-, 15-, 30-minute) intervals.	• Allows for calculations of discrete event volumes and loads. • Depending on installation location(s), allows quantification of volumes and loads into, out of and within BMP. • Directly correlates precipitation data to BMP volumes.	• Instrumentation can be expensive. • Requires frequent maintenance to ensure data are collected properly. • Generates a large dataset which must be carefully managed and processed.
Event-based	Monitoring is performed for the duration of a event to characterize the rising limb, peak, and falling limb of the hydrograph. For flow-weighted sampling flows should be monitored near-continuously and aliquots composited based on pre-determined compositing schedule.	• In the Lake Tahoe climate, discrete runoff events are the main source of stormwater volumes and pollutant loads. • Detailed data collection allows for improved understanding of event hydrographs and pollutant loading. • Loads can be calculated by discretely constraining event volumes.	• Resource-intensive (financial, equipment, personnel, time) • Requires careful monitoring of site and weather patterns to ensure runoff events are captured. • Requires personnel to be on-site during storm events, or shortly thereafter.
Monthly	Monthly samples (grab or short-term composite).	• Less resource intensive • Monitoring can be scheduled.	• Values can vary widely during events (rising, peak, falling limb) and therefore one value is not likely to adequately capture the true treatment of BMP. • Loads are difficult to quantify if associated volumes are not constrained.
Seasonal	Seasonal samples (grab or short-term composite).	• Less intensive. • Monitoring can be scheduled.	• Values can vary widely during events (rising, peak, falling limb) and therefore one value is not likely to adequately capture the true treatment of BMP. • Loads are difficult to quantify because volumes are not constrained.

4. Refine monitoring strategy as necessary.

   As the researcher determines the monitoring data required to address the selected research objectives and performance metrics, changes to the monitoring strategy may be necessary given available resources. This process is purposefully designed to be transparent to allow the researcher flexibility when designing the monitoring plan. Clear linkages are shown between the research objectives, performance metrics and monitoring data to ensure that the researcher is designing an effective BMP treatment performance monitoring strategy that is ultimately compatible with the Tahoe Stormwater and BMP Performance Database.

4.8 HYPOTHETICAL EXAMPLE

STEP 1. DETERMINE TREATMENT BMP TYPE

DB001 is a hypothetical Dry Basin located in the Lake Tahoe Basin. It is a constructed dry basin with 1 clearly defined inlet, 1 outlet and 1 bypass channel upstream of the inlet. It contains minimal vegetation, no permanent pool storage, and sandy soils. We will use the monitoring strategy matrix for a dry basin (MSM-DB).

STEP 2. DEFINE RESEARCH OBJECTIVES

For the performance evaluation of DB01, the chosen research objective categories are:

- Characterize Meteorology
- Characterize Catchment Hydrology and Pollutant Sources,
- Quantify Treatment BMP Pollutant Load Reductions, and
- Quantify Treatment BMP Surface Water Hydrology.

These categories are highlighted in dark grey in Figure 4.4. The specific research objectives of DB001 monitoring are summarized in the following questions:

(1) For which runoff event type (rain, rain on snow, event snowmelt, non-event snowmelt, post-event snowmelt, thunderstorm, baseline, other) does DB001 achieve the greatest pollutant load reductions? [Constrain Meteorology and Quantify Treatment BMP Pollutant Load Reductions]

(2) What fraction of the surface water volumes delivered to the BMP from the catchment during non-event snowmelt does DB001 treat? [Characterize Catchment Hydrology and Pollutant Sources, and Quantify Treatment BMP Surface Water Hydrology]

STEP 3. SELECT PRIORITY POLLUTANTS

Fine sediment particles (FSP) have been identified as the priority pollutant treated by DB001. The catchment is dominated by urban land uses, including high risk primary and secondary roads with frequent application of road abrasives during the winter months. The dry basin is designed to attenuate flow and infiltrate a significant percentage of surface water flows, allowing for FSP particle capture and settling.

Figure 4.4: DB01 - Hypothetical DB01 (Dry Basin) Monitoring Strategy Matrix highlighting selected Research Objectives and Performance Metrics

Monitoring Research Objectives / Performance Metrics of Treatment BMP All Treatment BMP research objectives can be analyzed on event, seasonal, or annual time scales for each priority pollutant at each monitoring location.	**General Site Information**												**Monitoring Data Inputs to Database by User**																													
	Catchment Characteristics				**Monitoring Locations**						**Soil Samples**	**Soil Properties**	**Meteorology Time Series**	**Surface Water Discharge Time Series**				**Groundwater Discharge Time Series**				**Discrete Samples**								**Event-Specific Data**												
																															Event Volumes				**Event Composite Samples**							
	Catchment Area	Land Use Distribution	Impervious Area	Land Use Condition	Location Type	Spatial Coordinates	Elevation	Groundwater Well Screen Interval	Groundwater Total Depth	Description		Treatment BMP Infiltration Rate		Inflow Discharge Time Series	Outflow Discharge Time Series	Change in Storage Time Series	Bypass Discharge Time Series	Local Upgradient WSE Time Series	Local Downgradient WSE Time Series	Regional Upgradient WSE Time Series	Regional Downgradient WSE Time Series	Inflow Concentration	Outflow Concentration	Treatment BMP Concentration	Bypass Concentration	Local Upgradient Groundwater Concentration	Local Downgradient Groundwater Concentration	Regional Upgradient Groundwater Concentration	Regional Downgradient Groundwater Concentration	Event Metadata (duration, type)	Event Inflow Time Series	Event Outflow Time Series	Event Change in Storage Time Series	Event Bypass Time Series	Inflow Composite	Outflow Composite	Treatment BMP Composite	Bypass Composite	Local Upgradient Groundwater Composite	Local Downgradient Groundwater Composite	Regional Upgradient Groundwater Composite	Regional Downgradient Groundwater Composite
Characterize Meterology																																										
Total Precipitation (in)	Desirable	Desirable	Desirable	Desirable	Required	Desirable	Desirable			Desirable			Required																													
Characterize Catchment Hydrology and Pollutant Sources																																										
Total Catchment Water Volume (cf)	Required	Required	Required	Required	Required	Desirable	Desirable			Desirable			Desirable	Required			Required																									
Catchment Concentration (ug/L)																																										
Catchment Load (lbs)																																										
Quantify Treatment BMP Pollutant Load Reductions																																										
Total Pollutant Load (g)																																										
Pollutant Load Reduction (lbs, %, # particles <16um)	Desirable	Desirable	Desirable	Desirable	Desirable	Required	Required			Desirable	Desirable		Desirable	Required	Required	Desirable						Required	Required	Required	Desirable					Required	Required	Required	Desirable		Required	Required	Required	Desirable				
Quantify Treatment BMP Surface Water Hydrology																																										
Hydraulic Residence Time (HRT) (days)																																										
Volume Infiltrated (cf)																																										
Volume Evaporated (cf)																																										
Volume Bypassed (cf)																																										
Treated Water Volume (cf)	Desirable	Desirable	Desirable	Desirable	Desirable	Required	Required			Desirable		Required	Desirable	Required	Desirable	Desirable														Required	Required	Desirable	Desirable									
Outflow Volume (cf)																																										
Volume Reduction (%, cf)																																										
Catchment Volume Treated by BMP (%)																																										
Duration BMP at Capacity (days)																																										
Duration BMP Inundated (days)																																										
Outflow Frequency (days, % of year)																																										
Quantify Treatment BMP Influent and Effluent Concentrations																																										
Pollutant Concentration Reduction (ug/L, %, # particles/L)																																										
Concentration Statistics (min, max, mean, median, stdev, etc)																																										
Comparison of Nutrient Ratios																																										
DIN:TN (molar)																																										
SRP:TP (molar)																																										
SRP:DIN (molar)																																										
<16um:TSS (by mass)																																										
Characterize Local Groundwater Impacts																																										
Volume Infiltrated (cf)																																										
Infiltration Concentration (ug/L)																																										
Effective Groundwater Volume (cf)																																										
Groundwater Concentration (ug/L)																																										
Groundwater Concentration Statistics (min, max, mean, etc)																																										
Comparison of Groundwater Nutrient Concentrations																																										
DIN:TN (molar)																																										
SRP:TP (molar)																																										
SRP:DIN (molar)																																										
<16um:TSS (by mass)																																										
Groundwater Discharge (cfs)																																										
Infiltrated Volume:Groundwater Volume																																										

Required
Desirable
Not Necessary

STEP 4. IDENTIFY PERFORMANCE METRICS

The performance metrics selected to and address the research objectives defined in Step 2 are as follows:

- Research Objective #1: FSP Load Reductions by Runoff Event Type [Constrain Meteorology and Quantify Treatment BMP Pollutant Load Reductions]
  - Total Precipitation to characterize event types.
  - Pollutant Load Reduction to quantify loads by event.
- Research Objective #2: Percentage of Catchment Volume Treated by BMP in Spring [Characterize Catchment Hydrology and Pollutant Sources, and Quantify Treatment BMP Surface Water Hydrology]
  - Total Catchment Water Volume by season.
  - Treated Water Volume by season.

The monitoring strategy matrix for a Dry Basin with the performance metrics (rows) selected for DB001 are highlighted in red in Figure 4.4; performance metrics not selected have been greyed out to improve readability.

STEP 5. DEFINE MONITORING PLAN

Figure 4.5 demonstrates the use of the monitoring strategy matrix to determine the required monitoring data for DB001. The selected research objective categories are highlighted in dark grey and the four performance metrics are highlighted in red. For clarity purposes, all other research objective categories and performance metrics have been greyed out. Across each of the three rows, green cells designate the required monitoring data to calculate the selected performance metrics. Monitoring frequency decisions further refine the selection of monitoring data. Based on the research objectives, event-based data collection is necessary to address Research Objective #1 and seasonal spring hydrology monitoring is necessary to answer Research Objective #2. The final selected monitoring data are shown highlighted in blue on Figure 4.5. For clarity purposes, all other monitoring data has been greyed out. For DB001, the selected monitoring data needed to calculate the three performance metrics are:

- Catchment Characteristics
  - Catchment Area
  - Land Use Distribution
  - % Impervious
- Monitoring Locations
  - Location Type
  - Spatial Coordinates
  - Elevation
- Soil Properties
  - Treatment BMP Infiltration Rate
- Meteorology Time Series
- Surface Water Discharge Time Series
  - Inflow Discharge Time Series
  - Bypass Discharge Time Series
- Event-Specific Data
  - Event Metadata
  - Event Inflow Time Series
  - Event Outflow Time Series
  - Inflow Composite
  - Outflow Composite
  - Treatment BMP Composite

The selected monitoring strategy for DB001 will compare the fine sediment particle load reductions across runoff event types for a dry basin located at the terminus of a highly urbanized catchment and evaluate its spring stormwater volume reductions relative to the overall catchment volumes.

Figure 4.5: Hypothetical DB01 (Dry Basin) Monitoring Strategy Matrix highlighting selected Research Objectives, Performance Metrics and Monitoring Data

Monitoring Research Objectives / Performance Metrics of Treatment BMP	General Site Information												Monitoring Data Inputs to Database by User																													
	Catchment Characteristics				Monitoring Locations						Soil Samples	Soil Properties	Meterology Time Series	Surface Water Discharge Time Series				Groundwater Discharge Time Series				Discrete Samples								Event-Specific Data												
																															Event Volumes				Event Composite Samples							
All Treatment BMP research objectives can be analyzed on event, seasonal, or annual time scales for each priority pollutant at each monitoring location.	Catchment Area	Land Use Distribution	Impervious Area	Land Use Condition	Location Type	Spatial Coordinates	Elevation	Groundwater Well Screen Interval	Groundwater Total Depth	Description		Treatment BMP Infiltration Rate		Inflow Discharge Time Series	Outflow Discharge Time Series	Change in Storage Time Series	Bypass Discharge Time Series	Local Upgradient WSE Time Series	Local Downgradient WSE Time Series	Regional Upgradient WSE Time Series	Regional Downgradient WSE Time Series	Inflow Concentration	Outflow Concentration	Treatment BMP Concentration	Bypass Concentration	Local Upgradient Groundwater Concentration	Local Downgradient Groundwater Concentration	Regional Upgradient Groundwater Concentration	Regional Downgradient Groundwater Concentration	Event Metadata (duration, type)	Event Inflow Time Series	Event Outflow Time Series	Event Change in Storage Time Series	Event Bypass Time Series	Inflow Composite	Outflow Composite	Treatment BMP Composite	Bypass Composite	Local Upgradient Groundwater Composite	Local Downgradient Groundwater Composite	Regional Upgradient Groundwater Composite	Regional Downgradient Groundwater Composite
Characterize Meterology																																										
Total Precipitation (in)																																										
Characterize Catchment Hydrology and Pollutant Sources																																										
Total Catchment Water Volume (cf)																																										
Catchment Concentration (ug/L)																																										
Catchment Load (lbs)																																										
Quantify Treatment BMP Pollutant Load Reductions																																										
Total Pollutant Load (g)																																										
Pollutant Load Reduction (lbs, %, # particles <16um)																																										
Quantify Treatment BMP Surface Water Hydrology																																										
Hydraulic Residence Time (HRT) (days)																																										
Volume Infiltrated (cf)																																										
Volume Evaporated (cf)																																										
Volume Bypassed (cf)																																										
Treated Water Volume (cf)																																										
Outflow Volume (cf)																																										
Volume Reduction (%, cf)																																										
Catchment Volume Treated by BMP (%)																																										
Duration BMP at Capacity (days)																																										
Duration BMP Inundated (days)																																										
Outflow Frequency (days, % of year)																																										
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Pollutant Concentration Reduction (ug/L, %, # particles/L)																																										
Concentration Statistics (min, max, mean, median, stdev, etc)																																										
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SRP:DIN (molar)																																										
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Effective Groundwater Volume (cf)																																										
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Groundwater Concentration Statistics (min, max, mean, etc)																																										
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SRP:TP (molar)																																										
SRP:DIN (molar)																																										
<16um:TSS (by mass)																																										
Groundwater Discharge (cfs)																																										
Infiltrated Volume:Groundwater Volume																																										

Required
Desirable
Not Necessary

4.9 STEP 6: GUIDANCE TO IMPLEMENT MONITORING PLAN

Step 6 is the actual collection of the data per the respective monitoring plan. This guidance document does not provide detailed field protocols, or recommendations for instrumentation, analytical laboratories, data analysis, etc. However, the guidance below provides considerations for the researcher as the monitoring plan is designed and implemented. Various resources for protocol development are available, including but not limited to:

- International BMP Database guidance document (Chapters 3 and 4, available at http://www.bmpdatabase.org/Docs/2009%20Stormwater%20BMP%20Monitoring%20Manual.pdf),
- California Surface Water Ambient Monitoring Program (SWAMP) quality assurance monitoring plan (available at http://www.swrcb.ca.gov/water_issues/programs/swamp/qamp.shtml), and
- USGS National Water Quality Assessment (NAWQA) method, sampling and analytical protocols (available at http://water.usgs.gov/nawqa/protocols/methodprotocols.html).

Furthermore, it is anticipated that the Tahoe Regional Stormwater Monitoring Program will provide additional guidance and recommended protocols for Treatment BMP and stormwater monitoring as that program continues to develop.

INSTRUMENTATION

- There are many different companies that supply monitoring equipment appropriate for the long-term monitoring described above. Selection considerations include:
    - Battery life/Power source – how often will the battery need to be recharged or replaced?
    - Data capacity and communications – how much data can the instrument store and how can the data be downloaded?
    - Cold weather performance – will the instrument function during freezing conditions?
    - Cost – what accessories (software, cables, etc) are also required?
    - Ease of use and programmability – how user-friendly is the software and operation? Are your field personnel familiar with the equipment operation and maintenance procedures?
    - Reliability – does the manufacturer have a proven record in cold climates?
    - Data format consistency – what is the level of data processing data management to get the format desired for data analysis?
- Site Selection Considerations
    - Access – can field personnel get to the site safely and easily?
    - Security – can the instrument be hidden from public view and protected against vandalism?
    - Representativeness – will the instrument capture the relevant data? (i.e., is surface water flow properly constrained?)
    - Potential sampling issues - does the site have potential backwater or other issues that may affect sampling performance? Can sites be reoccupied where previous knowledge of site idiosyncrasies can be leveraged to reduce complications?
    - Stable cross section – especially when calculating flow data, is the cross sectional area resistant to erosion or material accumulation?
    - QA/QC - consider installing a staff plate next to the instrument to collect manual measurements to verify instrument data.
- Thoroughly review the users manual and follow manufacturer’s recommendations for battery replacement, data download frequency, calibration, etc.

- Set up an instrument maintenance log to track site visits, maintenance performed, data downloads, changes in calibrations or settings, unusual upstream activities, etc. This should be completed during every site visit.

GENERAL FIELD SAMPLING

- Continually reference the selected research objectives to ensure data collection efforts are consistent with the goals of the monitoring.
- Be safe. Event sampling is by nature hazardous due to storm conditions. Field personnel should always wear proper protective clothing when outside during a storm. Personnel safety always comes first. Use best professional judgment. If conditions do not allow safe access to site, personnel should wait until safe conditions exist.
- Create field data sheets that list all required information. Complete datasheets during every site visit.
- Take detailed field notes in a field notebook, describing any additional information, observations, problems, suggestions not included on field data sheet.
- Take pictures detailing site conditions. Establish photo points (location, camera orientation) and repeat during site visits to document changes over time. Detail locations of each photo on field datasheet or in field notebook.

SAMPLE COLLECTION

- Take all precautions to avoid sample contamination by using clean sampling techniques. Sources of contamination vary by pollutant of concern.
  - Ensure all field equipment and sampling bottles are clean prior to site visit.
  - All samples should be collected in the volumes required by the lab, preserved according to laboratory requirements and delivered to the lab within the proper holding times.
  - Properly label samples to avoid mishandling (or lost labels).
  - Complete chain of custody prior to delivery to analytical laboratory.
  - Field replicates should be collected a minimum of once a year for QA/QC field sampling (see Appendix D). Field triplicates are collected at the same time and at the same location by the same field personnel.
  - Field blanks should be submitted to the laboratory a minimum of once a year for QA/QC purposes (see Appendix D). A sample of distilled, de-ionized water is collected using all appropriate field sampling equipment.
- Analytical laboratory QA/QC procedures should include the following (see Appendix D):
  - Accuracy using standard reference materials and percent sample recovery.
  - Precision using laboratory control samples, blind field triplicates and analytical replicates.
  - Recovery using method blanks, matrix spikes and matrix spike duplicates.

DATA MANAGEMENT

- All data points should include date and time information to properly relate information.
- Similar data should be standardized by format and units of measurement.
- All data entry requires proper QA/QC.
  - A second person should verify data entry for accuracy and completeness.
  - Any questionable data should be flagged for further review.
  - Datasheets should be stored for a minimum of 5 years.

SECTION 5. UPLOAD TO DATABASE AND CONDUCT PERFORMANCE ANALYSIS

Section 5 provides guidance to the researcher on the final three steps of completing a Treatment BMP performance evaluation (see Figure 3.1). Step 7 discusses the analysis of the collected monitoring data to prepare for upload to the Database. Step 8 provides the protocols to upload the monitoring dataset directly to the Database. The Database User Manual (Appendix A) provides the details of Database operation. Step 9 is the data analysis using the selected performance metrics (see Step 4) for the selected Treatment BMP(s) to document the knowledge gained from the research and then apply this knowledge to the broader water quality questions in the Lake Tahoe Basin, including modeling algorithms, BMP design and/or BMP maintenance. Step 9 considers the types of data queries and summaries the researcher may use to compare stormwater quality treatment performance across a range of Treatment BMP types, design parameters, catchment characteristics, etc.

5.1 STEP 7: PREPARE RAW DATA FOR DATABASE UPLOAD

Step 7 is the preparation of the various raw monitoring data into a form consistent with the Database fields and upload requirements. There are two parts to this step: (1) QA/QC the raw field and/or instrument data per the data management protocols established in the Monitoring Plan and (2) format the dataset to be consistent with the Database parameters and units. This guidance document focuses on the latter step and encourages the reader to consult the resources provided at the beginning of Section 4.9 for guidance on appropriate data QA/QC.

The monitoring data for the Treatment BMP is organized by monitoring location. Therefore, as the user QA/QC's the collected data and prepares for upload to the Database, the user should manage the datasets by each monitoring location defined in the monitoring plan. The Database also provides the user with the flexibility to define a range of monitoring parameters, depending upon the pollutants of concern defined in Step 2. However, to ensure consistency of data entry across different users for the Lake Tahoe priority pollutants, Table 5.1 provides a guide to the Database parameter names and codes associated with the key pollutants of concern defined in Section 4.5, as well as the associated measurement units. Refer to Table 4.4 for the measurement units consistent with the Database requirements for all types of monitoring data.

Table 5.1. Database Parameter Codes for Tahoe Priority Pollutants (see Section 4.5).

Priority Pollutant	Database Parameter	Parameter Code	Units
Total Suspended Solids (TSS)	Solids, Total Suspended	1101	mg/L
Fine Sediment Particles (FSP)	Solids, Fine Particulate (<16um)	1103	mg/L
Total Kjeldahl Nitrogen (TKN)	Nitrogen, Kjeldahl, Total (TKN) as N	1204	mg/L
Nitrate-Nitrite (NOx)	Nitrogen, Nitrate + Nitrite Dissolved (NOx) as N	1205	mg/L
Ammonia (NH4+)	Nitrogen, Ammonia Dissolved (NH4) as N	1203	mg/L
Total Phosphorous (TP)	Phosphorous, Total (TP)	1206	mg/L
Dissolved Phosphorous (DP)	Phosphorous, Dissolved (DP)	1207	mg/L
Soluble Reactive Phosphorous (SRP)	Phosphorous, Soluble Reactive (SRP)	1206	mg/L

5.2 STEP 8: UPLOAD MONITORING DATASETS TO DATABASE

The user should refer to the complete User Manual attached as Appendix A for step by step instruction on Database functions, use, and definitions of key terms. Appendix B provides the Database structure and specifications.

The user must first install the Tahoe Stormwater and BMP Performance Database Application (subsequently referred to as the application) and execute the program to verify that the application is connected to the remote database. Refer to the quick start guide (Appendix A) for a walk-through on how to install and verify the Database. The quick start guide also provides a general description of how to navigate the application interface.

Figure 5.1 translates the Database relational structure (see Appendix B for details) into a flow chart of data inputs. The schematic provides a visual link between the Section 4 guidance, including the monitoring strategy matrices and Table 4.4, and the Database User Manual (see Appendix A). The blue and green boxes in Figure 5.1 correspond, respectively, to the "General Site Information" and "Monitoring Data" described in Table 4.4 and shown in each MSM.

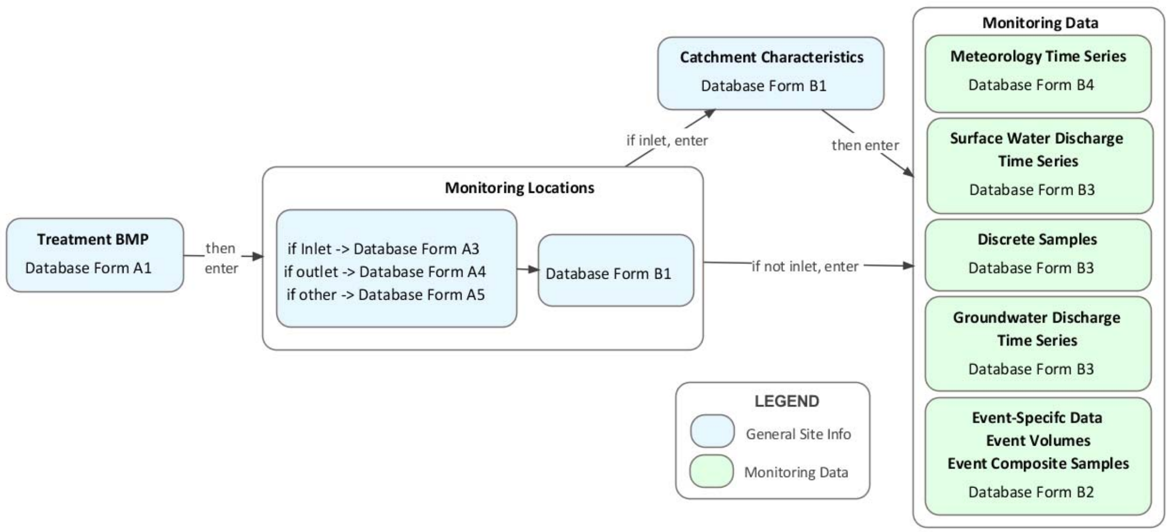

Figure 5.1 Flow of data input into Database.

The user begins by inputting the general site information about the monitored Treatment BMP and its distinct inlets, outlets, and other monitoring locations (see blue boxes in Figure 5.1) in Form A: General Site Information. ***For any location where monitoring occurs a corresponding location must be created in one of Forms A3, A4 or A5.*** Once the user has established the Treatment BMP record in the Database (Form A), monitoring data uploads can be accomplished using Form B: Monitoring Locations and Data.

The Tahoe BMP Database application makes it easy to upload datasets of any size by providing 2 ways of uploading data. The method you choose depends on the quantity and complexity of the data you have. The application allows users to enter data: 1) manually using the forms provided as part of the application interface, and/or 2) via bulk data uploads of preprocessed data. The second method is especially suited to the submission of time series records and other large datasets. The datasets supported by the Database and the forms that are used for both manual and bulk data submission of each dataset are shown in Figure 5.1. Below is a brief comparison of the two methods (see Appendix A for more details):

- Manual Data Uploads
    - All the data in the Database, except for water quality data, can be submitted manually through the interface by clicking through and adding one record at a time.
- Bulk Data Uploads
    - Bulk data can be uploaded on Forms B2, B3, and B4 (see Figure 5.1).
    - A Microsoft Excel worksheet template is provided to ensure the user properly formats the dataset so that the Database can read the data.

5.3 STEP 9: ANALYZE AND COMPARE TREATMENT BMP PERFORMANCE

The Database can increase consistency of Treatment BMP performance evaluations through standardization of data formats and the parameters and performance metrics used to evaluate the water quality benefit of a specific Treatment BMP. Data integration across research efforts will significantly increase the comparability and knowledge that can be gained from future water quality performance syntheses to improve our understanding of how site characteristics, BMP design parameters, drainage area conditions, maintenance activities, and influent water quality influence pollutant load reductions achieved by Treatment BMPs.

ASSESS TREATMENT BMP PERFORMANCE

The Database will provide researchers with a greater opportunity to evaluate their independent findings in the context of existing knowledge and complementary research efforts on Lake Tahoe Treatment BMPs. The researcher should present the desired performance metrics on event, seasonal and/or annual scales in a manner that clearly summarizes the ability of the Treatment BMP to remove each of the pollutants of concern. Researchers should continue to consider techniques to constrain and evaluate the limited discrete datasets obtained with inherent natural variability of meteorology. For instance, consider the water year type (wet, average, dry), event magnitude, event type, antecedent conditions and other potential factors that would influence the quantitative datasets obtained. The meteorological data will provide this context.

The catchment characteristics will provide insight into the differences in pollutant loads measured at the inlet across events, seasons and the duration of monitoring. Evaluations of the pollutant load reductions relative to the incoming water quality, and how this relationship changes over time, can inform our understanding of the relationship between performance and maintenance and/or how design characteristics of a specific Treatment BMP influence performance.

The water quality benefit of the Treatment BMP can be quantified using a variety of metrics. Below are a number of typical performance metrics and considerations when evaluating each metric for a specific Treatment BMP.

INFLUENT AND EFFLUENT EVENT MEAN CONCENTRATIONS

The term “EMC” is a statistical parameter used to represent the average concentration of a given parameter during a storm event. It is defined as the total constituent mass divided by the total runoff volume and is typically based on an analysis of a flow- or time-weighted composite sample. In most circumstances, the EMC approach provides the most useful means to quantify the pollution level resulting from a runoff event.

The evaluation of the change in the EMC from the inlet to the outlet for comparative samples can provide insight if the interaction with the Treatment BMP has resulted in a measurable and consistent reduction in the EMC for a pollutant of concern.

POLLUTANT LOADS

Pollutant loads are typically calculated by using an average concentration multiplied by the total volume of flow over the averaging period. A variety of methods are available for estimating both the average concentration and the total flow volume. The method chosen depends on the sampling and flow measurement techniques used at the site. Average concentrations may be estimated by collecting time-weighted samples, flow-weighted samples, or a combination of the two. Likewise, flow data can be collected near-continuously, intermittently, or modeled from other hydrologic information, such as rain gage information or from flow monitoring conducted in a nearby watershed that has been correlated to the flow at the water quality sampling location. Many Treatment BMP monitoring studies focus efforts on water quality sample collection and neglect flow measurement. Accurate flow measurement or well-calibrated flow modeling is essential for load estimation. Ideally, all flow through the monitoring site will be represented for each water year, without data gaps.

Pollutant loads are often most useful when assessing the impact to receiving waters, such as lakes or estuaries, where long-term loadings can cause water quality problems outside of discrete storm events. When the effluent flow rate from a particular Treatment BMP is small compared to the flow rate or volumes of the receiving water body, potential downstream impairments depend on the absolute load of pollutant rather than just the concentrations. Pollutant loads and load reductions are the central issue in the Tahoe TMDL (LRWQCB and NDEP 2010).

Dry weather runoff and base flows can contribute substantially to long-term loading. In addition, Treatment BMPs (e.g., wet basins and possibly cartridge media and bed filters) that have appreciable dry weather flows passing through them can have a reduced capacity for storage of wet weather pollutants. For example, wet basin performance may be affected by the amount of water in the basin prior to the event, and cartridge media and bed filters may lose some of their adsorption capacity because of pollutants and other constituents present during dry weather flows.

TREATMENT PERFORMANCE CALCULATIONS

The performance of Treatment BMPs can be evaluated in a number of ways, and understanding how Treatment BMP monitoring data will be analyzed and evaluated is essential to establishing a useful Treatment BMP performance evaluation monitoring study. The focus of this guidance is on quantifying the performance of Treatment BMPs with influent and effluent EMC and/or event volume data, and the pollutant load reductions should be quantified both as total loads reduced as well as percent removal and evaluated for each specific pollutant of concern.

The “percent removal” can be defined in a variety of ways, such as the efficiency ratio (ER), summation of loads (SOL), and efficiency of individual storm loads (ISL). For the ER method, the number of events (*N*) for the inflow and outflow need not be equal, but for SOL and ISL the number of events must be equal as defined below.

$$ER = 1 - \frac{\sum_{j}^{N_{out}} EMC_{out,j}/N_{out}}{\sum_{i}^{N_{in}} EMC_{in,i}/N_{in}}$$ **Equation 5-1**

$$SOL = 1 - \frac{\sum_{i}^{N} Load_{out,i}}{\sum_{i}^{N} Load_{in,i}}$$ **Equation 5-2**

$$ISL = \sum_{i}^{N} \left[1 - \frac{Load_{out,i}}{Load_{in,i}}\right]$$ **Equation 5-3**

A fundamental problem with the above approaches is that Treatment BMPs do not typically function with a uniform percent removal across a wide range of influent water quality concentrations. For example, a Treatment BMP that demonstrates a large percent removal under heavily polluted influent conditions may demonstrate poor percent removal when low influent concentrations or loads exist. The decreased efficiency of Treatment BMPs receiving low concentration influent has been demonstrated and it has been shown that in some cases there is a minimum concentration achievable through implementation of Treatment BMPs for many constituents (Schueler 2000; Minton 2005). Percent removal alone, even where the results are statistically significant, often does not provide a useful assessment of Treatment BMP performance. For this reason percent removal should be used only in context and fully evaluated with consideration of the inflow water quality and the total load reduction in mass per unit of time.

PERFORMANCE OF TREATMENT PROCESS

The performance of the Treatment BMP relative to the treatment processes relied upon should be directly discussed. For instance, the ability of the Treatment BMP to infiltrate should be evaluated by the inflow/outflow volume differences observed on a variety of relevant time scales. The condition of the BMP and its potential need for maintenance (see BMP RAM; 2NDNATURE 2009) or loss of treatment process function should also be considered in light of load and volume reductions achieved. Specific site and design characteristics should be considered during performance evaluations, including: site slope, soil type, depth to shallow groundwater, incoming pollutant loads, Treatment BMP capacity and morphology, hydraulic residence time, flow path length, etc. Comparisons of measured hydrologic performance to hydrologic and Treatment BMP sizing and associated hydrologic calculations completed during design would be useful feedback on design assumptions.

SYNTHESIS OF WATER QUALITY PERFORMANCE ACROSS TREATMENT BMPS

The value of any single monitoring dataset should be expanded by the application of the specific research findings into the broader understanding of Treatment BMP function and the opportunities and constraints on water quality treatment performance. The continued population of the Database by compatible Treatment BMP monitoring will greatly expand the ability to extrapolate knowledge from single studies and to begin to integrate data from multiple studies. The Database provides some functionality so that a researcher can query the raw data across a range of various monitoring characteristics and compare Treatment BMP performance results. Section 3.6 of the User Manual (Appendix A) provides information on this data retrieval process. Future versions of the Database intend to provide improved data retrieval and analysis capabilities. Below we provide a rudimentary list of potential analysis types and examples of possible research questions to demonstrate the power of the Database to integrate and compare the various monitoring datasets populated in the Database.

- By Treatment BMP type.
  - Which types are most effective at reducing the pollutant loading of phosphorous, a Tahoe priority pollutant?
  - Which types are most effective at infiltration, nutrient cycling, particle settling, media filtration?
  - How do observed pollutant load reductions compare to estimates in the TMDL, PLRM, etc?
- By design parameters of a specific Treatment BMP type.
  - What is the best range of dry basin target infiltration rates to provide the greatest FSP load reductions?
  - What is the most effective range of percent cover of wetland vegetation species in a wet basin?
  - Which active media filtration result in the greatest nutrient load reductions?
  - How effective are different types of pre-treatment at improving the pollutant load reduction of a Treatment BMP?
- By event type
  - Which event types deliver the greatest pollutant loads to Treatment BMPs?
  - Which Treatment BMP types most effectively treat the pollutant loads during the spring snowmelt?

- By catchment characteristics
    - Which Treatment BMP types most effectively treat the pollutant loads of catchments dominated by commercial and urban roads?
    - What should the design water quality volume of a dry basin be for a highly impervious small catchment?
    - How does treatment performance vary with differing quality in the inflowing water?
    - How are differences in inflowing water quality related to differences in catchment land use distribution?
    - How are differences in inflowing water quality related to the differences in catchment land use condition?

SECTION 6. CONCLUSION OF INITIAL DATABASE VERSION AND NEXT STEPS

The primary purpose of this initial version of the Database was to provide a robust, expandable system for collecting Tahoe Basin stormwater runoff information and a consistent format for reporting both stormwater quality and Treatment BMP performance data. While the current version accomplishes these goals it represents only the first step in what is ultimately intended to be a centrally managed database for the Tahoe Regional Storm Water Monitoring Program.

6.1 REVIEW OF THE INITIAL DATABASE CAPABILITIES

Four key directives were identified and addressed in the execution of this project: 1) a centralized system was created for accessing and analyzing existing data; 2) guidance has been provided (in this document and appendices) for reporting relevant Treatment BMP design information; 3) consistent formats have been developed for reporting stormwater runoff and Treatment BMP data; and, 4) requirements have been clarified for reporting drainage area characteristics and conditions.

The main problem in Tahoe stormwater assessment, prior to development of this Database, was that a fair amount of the stormwater and Treatment BMP monitoring data that existed were distributed among various entities that performed or funded the studies in the Lake Tahoe Basin, so reporting was inconsistent and data were not readily available nor comparable. The centralized storage represented by this Database provides access to existing data and will readily accommodate new monitoring data as it becomes available. It also collects project metadata and ancillary information, such as meteorological data. Furthermore, Treatment BMP design information is collected and stored, along with hydraulic parameters and other information, such as BMP Maintenance RAM (Rapid Assessment Monitoring) scores and maintenance interval. This will link performance data directly to important operations and maintenance information for subsequent analysis of Treatment BMP life-cycle performance. The Database requires that all monitoring data be reported in consistent formats, which will facilitate statistical analysis across Treatment BMP types and locations. However, new data types and formats can be added easily to the Database as appropriate analytic and reporting protocols become available. Finally, important information on physiographic characteristics of the drainage area is now recorded, such as slope, drainage area, land uses present, vegetative cover, impervious area, etc. Taken together, this information on drainage area characteristics and conditions coupled with design parameters and the detailed water quality and hydrology data will improve data synthesis and significantly improve our understanding of pollutant generation, fate and transport in Lake Tahoe urban areas. It will facilitate better water quality improvement projects with integrated pollutant source control, hydrologic source control and storm water treatment across multiple scales for the Tahoe Basin.

However, this version of this Database is not a web-based application. Users must download an executable file that interfaces with the Database, currently on a server hosted by Geosyntec Consultants. Thus, most functional updates to the Database will be distributed to users as a new executable file. Several features that would improve the functionality and general usefulness of this Database have not been included in the present version, primarily due to cost and the decisions that must be made ultimately about the purposes for which this Database will be used. The priority next steps are discussed below.

6.2 NEXT STEPS

The Database in its current version is available to support data collection, management and reporting for the Tahoe RSWMP. There is a minimum set of management tasks, however, that will need to be conducted on a regular basis to support the Database and periodically issue results. It is anticipated that these will be performed and funded through the Regional Stormwater Monitoring Program, or its equivalent. It is essential that the following functions are supported and managed on a continued basis for use of this Database by Tahoe Basin implementers, agencies and researchers. These functions include:

- **Quarterly review and verification of data entered into the Database.** This includes a Quality Assurance/Quality Control (QA/QC) plan for reviewing user-entered data. The Database should be analyzed by RSWMP staff on a quarterly basis to ensure that data entered meet the acceptance criteria and to otherwise identify any data inconsistencies or anomalies.
- **User correspondence and assistance.** This includes assisting users who have questions or issues with data entry and retrieval operations. Database users could submit questions, identify potential bugs, or request feature additions via email or an online forum. Then project support would promptly respond and archive all correspondence to assist with prioritizing bug fixes and future program enhancements.
- **Annual data summary reports.** Once per year, the data contained in the Database should be summarized and reports made available to all Database users. This Database Inventory Report would include counts of all data included in the Database and could generate a data summary for each BMP or stormwater monitoring site entered. These reports would include statistical summaries and relevant data plots for each monitoring location and BMP type.
- **Periodic updates to the Database and interface.** Based on team experience with managing the Database, it is anticipated that periodic updates will be required to address user feedback on bug reports and updates to Microsoft Windows. High priority updates, such as those required for continued program function, will be addressed immediately. Low priority updates, such as “nice-to-have” features, could be prioritized and addressed as budgets allow.

While the current version of this Database was developed as a fully functional system to meet initial goals and objectives for effective stormwater management, tracking and reporting in the Tahoe Basin, it was also designed and constructed for potential modification to implement as an online database application. The Database development team has worked with staff at the Tahoe Integrated Information Management System (TIIMS) to assure it will ultimately be compatible with their TIIMS operating system and hardware, although it could also be hosted at an alternate site. The benefits of an online version of the database interface over the current desktop application are many, including:

- Compatibility with any operating system. Users would only need access to a web browser and an internet connection.
- Updates would not require the user to reinstall any programs.
- Interface can be linked to existing databases on TIIMS, such as the agency contact information, the residential BMP database, and the EIP Tracking and Reporting Database.
- Could utilize the existing GIS Mapping Tool on TIIMS to provide interactive spatial linkage to Database contents.
- Would provide more interactive features and additional content through the use of hyperlinks.
- More flexibility for developing custom reports and data views.

Additional effort and cost will be required to eventually modify and port the current or any subsequent desktop versions of this Database to a fully functional online system. Although the support and funding for this extended development have not been determined, the necessary steps required would include:

- **Features Assessment and Documentation.** Assemble comments from users of the current desktop version, interview potential future users and other stakeholders, then document and prioritize the features perceived as most needed and relevant for an online version. Since TIIMS already has a number of data tables and required functionality implemented, the design team would work with TIIMS staff to identify existing data structures and interface functions that can be used or modified for this effort.

- **Architecture and Design Specification.** The project team would design and document a modular framework, operating within the limits of the requirements specification, to guide the implementation and coding of proposed enhancements. Automated database summaries, more sophisticated statistical analyses and queries would be evaluated, designed and documented. This design specification should include the implementation details for new framework elements, such online maps (web GIS) support as well as the implementation details of automated statistical summaries, queries and standard reports.
- **Implementation and Testing.** It is anticipated the most efficient approach for developing online enhancements would be through a phased implementation approach. The data layer would be extended to support additional framework elements such as web mapping. Modules could then be added to the existing Kentico content management system on TIIMS to provide incremental functionality in support of additional data entry and retrieval capabilities, as well as an administrative interface for verification and validation of data entered, and an interface for user role management and security. The project team would conduct tests throughout the development and implementation of the project to assure the final version passes usability tests in terms of the user interface and validity tests in terms of the data in the Database at the time of deployment.
- **Database Management and Support.** Ultimately, a plan would be developed for administering the online database. This includes the minimal set of management tasks previously outlined for the current version of the Database, as well as longer-term support needed to maintain hardware and supply staff time for administering the Database. This should also include implementation of a process for reviewing and recommending periodic updates, presumably through TIIMS and RSWMP, or equivalent groups to represent stakeholder interests and needs.

In any case, whether ultimately ported to a web-based implementation or simply maintained in its current desktop configuration, the greatest value of this Database will be periodic compilation and syntheses of the available datasets in an informed and strategic manner to leverage existing datasets for testing hypotheses of Treatment BMP performance and to help optimize design characteristics and appropriate maintenance actions.

SECTION 7. GLOSSARY AND LIST OF ACRONYMS

GLOSSARY

Bed Filter	Treatment BMP Type • Typically a settling/pretreatment basin followed by a filter bed (e.g., sand filter, activated alumina) with volume retention above the bed. Filtration is usually controlled by the rate of infiltration through the filter bed. However, outlet structures may also be used to control the flow rate. • The capture of particles and pollutants is achieved via filtration of stormwater through an activated alumina, sand or other media type. • Hydraulically similar to infiltration basins except the runoff is filtered through the bed, collected into an under drain, and discharged to an outlet rather than being infiltrated to the local unsaturated zone. Little to no volume loss occurs.
Cartridge Filter	Treatment BMP Type • Cartridge filters are contained within a confined space similar to treatment vaults. • Following screening, primary sedimentation, and possibly skimming, a cartridge filter includes a chamber with filters, which may be filled with a variety of media, such as zeolite, perlite, peat, compost, and various sorbent materials to target specific pollutants. • The proprietary filter media type targets removal of the pollutants of concern, resulting in downgradient stormwater concentration reductions. Typically, no volume loss occurs due to impervious base.
Database	Tahoe Stormwater and BMP Performance Database (Database) provides a data storage system that can assist in the planning and implementation of stormwater projects in the Lake Tahoe Basin. Specifically, the Database informs the following activities: 1) BMP selection, targeting specific pollutants of concern and anticipated water quality performance; 2) BMP design, including better linkages between BMP design and anticipated performance; and, 3) pollutant load reduction and performance modeling.
Dry Basin	Treatment BMP Type • A constructed basin with riser outlets designed to detain stormwater runoff for some minimum time to allow particle and associated pollutant settling. Outflow occurs at the top of the water column and/or through drain holes in the riser at discrete depths. • Designed to completely empty at some time after stormwater runoff ends (48-72 hours is typical). • The term "dry" implies that there is no significant permanent water pool between storm runoff events. • Water quality improvements downgradient expected as a result of (1) volume reduction via infiltration due to high hydraulic conductivity of footprint soil and (2) effluent concentration reduction due to residence time and particle capture. • Wetland and riparian vegetation species distribution is minimal to absent. Moderate distribution of grass and/or tree species likely and acceptable.
Fine Sediment Particles (FSP)	FSP refers to the mass fraction of the TSS (Total Suspended Solids) concentration that consists of particles 16 µm or smaller, expressed as a % TSS by mass and allowing a concentration of FSP to be simply calculated.

Infiltration	Treatment Process: Reduction of stormwater volume by infiltration through soil. Pervious soils capture stormwater runoff, reducing pollutant loads primarily due to volume reductions of stormwater that continues downgradient of the Treatment BMP. However, some pollutants contained within the infiltrated volumes, such as dissolved nutrients and fine sediment particles, are captured and trapped within the pore spaces of the unsaturated zone.
Infiltration Basin	Treatment BMP Type • Constructed basin that captures stormwater runoff and infiltrates it into the ground; an overflow weir is typically the only outlet. • Highly permeable substrate designed to rapidly infiltrate significant volumes of stormwater into unsaturated zone. Pollutant load reductions realized due to significant volume reductions. Performance primarily depends on the hydraulic properties of subsurface media (e.g. ability to infiltrate), groundwater table depth and gradient, and type of pollutants and loadings. • While vegetation can improve infiltration characteristics, its distribution may be minimal, depending upon site conditions.
Media Filtration	Treatment Process: Improvement of stormwater quality through the use engineered flow-through systems. Flow-through systems can be designed to (1) physically trap, separate, and/or sieve particulate matter and/or (2) use active media to treat dissolved constituents as stormwater is transported downgradient.
Monitoring Data	Information collected throughout the duration of the research study, such as meteorological time series, catchment land use characteristics, hydrology time series, and influent and effluent concentrations, to calculate performance metrics and evaluate water quality treatment performance of stormwater and BMP sites.
Monitoring Plan	The *what, where,* and *when* data is collected and managed to evaluate BMP performance. Implementation of the monitoring plan includes all data collection efforts for the duration of the research study, such as site instrumentation, continuous data downloads, event monitoring, water quality sampling, and data QA/QC.
Monitoring Strategy	The roadmap that justifies how the collection of specific monitoring data will evaluate the water quality load reductions (i.e., treatment performance) provided by a specific BMP. The researcher determines the Treatment BMP type, defines research objectives, and selects the priority pollutants of concern. Based on these decisions, the researcher chooses the appropriate data calculations (performance metrics) to properly evaluate the water quality treatment performance of the Treatment BMP and the necessary data collection (monitoring plan) to perform those calculations. The development of the monitoring strategy is an iterative process, and includes fiscal and political considerations, in addition to the scientific data needs.
Nutrient Cycling	Treatment Process: Concentration reductions of biologically available nutrients in stormwater due to uptake by growing vegetation, during photosynthesis. Fall and winter respiration of vegetation can result in increased biologically available nutrient release due to vegetation decay.

Particle Capture	Treatment Process: Removal of particulate matter in stormwater through flow attenuation. Decreasing flow velocity limits the transport capacity of stormwater, allowing particle settling and retention.
Performance Metric	Quantitative measures that facilitate data reporting communication and improve comparisons across monitoring sites and time periods. Performance metrics are applied to monitoring data to address research objectives and test hypotheses.
Research Objective	Research objectives synthesize how the researcher will investigate the water quality performance hypotheses about the selected treatment BMP. Research objectives can be grouped into six categories: Characterize Meteorology, Characterize Catchment Hydrology and Pollutant Sources, Quantify BMP Pollutant Load Reductions, Quantify BMP Surface Water Hydrology, Quantify BMP Influent and Effluent Concentrations, and Characterize Local Groundwater Impacts. These research objectives should be defined with an understanding of the water quality treatment processes relied upon by the respective Treatment BMP type determined in Step 1.
Stormwater Site	A single monitored location that does not have a treatment BMP associated with it.
Treatment BMP	Structural BMPs that accept, attenuate, and treat urban stormwater. Treatment BMPs are implemented to reduce pollutant loads in stormwater by either removing pollutants and/or by reducing surface water volumes. The BMP RAM defines Treatment BMP Types by the processes relied upon for water quality improvements. Users of the BMP RAM must define the Treatment BMP type by these processes, rather than rely on previous naming conventions.
Treatment Process	Physical, chemical, or biological means employed by a Treatment BMP to remove/retain the pollutants of concern and/or reduce stormwater volumes that ultimately reach Lake Tahoe. Treatment BMPs in Lake Tahoe rely on 4 primary, passive processes to reduce the load of pollutants in stormwater: infiltration, particle settling, media filtration and nutrient cycling.
Treatment Vault	Treatment BMP Type • Flow-through confined space structure that separates sediment, debris and other particulate pollutants from the water volumes via various screening and settling techniques. • Hydrodynamic separators, or vortex separators, are one type of treatment vault designed to remove suspended sediment and attached pollutants through screening (physical separation) and centrifugal gravity separation. Baffles can be included to facilitate the removal of floatable debris and oil and grease. • These devices are often installed below ground in precast or cast-in-place concrete vaults. • Water quality improvements of stormwater continuing downgradient expected as a result of particle capture. No volume loss occurs due to impervious base, thus pollutant load reductions realized only by concentration reductions associated with particle capture. • Typically manufactured and proprietary structures.

Wet Basin	Treatment BMP Type • A constructed basin that detains runoff and has a persistent pool of surface water typically through the wet season and intermittently and/or consistently in the dry season. A wet basin may or may not incorporate extended detention storage. The extended detention storage is an additional surcharge volume overlying the permanent pool that can be designed to attenuate peak flows. Wet basins require a permanent source of water to maintain vegetation and biological communities. Base flows must match or exceed infiltration and evapotranspiration rates. • Wet basin detention results in flow rate reductions, increased hydraulic residence times and particle aggregation and subsequent settling. Substrate is typically fine organic matter and silt making infiltration rates relatively low. Pollutant load reductions realized by particle capture and biogeochemical processes due to high vegetation presence. Annual stormwater volume reductions occur primarily by evapotranspiration. • A high frequency of stormwater inundation increases the vegetation density. Dominant vegetation is wetland species and can be supplemented with riparian species with very high densities.

LIST OF ACRONYMS

BMP	Best Management Practice
BMP RAM	Best Management Practice Maintenance Rapid Assessment Methodology
Crediting Program	Lake Tahoe Clarity Crediting Program
DIN	Dissolved Inorganic Nitrogen
FSP	Fine Sediment Particles; sediment particles defined as <16µm
MSM	Monitoring Strategy Matrix
PLRM	Pollutant Load Reduction Model
RAM	Rapid Assessment Methodology
SRP	Soluble Reactive Phosphorous
TMDL	Total Maximum Daily Load
TP	Total Phosphorous
TSS	Total Suspended Sediment
TN	Total Nitrogen

LITERATURE CITED

2NDNATURE. 2008. Water quality performance evaluation of Park Avenue Detention Basins; South Lake Tahoe. Prepared for City of South Lake Tahoe, Engineering Division. Final Report. August 15, 2008. ftp://www.2ndnaturellc.com/2ndnature/2NDNATURE_Reports/Lake%20Tahoe/Water%20Quality%20Performance%20Evaluations%20of%20Park%20Ave%20Detention%20Basins%202008.pdf

2NDNATURE, Northwest Hydraulic Consultants and Environmental Incentives. 2009. BMP Maintenance Rapid Assessment Methodology Technical Document, Lake Tahoe Basin. Prepared for the US Army Corps of Engineers, Sacrament District. September 2009. ftp://www.2ndnaturellc.com/2ndnature/2NDNATURE_Reports/Lake%20Tahoe/BMP%20RAM/

2NDNATURE. 2010. PLRM v1 Database Refinement: Focused Stormwater Monitoring to Validate Water Quality Source Control and Treatment Assumptions. Prepared for US Army Corps of Engineers, Sacramento District. Final Technical Report. March 2010. ftp://www.2ndnaturellc.com/2ndnature/2NDNATURE_Reports/Lake%20Tahoe/PLRM%20Refinement_FinalPhaseI_TechnicalReport.pdf

Burton, A. and R. Pitt. 2001. *Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers*. Lewis Publishers. www.epa.gov/ednnrmrl/publications/books/handbook/index.htm http://

Chow, V.T. 1954. The lognormal distribution and its engineering applications. *Proc., American Society of Civil Engineers*. 110, 607-628.

Harremoes, P. 1988. Stochastic models for estimations of extreme pollution from urban runoff. *Water Resource Bulletin*, 22, 1017-1026.

Helsel, D.R. and R.M. Hirsch. 2002. *Statistical Methods in Water Resources*. U.S. Geological Survey, Techniques of Water-Resources Investigations Book 4, Chapter A3. U.S. Geological Survey, Water Resources Division, Reston, VA.

Lahontan Regional Water Quality Control Board (LRWQCB) and Nevada Division of Environmental Protection (NDEP). 2009. Lake Clarity Crediting Program Handbook: for Lake Tahoe TMDL Implementation v0.99. Prepared by Environmental Incentives, LLC. South Lake Tahoe, CA. http://www.swrcb.ca.gov/rwqcb6/water_issues/programs/tmdl/lake_tahoe/index.shtml

LRWQCB and NDEP. 2010. Lake Tahoe Total Maximum Daily Load, Technical Report. California and Nevada. June 2010. http://www.swrcb.ca.gov/rwqcb6/water_issues/programs/tmdl/lake_tahoe/index.shtml

Maestre, A., Pitt, R., Durrans, S.R., and Chakraborti, S. (2005). "Stormwater Quality Descriptions Using the Three Parameter Lognormal Distribution." *In*: Effective Modeling of Urban Water Systems Conference Proceedings, Monograph 13. (edited by W. James, K.N. Irvine, E.A. McBean, and R.E. Pitt). CHI. Guelph, Ontario, pp. 247 – 274. 2005.

McGill, R., Tukey, J.W., and W.A. Larsen. 1978. *Variations of Box Plots*. The American Statistician, Volume 32, Issue 1. 12-16 p.

Minton, G.R. 2005. *Stormwater Treatment.* Resources Planning Associates, Seattle, WA.

Northwest Hydraulic Consultants (nhc), Geosyntec Consultants, and 2NDNATURE. 2009. PLRM Model Development Document. Prepared for Lake Tahoe Basin Storm Water Quality Improvement Committee. South Lake Tahoe, CA. A complete Users Manual as well as full source code and other supporting documents can be downloaded from www.tiims.org

Schueler, T.R. 2000. *Irreducible Pollutant Concentrations Discharged from Stormwater Practices*. Article 65 in The Practice of Watershed Protection, Schueler, T.R. and H.K. Holland (eds.). Center for Watershed Protection, Ellicott City, MD.

Stumm, W. and J.J. Morgan. 1996, Aquatic Chemistry: Chemical Equilibria and Rates in Natural Waters, 3rd ed. Wiley & Sons, Inc.: New York.

U.S. Environmental Protection Agency (EPA). 1983. *Results of the Nationwide Urban Runoff Program, volume I – Final Report.* U.S. Environmental Protection Agency, Water Planning Division, Washington D.C.

Van Buren M.A., W.E. Watt, and J. Marsalek. 1997. Applications of the Log-normal and Normal Distributions to Stormwater Quality Parameters. *Wat. Res.*, Vol. 31, No 1, pp. 95-104.