Final Report

Lake Tahoe BMP Monitoring Evaluation Process

Synthesis of Existing Research

Prepared for:
USFS Lake Tahoe Basin Management Unit
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2NDNATURE
ECOSYSTEM
SCIENCE + DESIGN

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1. Executive Summary

In the Lake Tahoe Basin, there is an imminent need to quantify the benefit of restoration and pollutant treatment efforts. The Tahoe World July 7, 2005 featured article states,

> "After millions of dollars have been spent on environmental restoration projects in recent decades, many are hopeful research will soon show those projects are having a positive effect. But no one has drawn that conclusion yet." (*Article entitled: 73.6 ft: Lake Tahoe is clearer today to a depth of almost 74 feet, but no one is saying the positive shift is permanent.*)

The BMP Monitoring Evaluation Process was funded by the USFS, Lake Tahoe Basin Management Unit (LTBMU) to compile and synthesize the existing research on BMP urban stormwater quality improvement performance. The synthesis consisted of a detailed review and evaluation of the study designs, study communications, available data and general BMP performance. The primary BMPs evaluated were dry detention basins (3), constructed wetlands/wet basin/meadow (3), and mechanical treatment structures (8). One source control study and three controlled experiments were also reviewed and incorporated into the synthesis. Based on the independent nature of Lake Tahoe water quality monitoring studies, the strengths and weaknesses of various studies were used to develop recommendations to standardize pollutant nomenclature, pollutant parameters of concern, monitoring study priorities, study communication structure, necessary BMP design and catchment characteristics to be included in study communications, data reporting structure, etc. The goal is to incorporate these recommendations into the LTIMP Lake Tahoe Monitoring Guidelines.

Preliminary quantitative comparisons of inflow and outflow BMP event mean concentrations (EMCs) and reported study BMP load and EMC reductions were conducted for each final report, where applicable. Evaluations of mechanical treatment structures, such as vaults, sand traps and roadside sediment basins, suggest effective treatment of particulate pollutants as measured by reductions in total suspended solids (TSS), total organic nitrogen (TKN) and particulate phosphorous (PP). The greatest limitation of mechanical treatment structure performance is inconsistent maintenance, which results in elevated effluent dissolved constituents such as nitrate (NOx), ammonia (NH_4^+), dissolved phosphorous (DP) and soluble reactive phosphorous (SRP). Detention basin evaluations suggest consistent and reliable treatment of particulate pollutants due to physical settling, but variable treatment of dissolved constituents was reported. Preliminary comparisons suggest detention basin characteristics may be unable to further reduce dissolved constituents when inflowing concentrations approximate NOx < 250 ug/L, NH_4^+ < 50 ug/L, SRP < 50 ug/L, and DP < 80 ug/L. Wetland/wet basin systems may provide the additional treatment capabilities to "polish" stormwater and further reduce dissolved nutrient loads when inflowing dissolved levels are moderate. The seasonal function of these BMPs should be evaluated since eutrophic wet environments that accept elevated levels of dissolved N and P have been observed to provide reliable removal of NOx through denitrification, yet variable treatment of the reduced N species, NH_4^+, as well as increases in SRP levels as a result of iron hydroxide reductions upon which phosphate will adsorb.

These results support a need for preliminary water quality evaluations to identify target pollutants in order to select and design appropriate BMPs, as well as a watershed treatment train approach for complete stormwater quality improvements prior to discharge to Lake Tahoe. While the data collection techniques and sampling protocols do vary across many of the projects, a standardized data reduction and database creation effort of existing water quality and hydrologic data would significantly improve the integration and power of these extensive data sets. A BMP Stormwater Analysis Database would make existing and future water quality data directly accessible for Phase II of the TMDL, the BMP Design Manual and other planning efforts that should be based upon Lake Tahoe-specific water quality observations. The BMP Synthesis recommendations aim to improve the accessibility of existing and future data to focus research, as well as facilitate greater collaboration between science, engineering and policy.

2. Problem Statement

Resource managers responsible for preserving the naturally oligotrophic Lake Tahoe place high priority on pollutant load reduction opportunities as a means to reverse the current decline in the Lake's treasured clarity. Until recently, the primary pollutants impairing clarity were identified as sediment and biologically available phosphorous (P). Other pollutants of concern include particulate phosphorous, nitrogen (N) species and iron. In 2005, research (Swift et al. 2006) on Lake Tahoe clarity suggested that very fine particles (< 16 um) remain in suspension within the water column and may be responsible for an average 58% of the annual clarity loss. These findings add a new challenge to scientists, engineers and resource managers to develop source control and treatment techniques that will reduce the delivery of these very small particles to the Lake.

One of the three largest sources of pollutant delivery to Lake Tahoe is stormwater runoff. Significant local and federal resources have been focused on implementing a variety of best management practices (BMPs) throughout the Basin to reduce stormwater pollutant loading. Popular BMPs include both source control techniques (e.g., rip rap protection, curb and gutter, revegetation, application reductions, etc.) and hydrologic stormwater treatment structures, such as detention basins, wet basins, constructed wetlands, vegetated swales and a variety of vault structures. The goal of many BMPs is to capture stormwater and improve the quality of the water transported downstream as a result of interaction with the structure.

Nowhere else in the country are resource managers in urbanized areas attempting to protect and preserve a naturally oligotrophic lake. The unique character of Lake Tahoe makes the application of standard BMP techniques and assumed pollutant removal effectiveness from national examples somewhat unrepresentative. The primary challenge of Lake Tahoe urban stormwater management is the sensitivity of the receiving waters—the Lake itself.

A variety of local, state and federal agencies have been implementing BMP projects at a furious rate without standard procedures that track each project. Due to an urgency to reduce pollutant loading in urban areas, the efforts have not always been investigated or monitored for effectiveness. A current problem stems from the discontinuity between stormwater pollutant reduction goals and our ability to track and measure the benefit of our current BMP solutions to achieve these goals. The questions remain, have we been reducing stormwater pollutant loading to the Lake and what can we learn from existing efforts?

A gamut of researchers, consultants, project managers and local agencies have undertaken BMP effectiveness evaluations in efforts to quantify the benefit of an array of BMP treatment and source control structures. However, many of these evaluations have been conducted independently. Although the majority of effectiveness studies have a similar objective - to quantify the water quality benefit of a particular BMP - studies vary significantly upon the type of site instrumentation, water sampling plan, data collection strategies, data management techniques, data interpretation, statistical evaluations, and overall BMP effectiveness reporting. The purpose of this BMP Synthesis Report is to provide a preliminary synthesis of the existing science on the performance of a suite of BMP treatment techniques to date. Where applicable, preliminary comparisons of study inflowing pollutant concentrations and reported treatment efficiencies are conducted. Based on the quality of the existing research and associated communications (i.e. final reports), recommendations are provided to improve the usability and applicability of basin BMP research to maximize the integration of the science into project design and resource planning.

The ultimate application of the BMP science is to facilitate adaptive management, where research and monitoring provide an iterative process to continue to improve BMP techniques based on qualitative performance information. Thus, the goal of applied research is to expand the application of data collection to complete the connection between science and management. The BMP Synthesis and recommendations herein are one more step towards effective BMP adaptive management in the Lake Tahoe Basin.

Eloise Basin, South Lake Tahoe, CA

Stormwater entering Lake Tahoe, downgradient of Park Avenue Basins, South Lake Tahoe, CA

3. Objectives and Methods

2NDNATURE was retained by the USFS LTBMU to document the collective scientific knowledge of BMP performance by synthesizing the findings and results of monitoring studies conducted in the Lake Tahoe Basin to date. The synthesis focuses on summarizing the study objectives, monitoring design and key scientific findings from 25 specific BMP performance evaluations (Table 1). Wherever possible, final study reports were reviewed, as these provide the final data and recommendations of the researchers. In cases where progress reports were all that was available, the information was viewed more cautiously. Based on the reported findings and focused discussions with a collection of the primary researchers (listed in the report acknowledgements), 2NDNATURE summarizes the status of scientific knowledge. Interviews with the researchers included study specific discussions of the successes, failures and lessons learned as a result of specific BMP monitoring. Researchers were also asked to provide their professional opinions regarding the state of the existing knowledge of BMP performance in Lake Tahoe, where scientific data gaps remain, and how management, science and engineering may be better integrated to improve future BMP design and performance. The findings and recommendations contained within have not been formulated by 2NDNATURE alone and should be considered a collective participation of Basin scientists.

The lack of current standardization of BMP performance reporting across studies, and available resources for this effort, limits the BMP Synthesis to a preliminary quantitative evaluation of BMP application and perceived performance. Based on limitations and inconsistencies of the existing research, recommendations are provided to improve the quantitative comparability of existing data, as well as improve future standardization of monitoring efforts. Continued integration of stormwater and BMP monitoring data and knowledge gained should be a primary BMP research goal.

Since 2NDNATURE was unfamiliar with many of the studies prior to reading the provided documents, much of the evaluation of the study hinged on the quality of the communication in the reports. Prior to report review, 2NDNATURE developed a standardized evaluation questionnaire to document the information provided by each of the 25 BMP performance reports. The evaluation included a qualitative ranking of 60 characteristics of each of the study reports to assist with the study summaries, lessons learned and the development of recommendations to improve study designs and communications (Appendix A). The assessment was based on scoring components of the study that relate to four primary aspects to assess study quality: monitoring study design, data collection, report communications, and conclusions and recommendations. The independent evaluations will not be released, but average performance scores of the four study components from each final study report are provided as Appendix B. Interim/progress report scores are not included in Appendix B.

TABLE 1

BMP COMMUNICATION REPORTS EVALUATED IN BMP SYNTHESIS (PAGE 1 OF 3)

Text Reference	Report Title	Report Date	Report Authors	Affiliation	Prepared For	Report Status
2NDNATURE 2005A	Village Green Pond Pilot Project Phase II, Progress Reports	Mar-05	Nicole Beck	2NDNATURE INC	Nevada Tahoe Conservation District (NTCD)	Progress Report
2NDNATURE 2005B	Lake Village Residential BMP Effectiveness Study, Progress Reports	Mar-05	Nicole Beck	2NDNATURE INC	US Forest Service (USFS)	Progress Report
2NDNATURE 2005C	Storm Filter Performance Analysis, South Lake Tahoe, CA	Apr-05	Nicole Beck	2NDNATURE INC	City of South Lake Tahoe (CSLT)	Final
2NDNATURE 2006	Detention Basin Treatment of Hydrocarbon Compounds in Urban Stormwater	Mar-06	Nicole Beck	2NDNATURE INC	South Tahoe Public Utility District (STPUD)	Final
Bachand/ TRG 2005	Adsorptive Media Investigations and Testing for Improved Performance of Stormwater Treatment Systems in the Tahoe Basin	Mar-05	Philip A. M. Bachand Alan Heyvaert	Bachand and Associates & UC Davis Tahoe Research Group (TRG)	Placer County Department of Public Works & California Tahoe Conservancy (CTC)	Final
Bachand/ TERC 2006	Chemical Treatment Methods Pilot (CTMP) for Treatment of for Urban Runoff – Phase I. Feasibility and Design	Apr-06	Philip A. M. Bachand John Reuter, Alan Heyvaert, R. Fujii	Bachand and Associates, Tahoe Environmental Research Center (TERC), City of South Lake Tahoe (CSLT), USGS	USFS and CSLT	Draft
CSU Sacramento 2004	Small-Scale Pilot Studies Using Coagulants for Turbidity and Phosphorus Removal at Lake Tahoe	Jul-04	John Johnston Jeff Curtis Dipen Patel Jeffrey Hauser	CSU Sacramento & EcoLogic Consulting Engineers	North American Surface Water Quality Conference	Final
CWS 2005	Evaluation of Angora Meadows as a Filter for Nutrients	Jun-05	Michael L. Johnson Jacob O. Iversen	Aquatic Ecosystems Analysis Laboratory, Center for Watershed Sciences (CWS), UC Davis	El Dorado County Department of Transportation (EDCDOT)	Final
DRI 2004A	Evaluation of Urban Runoff BMP Effectiveness through Assessment of Mechanical Treatment Technologies (Vaults) and Wetland Systems Employed at the Stateline Stormwater Project	Sep-04	Todd Mihevc Jim Thomas Melissa Gunter	Division of Hydrologic Sciences, Desert Research Institute (DRI), University and Community College System of Nevada	Tahoe Regional Planning Agency (TRPA)	Final
DRI 2004B	Evaluation of Effectiveness of Three Types of Highway Alignment Best Management Practices for Sediment and Nutrient Control	Dec-04	Theresa Jones Jim Thomas Todd Mihevc Melissa Gunter	Division of Hydrologic Sciences, DRI	USFS -Lake Tahoe Basin Management Unit (LTBMU) & Nevada Division of State Lands & Nevada Department of Transportation (NDOT)	Draft

TABLE 1

BMP COMMUNICATION REPORTS EVALUATED IN BMP SYNTHESIS (PAGE 2 OF 3)

Text Reference	Report Title	Report Date	Report Authors	Affiliation	Prepared For	Report Status
DRI & TERC 2005	Efficiency Assessment of Stormwater Treatment Vaults in the Round Hill General Improvement District	Apr-05	Alan Heyvaert, Ph.D. Todd Mihevc Roger Jacobson	Division of Hydrologic Sciences, DRI & Tahoe Environmental Research Center (TERC)	NTCD & Nevada Division of State Lands	Final
EDCDOT 2004	Woodland and Lonely Gulch portion of the Woodland/Tamarack/Lonely Gulch Erosion Control Project; 1st Year data report	Dec-04		El Dorado County Department of Transportation (EDCDOT), Tahoe Engineering Division	EDCDOT, Tahoe Engineering Division	Progress Report
EDCDOT 2005	Woodland portion of the Woodland/ Tamarack/Lonely Gulch Erosion Control Project; BMP Maintenance and Infiltration Study 2nd Year data report	May-05		EDCDOT, Tahoe Engineering Division	EDCDOT, Tahoe Engineering Division	Progress Report
Hydrologic Sciences 2004A	Simulated Rainfall Evaluation of Revegetation/Mulch Erosion Control in the Lake Tahoe Basin: 1. Method Assessment	Mar-04	M. E. Grismer M. P. Hogan	Hydrologic Sciences, UC Davis & Integrated Environmental Restoration Services, Inc. (IERS)	Peer Reviewed Journal (Land Degradation and Development)	Final
Hydrologic Sciences 2004B	Simulated Rainfall Evaluation and Monitoring of Revegetation/Mulch Erosion Control in the Lake Tahoe Basin: 2002-03 Assessment	Jun-04	M. E. Grismer M. P. Hogan	Hydrologic Sciences, UC Davis & IERS	CA Dept. of Transportation & USDA-Forest Service	Final
Hydrologic Sciences 2005	Simulated Rainfall Evaluation of Revegetation/Mulch Erosion Control in the Lake Tahoe Basin: 2. Bare Soil Assessment	Jun-05	M. E. Grismer M.P. Hogan	Hydrologic Sciences, UC Davis & IERS	Peer Reviewed Journal (Land Degradation and Development)	Final
IERS 2005	Cave Rock Revegetation Monitoring Program- Improving Sediment Source Control Projects in Lake Tahoe Basin (Final Draft)	Jul-05	M.P. Hogan	IERS	USFS-LTBMU, & Nevada Division of State Lands	Final Draft
John Muir Institute 2003	Review of Angora Meadows Nutrient Monitoring Report	May-03	Michael L. Johnson	John Muir Institute of the Environment, UC Davis		Final
SH+G 2003	Assessment of Seasonal Pollutant Loading and Removal Efficiency of Detention Basins	Feb-03	Nicole Beck, Ph.D.	Swanson Hydrology & Geomorphology (SH+G)	TRPA & US Environmental Protection Agency (EPA)	Final

TABLE 1
BMP COMMUNICATION REPORTS EVALUATED IN BMP SYNTHESIS (PAGE 3 OF 3)

Text Reference	Report Title	Report Date	Report Authors	Affiliation	Prepared For	Report Status
TERC 2005	Performance Assessment of the Coon Street Basin, Kings Beach CA	Mar-05	Alan Heyvaert, Ph.D. Andrea Parra, M. S.	Tahoe Environmental Research Center (TERC), UC Davis	Placer County Department of Public Works	Final
TRG 2005 *TRG 2004* *TRG 2005B*	Tahoe City Wetland Treatment System, Groundwater and Surface Water Assessment Report includes: *Subalpine Stormwater Treatment with a Constructed Surface-Flow Wetland* and *Groundwater Hydraulics and Chemistry at the Tahoe City Wetland Treatment System*	Jan-05 *Dec-04* *Jan-05*	Alan C. Heyvaert James C. Trask John E. Reuter Charles R. Goldman *Heyvaert, Reuter, Goldman* *Trask, Heyvaert*	Tahoe Research Group (TRG), UC Davis	Placer County Department of Public Works & CTC	Final
URS 2003	Angora Monitoring Project - Post Sampling Summary Report	May-03	URS	URS Corporation	EDCDOT, Tahoe Engineering Division	Progress Report
USGS 2005A	Chemistry of Runoff and Shallow Ground Water at the Cattlemans Detention Basin Site, South Lake Tahoe, California, August 2000 – November 2001 (and Appendix Cattleman's Basin Slug test appendix)	Jun-05	David E. Prudic Sienna J. Sager James L. Wood Katherine K. Henkelman Rachel M. Caskey	United States Geologic Survey (USGS)	EDCDOT, Tahoe Engineering Division	Final
USGS 2005B	Hydraulic Conductivity of Near-Surface Alluvium in the Vicinity of Cattlemans Detention Basin	Jun-05	Jena M. Green Katherine K. Henkelman Rachel M. Caskey	USGS	CTC & EDCDOT, Tahoe Engineering Unit	Final
USGS 2006	Changes in Ground-Water Flow and Chemistry after Completion of Cattlemans Detention Basin, South Lake Tahoe, California -- November 2001 to November 2003	Jan-06	David E. Prudic Jena M. Green James L. Wood Katherine K. Henkelman	USGS	EDCDOT, Tahoe Engineering Unit	Final

Pollutant Nomenclature

All concerned parties realize that the development and acceptance of monitoring guidelines is necessary to standardize basin BMP monitoring and improve the integration of existing and future data. In order to provide a scientific synthesis of the BMP reports, a consistent nomenclature must be established for the priority pollutants. In most instances the pollutants evaluated from study to study appear to be consistent, despite an inconsistent nomenclature. There are standard EPA analytical methods for each of the constituents investigated by basin researchers. These standard analytical EPA methods should continue to be used for concentration determinations of the constituents discussed below. For the purpose of discussions herein, we provide and utilize our recommendations for the specific nomenclature of sediment and nutrient constituents. Rationale providing support for our recommendations is provided where necessary.

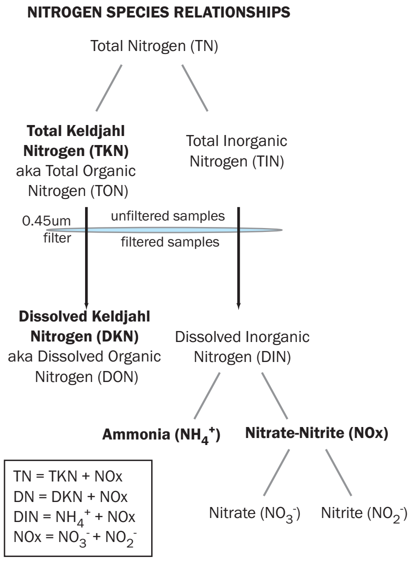
Sediment

The most common analytical technique to measure sediment concentrations and calculate sediment loads used in the Basin is Total Suspended Solids (TSS). TSS is the mass of sediment contained in a known volume of water. Typically, a 100mL aliquot is removed from the sample, dried and the mass of material is weighed (mg of material per L of water). While technically the composite of all material in the sample may include organic matter, colloids, salts, etc., it is reasonable to assume the majority of the particulate matter can be classified as sediment. Some discussions in the Basin have included the transition to use Suspended Sediment Concentration (SSC) to obtain more “accurate” values of the sediment concentrations. (Note that not one of the BMP reports reviewed utilized SSC as the reported analytical method to quantify sediment.)
The difference between the two methods is that SSC does not require an aliquot and the entire sample is dried and weighed. This eliminates the potential to remove an unrepresentative aliquot from the sample, which would skew the particle size distribution and perhaps total sediment concentration in the sample.

It is recommended the Basin researchers remain utilizing TSS as the primary analytical technique to evaluate sediment for two reasons.
First, there is a significant amount of existing stormwater and BMP data analyzed as TSS and no reliable technique exists to convert past TSS data to SSC concentrations. Secondly, regardless of analytical technique, the sample is inherently an aliquot of the stormwater in question and thus neither technique will provide completely accurate results. Building upon existing data has much greater value than the cost and potential benefit of determining SSC values in Tahoe stormwater.

Another common measure researchers use to evaluate sediment is turbidity (Tu)—a measure of the ability of light to pass through the water column. Turbidity readings can be very useful because automated probes provide continuous data sets. However, the real power of turbidity is when water samples analyzed for TSS are used to create a TSS/Tu rating curve. This analysis provides estimates of sediment flux and mass loading rates over specific events, seasonally and/or annually. Few studies reviewed linked these two parameters together, despite the collection of each.

Figure 1. Nomenclature of the nitrogen speciation of a water sample

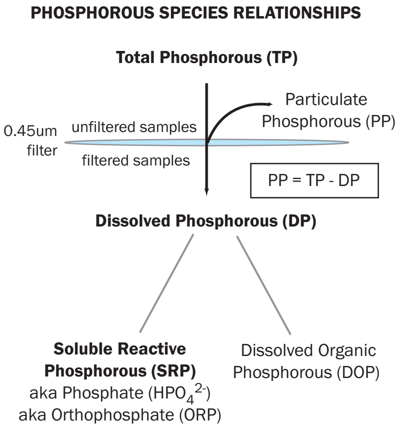


While none of the reviewed reports included detailed grain-size determinations as a component of BMP performance, the recent findings by Swift et al. (2006) should result in a future focus upon the specific dynamics of key particle size fractions. Basin researchers need protocols to ensure analytical methods and reporting techniques provide consistent grain size designations to facilitate the comparability of this information across studies.

Nutrient Species

The primary nutrients of concern in the Lake Tahoe Basin are nitrogen (N) and phosphorous (P). Throughout the reports synthesized herein, there has been some confusion on proper sample handing and many variations in reporting. Figures 1 and 2 are schematics of the key N and P species of concern in environmental monitoring and provide the nomenclature 2NDNATURE recommends for future reporting to avoid any further confusion. The schematics illustrate the relationship of each N and P species to one another. Dissolved nutrient species are of utmost importance because the inorganic dissolved compounds are typically biologically available, namely dissolved inorganic nitrogen (DIN) and soluble reactive phosphorous (SRP). To an analytical chemist, the word “total” in any analyzed aquatic compound implies the analysis of an unfiltered sample. The filtration of a water sample through a 0.45um filter is the operational definition of “dissolved”. The dissolved species that are biologically available are NOx, NH_4^+ and SRP, since it is assumed that when these compounds are adhered to particles larger than 0.45um photosynthetic organisms can not utilize them for organic biomass production.

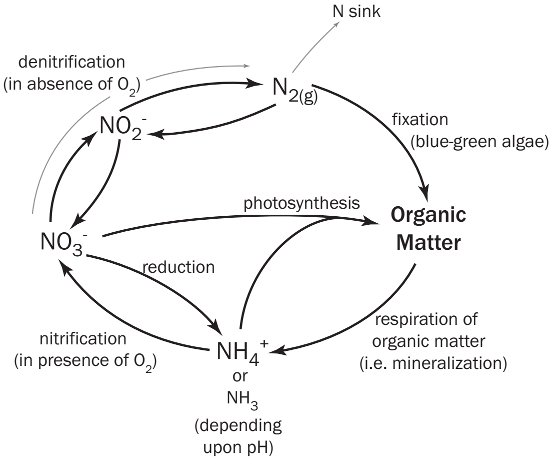
Figure 2. Nomenclature of the phosphorous speciation of a water sample



NOx is the product of an analytical method that measures the sum of nitrate and nitrite (Figure 1). In oxygenated environments, nitrite is not stable and will be oxidized to nitrate, thus NOx will be a direct measure of nitrate concentrations in these conditions. If anoxic conditions are observed or expected, analyses of nitrite (NO_2^-) may provide additional information of the redox state (i.e. a measure of the degree of anoxia) of the system in question. TKN is an analytical method that includes the total organic nitrogen and ammonia in a sample. Typically, TKN levels are orders of magnitude higher than NH_4^+ in aquatic samples, and thus NH_4^+ concentrations are not subtracted from TKN. TN then is the sum of TKN and NOx (Figure 1). For further edification, Figure 3 is provided as a simplified N cycling schematic, as these processes are referenced in the context of several specific studies.

Phosphorous (Figure 2) is not a redox element, which makes the cycling of P and the number of species less complicated than N (Figure 1). Typical and useful analytical P species include TP (an unfiltered sample), DP (the same analysis as TP but on a filtered sample) and SRP (a filtered sample with no digestion as performed on the prior two analyses). The fate and transport of particulate phosphorous is of interest in Lake Tahoe due to the potential for subsequent disassociation and biological availability once these particles are delivered to the Lake, or somewhere en route. Samples are not analyzed for PP, but rather the difference between TP and DP is the amount of P that was retained on the filter (Figure 2). A common term used by the USEPA is TDP (total dissolved phosphorous) as “The total phosphorous content of all material that will pass through a filter, which is determined as orthophosphate without prior digestion or hydrolysis”. This definition is technically incorrect and referring to a sample as “total dissolved phosphorous (TDP)” is an oxymoron. By our definitions TDP is SRP because this analysis is a measure of the immediately biologically available forms of phosphorous in the system being evaluated.

Figure 3. Nitrogen Cycle
(modified from Stumm and Morgan, 1996)



While the specific selection of which nutrients and/or other pollutants to evaluate for BMP performance will depend upon the specific purpose and target pollutants of the BMP and the objectives of the monitoring study, we have provided a standardized nomenclature of the Lake-impairing nutrient constituents. Surface water pollutant studies evaluating nutrient retention should include each of the constituents bolded in Figures 1 and 2. The evaluation of the primary dissolved nitrate, ammonia and SRP constituents in concert with the levels, fate and transport of the Total N and Total P provides valuable information on the relative biological availability (especially when expressed as ratios) and the relative magnitude of the nutrients. The dissolved nutrient species are immediately biologically available and of primary concern, but simple biogeochemical processes (e.g., phosphate adhering to a clay particle or nitrification) can quickly alter the biological availability of nutrients.

Groundwater investigations of nutrient fate and transport should limit analytical efforts to the dissolved nutrient species (NOx, NH_4^+, DKN, DP and SRP), since these are the only constituents that are mobile in a saturated subsurface environment. TKN, TP and PP concentrations are unnecessary when samples are collected from a groundwater monitoring well.

Constituent Selection

Each specific water quality data collection effort will have different specific goals and objectives, by which the proper analytical constituents should be selected to directly address those objectives. In general, it is recommended that BMPs designed to treat sediment should be evaluated with respect to reductions in TSS as well as the specific changes in each of the three primary particle grain size ranges (1 um - 10 um, 10 um - 100 um and 100 um - 1000 um). Additional detailed evaluations should focus on the fate and transport of particles less than 20 um in size.

In general, BMP systems designed to treat nutrient constituents should include detailed evaluations of total and dissolved constituents as provided in Figures 1 and 2 for surface water conditions, but groundwater samples need only to focus upon the dissolved constituents since these are the compounds mobile in a subsurface environment. Again some variations may exist depending upon the specific questions of the monitoring efforts.

4. BMP Performance Projects

Performance Evaluation

The existing monitoring studies represent a number of BMP types. Detention (dry) basins, retention (wet) basins, constructed wetlands, meadow diversions, and flow-through vault structures are all similar in that they have well-defined inlets and outlets. This allows constrained monitoring of potential pollutant changes as a result of introduction to and flow through the system in question. Efficiency has typically been quantified by “percent removal” based on differences in inflow and outflow pollutant loads. However, discrete events defined as 100% efficient (no surface outflow occurs) may be misleading if subsequent, unmonitored, events mobilize the stored waters downstream.

Park Avenue Detention Basin WY2003

Below we summarize the types of BMPs that have been monitored and evaluated by researchers in the Lake Tahoe Basin. For simplicity we have grouped the BMPs into three main types, detention basins, constructed wetlands and mechanical treatment structures. A few anomalous BMPs, such as Angora Meadow, are discussed where most applicable. The specifics of each of the sites, study objectives and data collection details are provided. Based on the collective evaluations for similar BMP or project types, a synthesis of the current knowledge is provided. The associated reports reviewed to compile the BMP Synthesis should be assumed to be study final reports, unless otherwise noted in Table 1. Specific BMP and monitoring information has been extracted and compiled into tables grouped by BMP type. Metadata concerning the BMP, catchment characteristics and monitoring study details were extracted from each report and provided in tabular format. Each future monitoring study should provide this information in tabular format, to simplify accessibility and increase the usefulness and quick study comparisons with other stormwater quality monitoring efforts.

Where possible, the average surface water inflow/outflow pollutant concentrations, average nutrient groundwater concentrations and study BMP performance, as reported by % pollutant load reduction and/or % EMC pollutant reduction, were extracted from each final study report. These values are provided in Appendix C for every study, noting where the values were obtained from the study communications. At the end of each summary for the three main types of BMPs (detention basins, wet basins, and mechanical systems) the reported average inflow concentrations and EMC % reduction values are presented. These values were extracted from Appendix C, then presented and sorted by N species, P species and TSS. The quantitative summary tables are ranked by the site with the highest inflow EMC and % EMC reduction of the most biologically available N and P species, nitrate and SRP, respectively. These quantitative comparisons across studies should be interpreted with caution, as many inconsistencies in reporting techniques between studies exist. Additional comparisons using the event data from each of the studies, and evaluated for both annual and specifically seasonal pollutant retention, will provide a more consistent evaluation of each BMP to reduce and retain pollutants of concern.

Detention (Dry) Basin Investigations

Dry detention basins are a common hydrologic BMP implemented to reduce, retain and infiltrate some fraction of the stormwater volume. Infiltration of stormwater volumes has become a primary treatment strategy in Lake Tahoe to reduce the surface water pollutant loads. A detention basin relies upon extended storage durations to provide water quality and hydrologic improvements to downstream resources. Typically, a detention basin is free of water in the dry months of the year and will experience sustained inundation during the peak of spring snowmelt. During stormwater runoff events dry basins experience variable inundation frequencies that are regulated by the respective watershed area, hydrologic characteristics and the storage capacity of the basin. The outlets of most Tahoe detention basins are controlled by a vertical 36” CMP (corrugated metal pipe) with a trash rack, facilitating basin outflow from the surface of the water column when the basin water storage reaches capacity. Detention basin morphology varies dramatically throughout Lake Tahoe. The morphology of specific basins appears to be somewhat limited by the available surface area necessary to satisfy the design criteria of the site-specific 20-yr, 1-hr storm volume. Detention basins have been assumed to provide some water quality treatment to the incoming stormwater as a result of particle settling, soil/water interactions due to infiltration, and vegetation nutrient uptake. According to the Water Quality Project Inventory (WQPI) created by the Nevada Tahoe Conservation District (NTCD) in 2005, over 1.1 million cubic feet of detention basin storage has been created in the Lake Tahoe Basin. In comparison, there is only 58,000 cubic feet of wetland/retention storage.

Typical vertical CMP with trash rack, Eloise Basin during snowmelt WY04

A total of five detention basins have been monitored in the Lake Tahoe Basin. Their associated communication reports were evaluated for the BMP Synthesis. General dry detention basin specifics provided in the reports are documented in Table 2 and study monitoring specifics are presented in Table 3.

- Coon Street Basin, Kings Beach, CA (TERC 2005)
- Northwood Ditch, Incline Village, NV (SH+G 2003)
- Eloise Basin, South Lake Tahoe, CA (SH+G 2003, 2NDNATURE 2006)
- Industrial Basin, South Lake Tahoe, CA (2NDNATURE 2006)
- Cattlemen’s Basin, South Lake Tahoe, CA (USGS 2006)

Study Summaries

Heyvaert and Parra (TERC 2005) evaluated the effectiveness of Coon Street detention basin at reducing nutrients and sediments in stormwater within a high density residential drainage. Event based surface hydrology and water sampling were conducted at the inlet and outlet to compare inflow and outflow nutrient and sediment EMCs and loads.

BMP	Coon Street Basin	Northwood Ditch	Eloise Basin	Industrial Basin	Cattlemen’s Basin
BMP Type	Dry detention basin	Dry detention basin	Dry detention basin	Dry detention basin	Dry detention basin
Location	Kings Beach, CA	Incline Village, NV	South Lake Tahoe, CA	South Lake Tahoe, CA	South Lake Tahoe, CA
Year Constructed	1996	1995	1991	2002	2001
Catchment Land Use	High density residential	Moderate density residential	Commercial, residential	Industrial	Residential
Catchment Area (acres)	22	24	130	53	N/P
% Catchment Impervious	36	N/P	70	35	N/P
Basin Storage Capacity (V) (ac-ft)	0.47	1.5	1.2	1.4	0.5
Basin Surface Area (SA) at Capacity (ft2)	13,142	34,100	21,120	102,000	27,300*
SA:V Ratio at Capacity	0.6	0.5	0.4	1.7	1.25
Maximum Basin Water Depth (ft)	3.0	3.1	3.2	.5	3.2
Basin Morphology Notes	Oval shaped, flow path not max length of basin	Narrow, long basin, flow path maximized	Oval shaped, flow path maximized	Expansive complex morphology, flow path maximized	Oval shaped, flow path maximized

N/P: information not provided in project report.

* calculated from site map provided

BMP DETAILS OF DETENTION (DRY) BASINS

TABLE 2

BMP	Coon Street (TERC 2005)	Northwood Basin (SH+G 2003)	Eloise Basin (SH+G 2003)	Eloise Basin (2NDNATURE 2006)	Industrial Basin (2NDNATURE 2006)	Cattlemen's Basin (USGS 2006)
Key Study Goals	Surfacewater treatment	Land use pollutant loading Surface water treatment		Fate and transport of hydrocarbon surface water to groundwater		Physical/chemical groundwater impacts of detention basin
Monitoring Span	WY03-WY04	WY02	WY02	WY04-Dec05	WY04-Dec05	WY01-WY03
Surface Water Hydrology	Continuous inflow/outflow, basin topography	Continuous inflow/ outflow	Continuous Sigma at inflow (limited), basin stage + topography	Basin stage + topography	Inundation observations, basin topography	No surface water inflow/outflow, surface water monitoring in adjacent Cold Creek
# of Surface Water Events Monitored	20	10	8	9	9	7
Surface Water Performance Metrics	Event EMCs, event mass loads, project loads	Event EMCs, event mass loads	Event EMCs, event mass loads	Basin inflow concentrations	Basin inflow concentrations	Cold Creek concentrations
Pollutants of Concern	TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-,TSS	TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-,TSS	TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-,TSS	MtBE, BTEX, TPH-gas, TPH-diesel, etc., TP, DP, SRP, TN, TKN, , NH_4^+, NO_3^-	MtBE, BTEX, TPH-gas, TPH-diesel, etc., TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-	DP, SRP, TKN, NH_4^+, NO_3^-, Fe major ions, trace metals, organic C
# of Groundwater Monitoring Wells	N/A	N/A	N/A	7	6	30
Groundwater	N/A	N/A	N/A	Continuous groundwater elevation + spot measurements	Continuous groundwater elevation + spot measurements	Continuous groundwater elevation + spot measurements
Detail Groundwater Hydrology Analysis	N/A	N/A	N/A	Yes	Yes	Yes
# of Groundwater Events Monitored for Water Quality	N/A	N/A	N/A	7	4	11

N/A: not applicable to project

STUDY DETAILS OF DETENTION (DRY) BASINS

TABLE 3

The SH+G 2003 study was designed to provide a land-use comparison of stormwater pollutant characteristics and evaluate the treatment effectiveness of three different detention BMPs accepting the commercial, residential and recreational runoff. Two of the three sites were dry detention basins—Northwood Ditch (residential) and Eloise Basin (commercial/industrial). BMP surface water effectiveness for these sites was calculated using event based flow-weighted inflow and outflow pollutant EMCs and load comparisons. The study focused on nutrients and fine sediments.

The purpose of the 2NDNATURE 2006 study, directed by the South Tahoe Public Utility District, was to evaluate the potential risk infiltration via dry detention basins may pose to the quality of the shallow water table with respect to hydrocarbon constituents. Data collection at Eloise and Industrial Basins focused on collecting stormwater first flush samples introduced to the basins during the onset of runoff events and subsequent groundwater monitoring adjacent to the detention basins when basin recharge was observed. Surface water samples were collected utilizing passive samplers, inflow grab samples and in-basin surface water grabs. No surface water outflow samples were collected. While the study was explicitly conducted to address the objectives of the hydrocarbon study, surface water and groundwater samples were collected and analyzed for total and dissolved nutrients as well.


Topographic survey of Industrial Basin, South Lake Tahoe, CA

The USGS 2006 study at Cattleman's Basin was designed to evaluate the changes in groundwater flow and chemistry resulting from the installation of a dry detention basin. Data collection included pre- and post-construction monitoring of localized groundwater flow dynamics and associated water chemistry to improve understanding of the potential impacts dry detention basins have on the shallow groundwater. The detention basin is located in close proximity to Cold Creek, thus surface water chemistry of Cold Creek was monitored above and below the potential groundwater influence of the newly constructed Cattlemen's Basin. No surface water samples were collected from the inflow to, or stored within, Cattlemen's Basin. The study evaluated the influence infiltration via Cattlemen's detention basin had on the shallow groundwater quality, as well as the chemical influence on a downgradient stream, Cold Creek.

An additional detention basin water quality monitoring study began in 2005 at the Park Avenue Basins in South Lake Tahoe, CA and is currently slated for completion in 2008. Under the management of the City of South Lake Tahoe, and in partnership with the USGS, 2NDNATURE is performing an assessment of the treatment capacity and potential infiltration influence on the shallow groundwater quality of these two consecutive basins. The study includes the installation and monitoring of numerous upgradient and downgradient monitoring wells, in-basin lysimeters, surface water monitoring stations and continuous water level recorders. The potential to conduct solute tracer experiments, coupled with slug tests, will improve the overall understanding of hydrogeologic processes occurring at this site. The products will include a detailed event-based water budget of the Park Avenue Basins, an evaluation of the fate and transport of key nutrient constituents introduced to this BMP, and the quantitative evaluation of the efficiency of this project to reduce pollutant loading to Lake Tahoe.

Results Summary

Five detention basins have been studied in the Lake Tahoe Basin in the last five years, all having a variety of evaluation objectives. Three of these, Coon Street Basin (TERC 2005), Northwood Ditch (SH+G 2003) and Eloise Basin (SH+G 2003), were evaluated for their ability to reduce surface water nutrients and sediment in stormwater. The data collection, data analysis and interpretation techniques for these three evaluations were similar (Table 3). Their evaluations focused on the differences in the EMCs and/or event loads as measured at the inlet and outlet of specific basins.

Many events observed at Coon Street Basin and Northwood Ditch did not include surface water outflow, thus 100% effectiveness is determined for those particular events. When outflow from a dry detention basin does occur, there is consistent data suggesting that the hydrologic environment of the detention basins slows flow velocities and enhances particle removal via physical settling. TSS and particulate phosphorous event loads and EMCs are reported to be consistently reduced as a result of the Lake Tahoe detention basins evaluated by TERC 2005 and SH+G 2003. The reduction in flow velocities and increased water detention storage times enhance the capture of particulate pollutants, such as sediment and phosphorous. The authors found that physical settling can be enhanced by extended flow paths that maximize the average hydraulic residence time and allow time for particulate settling. Extended flow paths also reduce turbulence or resuspension of particles near the outlet as a result of inflowing waters. Surface water outflow through the vertical risers preferentially traps particles in the basin that have settled to the bottom of the water column. Proper sizing of the detention system relative to the catchment hydrology can minimize the frequency the detention system is at capacity during large events.

The existing data suggests that dry detention basins have variable success at retaining and treating dissolved nutrients in stormwater. Coon Street Basin (TERC 2005) was observed to consistently provide reductions of NH_4^+, NOx, DP, and SRP, though the magnitude of the reductions from inflow to outflow was variable. The authors report event volume reduction ranging from 8-27% due to basin retention and/or infiltration. In most instances the effluent concentrations frequently achieved TRPA's surface water criteria for SRP and TP, but many times failed to meet the TN discharge criteria of 0.5 mg/L.

Vegetation at inlet of Northwood Ditch WY02, Incline Village, NV

Eloise Basin during the early Fall WY02 South Lake Tahoe, CA

Northwood Ditch and Eloise Basin also demonstrated a greater and more consistent reduction of particulates than dissolved nutrients (SH+G 2003). The authors noted that the variation in vegetation establishment in the two basins (see photos on left) may have influenced the observed poorer performance of Eloise Basin to retain dissolved N species in stormwater (NH_4^+ and NO_3^-). Since these two dissolved N constituents do not adhere to soil particles, we would not expect dissolved inorganic nitrogen (DIN) treatment without a biological component to facilitate uptake of this primary nutrient. Basin vegetation will increase the ability of detention basins to fix biologically available nitrogen during the spring and summer months when biological growth rates are maximized.

Two studies (USGS 2006, 2NDNATURE 2006) investigated the potential subsurface impacts of inducing infiltration via detention basin systems. While the objectives of these groundwater investigations were different, both documented a profound physical impact on groundwater flow dynamics as a result of detention basin construction. When detention basins have a relatively localized surface area of influence, such as Cattlemen's Basin (USGS 2006) and Eloise Basin (2NDNATURE 2006), researchers documented water mounding (reversed groundwater gradients) in the subsurface shallow water table when the basins were full of water. The mounding is the result of preferential recharge via the detention basin stormwater to the shallow groundwater. A third detention basin, Industrial Basin, was not reported to have as profound of an influence on the local groundwater gradients (2NDNATURE 2006), presumably due to a more expansive morphology that increased the surface area of recharge while expanding the volume of the shallow water table directly beneath the structure.

These two studies (USGS 2006, 2NDNATURE 2006) provide preliminary information concerning the potential impacts to shallow groundwater as a result of basin infiltration. While the nutrient data set is limited, 2NDNATURE (2006) suggests the potential for a snowmelt nitrate pulse to migrate in shallow groundwater. The USGS (2006) found that nutrient concentrations in groundwater, as well as Cold Creek concentrations above and below the basin influence, did not show any significant changes. Based on a mass balance estimate, the current annual nutrient load in the shallow groundwater downgradient of Cattlemen's Basin is at least two to three times less than the annual nutrient loads currently observed in Cold Creek. The sites for the 2NDNATURE (2006) study accept stormwater from roadways and urban areas, while Cattlemen's Basin is designed to treat roadway and residential stormwater.

2NDNATURE (2006) has substantiated that urban stormwater in Lake Tahoe does contain elevated levels of heavier hydrocarbon constituents, such as total petroleum hydrocarbons (TPH) as diesel, total extractable petroleum hydrocarbons (TEPH), and oil and grease. Less frequent detections (approximately 20%) were made of more soluble hydrocarbons including toluene and xylenes in stormwater. The absence of any detections of these hydrocarbons during recharge-based groundwater monitoring beneath two dry detention basins (Eloise and Industrial) suggest the vertical soil column effectively retains and removes these hydrophobic contaminants. The study collected and analyzed more than 40 stormwater samples, many of which were first-flush collections, and 77 groundwater samples during times of observed infiltration via the detention basins. None of the samples contained detectable levels of MtBE (methyl tert-butyl ether) (detection limit = 0.2 ug/L). Based on the elevated levels of heavier hydrocarbons in urban stormwater, the researchers do suggest that locations where urban stormwater is routed directly to the shallow groundwater without proper soil interaction (i.e. dry wells) may result in shallow groundwater contamination.

Quantitative Detention Basin Comparisons

Table 4 provides the surface water inflow and EMC % reduction comparisons for the relevant detention basin effectiveness studies. Coon Street Basin has the highest reported inflow EMC values for all pollutants of concern, as well as the greatest reported EMC reductions as a result of interactions with the basin. Based on the results shown in Table 4, detention basins can further reduce TSS concentrations when inflow concentrations are on the order of 100 - 500 mg/L. The existing data suggest there may be an effluent limit below which detention basin structures cannot provide a treatment benefit to dissolved nutrients. This statement is based on the comparison of pollutant % EMC reduction and the inflow concentrations. Coon Street Basin had significantly higher NOx, NH_4^+, SRP and DP levels than the other two detention basins. Coincidently, Coon Street was the only site to report consistent dissolved pollutant reductions. One interpretation of this data suggests that detention basins may provide little treatment when inflowing concentrations are approximately: NOx < 250 ug/L, NH_4^+ < 50 ug/L, SRP < 50 ug/L or DP < 80 ug/L. The variable and potentially poor detention basin removal of the biologically available nutrients (NOx, NH_4^+ and SRP) suggests that detention basins may not be a preferred BMP to treat these constituents when potential inflowing EMCs are in the lower end of the range.

Table 4. Detention basin quantitative comparisons of average study inflow concentrations and reported EMC % reductions for the relevant surface water studies. The sites are ranked in descending order by the constituents in red for each table. Details of values' origin are provided in Appendix C.

INFLOW N SPECIES CONCENTRATION (ug/L)	TN	TKN	NOx	NH_4^+
Coon Street (TERC 2005)	5085	4124	961	98
Northwood Basin (SH+G 2003)	1229	1056	173	11
Eloise Basin (SH+G 2003)	2301	2132	170	44
INFLOW P SPECIES CONCENTRATION (ug/L)	TP	PP	DP	SRP
Coon Street (TERC 2005)	1629	1480	149	116
Northwood Basin (SH+G 2003)	321	264	57	48
Eloise Basin (SH+G 2003)	955	898	57	23
INFLOW TSS SPECIES CONCENTRATION (ug/L)	TSS			
Coon Street (TERC 2005)	481			
Eloise Basin (SH+G 2003)	239			
Northwood Basin (SH+G 2003)	105			

N SPECIES % EMC REDUCTION	TN	TKN	NOx	NH_4^+
Coon Street (TERC 2005)	Y	65	66	29
Northwood Basin (SH+G 2003)	Y	7	65	-13
Eloise Basin (SH+G 2003)	Y	13	-51	-5
P SPECIES % EMC REDUCTION	TP	PP	DP	SRP
Coon Street (TERC 2005)	89	Y	53	77
Northwood Basin (SH+G 2003)	Y	64	13	-7
Eloise Basin (SH+G 2003)	Y	56	-41	-31
TSS SPECIES % EMC REDUCTION	TSS			
Coon Street (TERC 2005)	94			
Eloise Basin (SH+G 2003)	72			
Northwood Basin (SH+G 2003)	68			

Y: Metric not provided in the report, but could be calculated if additional data analysis were performed.

X: Metric justifiably not provided in the report because it was not the purpose of the investigations.

Constructed Wetland Studies

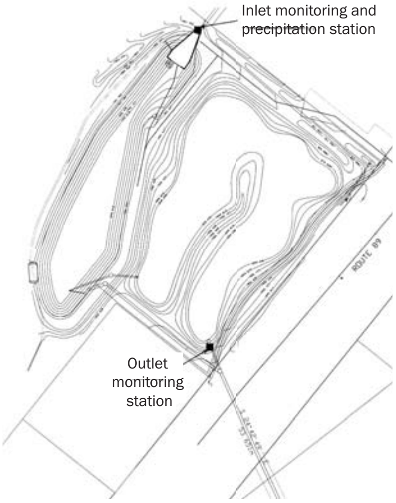
Constructed wetlands, wet retention basins, and natural meadows (herein collectively referred to as constructed wetlands) can retain pollutants by physical, chemical and biological mechanisms including soil/water interactions, particle settling, vegetation uptake and enhanced biogeochemical cycling. Unlike dry detention basins, constructed wetlands remain inundated for a much greater fraction of the year. Durations of standing water typically extend beyond discrete runoff events. The fraction of water loss via infiltration from a constructed wetland will be less than from a dry basin, due to higher localized shallow water tables, finer sediment grain size distribution at the base of the BMP, and reduced soil permeabilities. However, we can expect a greater loss due to evapotranspiration when the wetland is densely vegetated with wetland plants such as rush and cattail species.

Six monitoring studies have evaluated functional aspects of four constructed wetlands as BMPs that treat stormwater. Table 5 provides the general BMP specifics and Table 6 summarizes the specific monitoring details provided by the reviewed reports.

- Tahoe City Wetland Treatment System, Tahoe City, CA (TRG 2005).
- Village Green Pond, Incline Village, NV (SH+G 2003, 2NDNATURE 2005A)
- Edgewood Golf Course Ponds, Stateline, NV (DRI 2004A)
- Angora Meadow, South Lake Tahoe, CA (URS 2003, CWS 2005)

Tahoe City Wetland Treatment System, Tahoe City, CA (TRG 2005)

The Tahoe City Wetland Treatment System (TCWTS) accepts stormwater from a mixed, though primarily residential, land-use catchment. The wetland was constructed in 1997 to have an extended flow path and high surface area to storage volume ratio (see study site map to left). It appears to have been well sized for the contributing hydrology with well-established wetland vegetation. The TCWTS (TRG 2005) monitoring objective was to determine the effectiveness of a surface flow constructed wetland system for treatment of urban stormwater runoff at Lake Tahoe. The study included a local groundwater investigation to determine the amount of surface water lost from the wetland area to groundwater. It also assessed the associated impact of infiltration on the shallow groundwater quality during the same monitoring period (WY03). The evaluation included both automated surface water hydrology and sampling at the inlet and outlet of the wetland. In addition, there was monitoring of two upgradient and six downgradient monitoring wells and/or piezometers. The surface water and groundwater studies and reports are presented as two separate documents and will be reviewed independently.



TCWTS project site map (from TRG 2005)

BMP	Tahoe City Wetland	Village Green Pond	Edgewood Golf Course Ponds	Angora Meadow
BMP Type	Constructed wetland	Wet Basin	Wet Basin	Natural Meadow
Location	Tahoe City, CA	Incline Village, NV	Stateline, NV	South Lake Tahoe, CA
Year Constructed	1997	1998	2000	1998
Catchment Land Use	18% commercial 29% highway 35% residential	Fertilized recreational turf	Urban upper catchment, adjacent fertilized recreational turf	Residential
Catchment Area (acres)	56	5	77	400
% Catchment Impervious	80	0	N/P	N/P
Basin Storage Capacity (V) (ac-ft)	N/P	0.2	N/P	N/P
Basin Surface Area (SA) at Capacity (ft^2)	68,000	5,000	N/P	113,000
SA:V Ratio at Capacity	N/A	0.6	N/A	N/A
Maximum Basin Water Depth (ft)	N/P	1.8	N/P	N/P
Morphology Notes	Torturous maximized flow path	Oval in shape, maximized flow path	Very little information provided	Expansive meadow, maximized flow path, dissected by roadway

N/P: information not provided in project report.
N/A: information not available to make calculation.

BMP DETAILS OF CONSTRUCTED WETLANDS

TABLE 5

BMP	Tahoe City Wetland (TRG 2005)	Village Green Pond (SH+G 2003)	Village Green Pond (2NDNATURE 2005A)	Edgewood Golf Course Ponds (DRI 2004A)	Angora Meadow (URS 2003)	Angora Meadow (CWS 2005)
Key Study Goals	Surfacewater treatment and groundwater impacts	Land use pollutant loading Surface water treatment	Groundwater impacts and BMP management alternatives	Limited grab sampling of ponds	Surface water treatment and groundwater impacts	Meadow function as a nutrient filter
Monitoring Span	WY03	WY02	WY04-WY06 (ongoing)	WY04: Feb, Apr, May, July + Aug	WY00-WY03	2004 (assumed)
Surface Water Hydrology	Continuous inflow/outflow, basin topography	Continuous inflow, basin topography + water budget	Continuous inflow, basin topography + water budget	None for ponds, grab sampling	No hydrology reported, samples collected using automated instruments	N/A
# of Surface Water Events Monitored	24	11	ongoing	5	27	N/A
Surface Water Pollutant Metrics	EMCs, loads, concentrations	EMCs, loads, concentrations	EMCs, loads, concentrations	concentrations	concentrations	N/A
Pollutants of Concern	Surface: TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-,TSS groundwater: major ions, trace metals, TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-, TSS, Tu	TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-	Surface: TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-, chlorophyll groundwater: DP, SRP, DKN, NH_4^+, NO3	TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-, TSS, Tu	Primary: TN, TKN, TP Secondary: DP, SRP, NH_4^+, NO_3^-, TSS	Proxies for sediment deposition and nutrient dynamics. Sediment radioisotopes, plant N:P, sediment N: P, O_2 isotopes, particle size, etc.
# of Groundwater Monitoring Wells	8 (4 are piezometers)	N/A	10	N/A	8	Sampled existing wells
Groundwater Hydrodynamics	Continuous groundwater elevation + spot measurements	N/A	Continuous groundwater elevation + spot measurements	N/A	Spot measurements	None
Detail Groundwater Hydrology Analysis	Yes	N/A	To be provided	N/A	No	No
# of Groundwater Events Monitored for Water Quality	14	N/A	8 (to date)	N/A	8	1 (?)

N/A: not applicable

STUDY DETAILS OF CONSTRUCTED WETLANDS

TABLE 6

The surface water performance of the TCWTS was documented within the TRG (2005) report as, “Subalpine stormwater treatment with a constructed surface-flow wetland” (TRG 2004). This BMP performance evaluation is well designed and documented, expressing performance as EMC and pollutant load reductions, as well as annual mass retention estimates. These results were recently published in the Journal of American Water Resources (Heyvaert, Reuter & Goldman 2006). The findings are compared to other findings on wetland nutrient removal performance, illustrating the TCWTS performs within the limits of other similar systems. The wetland was heavily monitored (24 events) at the inlet and outlet during WY03. The results represent the seasonal hydrologic water quality variations at the site. Sediment loading to the wetland was reported to be relatively low. This is attributed to responsible source control measures in the catchment. The wetland further reduced TSS effluent concentrations to levels consistently below 20 mg/L. The findings from the monitoring indicate consistent and significant reductions in N-species, particularly nitrate, due to accelerated N-cycling in a vegetated wetland environment. This occurred even though nitrate effluent concentrations remained higher than ammonium. Organic nitrogen (TKN) is more difficult to consistently remove because of the high rates of organic production in a wetland environment. Of particular note are the substantial reductions of SRP and DP EMCs, 57% to 66%. Effluent EMCs typically remained below 40 and 60 ug/L, respectively. The WY03 monitoring suggests the TCWTS is having a positive impact on nutrient and sediment retention of local stormwater. Continued performance monitoring was recommended as this relatively young wetland continues to mature.

The groundwater investigation is presented within the TRG (2005) report as a document entitled, “Groundwater hydraulics and chemistry at the Tahoe City Wetland Treatment System” (TRG 2005B). The objectives of the groundwater study are to investigate the amount of surface water loss from the wetland area to the groundwater and assess the water quality impact of infiltration on the shallow groundwater. The organization and density of the report is difficult to follow and limits the readers’ ability to extract information that addresses the objectives of the study.

Water quality sampling of the groundwater was conducted on 14 separate occasions during WY03. The groundwater nutrient chemistry is compared above and below wetland influence in table format, but the nutrient data in the monitoring wells are significantly higher than the values found in the shallower piezometers. The piezometers are documented to be screened at depths of 4-6’ below ground surface. However, no specific details of the monitoring well and piezometer depths and screen intervals are explicitly provided. We suspect their vertical sampling locations are very different. Additional efforts to improve data presentation and communications may expand the hydrodynamic understanding and comparability of this valuable groundwater hydrologic and chemistry data set.

The groundwater findings presented by the researchers were found in the executive summary of the two documents. The summary of findings included:

- Estimates of annual infiltration suggest 3% of the annual flow is lost to infiltration.
- Nitrate concentrations are significantly lower beneath the wetland relative to upgradient groundwater and ammonium is nearly 500% greater. This is typical of shallow groundwater conditions beneath a dense organic carbon source that creates a reducing geochemical environment (i.e., vegetated wetland).
- In comparison to the upgradient conditions, dissolved phosphorous and SRP groundwater values were lower in the locations influenced by the wetland.

Village Green Pond, Incline Village, NV (SH+G 2003, 2NDNATURE 2005A)

Monitoring of Village Green Pond began in 2002 as one of the three sites included in the SH+G 2003 study. Village Green Pond (VGP) was constructed in 1998 in order to capture and treat tile drain effluent from the upgradient irrigated Village Green Ballfields. Its construction was a component of the lower Incline Creek restoration project. The basin is oval in shape and its morphology is relatively homogeneous. Due to turf management and irrigation, VGP is inundated throughout the dry months of the year. Continuous inflow hydrology and water sampling were coupled with a surface water budget and grab water sampling from the pond to evaluate the effectiveness of VGP at reducing nutrients in irrigation tail waters.

Village Green Pond in Fall 2004

Monitoring completed for the SH+G 2003 evaluation focused primarily on irrigation runoff and included data from only one storm runoff event. During the summer months, the pond storage capacity is not exceeded by irrigation effluent, deeming the pond 100% effective by surface water mass balance standards. Inflow monitoring indicated that SRP and DP concentrations loaded to the pond were nearly two orders of magnitude higher than levels observed at inlet monitoring at residential and commercial BMP sites. Accelerated biogeochemical cycling in the eutrophic VGP resulted in nearly complete removal of nitrate concentrations by denitrification. This also increased the biologically available forms of P. Anaerobic conditions facilitate the release of P adsorbed to hydroxide compounds, further increasing the standing soluble P concentrations in the pond to 1 mg/L SRP. As reported with TCWTS, ammonia was the primary dissolved nitrogen species. This is a result of high rates of bacterial respiration mineralizing NH_4^+ and reducing nitrate by denitrification in eutrophic systems (see Figure 3). During the first rain event in October 2002, the pond capacity was exceeded for the first time since monitoring began in April 2002. The P-enriched surface water was transported downstream to the adjacent Incline Creek. No further monitoring was

Village Green Pond in Spring 2002
Incline Village, NV

conducted in accordance with this specific study. This study provides an ideal example of the necessity to evaluate a BMP in all climatic and runoff conditions, properly representing the inherent annual variability.

In 2004, 2NDNATURE and the Nevada Tahoe Conservation District (NTCD) expanded the preliminary surface water investigation at VGP to include groundwater monitoring and extended the evaluations of this BMP performance to include all seasons (2NDNATURE 2005A). The current phase of the study includes the evaluation of a number of alternative turf management strategies, including the elimination of phosphorous containing fertilizers, reuse of tile-drain effluent stored in VGP, and pond vegetation management. The Village Green Pond Pilot Monitoring Project, Phase II, is scheduled for completion in early 2007.

Edgewood Golf Course Ponds, Stateline, NV
(DRI 2004A)

The Stateline Stormwater Project (DRI 2004A) evaluated the effectiveness of the mechanical and natural treatment systems to remove biologically available nutrients from stormwater that is generated in the casino core of Stateline, Nevada. The mechanical treatment consists primarily of a two Vortechnics vaults located several feet beneath the Horizon Casino parking lot (the details of which are discussed below in the mechanical treatment section). The effluent from the vault system is routed to a series of open water constructed ponds within the Edgewood Golf Course, eventually reaching the Lake. While the pond sampling was not the focus of the study, the authors used the nutrient concentrations from five independent surface water grab samples to create graphics that show a steady decline in the surface water nutrient concentrations progressing downstream from the vault system through the series of wetland ponds. From these graphics, they conclude that the ponds increased and maximized nutrient treatment as the stormwater moved through these wet basins. Many problems exist with these conclusions including additional surface water sources to the ponds, the potential for vertical variations of nutrient constituents in wet basins, the lack of any simultaneous water budget or flow measurements, and the limitation of the sampling to the dry summer months (with one February sampling exception).

Angora Meadow (Natural Meadow), South Lake Tahoe, CA
(URS 2003, CWS 2005)

Stormwater in an residential catchment was routed to Angora Meadow in 1998 during infrastructure improvements. The Meadow was hoped to provide a water quality improvement to the stormwater, including nutrient removal and capture of soil and sand abrasives applied to roads during de-icing efforts. The meadow surface area at capacity is approximately 113,000 ft^2 with a predominant flow path of over 650 ft and contains well established vegetation. Angora Meadow is unique from the typical “wetland” in that it is an open relatively dry area with a more repressed

Typical automated flowmeter, sampler and housing used in Lake Tahoe.

groundwater table than a typical wetland BMP. Angora Meadow was an existing open meadow to which stormwater has been routed as residential development increased in the surrounding areas. The WY00-WY03 monitoring was established to evaluate the effectiveness of the meadow at reducing stormwater nutrient loads (URS 2003). Five automated sampling stations were installed and operated at the site. Many problems with the data collection efforts were encountered, including the lack of a detailed monitoring plan at the onset of the study. Eight groundwater wells were also installed throughout the study area.

The final URS report (2003) focuses on the total nitrogen and total phosphorous sample concentrations observed in surface water and groundwater samples. No surface water hydrology is presented in the report and the evaluation of the hydrogeology is minimal. This study is a good example of the need for research teams to establish a clear and detailed sampling plan that outlines the objectives of the study and logistics of data collection. There should be a peer-review process by scientists to ensure the monitoring design is cost effective and will collect data that directly addresses the study objectives and coincides with the BMP design. While the study and report suffered from a lack of structure, there did appear to be a large amount of sampling and data collection that occurred at Angora Meadows over the study period. This system is unique compared to other wetlands studies in Tahoe and some comparative water quality information from the Angora monitoring may still be gained from the existing data.

Based upon the inadequacies of the URS study as reviewed by Johnson (John Muir Institute 2003) and the author's recommendations for improved monitoring, additional funding was provided to evaluate sediment deposition rates, the N:P ratios of the resident plants in comparison to the surface sediment N:P ratios, and particle size distribution evaluations to infer surface water/groundwater interactions. These findings are summarized in the CWS 2005 report.

Johnson and Iversen (CWS 2005) provide an interesting application of analytical and scientific methods by using proxies to evaluate the potential for Angora Meadows to filter/uptake/retain nutrients. Integrating academics into Lake Tahoe research questions should be encouraged because they can answer specific scientific process questions. This academic exercise included radioactive lead (^{210}Pb) and cesium (^{137}Cs) isotopic analyses of meadow sediments to infer average annual sediment deposition rates in the upper and lower meadows. The dating techniques allow the determination of absolute dates of particular sediment layers due to their isotopic composition, particularly the layers that correspond to 1954 (no Cs content) and 1963 (peak Cs content). Annual deposition rates can then be calculated based on the depth of deposition over the constrained time periods. The authors find a greater average annual sediment deposition in the lower meadow, relative to the upper meadow, for the time period from 1964-2005. This seems somewhat counterintuitive since the URS

(2004) report states that the upper meadow receives a significant amount of road abrasives from the contributing watershed, and the bulk of water, sediments and nutrients appear to be routed from the upper to the lower watershed based on provided site maps by URS (2003). The particle analysis did determine that there is a greater fraction of sand (85%) in the upper meadow than in the lower meadow (70%). These findings seem consistent with the upper meadow acting as a sand trap for road abrasives and grain sizes decreasing as they are transported along the meadow flow path.

The N:P (nitrogen: phosphorous) ratios of collected plant material were compared to the N:P ratios of the surface soils to infer vegetation nutrient limitations. As with most meadow environments, the Angora soil and vegetation is N-limited, although compared to other meadow environments Angora is reported to possess a greater N depletion. This N depletion is also attributed to the relative fraction of coarser surface sediments than most meadow environments.

Brief comparisons of snow and shallow groundwater nutrient concentrations are used to conclude that the meadow is leaching nutrients. However this conclusion does not appear to be substantiated from the data provided. Groundwater concentrations, especially of an unfiltered TKN sample collected from the subsurface, would always be expected to be lower than surface water TKN values sample due to the natural filtering capacity of the subsurface and regional groundwater dilution. The other dissolved nutrient comparisons provided between surface water and groundwater appear at the detection limit and do not reflect a difference (Figure 10 in CWS 2005). The dynamic and complex nature of the subsurface requires an extended temporal and spatial monitoring design to begin to evaluate surface water/groundwater interactions as a result of various BMP structures.

The authors suggest flows through the meadow preferentially remove fine particles from the surface due to the hydrologic configuration of the meadow, but chronic delivery of road abrasives from the surrounding watershed could also contribute to the relatively coarse sediment layer observed on the surface of Angora Meadow. The authors recommend hydrologic and physical modifications to the system to increase hydraulic retention times and connectivity of the upper and lower meadows, both of which may improve the physical, chemical and biological function of the system.

Quantitative Performance of Constructed Wetlands

Table 7 provides the inflow EMC concentrations and EMC % reduction comparisons for the relevant wetland and wet basin effectiveness studies. The two primary sites that have relevant data to discuss treatment capability are the Tahoe City Wetland and Village Green Pond, though

Angora Meadow values, where available, were included for comparison. The key pollutants of concern for wetlands are dissolved nutrients, since it is assumed that biological processes in wetland and wet basin environments will provide greater treatment of these pollutants. Comparison of the EMC % reductions between Table 4 (detention basins) and Table 7 below support this assumption.

In regards to inflowing concentrations, Village Green Pond has the highest reported inflowing EMC values for all nutrient constituents except for NOx, due to the contributing land use of a fertilized field. Treatment of N species at both the wetland and wet basin was reported to be consistent. Biologically available P treatment at Village Green Pond was reported to yield an average 40% EMC reduction, but the effluent EMC concentrations from Village Green Pond (> 400 ug/L, Appendix C) remained at least two times the inflow SRP levels observed at the Tahoe City Wetland. P retention and burial can be improved by preventing anoxic conditions in these inundated, poorly circulating, BMP structures. Regardless, some form of maintenance is required to ensure water retention capacity and treatment capacity is maximized in a wet basin and/or constructed wetland.

Tahoe Meadows during Winter 2006, South Lake Tahoe, CA

Table 7. Constructed wetland, wet basin and natural meadow quantitative comparisons of average study inflow concentrations and reported EMC % reductions for the relevant studies. The sites are ranked in descending order by the constituents in red for each table. Details of values provided can be found in Appendix C.

INFLOW N SPECIES CONCENTRATION (ug/L)	TN	TKN	NOx	NH_4^+
Tahoe City Wetland (TRG 2005)	1966	1214	722	47
Village Green Pond (SH+G 2003)	6604	6404	200	468
Angora Meadow (URS 2003)	954	796	Y	Y
INFLOW P SPECIES CONCENTRATION (ug/L)	TP	PP	DP	SRP
Village Green Pond (SH+G 2003)	1433	607	826	730
Tahoe City Wetland (TRG 2005)	542	X	139	112
Angora Meadow (URS 2003)	230	Y	Y	Y
INFLOW TSS SPECIES CONCENTRATION (ug/L)	TSS			
Tahoe City Wetland (TRG 2005)	120			
Village Green Pond (SH+G 2003)	X			
Angora Meadow (URS 2003)	Y			

N SPECIES % EMC REDUCTION	TN	TKN	NOx	NH_4^+
Village Green Pond (SH+G 2003)	49	47	96	93
Tahoe City Wetland (TRG 2005)	49	28	84	43
Angora Meadow (URS 2003)	33	24	NP	NP
P SPECIES % EMC REDUCTION	TP	PP	DP	SRP
Tahoe City Wetland (TRG 2005)	63	Y	57	66
Village Green Pond (SH+G 2003)	44	59	32	37
Angora Meadow (URS 2003)	77	NP	NP	NP
TSS SPECIES % EMC REDUCTION	TSS			
Tahoe City Wetland (TRG 2005)	74			
Village Green Pond (SH+G 2003)	X			
Angora Meadow (URS 2003)	NP			

Y: Metric not provided in the report, but could be calculated if additional data analysis were performed.

X: Metric justifiably not provided in the report because it was not the purpose of the investigations.

Mechanical Treatment Structure Evaluations

Mechanical stormwater treatment systems consist of engineered flow through structures. Depending on the target pollutant, these engineered treatment structures are designed along a range of stormwater detention durations. Systems that treat coarser materials (debris and coarse sediment) preferentially settle and trap particles and debris in runoff with little storm volume retention. As the target pollutants become smaller, hydrodynamic and volumetric separation in large subsurface vault structures can capture and treat large volumes of silt, sand and associated particulate pollutants. Systems have also been designed to provide stormwater filtration through an active media flow-through system that can reduce the dissolved stormwater loads of charged compounds and hydrophobic compounds, as well as particulates. Vaults provide advantages over natural detention/retention systems in urban areas. A relatively small footprint and frequent below-ground installation eliminate surface area coverage issues. When properly maintained, these systems can be effective at removing particles, debris and sediment, although there still remains some question of their ability to remove the key pollutants affecting Lake Tahoe clarity (nutrients and fine inorganic particles). Only two of the mechanical treatment structures evaluated for this synthesis is designed to reduce stormwater volumes by infiltration.

Lake Tahoe has installed a variety of mechanical BMP stormwater treatment alternatives. According to the WQPI, 74 treatment vaults and 482 sediment traps have been installed in the Basin. Eight specific systems have been evaluated by researchers and reviewed as part of the BMP Synthesis. Tables 8 and 9 provide specific information on the mechanical treatment BMPs and their monitoring.

- CDS Stormwater Vault, Zephyr Cove, NV (DRI & TERC 2005)
- Vortechnics Vault, Zephyr Cove, NV (DRI & TERC 2005)
- Jensen Vault, Zephyr Cove, NV (DRI & TERC 2005)
- Stormceptor®, Highway 28 near Secret Harbor, NV (site NDOT4) (DRI 2004B)
- Sediment Trap, Highway 28 near Secret Harbor, NV (site NDOT2), (DRI 2004B)
- Sediment Basin, Highway 50 near Spooner Summit, NV (Site NDOT3), (DRI 2004B)
- StormFilter® Vault, South Lake Tahoe, CA (2NDNATURE 2005C)
- Vortechnics Vault, Stateline, NV (DRI 2004A)
- Infiltration Chamber Series, El Dorado County, CA (EDCDOT 2004, EDCDOT 2005)

BMP	CDS Vault	Vortechnics Vault	Jensen Vault	Stormceptor® STC 900	Sediment Trap	Sediment Basin	StormFilter® Vault	Vortechnics Vault	Infiltration Chamber Series
Location	Roundhill GID, Zephyr Cove, NV	Roundhill GID, Zephyr Cove, NV	Roundhill GID, Zephyr Cove, NV	Hwy 28 near Secret Harbor, NV	Hwy 28 near Secret Harbor, NV	Hwy 50 near Spooner Summit, NV	Ski Run Marina parking lot, South Lake Tahoe, CA	Horizon parking lot, Stateline, NV	Woodland ECP project, El Dorado County, CA
Year Constructed	Post-2001	Post-2001	Post-2001	Post-1997	Post-1997	Post-1997	2001	N/P	2003
Catchment Land Use	Low density residential	Low density residential	Unimproved and residential road	Rural highway	Rural highway	Rural highway	Parking lot, commercial	Commercial, dense urban	Residential
Catchment Area (acres)	N/P, difficult to quantify	N/P, difficult to quantify	N/P, difficult to quantify	0.24	0.37	0.72	N/P	77	N/P
% Catchment Impervious	N/P	N/P	N/P	100	100	100	Assumed 100%	N/P	N/P
BMP Storage Capacity (ft^3)	380	450	N/P	127 (water) 75 (sediment)	110*	413	N/P	4300 (2 vaults at 2150 each)	N/P
BMP Structure Description	Flow separation system to trap sediment and debris	Flow separation system to trap sediment and debris	Flow separation system to trap sediment and debris	Flow separation system to trap sediment and debris	Flow through system to capture sediment and debris	Sediment capture, stormwater infiltration system	Active media stormwater filtration system	Flow separation system to trap sediment and debris	Stormwater capture and infiltration device

N/P: information not provided in report
* Estimated from site map provided

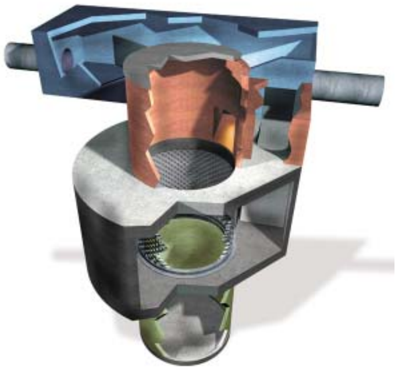
BMP	CDS Vault (DRI & TERC 2005)	Vortechnics Vault (DRI & TERC 2005)	Jensen Vault (DRI & TERC 2005)	Stormceptor® STC 900 (DRI 2004B)	Sediment Trap (DRI 2004B)	Sediment Basin (DRI 2004B)	StormFilter® (2NDNATURE 2005C)	Vortechnic Vault (DRI 2004A)
Monitoring Span	WY03-WY04	WY03-WY04	Jan-Oct 04	WY03	Nov 02-Apr 04	WY03	Nov 01-Jan04	WY03-WY04
Surface Water Hydrology	Continuous via flume (automated samplers at inflow/outflow)	Continuous via flume (automated samplers at inflow/outflow)	Continuous via area velocity (automated samplers at inflow/outflow)	Continuous via flume (automated samplers at inflow/outflow)	Continuous via flume (automated samplers at inflow/outflow)	Continuous (complications)	Continuous via area velocity (automated samplers at inflow/outflow)	Continuous via area velocity (automated samplers at inflow/outflow)
# of Surface Water Events Monitored	19	15	8	16	18	6	10	29
Surface Water Pollutant Metrics	EMCs, loads (including captured material), concentrations	EMCs, loads (including captured material), concentrations	EMCs, loads, concentrations	EMCs, loads, concentrations	EMCs, loads, concentrations	concentrations	Loads, average concentrations	Event loads, concentrations
Pollutants of Concern	TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-, TSS	TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-, TSS	TP, DP, SRP, TN, TKN, NH_4^+, NO_3^-, TSS	TP, DP, SRP, TKN, DKN, NOx, TSS, Tu (NH_4^+ and NO_2^- low on first sampling, so not monitored)	TP, DP, SRP, TKN, DKN, NOx, TSS, Tu (NH_4^+ and NO_2^- low on first sampling, so not monitored)	TP, TN, TSS (NH_4^+ and NO_2^- low on first sampling, so not monitored)	TP, DP, TKN, TSS, Fe (SRP, NOx, NH_4^+ samples not filtered)	TP, DP, SRP, TN, TKN, NH_4^+, NO3, TSS, Tu, Conductivity, Temperature
# of Groundwater Monitoring Wells	2 downgradient of vault effluent		N/A	N/A	N/A	N/A	N/A	N/A
Groundwater Hydrodynamics	Continuous water level in one well		N/A	N/A	N/A	N/A	N/A	N/A
Detail Groundwater Hydrology Analysis	None		N/A	N/A	N/A	N/A	N/A	N/A
# of Groundwater Events Monitored for Water Quality	12 (MW-1), 8 (MW-2)		N/A	N/A	N/A	N/A	N/A	N/A

N/A: not applicable

TABLE 9

STUDY DETAILS OF MECHANICAL TREATMENT STRUCTURES

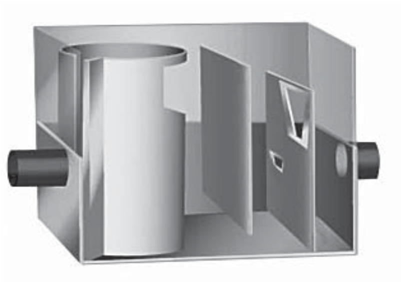
CDS Stormwater Vault, Vortechnics Vault, Jensen Vault (DRI & TERC 2005)



CDS Vault Schematic
(www.stormwater.com)

The Stormwater Vault Evaluation at Roundhill GID was a cooperative effort between TERC and DRI. Two proprietary stormwater vaults (CDS and Vortechnics) were constructed side-by-side downgradient of a low-density residential community. Through flow separation techniques, both systems provide capture of debris and particles in stormwater (see schematics at left). A third Jensen vault was installed to treat roadway and undeveloped land. The purpose of the evaluations was to "provide data on the effectiveness of hydrodynamic treatment vaults in general at removing nutrients and sediment from stormwater runoff" in a residential drainage. The majority of the study focuses upon the CDS and Vortechnics systems, with information on the Jensen Vault limited to an EMC inflow/outflow evaluation in WY04. The exact catchment land use designation of each vault was difficult for the researchers to determine, due to a lack of detailed hydrologic routing information.

The monitoring design and sampling techniques appropriately address the objectives of the study for the CDS and Vortechnics vault structures. Automated outflow hydrology and inflow/outflow water sampling were conducted at the vault structures over WY03 and WY04. Due to infiltration of the effluent from the vault structures, groundwater nutrient characteristics were evaluated downgradient of the outlets of the CDS and Vortechnics sites. A number of instrument limitations were documented. These limitations include sediment burial of sensors, inability of samplers to physically pull coarser material from stormwater, and difficulties of sampling and monitoring very small water depths during low flow conditions. The researchers circumvented some of the sampling issues by quantifying the mass and characteristics of the material trapped by the CDS and Vortechnics vaults and including these values in the performance evaluations.



Vortechnics Vault Schematic
(www.vortechnics.com)

Due to continuous hydrology records, the researchers are able to estimate the fraction of the annual discharge volume represented by the monitoring each year, approximately 25% for WY03 and 50% of WY04. These estimates can be extremely useful when extrapolating the findings to seasonal and annual performance values. These vault structures were typically found to be successful at retaining high fractions of event sediment loads and reducing TSS EMCs, though some exceptional events were observed.

While the vault effluent continually met surface water discharge standards, the inflow nutrient concentrations were in compliance prior to vault treatment. Using the observations of mass of pollutants retained in the vault and the amount lost from the vault (mass of constituent in vault / (mass of constituent in vault + mass of constituent monitored in outflow) the researchers suggest the vaults retained 23 to 75% of TN and 7 to 18 % of TP. The specific event performance of both the CDS and the Vortechnics dissolved and total N and P species was extremely variable. Following vault treatment, many events displayed significant increases in nitrate and ammonium loads and EMCs.

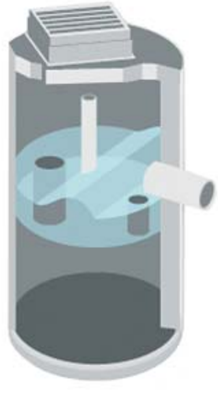
Dissolved P retention was reported to be slightly more consistent than reported for dissolved N species. This was attributed to the attraction and potential for P adsorption onto particle surfaces contained within the vaults. These results agree with other recent studies in the Basin and indicate that biologic activity within stormwater vaults is a likely contributor to the occasionally increased nitrogen loads released from organic material trapped and decomposing within these vault structures.

Porous soils present at the outlet of the vaults were observed to rapidly infiltrate the treated stormwater. Nutrient groundwater quality monitoring was conducted at two monitoring wells located downgradient of the vault effluent to investigate potential shallow groundwater impacts. While dissolved nutrient concentrations in the groundwater are observed to be significantly lower than vault effluent concentrations, the lack of an upgradient groundwater sampling point control limits the applicability of these findings.

The authors appropriately recommend that future vault performance assessments include quantification of the pollutant mass accumulation contained within the vault structure. This will provide more accurate estimates of treatment capability. The need for consistent and routine maintenance of these vault systems is continually discussed. Diligent maintenance will provide the best possible improvements to effluent stormwater. The continued release of dissolved nutrients from these vaults further substantiates the water quality benefit of routine material removal prior to subsequent runoff events.

Stormceptor® and Sediment Trap near Secret Harbor, NV and Sediment Basin near Spooner Summit, NV (DRI 2004B)

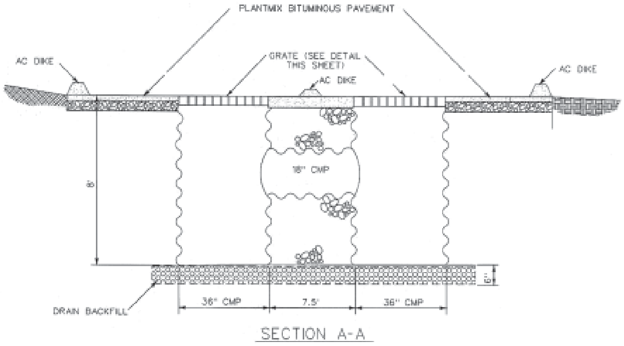
The primary objective of the DRI (2004B) study was to determine and compare the effectiveness of a sediment trap, sediment basin and a Stormceptor® unit. These devices are designed to remove pollutants and suspended sediments from stormwater roadway runoff. The study report provides a very useful literature review and summary of BMP types, assumed stormwater treatment function, and feasibility of roadside BMP applications. However, site nomenclature was inconsistent throughout the report, confusing the reader as to which BMP was associated with which NDOT site.



Stormceptor® schematic (www.stormceptor.com)

A Stormceptor® is a typical mechanical BMP designed to settle and trap particles and debris while occupying a relatively small surface area, ideal for roadside applications. Automated sampling at the Stormceptor® inlet and outlet was conducted. Outlet flow was monitored using a flume-stage system. Sixteen storms over a two-year period were used to calculate inflow and outflow of total nutrients, dissolved nutrients and solid loads observed over the monitoring efforts. Load reductions for all constituents were greater than 20% with NOx displaying a total load reduction of 65% and SRP a reduction of 51%. The authors utilized calculations of P values to determine if the differences between the inflow and outflow loads were statistically significant to the 95% percentile confidence limit. All of the dissolved and total nutrients, as well as solid load difference in the inflow and outflow at the Stormceptor® site, were deemed statistically significant. The authors were surprised at the findings that the Stormceptor® consistently treated dissolved nutrients and suggest additional evaluations may be necessary to validate these findings. One useful exercise may be to compare the influent and effluent concentrations and total annual dissolved nutrient loads at these NDOT roadway sites to other vaults monitored in the Lake Tahoe Basin that accept different land use runoff. The total study NOx and SRP load retentions in the Stormceptor® were only 19 and 5 grams, respectively. Other vault monitoring studies reviewed are reporting hundreds of grams of NOx and SRP transported for independent events.

A sediment trap is a cost-effective, low-tech mechanical BMP that utilizes the same physical debris and particle trapping technique. However it lacks the engineering sophistication and flow separation of prefabricated models. A typical roadside sediment trap is a simple design, consisting of two or more 36-inch diameter corrugated metal pipes (CMP) placed vertically in the ground to depths of eight feet. Trash grates are placed on the top. The vertical pipes are placed in series along the direction of surface water flow and connected by a horizontal 18” CMP near the top. Heavy debris and particles will be trapped at the base as cleaner surface water continues downgradient (see schematic below). The sediment trap performance monitoring consisted of automated inflow and outflow stormwater sampling and continuous hydrology to facilitate EMC and event load comparisons to estimate the sediment and nutrient removal efficiency.



Sediment trap schematic from DRI 2004B

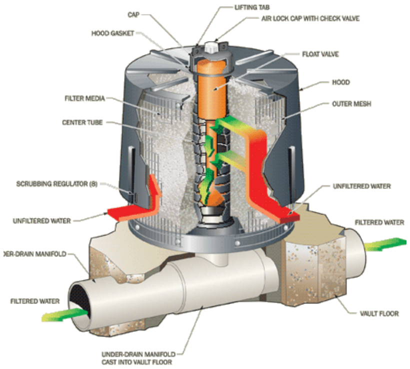
The sediment trap proved less effective at dissolved N species than the Stormceptor®. Over the duration of the study the trap appeared to be a net source of DKN, NOx and DP. While total study mass load reductions were observed for nearly all other nutrient species and solids, none of the influent/effluent differences proved statistically significant at the 95% confidence interval. The authors report a negative efficiency of at least one constituent was observed over the 13 events monitored, including a net increase in TSS mass load during six out of the 13 storms. The sediment trap effluent discharges into Secret Harbor Creek. Water quality evaluations in Secret Harbor Creek were performed upstream and downstream of the sediment trap, though the information gained from this monitoring appears to be minimal. The lack of sediment trap cleaning was extensively discussed and the poor observed performance of this BMP is assumed to improve only with regular maintenance between storms. To evaluate the true potential function of a sediment trap for roadside applications, performance evaluations of these simple, cost-effective sediment capture systems should be done in concert with diligent maintenance.

DRI (2004B) also investigated a small, roadside sediment basin located on Highway 50 near Spooner Summit. A roadside sediment basin is constructed with interlocking open-celled concrete blocks resulting in approximately 20% open surface area. This area allows for some vegetation development and infiltration of stormwater. Numerous monitoring complications were reported at the sediment basin by the researchers, including the initial improper construction of the structure that allowed water to exit through the overflow path rather than the designed outlet. The authors conclude that the sediment basin is the most effective of the three structures (sediment basin, sediment trap and Stormceptor®). Once properly constructed, little to no outflow was observed at the sediment basin, providing complete pollutant and stormwater reductions. There were a number of inherent problems with the monitoring of this particular BMP, the majority of which appear to be out of the control of the researchers. A true assessment of the treatment performance is somewhat limited.

The authors also provide a simple cost comparison between the sediment trap and Stormceptor®. The comparison includes percent of each pollutant reduced per year, illustrating the greater cost of a Stormceptor® system over less high tech alternatives, even when the performance of the Stormceptor® appeared superior to the other systems. It may be cost-effective to quantify the performance of a well maintained sediment trap prior to purchasing and installing a number of Stormceptors® in rural roadside applications.

StormFilter® Vault, South Lake Tahoe, CA (2NDNATURE 2005C)

A StormFilter® Vault was installed in the Ski Run Marina parking lot in 2001. The StormFilter® is a passive, flow-through stormwater filtration system that contains rechargeable cartridges filled with a variety of filter media housed within a concrete vault (see illustration at left). Particulate and dissolved pollutants are assumed to be retained within the filtered cartridges, thus reducing the effluent nutrient and sediment loads to the receiving waters. The monitoring design was created and implemented by the City of South Lake Tahoe (CSLT). It included automated inflow and outflow hydrologic and water sample collection. The monitoring goal was to quantify the nutrient, fine sediment and iron retention capability of the treatment structure. At the completion of the data collection, 2NDNATURE was provided the digital hydrology and laboratory water quality results to document and summarize the findings of the monitoring efforts. Limited resources were available to conduct an extensive BMP analysis and data interpretation.



StormFilter® media cartridge
www.contechstormwater.com

A total of ten events were successfully monitored at the inlet and outlet over a 2.5-year period. While the structure is designed to filter the majority of introduced/detained water, the system is supposed to eventually drain between each event after filtration has been accomplished. Based on inflow and outflow volume comparisons, the StormFilter® system at Ski Run Marina was estimated to retain an average of 25% of each storm event volume. Visual observations confirmed some retention of stormwater at the base of the vault between storms. Difficulties of monitoring chronic low flows at the outlet (i.e. water depths < 2”) were considered another possible reason for measured volume differences.

During this monitoring, 151 samples were collected. However, due to miscommunications with the laboratory, samples submitted for typically dissolved nutrient species (nitrate, ammonia and SRP) were not filtered prior to analysis (see Figures 1 and 2). Unfortunately, while inflow and outflow comparisons were made for a performance evaluation for this particular study, these data are not applicable if compared to other nitrate, ammonia or SRP data in the Basin because of sample handling discrepancies.

StormFilter® vault construction at Ski Run Marina in 2001

Another lesson is learned regarding the implementation of similar systems. The construction of the concrete vault and securing of the filtration system created a significant amount of dust and debris that remained within the vault system until the first storm event. The lack of manual flushing and effluent capture of the newly constructed system marked the first two events with significantly elevated TSS effluent loads relative to the inflow.

Similar to other mechanical systems, once properly conditioned the StormFilter® produced consistent and significant reductions in pollutants associated with particles, TSS, TKN, TP, Fe and PP. Retention and removal of total nitrate, total ammonia and total SRP were more variable across the events monitored, but average and total load reductions were reported to be net reductions. The only true dissolved constituent evaluated for this study, DP, displayed the poorest performance with a net pollutant load reduction of 12%. This is less than half of the potential pollutant reduction explained by the event inflow and outflow event volume differences alone (25%). Seasonal and/or annual maintenance of the vault and flushing of the filter media may improve the vault pollutant retention performance. Opportunities exist to augment the filters contained in the StormFilter® with alternative adsorptive media that are expected to have a greater ability to retain phosphorous species and fine inorganic particles. Such an augmentation would allow a controlled in-situ performance investigation of alternative media to treat the target Lake Tahoe pollutants (see Bachand/TRG 2005).

Vortechnics Vault, Stateline, NV (DRI 2004A)

The Stateline Stormwater Project monitored inflow and outflow of a Vortechnics vault to evaluate its effectiveness at removing biologically available nutrients from stormwater generated in the casino core of Stateline, Nevada. The vault effluent is routed to a series of wetland ponds on the Edgewood Golf Course that provide a treatment train approach. The pond monitoring is described above in the constructed wetlands section. The report fails to provide units of measure in some graphics, tables and discussions. The study also uses multiple units to express discharge. This is another example of how consistency of reporting wherever possible will improve the reader's ability to evaluate results.

The vault inflow and outflow were monitored utilizing automated instrumentation for hydrology and event based water sampling for 25 discrete events over a non-consecutive 15-month monitoring period. However, as many as six days are reported to contain more than one discrete event. The pollutant dynamics may be better served by the TERC designation that an event is defined when no water is observed at the inflow for a 24-hr period (TERC 2005). Instrumentation facilitated time series graphics of conductivity, temperature and turbidity, but this data is not used to assess performance and the specific location of the data collection (vault inflow or outflow) is not provided. The authors report a number of difficulties and complications with the automated monitoring efforts, including unexplained malfunction, sample line freezing, and high sedimentation rates that bury sensors.

The total event loads were calculated at the inlet and outlet for each event and percent removal values were calculated. TSS was the most effectively reduced by the system (46% reduction) followed by TKN, TP and a 23% reduction in ammonia. The study documented a 34% increase in NOx and 9% increase in SRP in the outflow relative to the inflow. An increase in nitrate is curious, as ammonia would be expected to be the dissolved N-species released from decomposing material contained in the vaults between storms. Ammonia can be oxidized to nitrate in the presence of oxygen, thus suggesting the material retained in the vault is oxic as a result of the reported perennial flow.

Infiltration Chamber System, El Dorado County, CA (EDCDOT 2004, EDCDOT 2005)

The El Dorado County DOT provided a BMP maintenance monitoring of an infiltrating culvert system constructed in the Woodland and Lonely Gulch portion of the Woodland/Tamarack/Lonely Gulch ECP project. In-situ continuous water level data in the chambers was used to determine if infiltration was diminished at the site due to capture of fine particles in the structures. Water levels in the infiltration chambers appear to rapidly recede following the few runoff events presented in the report and visual observations indicate no debris or sediment build up. The water depth in the monitored infiltration chambers never exceeded 4 ft, which is the critical elevation to result in surface water outflow from the chamber. No comparisons were made to determine if infiltration rates had changed over the period of observation to address the question of reduced infiltration capacity. Rather maximum function was assumed due to lack of overflow. Additional monitoring objectives included "sediment particle size of material retrieved from the BMP, the fate of nutrients, the fate of sediment, and determine the sediment capture rate." The lack of material captured in the infiltration basins prevented the sediment and nutrient evaluations.

Quantitative Mechanical Structure Comparisons

Table 10 provides the inflow and EMC % reduction comparisons for the relevant mechanical structure effectiveness studies. The average study nitrate values introduced to the mechanical vault structures ranged from 100 to 300 ug/L, levels that could be considered moderate in comparison to inflow concentrations observed at Coon Street Detention Basin and TCTWS (> 700 ug/L). As discussed by the researchers, consistently poor performance was observed with respect to nitrate treatment, with EMC % reduction values (Table 10) ranging from -15 to -77 % removal (i.e. outflow increase). The one exception being the findings at the Highway 50 Stormceptor® monitored by DRI (2004B), though the researchers question these findings. SRP levels observed at these urban, residential and roadway sites appear consistent with concentrations inflowing to detention basins and wetlands (Village Green Pond as the exception) and none of the structures reported an EMC reduction beyond 15%, again with the Stormceptor® (DRI 2004B) being the exception. TSS inflow concentrations are relatively elevated compared to other land uses and an overall variable capability to trap particulates was observed. Since these systems are designed specifically to trap particulate pollutants, further studies following proper maintenance of these structures may be warranted. Unfortunately, PP was not a pollutant of concern for most mechanical structure researchers to provide more information on the particulate removal performance of these physical systems. PP should be calculated for future mechanical treatment structure evaluations.

Table 10. Mechanical structure quantitative comparisons of average study inflow concentrations and reported EMC % reductions for the relevant studies. The sites are ranked in descending order by the constituents in red for each table. Details of values provided are given in Appendix C. Note: The Stormceptor® (DRI 2004B) % EMC reduction values were not provided by the researchers in the final report. However, since only outflow discharge was monitored at the site, we assume the reported load reduction and EMC % reduction values are synonymous.

INFLOW N SPECIES CONCENTRATION (ug/L)	TN	TKN	NOx	NH_4^+	DKN
Stormceptor® STC 900 (DRI 2004B)	5000	5000	300	NP	1000
StormFilter® (2ND 2005C)	1629	1371	241	328	X
Jensen Vault (DRI & TERC 2005)	2456	2274	182	183	X
Vortechnic Vault (DRI 2004A)	7250	7070	180	130	X
Vortechnics Vault (DRI & TERC 2005)	1941	1794	148	35	X
Sediment Trap (DRI 2004B)	2560	2430	130	NP	X
CDS Vault (DRI & TERC 2005)	2227	2123	88	51	X
Sediment Basin (DRI 2004B)	2500	Y	Y	NP	X
INFLOW P SPECIES CONCENTRATION (ug/L)	TP	PP	DP	SRP	
CDS Vault (DRI & TERC 2005)	636	510	126	99	
StormFilter® (2ND 2005C)	363	258	105	83	
Vortechnics Vault (DRI & TERC 2005)	872	769	97	75	
Vortechnic Vault (DRI 2004A)	380	Y	Y	70	
Stormceptor® STC 900 (DRI 2004B)	1050	960	90	50	
Jensen Vault (DRI & TERC 2005)	479	373	106	41	
Sediment Trap (DRI 2004B)	1080	1030	50	30	
Sediment Basin (DRI 2004B)	600	Y	Y	Y	
INFLOW TSS SPECIES CONCENTRATION (ug/L)	TSS				
Stormceptor® STC 900 (DRI 2004B)	1000				
Sediment Trap (DRI 2004B)	784				
Vortechnics Vault (DRI & TERC 2005)	680				
Sediment Basin (DRI 2004B)	600				
StormFilter® (2ND 2005C)	241				
CDS Vault (DRI & TERC 2005)	226				
Jensen Vault (DRI & TERC 2005)	120				
Vortechnic Vault (DRI 2004A)	115				

N SPECIES % EMC REDUCTION	TN	TKN	NOx	NH_4^+
Stormceptor® STC 900 (DRI 2004B)	21	21	65	NP
CDS Vault (DRI & TERC 2005)	11	8	-15	-4
Sediment Trap (DRI 2004B)	Y	11	-20	NP
Vortechnics Vault (DRI & TERC 2005)	1	17	-26	15
StormFilter® (2ND 2005C)	13	23	-33	45
Vortechnic Vault (DRI 2004A)	Y	83	-33	46
Jensen Vault (DRI & TERC 2005)	36	42	-77	22
P SPECIES % EMC REDUCTION	TP	PP	DP	SRP
Stormceptor® STC 900 (DRI 2004B)	25	Y	40	51
StormFilter® (2ND 2005C)	45	57	16	15
Sediment Trap (DRI 2004B)	26	Y	-1	14
CDS Vault (DRI & TERC 2005)	-4	Y	3	10
Vortechnics Vault (DRI & TERC 2005)	17	Y	7	9
Vortechnic Vault (DRI 2004A)	55	Y	Y	-14
Jensen Vault (DRI & TERC 2005)	52	Y	-10	-33
TSS SPECIES % EMC REDUCTION	TSS			
StormFilter® (2ND 2005C)	80			
Vortechnic Vault (DRI 2004A)	60			
Jensen Vault (DRI & TERC 2005)	58			
Vortechnics Vault (DRI & TERC 2005)	35			
Sediment Trap (DRI 2004B)	35			
Stormceptor® STC 900 (DRI 2004B)	31			
CDS Vault (DRI & TERC 2005)	11			

Y: Metric not provided in the report, but could be calculated if additional data analysis were performed.

X: Metric justifiably not provided in the report because it was not the purpose of the investigations.

Source Control Evaluations

The only source control effectiveness studies reviewed for the BMP Synthesis have been conducted by Michael Hogan and Mark Grismer (Hydrologic Sciences 2004A, 2004B, and 2005, IERS 2005). These researchers focus on revegetation and soil function restoration as a viable source control of sediment and associated nutrients. Four specific reports were reviewed and evaluated by these authors (Table 1). All of the reports build upon another as rainfall simulation, data collection and site evaluation methods were developed and documented. The report has a detailed literature and soil erosion process review that helps educate the audience on key components of soil and vegetation function. The authors argue that reestablishing the components of a functional soil horizon is the key to a successful revegetation program. Successful revegetation will inherently reduce erosion, enhance on-site nutrient retention, increase infiltration rates and provide a variety of ecological benefits. The methods and applications described below facilitate the evaluation of the specific function of a revegetation project to minimize erosion potential.


Example of roadside erosion in South Lake Tahoe, CA

Based on the functional components of soil and vegetation stability, Hogan and Grismer (Hydrologic Sciences 2004A) developed a detailed method that quantifies baseline hydrologic and sediment loss conditions on disturbed soils using a rain simulator. Monitoring methods are developed to specifically quantify the ability of a BMP to meet its intended objectives. While qualitative methods are cost-effective and simple to collect, they are often not defensible and not necessarily accurate. A rainfall simulator allows the researchers to control the rate and volume of water applications on a variety of in-situ soil surfaces, thereby removing the variability of rainfall intensity and duration on measured components of the system. They determined the key components that will indicate natural soil function including soil infiltration capacity, time to runoff, sediment yield, average sediment concentration, sediment grain size, and nutrient concentrations (TKN and DP) in the runoff. These specific components in soil/vegetation environments are expected to change in a predictable manner and indicate positive changes in the overall function of the soil/vegetation system. The magnitude of change of these parameters between pre- and post-restoration conditions can serve to quantify success and be compared to the original performance goals of the project.

The developed rainfall simulator method was then used to compare the soil functionality at a number of disturbed ski-run and cut slope areas within undisturbed sites (Hydrologic Sciences 2005). The purpose of the effort was to establish baseline soil characteristics on disturbed sites. These measured components could then be compared at revegetated sites to allow for success quantification. The sample sites included undisturbed areas, volcanic and granitic ski runs, and volcanic and granitic cut slopes. Volcanic ski run soils and both types of cut slope soils exhibited nearly an order of magnitude greater sediment yield than that from the native/relatively undisturbed sites. The greatest observed source of sediment was found to be granitic ski run soils, producing nearly four-times more sediment during simulations than undisturbed areas. Ski run soils were also found to produce a greater concentration of finer-sized particles than road cuts. And the volcanic soils were finer than their granitic counterparts. From a management perspective, ski-run soil stability efforts in areas of volcanic soil should be source control priority.

The evaluation of nutrient concentrations showed no discernible difference between rain water and runoff. However, the researchers limited their evaluation to TKN and DP. A more detailed investigation of the nutrient dynamics at disturbed erosion sites in undeveloped areas may indicate that these locations are not significant sources of the key nutrients of concern in Lake Tahoe. Such a conclusion could assist with focusing stormwater treatment strategies.

To document the success of the Cave Rock Revegetation project, IERS (2005) documents the application of monitoring techniques on a site-specific source control project. The Cave Rock assessment did not include the well-developed rainfall simulation methods, because of funding restrictions. However, additional monitoring components were used to evaluate revegetation success. Components used to facilitate adaptive management at Cave Rock included penetrometer monitoring (a cost-effective proxy to evaluate potential soil infiltration capability), total vegetation cover monitoring and soil nutrient analysis. With relatively little cost, these monitoring components were found to provide quantitative and repeatable information concerning soil sustainability and revegetation success. Locations not meeting reasonable criteria for success were attended to in appropriate ways in hopes of further improving the key components of soil/vegetation function.

Lake Village Residential Complex, Douglas County, NV (2NDNATURE 2005B)

Another study currently underway to monitor source control efforts is the multi-year water quality monitoring study at the Lake Village Condominium Complex in Lake Village, NV (2NDNATURE 2005B). The complex is slated to implement CIPs and BMPs in the summer of 2006, including curb and gutter improvements, roof line drip protection, and detention basin construction. Starting in 2003, 2NDNATURE and NTCD conducted pre-implementation hydrologic and water quality monitoring throughout the site to establish pre-project, baseline conditions. An additional monitoring site is located outside the influence of the scheduled improvements to provide a paired-watershed approach. Detailed automated surface water sampling stations have been installed, calibrated and operating since fall of 2003. Innovative techniques have been employed to document soil and water volume loss from individual residences as a result of untreated roof, deck and structure drip lines. To quantitatively evaluate the hydrologic and water quality benefit of residential source control BMP implementations throughout the Lake Village Complex, monitoring of the site will continue during and post-construction. A final report is anticipated in 2008.

Chemically Enhanced BMPs

Three controlled laboratory experiments (Bachand/TRG 2005, Bachand/TERC 2006 and CSU Sacramento 2004) investigated alternative applications that improve the retention of stormwater pollutants, particularly phosphorous species, in existing types of Lake Tahoe BMPs. Since phosphorous is one of the key primary pollutants of concern with respect to Lake Tahoe clarity, P source control has been a primary management concern.

There are both short-term and long-term removal opportunities of phosphorous in a wetland and/or detention basin BMP treatment structure. Short-term removal options of P from solution include biological uptake as a primary nutrient and particle adsorption. Uptake by standing vegetation, rather than algae, will increase retention time of the P molecule in place. Algae have relatively shorter life spans and can be transported with surface water flows. However, seasonal variations in plant growth and decomposition only provide a short-term removal of P from the aquatic resources. The short-term sink of vegetation uptake can be extended to a P net removal if the vegetation is extracted and removed from the system prior to decomposition. This prevents the re-release of the inorganic nutrients back into the aquatic environment. The high affinity of P for particle adsorption also provides an opportunity to transform a short-term sink into a net removal of phosphorous. Particulate P that can be captured and buried, preventing further transport, is a long-term sink.

If stormwater with dissolved P is filtered through a soil column with a high adsorption capacity for P retention, dissolved P can be retained in the soils and prevented from traveling downstream. The limitation is the adsorption/desorption kinetics of phosphorous. The variations in the chemical and biological conditions can subsequently disassociate P from the particles and allow phosphorous molecule migration to continue. This process of temporarily delaying downstream P migration is called retardation. The high-affinity of P for particle adsorption is a key process that researchers hope to maximize by augmenting existing BMP structures. Within the Basin, future efforts to maximize long-term sinks of P in stormwater may utilize processes that enhance adsorption and burial. This process may need to be followed by manual extraction and removal of the P-enriched material to guarantee no future migration.

The recent determination that particles smaller than 16 um may be responsible for over 50% of Lake Tahoe's clarity loss makes alternative treatment strategies to reduce and retain these small particles in urban locations a high priority. Chemical dosing with compounds that promote small particle aggregation, thus enhancing setting and removal by existing BMPs, is being investigated. Given the sensitivity of the receiving waters of Lake Tahoe, efforts to develop alternative and innovative treatment opportunities to remove fine particles and nutrients from stormwater should continue to be explored.

Adsorptive Media Investigations and Testing for Improved Performance of Stormwater Treatment Systems in the Tahoe Basin (Bachand/TRG 2005)

An ongoing investigation by Bachand and Heyvaert (Bachand/TRG 2005) tests the applicability of adsorptive media applications to improve the performance of stormwater treatment structures that remove and retain dissolved P given typical levels observed in Lake Tahoe stormwater. One key variable that will affect P adsorption is particle size distribution and the associated surface area of the particle. Smaller particle sizes provide more surface area per volume, therefore a greater number of potential adsorption sites to retain dissolved P.


Ski Run Basin in South Lake Tahoe, CA

The laboratory experimental design was appropriately conducted in phases. A large number of media was initially tested for potential to remove SRP from solution using isotherm experiments. Using a more complex column experimental design, the most promising media were selected and tested for adsorption and filtration capabilities. Tahoe soils from a number of existing detention basins including Eloise Basin (South Lake Tahoe) and Coon Basin (Kings Beach) were also tested. The native soils were found to have a very low uptake capacity and did not retain SRP. This low uptake is because of their chemical and physical characteristics, further substantiating the potential value of these adsorptive media efforts. The column experiments included filtration of Tahoe stormwater, both as collected and with additions of dissolved P, to evaluate true retention capabilities of the media. Activated alumina and lanthanum coated diatomaceous earth have shown potential to retain P at both elevated and low level SRP conditions. However, activated alumina can result in the leaching of aluminum given changes in the chemical conditions of the environment (particularly pH). This has the potential to create toxic conditions for aquatic species. The researchers have found that diatomaceous earth experiences physical failure whereby the hydraulic conductivity of the media becomes significantly reduced and waters can no longer percolate vertically (Bachand pers. comm.). Iron hydroxide ($Fe(OH)_3$) is another potential media. Although it has not yet been tested by the Tahoe team, studies in Florida have shown iron hydroxide dosing can successfully retain P from runoff in stormwater (Bachand pers. comm.). The final results of the study have not yet been released, but potential applications of preferred media may include detention basin and/or wetland soil amendments in infiltration zones. These applications may improve dissolved phosphorus removal performance and retard the movement of any subsurface P plumes.

There is little information on the treatment capabilities of existing BMP structures in Lake Tahoe to retain the very fine particles (<16 um). These particles are currently responsible for over 58% of annual clarity impairment of the Lake (Swift et al. 2006). However, the physical nature of very small particles suggests current BMP techniques may not be adequate. Approaches to stormwater treatment in the Basin must continue to explore innovative alternatives. While not included in the documents provided for the BMP Synthesis, Bachand et al. (pers. comm.) are also currently investigating the potential application and logistics of chemical dosing stormwater detention systems with coagulants. While toxicity to the base of the food chain ecology is a primary concern, physically injecting and/or manually applying an alumina or other media into standing waters may enhance small particle consolidation to a size and mass large enough to promote particle removal via physical settling.

Chemical Treatment Methods Pilot (CTMP) for Treatment of for Urban Runoff – Phase I. Feasibility and Design Draft Final Report
(Bachand/TERC 2006)

A feasibility study was conducted, Chemical Treatment Methods Pilot (CTMP), in the Tahoe Basin to improve the overall fine particle (less than 10 um) and total phosphorous retention of stormwater detainment BMPs structures. The recommended approach investigates the applicability of coagulant dosing of stormwater entering detention basins or treatment wetlands to enhance particle aggregation and phosphorous precipitation.

The draft final report includes:

- laboratory evaluations of the ability of a variety of compounds to remove fine particles and phosphorous from stormwater,
- results from toxicity screening of 4 compounds at optimum dose and the water quality and toxicity evaluations of one compound at and above (up to 3 times) the optimum dose, and
- preliminary site selection and conceptual approach to field testing chemical dosing in an existing Lake Tahoe BMP.

The Low Intensity Chemical Dosing (LICD) of coagulants is expected to increase the size of fine particles in the system, thus increasing the mass and associated settling velocities of particles in standing waters. It is hoped that LICD will provide a safe and reliable alternative to meet the stringent Lake Tahoe water quality discharge standards. The draft final report was still very much in draft form at the time of this report, so the summary below provides highlighted findings as presented by the researchers.

An initial laboratory testing was conducted of the relative capability of a wide range of 25 coagulant products to reduce the turbidity and total phosphorous of Lake Tahoe stormwater in order to identify a subset of the most promising products. Performance of select products was evaluated based on the removal of turbidity and phosphorus with varying dosing levels, the dosing levels required for satisfactory removal, the settling characteristics of the produced flocculates, and the effects on pH of the treated water. From these results the researchers identified the four most promising products: JenChem 1720, Pass-C (a product tested by CalTrans study reviewed below), PAX-XL9, and SumaChlor 50. These products were able to consistently reduce column effluent below 20 NTU turbidity and 0.1

mg/L total phosphorous. The researches found that PAX-XL9 and Pass-C (both polyaluminum chlorides (PACls)) are the most effective coagulants for potential in-situ applications and performance does not appear to be influenced by temperature, mixing regime, quality of stormwater or the dose of the coagulant. However these two products contain high levels of aluminum. Aluminum species are known to be toxic to aquatic organisms and overdosing of these coagulants is possible, potentially resulting in increases in dissolved aluminum in natural system. Based on the screening results, the researchers recommended continued testing of all four above products since the potential environmental effects of elevated dissolved aluminum release is less likely with the JenChem 1720 and SumaChlor 50 because of their lower required dosing levels. JenChem 1720 and SumaChlor 50 were not as consistent at reducing turbidity and phosphorous.

The researchers then tested the ability of the 4 selected compounds to reduce turbidity and total phosphorous in Lake Tahoe specific stormwater. Lake Tahoe stormwater was collected from three locations, Tahoe City Wetland, Ski Run and Stag, and placed in drums. The experiment consisted of each Tahoe stormwater dosed with the optimum level of each the 4 coagulant products and a non-treated control. Water samples were extracted from 3 vertical locations in the columns at the onset of the experiment, 30 minutes following and then at variable time intervals up to 72hrs and analyzed for turbidity and phosphorous levels.

The authors make a number of potential grain size distribution and settling time estimates in stormwater retention scenarios based on the observed changes in turbidity over time in the column experiments. The time step samples of turbidity and TP were used to calculate average settling velocities of particles within the column. The researchers found one to two order of a magnitude increases in the average particle settling velocities in the treated columns relative to the untreated control. Project data illustrates the immediate reduction of turbidity and TP, respectively, in treatments relative to the control (Figures 4-4 and 4-5[1]). Ninety-five percent of the turbidity removed after 72hrs had settling velocities greater then 0.01 cm s^{-1} (Figure 4-8) when stormwater was treated with JenChem 1720 or PAX-XL9, compared to untreated stormwater settling velocities estimated on the order of 0.001 cm s^{-1} or greater.

Applying Stokes Law to estimate average particle size, the authors document a mean particle size remaining in suspension following coagulant application over 72hrs of < 4 um. Based on the results of changes in particle settling rates due to chemical dosing, the researchers estimate hypothetical hydraulic residence times of stormwater retention structures can be an order of magnitude shorter in systems treated with coagulants and the effluent will be more likely to satisfy water quality objectives for turbidity and TP.

At the completion of the experiments the particulate matter that settled out of the system was collected and subjected to thermal freeze-thaw conditions to determine the mass loss and relative stability to extreme temperature variations of the flocculent formed by each coagulant. The evaluation determined that the flocculent formed by the combination of stormwater and coagulants appears to be more thermally stable than the raw stormwater or the individual coagulates. This implies a more resistant precipitate will remain at the base of the BMPs following freeze-thaw conditions. The flocculent is assumed to have greater phosphorous adsorption capacity than natural or in-situ BMP soils, thus providing an additional benefit of potentially improving long-term retention of phosphorous species at the sediment-water interface and reducing DP migration to the shallow groundwater. Wind, mixing, turbulence and other physical factors will likely influence the effectiveness of coagulation and ultimate retention of particles within the detention system.

Three independent toxicity studies were conducted to evaluate the potential toxicity of the coagulants:

- An EPA 4 species test included changes in algae counts, zooplankton reproduction rates and mortality, and fish weight and mortality. The EPA 4 species tests were conducted on Lake Tahoe stormwater both untreated and with optimum doses of the 4 compounds discussed above: JenChem 1720, Pass-C, PAX-XL9, and SumaChlor 50.
- Laboratory toxicity tests were conducted on the Madaka to evaluate the effects of Lake Tahoe stormwater and coagulant applications on Madaka fecundity, mortality, egg hatching rates and larvae. Madaka (Oryzias latipes) is a common model organism used in biological research. It is a simple, short-lived, hardy species that is reproductively prolific and easy to rear in the laboratory. The Madaka toxicity tests were conducted on Lake Tahoe stormwater both untreated and with optimum doses of the 4 compounds discussed above: JenChem 1720, Pass-C, PAX-XL9, and SumaChlor 50.
- An ecotoxicity test, which appears to be very similar to the EPA 4 species test (no detailed methods section), was conducted on the Lake Tahoe stormwater. This experiment includes doses of PX-XL9[2] at 2 and 3 times above optimal. A new coagulant, Chitosan, was also evaluated at optimum dose. The three other candidate coagulants, JenChem 1720, Pass-C, and SumaChlor 50, were not included in evaluations above optimum dosage.

The EPA 4 and Madaka results are discussed first, followed by the results of the "above optimum tests". The toxicity metrics were first evaluated on the Tahoe stormwaters (referred to as "non-treated" stormwater) collected from 3 locations during spring runoff events, Tahoe City Wetland, Ski Run and Stag. A control was also included in the evaluations and the results of the collection of ecological metrics were compared to the controls. The researchers identified variable toxicity results from each of the stormwater conditions relative to the control, indicating the stormwater quality alone produced some significant toxic responses from some of the organisms investigated, namely algal counts and flat head fish mortality.

The Tahoe stormwater was then dosed with optimum levels of each coagulant (JenChem 1720, Pass-C, PAX-XL9 or SumaChlor 50) and the suite of the EPA 4 species and Madaka toxicity tests were run again. The study indicated that primarily reductions in zooplankton reproduction were affected by additions of coagulants to the systems. Algae cell counts and flathead fish mortality were impaired by untreated stormwater and the toxic responses were still observed when coagulants were added to the stormwater. It seems difficult to infer if toxicity is the result of coagulant additions to the ecologic metrics when a toxic response is shown to stormwater alone.

The third toxicity study was conducted using a range of PX-XL9 doses, as well as optimum levels of Chitosan. The results of the algal cell toxicity did not produce statistically significant results due to the large variability of the control conditions, thus it is difficult to decipher whether the treatments will change algal production. Intuitively, in systems where P is the limiting nutrient, we would expect algal counts to be reduced as a result of dosing, simply due to the reduction in nutrient availability. Experiments should be designed to isolate toxicity from nutrient availability effects to primary producers.

In general, ecological metrics indicated increased toxicity when dosing was above optimum levels. Zooplankton mortality was not observed during a range of PX-XL9 dosing, but reproduction rates appeared to decline when tests were compared to controls. At 3 times optimum dosing of PX-XL9, 100% of the zooplankton died in the Ski Run and Tahoe City Wetland stormwater. Some increases were observed in flathead fish mortality and survivor biomass due to coagulant applications.

The third experiment also included testing the effects of dosing of two coagulants (optimum doses of Chitosan and 1/2, 1, 2, and 3 times the optimum doses of PX-XL9) on water quality changes, including dissolved metals, pH, alkalinity, TDS, DOC etc. The most important of the water quality impacts found are the reductions in pH due to elevated dosing, and the coincident increases in both total and dissolved Al. The greatest toxicity risk of LICD of the selected coagulants will be due to increases in aluminum concentrations in the system. Aluminum toxicity will increase with reductions in pH.

There is considerable evidence that Al is toxic to a wide array of organisms. There is still some uncertainly to the form of biologically available Al and the mechanisms that cause toxicity. One agreed upon component is that Al is more toxic at lower pH due to speciation changes and typically Al^{3+} and $Al(OH)^2$ have been identified as biologically toxic species (Driscoll & Schecher 1990). Reductions in pH can significantly increase the concentrations of dissolved Al because Al^{3+} is out-competed for complexation sites by the free hydrogen ions (H^+). This is the reasoning behind the EPA statement included on page 72 of the draft document, “The EPA guidance notes that aluminum is ‘substantially less toxic at higher pH and hardness’”. Aluminum speciation is very sensitive to the pH changes that can occur in natural waters. Redox chemistry in low oxygen environments may also make Al more soluble when hydroxides are reduced and potentially increase dissolved aluminum concentrations (Stumm and Morgan 1996). Considering the preliminary findings that over-dosing of PX-XL9 created concurrent reductions in pH and increases in Al and that many times the optimum dose may occur as the result of reoccurring application of coagulants to a Tahoe BMP, additional investigations of water chemistry, aluminum speciation, pH changes and potential toxicity may be warranted.

The team presented a conceptual design and process for a field pilot testing of chemical dosing in the Lake Tahoe Basin. Six to nine treatment cells are planned and each cell would be on the order of a few hundred to a few thousand square feet each. Osgood Basin at Ski Run, South Lake Tahoe, El Dorado County was selected as the potential site based on the availability of historical data, implementation logistics, environmental issues and concerns, experimental design considerations and community support. The conceptual design for field implementation includes opportunities to control hydrologic conditions and automate chemical dosing as stormwater moves through the wetland. Coagulants would be introduced at the inlet of the basin with a mechanical mixing devise and the particles would settle as the waters continued through the flow path of the BMP system. The designs presented are very conceptual and numerous logistical details still remain.

Small-Scale Pilot Studies using Coagulants for Turbidity and Phosphorous Removal at Lake Tahoe
(CSU Sacramento 2004)

In cooperation with CalTrans, Johnson et al (CSU Sacramento 2004) tested alternative stormwater treatment technologies. These tests were given in effort to meet the surface water discharge limits as required by National Pollutant Discharge Elimination System (NPDES) permits. A coagulant is defined as, “A material, such as alum, which will form a gelatinous precipitate in water, and cause the agglomeration of fine particles into larger particles which can then be removed by settling and/or filtration” (Webster.com). Using stormwater collected within the Lake Tahoe Basin, controlled experiments were conducted. These experiments evaluate the effectiveness of applying coagulants to the stormwater to improve sediment and phosphorous removal as the stormwater/coagulant mixture was filtered through a vertical sand column. The study compared mechanized and non-mechanized treatments. Mechanized treatment refers to manual mixing of the stormwater and coagulant compounds to enhance the chemical binding of the nutrients with the coagulant. This simulates the processes implemented at a stormwater treatment facility. The mechanized treatments consistently reduced turbidity and P levels in snowmelt stormwater to levels below the effluent requirements. Non-mechanized assumes no manual mixing and evaluates effluent quality following a dosing with the selected PASS-C® liquid polyaluminum chloride coagulant compound and filtration through vertical fine sand column. The non-mechanized treatment is analogous to infiltration of stormwater through a detention/retention structure following coagulant dosing. Effluent concentrations were improved when dosing was optimized to inflow concentrations, but testing results did not produce consist effluent concentrations below the regulatory turbidity and total P limits, 20 NTU and 0.1 mg/L respectively. In comparison to non-dosed replicates, the filtration capability was greatly improved when the stormwater was dosed with Pass-C prior to filtration.

Footnotes:

[1] The figures would be more powerful if initial turbidity and TP values were plotted for each experiment.

[2] We assume that PX-XL9 is the same compound as PAX-XL9 used in the other controlled experiments.

5. Summary of Existing Knowledge

Dry Detention Basins

What We Do Know

Surface Water Treatment

- The primary pollutant mechanism is physical settling of particles due to reduced competency of flows to maintain particle suspension in the water column.

Three detailed detention basin effectiveness studies were reviewed. According to the findings (Table 4 and Appendix C):

- Detention basins consistently reduce TSS concentrations with existing studies reporting at least 68% EMC reduction in TSS, with Coon Basin documenting a study TSS EMC reduction of 94%. Average inflow TSS concentrations ranged from 100 to 500 mg/L at these sites.
- Detention basins were observed to consistently reduce inflowing stormwater for TKN and PP pollutants.
- Detention basin monitoring suggests variable success to reduce stormwater dissolved pollutants. The existing data suggest there may be an effluent limit below which detention basin structures cannot provide a treatment benefit to dissolved nutrients. The available data suggests that detention basins may provide little treatment when inflow conditions approximate NOx < 250 ug/L, NH_4^+ < 50 ug/L, SRP < 50 ug/L and DP < 80 ug/L.
- The ability to provide effective treatment is highly dependent upon the basin's ability to retain and infiltrate stormwater from a mass loading perspective (TERC 2005, SH+G 2003).
- Vegetation presence in basin appears to improve seasonal dissolved nutrient uptake, but may or may not result in complete long-term capture (SH+G 2003).
- When properly sized for the respective catchment hydrology, detention basins appear to be appropriate stormwater quality treatment structures that treat nutrients and sediment loads typical of residential communities (TERC 2005, SH+G 2003).

Roadside detention swales, Meyers, CA

Groundwater Treatment
Two studies investigated the potential subsurface impacts of inducing infiltration via detention basin systems. According to the findings (Appendix C):

- Detention basins create a hydrologic conduit that effectively routes stormwater into the subsurface. The effectiveness of infiltration to reduce stormwater volumes is dependent upon the area of infiltration, the hydraulic conductivity of the soils and the thickness of the unsaturated zone (USGS 2006, 2NDNATURE 2006).

Industrial Basin in Summer 2005, South Lake Tahoe, CA

- No significant impact to the shallow groundwater quality with respect to nutrients (and most other chemical compounds, Fe being the exception) has been observed at Cattlemen's detention basin, which accepts runoff from a residential catchment (USGS 2006).

- Nitrate is known to migrate freely in groundwater. Urban stormwater infiltration may pose a risk to shallow groundwater in locations where nitrate concentrations are elevated. Limited nutrient sampling results suggest a nitrate pulse via shallow groundwater may exist during spring snowmelt conditions (2NDNATURE 2006).

- Groundwater quality impacts, with respect to hydrophobic hydrocarbons typical of Tahoe urban stormwater do not appear to pose a risk if introduced to an adequate soil horizon. Questions remain regarding the potential impact of urban hydrocarbon pollutants when introduced to dry wells or other infiltration features that provide little, if any, soil/water contact (2NDNATURE 2006).

- Basin morphology can improve pollutant treatment via infiltration. The greater the surface area to volume ratio, the greater the horizontal soil/water interactions and pollutant retention potential. The greater the depth to groundwater is, the greater the vertical soil treatment capability of infiltration (2NDNATURE 2006).

- If a detention basin's purpose is to provide treatment by infiltration, and no risk to shallow groundwater quality is expected, maintenance will be necessary to maintain original infiltration rates due to fine particle accumulation in the base of the detention basins (2NDNATURE 2006).

Dry Detention Basins

What We May Not Know

- What is the treatment/retention capability of fine sediment fractions (<16 um)? What functional components of detention basins can be modified to maximize capture and retention of fine particles?

- The Cattlemen Basin results (USGS 2006) suggest groundwater quality impacts, with respect to nutrient loads from detention basins in residential communities, may not pose a risk. However, subsurface fate and transport of pollutants, where dissolved nitrogen and phosphorous levels are expected to be elevated (DIN > 500 ug/L and DP > 200 ug/L), are still unknown.

- What is the spatial distribution and relative density of BMPs and other features that infiltrate stormwater? Future investigations should identify and focus on locations where infiltration of stormwater poses a risk to the quality of the shallow groundwater.

- What is the true seasonal capability of detention basins to treat dissolved nutrients? Are there opportunities to monitor the effectiveness of management alternatives to improve the retention of dissolved and total nutrients?

- What is the feasibility and reality of filter media and/or chemical dosing to improve the water quality benefit of detention basins? Augmentation of detention basin soils could enhance P retention and net removal from these systems. Chemical dosing may enhance coagulation and fine particle removal as well as SRP from the water column. One of the concerns of this process is the potential toxicity of these chemical additions.

Constructed Wetlands

What We Do Know

One constructed wetland and one constructed wet basin were evaluated for pollutant reduction performance relative to inflow concentrations (EMCs). Table 7 and Appendix C provide the quantitative data.

- Wetland vegetation may provide a greater dissolved nutrient treatment to stormwater with relatively low sediment loads. Pre-treatment and catchment source control that minimize sediment loading will likely increase wetland nutrient treatment performance (TRG 2005).

- Dissolved nitrate and ammonia reductions via wetland environments were consistently observed at both sites with study averages of NOx EMC reductions over 80% for both BMPs (Table 7). Nitrogen cycling in a productive environment is expected to decrease NOx level either by biological metabolism and/or denitrification when oxygen is limiting (see Figure 3). Ammonia EMC reductions were less dramatic, but still more consistent than detention basin performance.

- Dissolved phosphorous and SRP average inflow concentrations Village Green Pond are over 5 times greater then the residential stormwater introduced to Tahoe City Wetlands. The EMC reductions average observed at Village Green Pond were 32% for DP and 37% for SRP. Even with this treatment, effluent concentrations during runoff events from Village Green remained above 400 ug/L (Appendix C).

- The inflow concentrations to Tahoe City Wetland were comparable to dissolved nutrient levels introduced to Coon Street detention Basin. No discernible difference of SRP and DP treatment capability is present when comparing these general study performance values. A more detailed seasonal evaluation of these study results may illuminate functional variations of dissolved P treatment by detention basins versus wetland BMPs for levels typical of residential stormwater.

- Extended complex flow paths and properly sized wetlands will enhance sediment and particle (and associated pollutant) retention, especially during larger runoff events. A wetland's ability to reduce dissolved nutrients is strongly dependent upon longer hydraulic residence times that provide ample time for chemical and biological processes to occur (TRG 2005).

- Lack of mixing and stagnant water in a eutrophic wetland can result in anoxic conditions. This condition promotes denitrification (net N removal) as well as phosphorous disassociation from particles (soluble P increase) (SH+G 2003). The perennial baseflow at TCWTS may enhance oxygenation and contribute to consistent reductions in dissolved N and P species (TRG 2005). Other management opportunities should be explored to provide an oxygen source to nutrient-enriched open water structures.

- Infiltration as a primary treatment strategy in a wetland may not be feasible because of the low hydraulic conductivities and associated infiltration capacities of the fine grained organic soils (TRG 2005).

- Shallow groundwater influenced by a wetland system may be significantly impacted by ammonia levels due to subsurface mineralization of organic material (TRG 2005).

Constructed Wetlands

What We May Not Know

- What are the fate and transport of dissolved P constituents beneath wetland systems chronically accepting elevated P concentrations? (Village Green Pond Pilot Project, Phase II is addressing this issue.)

- Are elevated groundwater ammonia levels a common impact of constructed Alpine wetlands? If so, is this a concern?

- How is vector control achieved while maintaining wetland biogeochemical function and maximizing pollutant treatment?

- What is the seasonal nutrient fate and transport from ponds and wetlands on fertilized surfaces? Are they a significant seasonal source of dissolved nutrients to the Lake?

- Are there maintenance opportunities that would maximize long-term dissolved nutrient retention by constructed wetland systems?

Mechanical Treatment Structures

What We Do Know

Four studies investigating the effectiveness of eight mechanical treatment structures were reviewed. Table 10 and Appendix C present the qualitative data.

- Mechanical structures designed to trap sediment and debris require regular maintenance in order to maximize potential treatment benefits. Variable and poorer than expected performance of these structures to reduce TSS levels has been observed (DRI 2004A, DRI 2004B, DRI & TERC 2005, 2NDNATURE 2005C). Routine and diligent maintenance programs are suspected the most cost-effective means to maximize potential stormwater quality benefits of sediment capture systems.

- The average study nitrate values introduced to the mechanical vault structures studied ranged from 100 to 300 ug/L, levels that could be considered moderate in comparison to inflow concentrations observed at Coon Street Detention Basin and TCTWS (> 700 ug/L). All but one study of vault structures found extremely variable and typically poor performance of these systems to reduce NOx values. In fact, biological degradation of material stored within the vaults appears to be a source of dissolved N species in effluent waters.

Concrete forebay of Golene Basin, South Lake Tahoe, CA

- Roadway and residential land use catchments investigated for the mechanical vault studies are in the range of inflow dissolved P EMC values observed at other sites (DP < 130 ug/L and SRP < 100 ug/L). Similar to dissolved N treatment, the project average performance comparisons suggest poor dissolved P retention.

- Little treatment of dissolved N and P can be expected from a mechanical structure that performs physical separation of material. When regularly cleaned, sediment traps, Stormceptor®, Vortechnics, Jensen, CDS, and possibly StormFilter® vault systems should retain significant fractions of stormwater sediment and particulate pollutants (DRI 2004A, DRI 2004B, DRI & TERC 2005, 2NDNATURE 2005C). When regularly cleaned between storms, the likelihood of subsequent flushing of dissolved pollutants to downstream resources may be significantly reduced.

- Proper construction and pre-conditioning of constructed vaults systems may be necessary to ensure proper performance and to avoid inadvertent pollution downstream during the initial stormwater events (2NDNATURE 2005C).

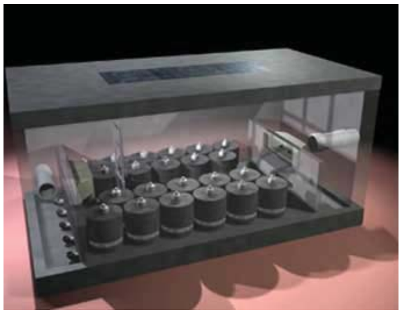
- Mechanical structures provide ideal opportunities for initial stormwater treatment in areas of limited surface area (i.e., dense urban and/or roadside applications). In catchments where dissolved nutrient loads are a concern, secondary treatment BMPs that better provide such treatment should be implemented downstream.

Mechanical Treatment Structures

What We May Not Know

- How well does a Stormceptor®, sediment trap, Jensen, CDS, Vortechnics, StormFilter®, etc. perform when properly maintained?

- Sediment traps are significantly simpler than the pre-constructed manufactured mechanical structures. If routinely and diligently maintained, do these simple structures provide comparable sediment and debris capture capability to the sophisticated models? Rather than implementing expensive treatment structures, would resources be better spent on increased maintenance and source control efforts?



StormFilter® illustration
www.ingalenviro.com/stormfilter

6. Recommendations

Potential Quantitative Value of Existing Data

It is unrealistic and unnecessary to conduct detailed monitoring evaluations of every BMP constructed within Lake Tahoe Basin. Given the limitations from the lack of standardization and coordination of previous data collections, an opportunity still remains to integrate a large amount of the existing data into a Lake Tahoe BMP Stormwater Analysis Database. The Lake Tahoe BMP Stormwater Analysis Database would improve BMP design, selection and prioritization of projects by managers, as well as allow researchers to expand the applications of future studies and definitively identify research gaps. The quantitative stormwater and BMP data, both existing and future, should be in a format capable of serving as an engineering tool for BMP design, expected performance, and maintenance scheduling. A usable quantitative database would also facilitate realistic estimates of TMDL pollutant loading reductions or effluent concentrations based on site-specific Lake Tahoe data. The database would improve the accessibility for Basin researchers to increase understanding of BMP function and to allow for more informed identification of research opportunities and knowledge of limitations. The following steps are recommended to increase the power of the existing and future BMP monitoring data:

STEP 1: Utilize a selection of the existing stormwater BMP data sets to create a functional digital database (Lake Tahoe BMP Stormwater Analysis Database). The structure, format and protocols could lend from many existing on-line databases, including the National BMP database. Ideally, Lake Tahoe BMP data would be easily integrated and comparable to other cold weather climate BMP performance evaluations, when desired.

STEP 2: Use the results of the data integration exercise to further identify the necessary details in order to standardize future monitoring, as to be documented by the Lake Tahoe Interagency Monitoring Program (LTIMP) Monitoring Guide. This interaction and feedback will ensure future monitoring data is compatible with the BMP Stormwater Analysis Database.

STEP 3: Once designed, integrate all existing data based on database protocols and structure. Utilize the BMP Stormwater Analysis Database to provide stormwater and BMP data for the next phase of Lake Tahoe Pollutant Load Reduction (PLR) Methodology developed by the USACE and LRWQCB. The database would integrate independent data sets, thereby increasing the quantitative power of existing and future stormwater quality and BMP performance data.

STEP 4: Quantify existing knowledge of stormwater quality and BMP performance across BMP type, BMP design criteria, catchment characteristics, hydrologic settings, pollutants of concern, effluent requirements, etc. The goal of a quantification summary would be to support the development of the Lake Tahoe BMP design manual with Tahoe specific data, assist with the Phase II of the TMDL and pollutant reduction goals, as well as identify research data gaps and direct future scientific needs.

STEP 5: Once the BMP Stormwater Analysis Database structure, procedures, protocols and functionality have been finalized, transfer programmatic responsibilities to appropriate agency.

Recommendation to Resource Managers and/or Science Community:

- Research contracts for all studies should include the necessity to produce a detailed Monitoring Plan. The monitoring plans should document the primary objectives of the study and detail the data collection techniques that will be employed to achieve these objectives.

- The project team should obtain an independent, competent researcher knowledgeable of Lake Tahoe research issues to provide peer review of the study design. This would ensure the monitoring design will directly achieve study objectives and improve the integration of independent studies with the bigger picture water quality questions ongoing in the Basin.

Storm monitoring

- There are no performance standards or quantitative goals by which to measure success. The most valuable lessons provided by the work of Hogan and Grismer (Hydrologic Sciences 2004A, 2004B, 2005, and IERS 2005) is the insistence that performance is impossible to quantify unless indicators of success or anticipated function are associated with the project. By utilizing indicators of system function, scientists can better quantify performance of these indicators to pre-project goals.

- Development, distribution and utilization of the updated LTIMP Monitoring Guide would assist researchers with monitoring design and reporting standards. The update of the LTIMP Monitoring Guide should be coordinated and/or follow the structure and key findings from the development of Lake Tahoe BMP Stormwater Analysis Database. The Monitoring Guide should include, but not be limited to:
    - Data collection priorities depending upon type of BMP and pollutant routing research goals
    - Primary constituents, associated analytical protocols, and specific nomenclature
    - Data reporting units
    - Typical data calculation procedures for EMCs, event loads, overall study performance values, etc.
    - Data reporting parameters
    - Study report structure and necessary information concerning BMP, catchment, hydrology, etc.

- The Lake Tahoe BMP Stormwater Analysis Database should be created to provide a universal structure and format for existing and future stormwater and BMP performance data. A well-maintained database would increase the exposure and sharing of Tahoe-specific hydrologic and water quality data. This would make monitoring results more accessible to the science community, agency personnel, engineers and the public. A procedure to make individual reports more accessible should also be developed.

- It is cost-effective to continue monitoring efforts at existing BMP monitoring sites due to existing instrumentation, knowledge of site nuances and long-term data sets. Many evaluations have study-specific recommendations that would improve BMP function. Implementation of scientific recommendations and subsequent monitoring will facilitate evaluations of modification success and work forward to achieve adaptive management goals.

- Lake Tahoe managers should continue to consider innovative alternatives to improve BMP performance. Low intensity chemical dosing (LICD) provides promising alternatives that directly address treatment for the primary pollutants of concern impairing Lake clarity. Laboratory results led to the selection of four aluminum containing compounds that showed order of magnitude increases in particle settling rates and significant reductions in stormwater turbidity and phosphorous relative to controls. Preliminary toxicity studies on laboratory organisms suggest potential toxic conditions may develop as a result of coagulant applications. The potential geochemical and ecological impacts of chronic applications of these aluminum containing compounds to the Tahoe environment should be further investigated. Future controlled dosing experiments that can directly evaluate the performance and potential toxicity to Lake Tahoe ecology will improve our understanding of the feasibility of using LICD to retain stormwater pollutants. Any future controlled experiments should be certain to control any potential release or migration of treated waters to natural downstream resources until the potential water quality and ecological side-effects are better understood.

- The groundwater investigations reviewed at all types of BMP structures show extreme variability in monitoring design, data presentation and use of data. Better scientific guidance is needed with respect to the design and communication of the groundwater hydrogeologic and water quality data sets.

Recommendations to Researchers:

- Monitoring of BMP treatment structures, such as detention basins, constructed wetlands and mechanical treatment systems, should make continuous and accurate water budgets the priority. Pollutant transport dynamics are inherently variable and there has been no definitive evidence to suggest more pollutant analytical data will necessarily constrain the variability. Composite event sampling may be sufficient. Additional resources should be expended to obtain complete hydrologic dynamics of these systems through at least one complete annual cycle.

- If feasible, pre-project monitoring will provide valuable pollutant and hydrologic information that will assist with design. Also baseline data can be used to directly quantify BMP performance following implementation and monitoring.

- BMP monitoring objectives must be clear and directly address the purpose and intent of the evaluated BMP.

- Project-specific monitoring plans should be developed for each study and designed to directly address the project objectives with quantifiable data collection. As stated above, monitoring plans should be peer-reviewed by a qualified scientist(s) and accepted prior to implementation.

- The quality and standardization of future scientific BMP evaluation reports should be improved. Below we provide a recommended format to improve communication between science, policy and engineers.

- The responsibility of the researchers in the Lake Tahoe Basin include guiding the direction of the necessary science, providing scientifically defensible evaluations of natural system functions, and communicating these findings in a manner that resource managers can understand. Based on the quality of reviewed reports, the following recommendations are provided as a starting point. The recommendations will assist with the development of reporting procedures, however they are hardly exhaustive.

Park Avenue Basin in Winter 2006, South Lake Tahoe, CA

Research Communication Recommendations

The BMP Synthesis effort was primarily focused upon gleaning information from study report communications. The process of report review and project evaluation has led to recommendations to improve and standardize future research and monitoring communications. Resource managers should adopt appropriate monitoring communications guidelines associated with research funding to provide further direction as to the structure of stormwater and BMP documentation and reporting.

I. Executive Summary
II. BMP/Project Background
  - A scaled map of the catchment and the subject BMP
  - Construction details of BMP
  - Specific purpose of BMP
  - Indicators of performance
  - Regional setting
  - Catchment area
  - Land use distribution
  - Hydrologic information generated by design team, etc.

III. Monitoring Objectives
Specific objectives of data collection evaluation should be clearly stated and the following data and evaluation should be used to directly achieve the study objectives.

IV. Methods
  - There should be enough detail to allow another researcher to repeat the same study.
  - The reader must be able to understand and follow the monitoring design and data collection. Ultimately, this information is the backbone of the results and interpretations of BMP performance.
  - Details should include identification of specific instrumentation, purpose of instrumentation, limitations of instrumentation, dates during which instrumentation was operational, etc.
  - A site location map should clearly indicate monitoring locations using nomenclature consistent with text.
  - Any data not used to formulate results should be documented.
  - Assumptions should be documented.
  - Data interpretation methods should be documented.
  - All calculations should be provided in enough detail for another researcher to replicate.

V. Results
  - The results section should be presented in a clear and organized manner.
  - Graphics should provide a summary of the data collection efforts over the duration of the study.
  - Graphics should be used to express the most relevant data necessary to achieve the objectives of the study and drive the discussions of the findings.

- Graphics should be information rich, properly labeled with all units provided, and complete with supporting text that will facilitate interpretation and understanding by the reader.
- All graphics provided should be directly relevant toward meeting the objectives of the study. Extraneous graphics that do not strengthen the conclusions should be eliminated.
- Time series graphics of data collection results is an effective way to provide readers with a clear summary of monitoring efforts
- A complete hydrologic picture will allow an assessment of temporal distribution of the monitoring efforts and provide insight on the seasonal and annual representativeness of the monitoring efforts.

VI. Conclusions

The conclusions should highlight the specific findings of the study based on the data in hand, essentially summarizing the key results.

- Conclusions should be concise and directly address the objectives of the study.
- The conclusions should be based on the data and observations. Caution should be taken not to extend the conclusions and interpretations of BMP function or other findings beyond the power of the specific data collected.
- Study limitations should be clearly stated.
- What questions still remain regarding the functional aspects of the particular BMP? Function can imply information regarding the complete seasonal and annual performance. Were the data collection and observations a reasonable representation of the system function over an array of climatic, hydrologic, and pollutant loading conditions?
- Expand and compare the data in hand with other relevant research. How do the findings of this study compare to findings documented by other researchers? Efforts should be made to compare results from subject study to similar relevant findings by other studies (preferably within the Basin in most cases). This will integrate and build our knowledge with each piece of new research.

VII. Recommendations

Recommendations can be used to apply best professional judgment in an effort to apply the science to engineering and resource management.

- Based on professional scientific judgment, what components of the specific existing BMP could be modified to improve performance? Can this be applied to other similar BMP structures, either existing and/or future implementations?
- Based on observations and quantified BMP performance, what are assumed to be the best applications of the particular BMP to maximize pollutant treatment? Applications should include catchment area, percent impervious, ideal target pollutants, expected pollutant load of target pollutants, etc.

- Based on observations and quantified BMP performance, what are the conditions that appear to limit the performance of the particular BMP? Limitations can include lack of maintenance schedule and strategy, hydrologic conditions, seasonal conditions, physical conditions etc.
- What, if anything, could be modified to alleviate limitations and improve system performance? These changes can include physical, biological, chemical and/or management modifications.
- Continued efforts to provide innovative scientific hypotheses to maximize BMP performance will assist resource managers with prioritizing funding allocations to facilitate adaptive management.

View from Lake Village Residential Complex, Stateline, NV

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In addition to those listed in Table 1:

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APPENDIX A: BMP Synthesis Communication Report Evaluation created by 2NDNATURE

2NDNATURE Project/Report Survey
1: poor quality
3: expected quality
5: outstanding quality

Project and Report Quality Summary
(average values of each survey section)
Section I. Monitoring Study Design and Management Quality
Section II. Data Collection Quality
Section III. Report Communication/Presentation Quality
Section IV. Conclusions/Recommendations

I. Monitoring Study Design and Management Quality

1. Did the study appear to have clear objectives and goals?
2. Did the researchers refer to existing literature and previous studies to improve study design and data interpretation?
3. Did the sampling techniques, methods and study design appear to facilitate a data set that would directly address the success of the project to meet the intended goals and objectives?
4. Were the data analysis and calculations appropriate to directly evaluate the study objectives?
5. Was study data periodically reviewed and interpreted to ensure data value was as the original study and sampling design intended?
6. Did the project managers integrate lessons learned during study data collection to iterate techniques and remove unnecessary components that were not as valuable as intended?

II. Data Collection Quality

1. Did the data collection (field) team appear to have a clear and consistent data collection techniques and established protocols?
2. Was the data collection standardized and repeatable, thereby capable of producing representative data to evaluate the system in question?
3. Were the intended sampling techniques appropriate to meet the objectives of the study?
4. Did the study include surface water monitoring?
    a. Were the sampling locations appropriate to address the objectives of the study?
    b. Did data collection include both hydrology and water quality to facilitate surface water load removal evaluations and EMCs?
    c. Did data collection include innovative qualitative data collection techniques to improve project success determination beyond water quality measures?
    d. Were sample collection techniques and timing appropriate to acquire effective data to meet the objectives of the study?

    e. Were surface water samples analyzed by the laboratory for proper constituents to directly address the objectives of the study?
5. Did the study included groundwater monitoring?
    a. Did the monitoring well locations have the potential to address the objectives of the study?
    b. Did the groundwater monitoring and sample collection program directly address the objectives of the study?
    c. Were groundwater samples analyzed for proper constituents to directly address the objectives of the study?
    d. Was an upgradient/baseline well(s) established and monitored?
    e. Were bore logs created and used to graphically provide stratigraphic cross sections of subsurface?
    f. Were the well heads surveyed to provide groundwater elevation and gradient information?
    g. Is time series groundwater elevation data collected and presented and applied to project conclusions?
    h. Did the researchers collect and evaluate relevant hydrogeologic site information to document site infiltration rates, groundwater flow rates, hydraulic conductivites and other characteristics to improve our understanding?
6. Did the study include source control BMP monitoring?
    a. Did the tests and data collection techniques directly address the objectives of the study?
    b. Could the data collection techniques quantify the relative success of the source control efforts?
    c. Were these techniques useful for future source control BMP monitoring in Lake Tahoe?
    d. Were the techniques innovative, expanding typical applications of monitoring to meet the unique needs of Lake Tahoe water quality?
7. Did the project include qualitative data collection techniques?
    a. Did the qualitative monitoring provide effective information concerning project success?
    b. Were the results from qualitative monitoring reliable enough to support study findings?

III. Report Communication/ Presentation Quality

1. Did the report communicate the study design, methods and results in an effective and defensible manner?
2. Does the report have an effective executive summary?
3. INTRODUCTION/BACKGROUND
    a. Does report have clearly stated project and study objectives?
    b. Does report have clear site map to allow complete understanding of site layout and characteristics?
    c. Does report have proper BMP schematics to document

    system hydrologic function?
    - d. Does the report include proper technical background and explanation to properly inform resource managers of critical chemical, physical or biological components considered and evaluated?
    - e. Does the report clearly present the significance of the monitoring and what information the resource managers hope to gain by funding the efforts?

4. METHODS
    - a. Are the general data collection methods presented in enough detail for the monitoring techniques to be repeated by an independent researcher?
    - b. Are consistent and defensible sampling methods employed that provide reasonable confidence that data set variations and trends are representative of site characteristics?
    - c. Does the report clearly present the shortcomings/ difficulties of the data collection efforts?
    - d. Were the proper pollutant constituents and/or data presented in the report to address the project and study objectives?
    - e. Does the report clearly state data manipulation and calculation techniques?
    - f. Are the calculations/data manipulations and data presentations appropriate to meet the study objectives?
5. RESULTS
    - a. Are the results presented in a clear, organized and coherent manner?
    - b. Were data manipulation techniques reasonable to evaluate BMP effectiveness?
    - c. Are the findings well presented for each constituent and parameter sampled that would directly address the objectives of the study and the project?
    - d. Are the findings well presented for each runoff or focused monitoring event type?
    - e. Does the presentation of the findings make sense to the reader?
    - f. Are the graphics properly selected and information rich?
    - g. Are all graphics, figures, data tables properly explained and referred to in the text?
    - h. Are the units of all metrics and values (sample concentrations, pollutant loads, calculations etc) clearly provided?
    - i. Are the study data relied upon for results and interpretations readily available for review?
    - j. Is there reasonable justification provided for the exclusion of select data by the author?

IV. Conclusions/Recommendations

1. Does the report provide ample scientific background information, terminology definitions and associated explanations to allow readers of all technical backgrounds to gain a clear understanding of processes considered and evaluated?
2. Are the findings, interpretations and conclusions clearly supported by the study data?
3. Are the results compared with findings from similar studies within the Lake Tahoe Basin?
4. Are the results compared to previous assumptions about project (BMP) function and objectives?
5. Are the results used to quantify the “success” of the project (BMP) to meet the intended goals of stormwater treatment and/or source control?
6. Are findings and lessons learned incorporated into clear recommendations to assist scientist to improve future BMP performance monitoring studies?
7. Are findings and lessons learned incorporated into clear recommendations to assist resource managers and engineers to improve future BMP function and design?
8. Were resource managers left with reliable recommendations that could improve future BMP implementations and build on existing knowledge of BMP function?

Future information use

1. Given the data and information provided in the report, is there a potential to revaluate the data into more meaningful interpretations?
2. What level of effort would be required to improve data presentation and interpretations?
3. Is there potential to revaluate the water quality data for comparison to other monitoring results?

APPENDIX B: BMP Synthesis Communication Report Evaluation Performance Summary

Final Report Reference (*See Table 1 for complete report titles*)	Monitoring Study Design and Management Quality	Data Collection Quality	Report Communication/ Presentation Quality	Conclusions/ Recommendations	Report Average Score
2NDNATURE 2005C	2.0	2.3	2.7	2.3	2.3
2NDNATURE 2006	3.1	3.0	3.2	3.4	3.2
Bachand/TRG 2005	5.0	5.0	4.8	5.0	4.9
CSU Sacramento 2004	2.9	3.0	3.1	2.9	3.0
CWS 2005	2.0	1.0	2.0	2.1	1.8
DRI & TERC 2005	3.5	2.3	2.9	2.5	2.8
DRI 2004A	2.3	2.0	2.5	1.3	2.0
DRI 2004B	3.0	2.7	2.6	2.6	2.7
EDCDOT 2005	1.2	1.5	1.3	1.1	1.3
IERS 2005	5.0	4.5	2.5	2.4	3.6
SH+G 2003	4.4	3.2	2.9	3.1	3.4
TERC 2005	2.5	2.6	2.6	2.5	2.6
TRG 2004	3.0	2.5	2.8	2.8	2.8
TRG 2005B	2.5	2.4	2.0	2.3	2.3
USGS 2006	3.1	3.3	3.2	2.8	3.1
Average Score by Section	3.0	2.7	2.7	2.6	2.8

Scoring criteria 1: poor quality
3: expected quality
5: outstanding quality

APPENDIX C: BMP Existing Research Preliminary Quantitative Comparisons

TABLE C1: BMP averaged surface water inflow and effluent EMC concentrations as reported by the study communications. If average EMC values were not provided, average sample concentrations were reported.

	Coon Street (TERC 2005)	Northwood Basin (SH+G 2003)	Eloise Basin (SH+G 2003)	Eloise Basin (2ND 2006)	Industrial Basin (2ND 2006)	Cattlemen's Basin (USGS 2006)	Tahoe City Wetland (TRG 2005)	Village Green Pond (SH+G 2003)	Edgewood Golf Course Ponds (DRI 2004A)	Angora Meadow (URS 2003)	CDS Vault (DRI & TERC 2005)	Vortechnics Vault (DRI & TERC 2005)	Jensen Vault (DRI & TERC 2005)	Stormceptor® STC 900 (DRI 2004B)	Sediment Trap (DRI 2004B)	Sediment Basin (DRI 2004B)	StormFilter® (2ND 2005C)	Vortechnic Vault (DRI 2004A)
AVERAGE BMP INFLOW POLLUTANT EVENT MEAN CONCENTRATIONS																		
TN (ug/L)	5085	1229	2301	3710	3205	X	1966	6604	X	954	2227	1941	2456	5000	2560	2500	1629	7250
TKN (ug/L)	4124	1056	2132	3270	2948	X	1214	6404	X	796	2123	1794	2274	5000	2430	Y	1371	7070
NOx (ug/L)	961	173	170	440	257	X	722	200	X	Y	88	148	182	300	130	Y	241	180
NH_4^+ (ug/L)	98	11	44	142	152	X	47	468	X	Y	51	35	183	NP	NP	NP	328	130
DKN (ug/L)	X	X	X	1910	1114	X	X	X	X	X	X	X	X	1000	X	X	X	X
TP (ug/L)	1629	321	955	613	759	X	542	1433	X	230	636	872	479	1050	1080	600	363	380
PP (ug/L)	1480	264	898	X	X	X	X	607	X	Y	510	769	373	960	1030	Y	258	Y
DP (ug/L)	149	57	57	136	102	X	139	826	X	Y	126	97	106	90	50	Y	105	Y
SRP (ug/L)	116	48	23	74	83.1	X	112	730	X	Y	99	75	41	50	30	Y	83	70
TSS (mg/L)	481	105	239	X	X	X	120	X	X	Y	226	680	120	1000	784	600	241	115
AVERAGE BMP EFFLUENT EVENT MEAN CONCENTRATIONS																		
TN (ug/L)	1102	940	1916	X	X	X	1,020	3389	370	726	2461	2074	1132	3000	2290	2500	1420	1420
TKN (ug/L)	859	892	1729	X	X	X	749	3381	356	535	2380	1863	1049	3000	2140	Y	1059	1180
NOx (ug/L)	242.5	48	187	X	X	X	262	8	14.4	Y	82	212	83	200	150	Y	321	240
NH_4^+ (ug/L)	25	11	36	X	X	X	14	33	18.4	Y	35	25	180	NP	NP	NP	181	70
DKN (ug/L)	X	X	X	X	X	X	X	X	X	X	X	X	X	900	X	X	X	X
TP (ug/L)	135.5	163	307	X	X	X	122	805	39.6	53	692	640	133	950	800	500	198	170
PP (ug/L)	84	83	253	X	X	X	63	246	29.4	Y	571	552	82	870	750	Y	110	Y
DP (ug/L)	51.5	81	54	X	X	X	59	560	10.2	Y	121	88	51	80	50	Y	88	Y
SRP (ug/L)	27	63	31	X	X	X	38	460	2484.6	Y	84	72	24	30	21	Y	71	80
TSS (mg/L)	15	25	66	X	X	X	10	X	4.08	Y	263	178	24	800	483	400	48	47

X metric not provided in report because the metric was not the purpose of the study and justifiably excluded.
Y metric not provided in report, but could be calculated if additional data analysis performed.
NP pollutant fate and transport not included in study or presented in report, but inclusion may have improved study.
Grey value indicates value was not provided in subject report, but easily calculated by 2NDNATURE for the purposes of this comparative table. TN = TKN + NOx; PP = TP- PP

Coon Street (TERC 2005): Mean inflow EMCs provided for 2003 (Table 10) and 2004 (Table 11) monitoring were averaged. Mean outflow EMCs provided for 2003 (Table 10) and 2004 (Table 11) monitoring were averaged.

Northwood Basin (SH+G 2003): Inflow and outflow EMC values provided in Table 5 were averaged.

Eloise Basin (SH+G 2003): Inflow and outflow EMC values provided in Table 3 were averaged.

Eloise Basin (2NDNATURE 2006): Average surface water concentrations from 2NDNATURE raw data presented in Appendix E.

Industrial Basin (2NDNATURE 2006): Average surface water concentrations from 2NDNATURE raw data presented in Appendix E.

TCWTS (TRG 2005): Surface water inflow EMC average concentrations from Table 1 as presented in Heyvaert et al 2006.

Village Green Pond (SH+G 2003): Average inflow sample concentration values provided in Appendix B. No outflow sampled. Values provided are average concentration of pond samples collected at outlet (Appendix B).

Edgewood Golf Course Ponds (DRI 2004A): Average pond grab sample concentration values for Pond #1 provided in Table 9. Report graphics (Figure 12-16) suggest Pond #1 most downgradient pond in series of locations sampled.

Angora Meadow (URS 2003): Average sample inflow TN, TKN, and TP values for station #1, upgradient sampling location provided in Appendix B data table. Average effluent TN, TKN and TP water sample concentrations for station #5 located at the end of Angora Meadow (Appendix B). Limited raw data for surface water and groundwater samples included analytical results for NOx, NH_4^+, nitrite, SRP, DP, TSS and Fe (Appendix E), but not included in data analysis, results or project discussion.

CDS Vault (DRI & TERC 2005); Average of mean WY2003 and WY2004 EMC values presented for inflow and outflow (Tables 3 and 5).

Vortechnics Vault (DRI & TERC 2005): Average of mean WY2003 and WY2004 EMC values presented for inflow and outflow (Tables 4 and 6).

Jensen Vault (DRI & TERC 2005): WY2004 mean EMC values provided in Table 7.

Stormceptor® STC 900 (DRI 2004B): EMC project mean values not easily extracted from report. Raw data tables included but discrepancies exist between raw data and concentration/EMC data provided in graphics. Additional discussions with researchers and data analysis may be necessary.

Sediment Trap (DRI 2004B): Mean EMC inflow and effluent values provided in Table 4.2.

Sediment Basin (DRI 2004B): EMC project mean values not easily extracted from report. Additional discussions with researchers and data analysis is necessary to ensure representative values presented.

StormFilter®(2NDNATURE 2005C): Event sample mean concentrations in Table 2 were averaged for inflow and effluent study averages. NOx, NH_4^+, SRP samples were not filtered prior to analysis, thus concentrations presented are higher than true values.

Vortechnics Vault (DRI 2004A); Average storm event inflow and effluent concentrations for project presented in Table 5. Baseflow pollutant concentrations not reported here.

TABLE C2. BMP pollutant reduction as reflected by pollutant load and event EMC performance as presented by the project communications. Average performance for each BMP type per pollutant has been calculated and presented for comparison below.

	Coon Street (TERC 2005)	Northwood Basin (SH+G 2003)	Eloise Basin (SH+G 2003)	Industrial Basin (2ND 2006)	Cattlemen's Basin (USGS 2006)	Tahoe City Wetland (TRG 2005)	Village Green Pond (SH+G 2003)	Village Green Pond (2ND 2005A)	Edgewood Golf Course Ponds (DRI 2004A)	Angora Meadow (URS 2003)	Angora Meadow (CWS 2005)	CDS Vault (DRI & TERC 2005)	Vortechnics Vault (DRI & TERC 2005)	Jensen Vault (DRI & TERC 2005)	Stormceptor® STC 900 (DRI 2004B)	Sediment Trap (DRI 2004B)	Sediment Basin (DRI 2004B)	StormFilter® (2ND2005C)	Vortechnic Vault (DRI 2004A)
	% pollutant load reduction for study (negative value indicates load increase at outlet of respective pollutant)																		
Q	18	30	53	X	X	3	Y	Final report and data release expected 2007.	NP	80	Not a pollutant mass balance study.	X	X	X	X	X	Limited hydrology obtained at site	25	NP
TN	Y	Y	Y	X	X	59	Y		X	No hydrology data presented in report, but load calcs may be possible		-14	-2	60	21	32		27	Y
TKN	61	33	55	X	X	59	-100		X			-16	- 1	60	21	33		36	34
NOx	60	81	38	X	X	59	0		X			10	-11	63	65	-15		1	-34
NH_4^+	47	37	33	X	X	76	-7		X			40	26	-21	NP	NP		36	23
DKN	X	X	X	X	X	X	X		X			X	X	X	27	10		X	X
TP	80	Y	Y	X	X	79	-24		X			-8	16	79	25	42		44	31
PP	Y	34	78	X	X	Y	Y		X			Y	Y	Y	Y	Y		63	Y
DP	46	28	58	X	X	71	-11		X			12	14	66	40	14		12	5
SRP	60	30	51	X	X	74	-9		X			24	13	68	51	35		24	-9
TSS	91	74	83	X	X	88	X		X			4	45	94	31	51		76	46
	% pollutant EMC reduction (negative value indicates project EMC increase at outlet relative to inlet for respective pollutant)																		
TN	Y	Y	Y	X	X	49	49	Final report and data release expected 2007.	X	33	Not a pollutant mass balance study.	11	1	36	21	Y	Data presented in Chapter 6 figures do not agree with raw data in Appendix B	13	Y
TKN	65	7	13	X	X	28	47		X	24		8	17	42	21	11		23	83
NOx	66	65	-51	X	X	84	96		X	NP		-15	-26	-77	65	-20		-33	-33
NH_4^+	29	-13	-5	X	X	43	93		X	NP		-4	15	22	NP	NP		45	46
DKN	X	X	X	X	X	X	X		X	X		X	X	X	27	Y		X	X
TP	89	Y	Y	X	X	63	44		X	77		-4	17	52	25	26		45	55
PP	Y	56	64	X	X	Y	59		X	NP		Y	Y	Y	Y	Y		57	Y
DP	53	-41	13	X	X	57	32		X	NP		3	7	-10	40	-1		16	Y
SRP	77	-31	-7	X	X	66	37		X	NP		10	9	-33	51	14		15	-14
TSS	94	72	68	X	X	74	X		X	NP		11	35	58	31	35		80	60

X metric not provided in report because the metric was not the purpose of the study and justifiably excluded.
Y metric not provided in report, but could be calculated if additional data analysis performed.
NP pollutant fate and transport not included in study or presented in report, but inclusion may have improved study.
Grey value indicates value was not provided in subject report, but easily calculated by 2NDNATURE for the purposes of this comparative table. TN = TKN + NOx; PP = TP- PP

DATA DETAILS
Coon Street (TERC 2005): Range of % pollutant reduction values reported in Executive Summary and Conclusions by authors were averaged.
Northwood Basin (SH+G 2003): % load reduction values provided in Figure 22. EMC values in Figures 19-21 used to calculate average % EMC reduction for each pollutant.
Eloise Basin (SH+G 2003): % load reduction values provided in Figure 17. EMC values in Figures 14-16 used to calculate average % EMC reduction for each pollutant.
TCWTS (TRG 2005) as presented in Heyvaert et al 2006: % load reduction values provided in Table 3. Median % EMC reduction provided in Table 2.
Village Green Pond (SH+G 2003): % load reduction calculated from values presented in Figure 24 for only event where outflow was observed (winter rain 11/8/02). EMC % reduction calculated from values in Table C1 (this report).
Angora Meadow (URS 2003): EMC % reductions calculated by 2NDNATURE using inflow and effluent average pollutant concentrations presented in Table C1 (this report).
CDS Vault (DRI & TERC 2005): Cumulative event load reductions for WY2003 and WY2004 averaged (Appendix 7). Median EMC reductions for WY2003 and WY2004 estimated from Figures 23 and 24 and averaged by 2NDNATURE since tabular values not provided in report.
Vortechnics Vault (DRI & TERC 2005): Cumulative event load reductions for WY2003 and WY2004 averaged (Appendix 7). Median EMC reductions for WY2003 and WY2004 estimated from Figures 25 and 26 and averaged by 2NDNATURE since tabular values not provided in report.
Jensen Vault (DRI & TERC 2005): Cumulative event load reduction for WY2004 provided in Appendix 7. Median EMC reductions for WY2004 estimated from Figures 27 by 2NDNATURE since tabular values not provided in report
Stormceptor® STC 900 (DRI 2004B): % pollutant load reduction values presented in Table 7.1. The same % load reduction values are used for % EMC reduction values since discharge for the system was only monitored at the outlet and assumed to be consistent at inlet.
Sediment Trap (DRI 2004B): % load reduction provided in Table 8.1 and reported above. Different % load reduction values presented in Table 4.3 not presented above. % reduction in EMC values provided in Table 4.2.
StormFilter® (2NDNATURE2005C); Cumulative load % reduction presented in Table 2. EMC % reductions calculated by 2NDNATURE using inflow and effluent average pollutant concentrations presented in Table C1 (this report). NOx, NH_4^+, SRP samples were not filtered prior to analysis.
Vortechnics Vault (DRI 2004A); % load reduction values for project presented in Table 8. Inflow and outflow average concentrations (Table 5) used to calculate % EMC performance by 2NDNATURE for the purposes of this comparison.

TABLE C3. Mean groundwater concentrations downgradient of and/or in locations influenced by BMP.

	Coon Street (TERC 2005)	Northwood Basin (SH+G 2003)	Eloise Basin (SH+G 2003)	Eloise Basin 2ND (2006)	Industrial Basin (2ND 2006)	Cattlemen's Basin (USGS 2006)	Tahoe City Wetland (TRG 2005)	Village Green Pond (SH+G 2003)	Edgewood Golf Course Ponds (DRI 2004A)	Angora Meadow (URS 2003)	CDS Vault (DRI & TERC 2005)	Vortechnics Vault (DRI & TERC 2005)	Jensen Vault (DRI & TERC 2005)	Stormceptor® STC 900 (DRI 2004B)	Sediment Trap (DRI 2004B)	Sediment Basin (DRI 2004B)	StormFilter® (2ND2005C)	Vortechnic Vault (DRI 2004A)
											Groundwater representative of both vault systems							
Groundwater concentrations downgradient of and/or influenced by BMP																		
TN (ug/L)	X	X	X	X	X	X	541.2	X	X	156	X		X	X	X	X	X	X
TKN (ug/L)	X	X	X	X	X	X	143.4	X	X	83	X		X	X	X	X	X	X
NOx (ug/L)	X	X	X	242	744	73	19.9	X	X	Y	106		X	X	X	X	X	X
NH_4^+ (ug/L)	X	X	X	20	21	1000	114.3	X	X	Y	14		X	X	X	X	X	X
DKN (ug/L)	X	X	X	264	92	1500	NP	X	X	NP	NP		X	X	X	X	X	X
TP (ug/L)	X	X	X	X	X	X	X	X	X	88	X		X	X	X	X	X	X
PP (ug/L)	X	X	X	X	X	X	X	X	X	Y	X		X	X	X	X	X	X
DP (ug/L)	X	X	X	26	19	130	113.6	X	X	Y	18		X	X	X	X	X	X
SRP (ug/L)	X	X	X	17	27	110	89.0	X	X	Y	10		X	X	X	X	X	X
TSS (mg/L)	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X

X metric not provided in report because the metric was not the purpose of the study and justifiably excluded.
Y metric not provided in report, but could be calculated if additional data analysis performed.
NP pollutant fate and transport not included in study or presented in report, but inclusion may have improved study.
Grey value indicates value was not provided in subject report, but easily calculated by 2NDNATURE for the purposes of this comparative table. TN = TKN + NOx; PP = TP- PP

Data details.

Eloise Basin (2NDNATURE 2006): Average groundwater nutrient concentrations from shallow monitoring wells downgradient of detention basin (Table 17).
Industrial Basin (2NDNATURE 2006): Average groundwater nutrient concentrations from shallow monitoring wells downgradient of detention basin (Table 17).
Cattlemen's Basin (USGS 2006); Average nutrient concentration values from shallow monitoring wells downgradient of detention basin (Table 4).
TCWTS (TRG 2005): Average groundwater values in wells downgradient of wetland termed “best” calculation in Table 6a.
Angora Meadow (URS 2003): Groundwater values average of all sample means for monitoring wells #5, #6, #7 and #8 located in lower meadow (Appendix D). Limited raw data for surface water and groundwater samples included analytical results for NOx, NH_4^+, nitrite, SRP, DP, TSS and Fe (Appendix E), but not included in data analysis, results or project discussion.
CDS Vault (DRI & TERC 2005) and Vortechnics Vault (DRI & TERC 2005): These BMP vaults are located side by side, though accepting waters from different catchments. Groundwater wells located downgradient of effluent. Mean pollutant concentrations for monitoring well #1 and monitoring well #2 (Table 20) averaged and presented above.