2007.01

Technical Memorandum

Task 2. BMP treatment technologies, monitoring needs, and knowledge gaps:
Status of the knowledge and relevance within the Tahoe Basin

By

P.A.M. Bachand and S.M. Bachand,
Bachand & Associates,

A. Heyvaert,
The Tahoe Research Group of the University of California Davis,

California State University Sacramento, Office of Water Programs

April 2005

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EXECUTIVE SUMMARY

This Technical memorandum fulfills Task 2 for Agreement 03-495 between El Dorado County and the Office of Water Programs at California State University Sacramento and their co-authors, Bachand & Associates and the University of California Tahoe Research Group:

1) a review of current stormwater treatment Best Management Practices (BMP) in the Tahoe Basin and their potential effectiveness in removing fine particles and reducing nutrient concentrations;
2) an assessment of the potential for improving the performance of different types of existing BMPs through retrofitting or better maintenance practices;
3) a review of additional promising treatment technologies not currently in use in the Tahoe Basin; and
4) a list of recommendations to help address the knowledge gaps in BMP design and performance.

Review of current stormwater treatment BMPs and an assessment of their potential effectiveness in removing fine particles and reducing nutrient concentrations

The approach used in this review of current stormwater treatment BMPs is to first identify pollutant sources in stormwater runoff in the Tahoe Basin to provide some context behind the assessment of different BMPs; develop models describing cycling and removal of PoC; analyze the performance of these different existing treatment BMPs based on data available from national datasets and an understanding of the processes likely removing the different pollutants of concern (PoCs) from stormwater; and then to discuss the potential of existing stormwater treatment BMPs to meet regulatory requirements in the Tahoe Basin.

Pollutant Sources

Pollutants of Concern (PoCs) are those pollutants most likely to affect lake clarity. Phosphorus (P) and, to a lesser extent, nitrogen (N) are considered to be the nutrients limiting algal growth in Lake Tahoe. An estimated 75% of the annual load of bioavailable P, soluble reactive P, is mobilized by rain events while about 60% of bioavailable nitrogen, ammonia and nitrate, is mobilized by snowmelt (Strecker and Howell, 2003). Fine suspended sediments less than 10 µm, commonly defined as clays or fine silt, degrade water clarity at Lake Tahoe by 50% or more. Particles less than 20 µm are not effectively targeted by most structural BMPs; larger fine particles up to 63 µm are generally less effectively treated by most structural BMPs than particles greater than 63 µm.

Models

Cycling and transport models for the primary PoC (nitrogen, phosphorus, and fine particles and solids) are developed in this document. The goal of these models is to provide the reader with an

understanding of the important processes controlling cycling, transport and removal. By understanding these processes, designers and engineers are more likely to be able to more effectively target PoC treatment with existing and future stormwater treatment BMPs. The models can be found in Section 2.2.

Predicting Performance of Existing BMPs and Assessing the Potential of Existing BMPs to Meet Tahoe Basin Regulatory Requirements

Existing stormwater treatment BMPs in use in the Tahoe Basin and their abundance were identified from a qualitative survey to several agencies in the Basin (e.g. El Dorado County, Placer County, the City of South Lake Tahoe) and to CSUS Office of Water Programs representing Caltrans. Data was provided by Place County, the Office of Water Programs and the City of South Lake Tahoe. The survey indicated that hydrodynamic devices, used to remove particulates, are by far the most numerous BMPs. Relatively numerous and widespread BMPs include dry detention basins, infiltration basins, bioretention basins, and water quality swales. Less numerous are vegetated filter strips, wet ponds and stormwater wetlands. Very little use is reported for media filters, infiltration trenches, porous pavement, and filtering drain inlets.

The general effectiveness of these different BMPs was assessed through a review and analysis of two national datasets. In this assessment, we identified outflow concentration and load reduction achieved for each PoC. Based on these analytical results, we predicted if these existing BMPs can be expected to meet Tahoe Basin surface water or infiltration discharge standards. We also ranked the existing BMPs based on their ability to meet the discharge standards as well as on the load reduction that would be expected for the different BMPs. In this way, we assessed BMPs from both an effluent-based and TMDL-based regulatory environment.

Several conclusions were made regarding the expected performance of existing BMPs for each PoC. Key conclusions are shown below though greater detail can be found in the report:

Nitrogen
- Reported outflow concentrations from these systems are similar. More effective BMPs achieve TN concentrations in the 0.9 to 1.5 mg/L. Less effective systems achieve TN concentrations in the range of 1.7 to 3.8 mg/L. Some of these systems see an increase in TN which in part may be due to asynchronous sampling or the flushing of organics during storm events. Some increase in TN may also be due to organic matter accumulation during and between storm events and then its flushing during subsequent storm events.
- Surface water discharge standards are unlikely to be met by any of these BMPs under typical conditions and configurations.
- BMPs are more likely to differentiate themselves in a TMDL environment under which load reduction is more important. Data suggests that several BMPs may be above average performers: media filters, dry basins, wet ponds, wetland channels, infiltration basins, infiltration trenches and porous pavement. Wet ponds seem the best choice for TN load reduction based upon the reliability of the data. Overall, TN removal is likely to be in the range of about 20 to 40%. The actual value will likely depend upon BMP

     operation, design and maintenance, and may be limited by the BMP's minimum achievable nitrogen concentration, or irreducible concentration.

- There may be a TN concentration that defines the lowest achievable level that can be achieved through treatment. This concentration is likely to exceed the surface discharge limit of 0.5 mg/L and we believe it will be in the range of 1 to 1.5 mg/L based on the data presented in these datasets.

Phosphorus

- When assessing the BMPs from an effluent standard perspective, the data suggest the different existing stormwater BMPs will be ineffective in meeting surface water discharge standards. The minimum mean TP outflow concentrations achieved are in the range of 0.1 to 0.2 mg/L (dry detention basins, media filters, wetland channels, stormwater wetlands). The data suggests a minimum achievable (or irreducible) outflow concentration around 0.1 mg/L.
- From a load removal perspective, the more effective systems for P removal tend to be BMPs in which there is a biotic component: wetlands, wet ponds and wetland channels. Removal rates are expected to be in the range of 22 to 50%.
- Other BMPs may have above average performance from the load reduction perspective and these include media filters, infiltration basins, infiltration trenches and porous pavement. Oil grit separators, centrifugal concentrators, grass filter strips (biofilters) and dry detention basins are not expected to perform as well and some may perform badly.
- Total phosphorus that is incorporated in medium and coarse particles is likely to be removed more effectively by existing BMPs than dissolved phosphorus or phosphorus incorporated with fines.
- There is insufficient data to assess the effectiveness of the different BMPs for ortho-P or dissolved organic P removal. Both these forms of P are more biologically available, with ortho-P the most biologically available.

Fine Particles and Solids

- Current surface water turbidity standards will be difficult to meet for any of these stormwater treatment BMPs. Turbidity infiltration standards are likely to be met.
- No data exists in the datasets to assess the distribution of fine particles. Fine particles may become a focus of the TMDL though how the metric that will be used has not been determined at this time.
- A number of stormwater BMPs are expected to be able to achieve above average load reduction. Possible BMPs include media filters, wetland channels, stormwater wetlands, wet ponds, filter strips, infiltration basins and porous pavement. The data for media filters, wetland channels and stormwater wetlands is more robust. The other BMPs listed here will likely need more field testing to improve confidence in this conclusion.

In consolidating the results for each PoC and considering both an effluent-based and TMDL-based regulatory environment, we were able to make several conclusions regarding the existing BMPs. In an effluent-based regulatory environment, different stormwater BMPs currently being implemented in the Tahoe Basin are unlikely to meet surface water discharge standards for TN, TP and turbidity, though they are likely to meet infiltration standards. In general, all the BMPs are expected to perform similarly with regard to meeting TN and TP infiltration standards though

some BMPs will be more effective at meeting turbidity infiltration standards. In a TMDL based regulatory environment, we expect the BMPs selected will have more of an effect on meeting regulatory standards. For TN removal, wet ponds are likely the most effective and a number of other BMPs, including media filters, dry basins, wetland channels, infiltration basins, infiltration trenches, and porous pavement could potentially provide above average performance for load reduction. For TP, wet ponds, wetlands and wetland channels are expected to be the most effective for load reduction and several others including media filters, infiltration basins, infiltration trenches and porous pavement have potential to provide above average removal. For turbidity removal, media filters, wetland channels, and wetlands are expected to provide the greatest load reduction and others such as wet ponds, biofilter strips, infiltration basins, infiltration trenches and porous pavement may provide above average performance. Overall, media filters, wet ponds, wetland channels (water quality swales) and stormwater wetlands are considered the more effective stormwater BMPs based upon their overall predicted load reduction for each PoC.

The Potential for Improving the Performance of Different Types of Existing BMPs through Retrofitting or Better Maintenance Practices

Potentially, opportunities to improve the performance of existing BMPs are found through improved maintenance activities or through retrofitting the existing BMPs.

Maintenance

Existing maintenance activities focus on maintaining the functionality of the existing BMPs such as maintaining structural integrity, preventing sediment buildup, preserving appropriate flow characteristics (preventing short-circuiting), reducing mosquito breeding potential, and sustaining and trimming vegetation. Documents have been developed by Caltrans and TIRRs to address these issues. These documents appear to rely upon nationally-based recommendations for maintenance and upkeep. Data relating performance to maintenance is generally no available.

Another approach to maintenance would be to focus on enhancing the processes most important to PoC removal within the BMPs. This approach to maintenance would go beyond a strict focus on functionality. Rather than asking the question of what is required to keep a system functional, questions can be asked on what processes are we trying to enhance and how different maintenance activities affect those processes. This approach has not been tested in the basin, and as data relating performance to maintenance is generally not available, there is no certainty that this change in maintenance strategy will greatly affect performance. In fact, the performance of the existing stormwater treatment BMPs in the Tahoe Basin may be relatively insensitive to these process-based maintenance activities and the level of performance improvement may be relatively small.

Retrofitting

Retrofitting is likely to have a greater affect on performance then changing maintenance methods. Retrofitting can focus on improving hydrology and enhancing performance.

Appropriate hydrology is very important for effective operation of any stormwater treatment BMP. This consideration is important for treatment BMPs because without proper delivery of the stormwater, treatment cannot be accomplished effectively. Retrofit activities that minimize flow short-circuiting, lead to even distribution of flow, prevent shortening of hydraulic retention times, and maintain desired wetting frequencies and water depths are likely to improve the performance of the BMPs to which they are applied.

Other opportunities for retrofit exist with some of these based upon our review on new BMP technologies. Depending upon the PoC targeted by a specific BMP, different retrofit strategies may be pursued. These retrofits are likely to generally fall in a few different categories which are listed below:

- Chemical Dosing Technologies to improve removal of phosphorus, fine particles and particulate nitrogen
  - o Passive or Active
  - o Chemical or electrical
- Adsorptive Media to improve adsorption of dissolved phosphorus and other dissolved organics
- Adsorptive Media to improve filtration of fine particles and particulate PoC
- Energy Dampening to improve setting and reduce resuspension of fines
  - o Biotic (vegetation) or abiotic (grids, baffles)
- Implementation of biotic community (vegetation, microbial population) to improve uptake and processing of biologically available nutrients

These retrofit opportunities are likely most applicable to wet and dry basins, treatment wetlands and infiltration systems. Investigations of technologies for the purpose of retrofit have begun in the Tahoe Basin and have been supported from funding by the U.S. Forest Service and Caltrans and supported by the City of South Lake Tahoe and Placer County.

For any of these retrofit ideas listed above, more work is required for proof of concept before they can be implemented at full-scale. Performance questions will need to be addressed such as which PoC will be affected, what improvement in removal can be expected and will these retrofits enable the stormwater treatment BMPs to meet current surface water discharge standards. Data suggest some of these retrofits, such as chemical dosing, potentially may enable existing stormwater treatment BMPs in the basin to meet current surface water discharge standards for PoC and to improve load removal rates of PoC. Others retrofit technologies, such as utilizing adsorptive media, may have more limited retrofit potential but easier deployment may enable a broader range of strategies when considering opportunities in a TMDL environment.

In addition to performance issues, logistical, environmental and other issues will need to be addressed. These issues need to be addressed through activities such as literature reviews and smaller-scale laboratory and field testing such as that which is underway for a number of technologies.

Additional Promising Treatment Technologies Not Currently in use in the Tahoe Basin

Promising stormwater treatment technologies are reviewed in this document in the context of PoC removal.

Targeted Removal Processes

Based upon the transport and cycling models that we present in this document and a review of the data, we have identified processes and mechanisms that should be targeted in these new technologies to improve performance over existing stormwater treatment BMPs (Section 3.1). For turbidity and solids removal, structures or designs, biotic or abiotic, that dampen energy will improve settling and reduce resuspension of fine particles. Chemical dosing (or biotic processes0 that lead to coagulation and precipitation will also lead to enhanced removal of fines over those that can be achieved with the existing treatment BMPs. Phosphorus removal can be enhanced through a number of processes that include P adsorption and precipitation, improve settling rates and/or include biotic processes. Inorganic nitrogen removal is most effectively removed through the microbial processes of nitrification and denitrification. Actions and designs that enhance those processes should enhance inorganic N removal. Organic N is more problematic and is likely to be most effectively removed when it is removed through chemical dosing. This may occur for particulate organic N through improved settling. Importantly, designs and actions should be taken to prevent the recycling of N back into the stormwater treatment BMPs. These principals can generally be used to assess new technologies as well as to develop retrofit designs.

New Technologies

Several new technologies that have been laboratory or small-scale field tested are reviewed in Section 3.2:

- Dual Media (Adsorptive Media) Filter,
- Chemical Dosing followed by Settling,
- Ion Exchange,
- Sand Filters, and
- Passive Chemical Delivery.

Some other promising technologies have not been tested in the Tahoe Basin are reviewed in Section 3.1:

- Electro-coagulation,
- Engineered Chemical Dosing and Filtration, and
- Passive Chemical Dosing followed by Baffle Grids or Particle Curtains.
- Small-Scale Stormwater Treatment Systems.

These technologies were reviewed for their potential to treat stormwater to meet Tahoe regulatory requirements, including N, P and fine particle load removal expected under the upcoming TMDL framework. With the exception of sand filters, these technologies are likely to significantly improve outflow water quality because they focus on removal of dissolved

phosphorus and fine particles. In general, they utilize either adsorptive to enhance fine particle removal or chemicals to enhance coagulation and the creation of settleable and filterable solids. These processes are important when targeting dissolved, ortho- and total P, as well as fine particles. Data suggests that some of these technologies may also improve the removal of organic N and other pollutants. Thus, some of these technologies will provide improved treatment of PoCs if they can be cost-effectively and reliably implemented.

Of these technologies, those new technologies considered most promising are Dual Media (Adsorptive Media) Filters (3.2.1), Chemical Dosing and Settling (3.2.2), Passive Chemical Delivery (3.2.5), Electro-coagulation (3.3.1), Engineered Chemical Dosing and Filtration Systems (3.3.2), and Passive Chemical Delivery and Baffle Grids (3.3.3).

Recommendations to Help Address Knowledge Gaps in BMP Design and Performance

This section lists recommendations to address knowledge gaps in BMP design and performance by providing proposal ideas that will aid agencies in specifying design standards and quantifying BMP performance for addressing storm water permitting and TMDL needs. These recommendations are not specific to El Dorado County but are for the Tahoe community. These activities should progress concurrently with activities by state and federal agencies to develop the TMDL and efforts should be made that these two activities are developing complementary information.

More details on the rational and justification behind the different justifications can be found in Chapter 5.

Quantify Performance of Current and Future Stormwater Treatment BMPs in the context of meeting Current and Future Regulatory Needs.

Recommendation 5.1a.   Standardize sampling and monitoring procedures at the Tahoe Basin.

Recommendation 5.1b.   Conduct necessary laboratory and field studies to predict the performance of the more promising existing stormwater treatment BMPs, retrofit activities, and promising BMP technologies

Recommendation 5.1c.   Survey current stormwater treatment BMPs being implemented by different agencies and identify retrofit opportunities for each agency

Recommendation 5.1d.   Investigate and better understand outflow and internal hydrologic control options available for managing hydrology in basins, infiltration systems and wetlands.

Recommendation 5.1e.   Develop Watershed Model to Estimate Watershed Loads Under Different BMP Deployment Strategies.

Recommendation5.1f.   Support efforts to develop source control BMPs.

Develop a More Coordinated Approach to Stormwater BMP Development and Implementation

Recommendation 5.2a.   Promote the formation of a Stormwater BMP Working Group to Coordinate Stormwater BMP Research and Implementation:

- provide a forum for frequent discussion of BMP research and activities in the Tahoe Basin;
- be involved in identifying research and implementation actions, and for securing funding for those actions through agreements with funding organizations;
- oversee and manage the development of a technical design manual for BMPs;
- Organize and manage conferences on BMP technologies; and
- Provide peer review of design and implementation strategies.

Recommendation 5.2b.   Better define PoC and Regularly Report Progress to Local Agencies.

Acronyms

Technical Terms

Al	Aluminum
BMP	Best Management Practice
CI	Confidence Interval (statistical term)
CTMP	Chemical Treatment Methods Pilot (i.e. LICD)
DOC	Dissolved Organic Carbon
DON	Dissolved Organic Nitrogen
DP	Dissolved Phosphorus (Filtered Total Phosphorus)
DI	Dionized (water)
Fe	Iron
FPOM	Fine particulate organic matter
mg/L	milligrams per liter (ppm)
MT/y	Metric Tons per year
N	Nitrogen
NH_4	Ammonium
NO_2	Nitrite
NO_3	Nitrate
NOx	Atmospheric Nitrogen Oxides
N_2	Nitrogen gas
N_2O	Nitrous Oxide
NTU	Nephlometric Turbidity Units
P	Phosphorus
PACl	Polyaluminum chloride (broad class of aluminum based coagulants)
PAM	Polyacrylamide (anionic coagulant)
PoC	Pollutant of Concern
PON	Particulate Organic Nitrogen
ppm	parts per million (mg/L)
ppb	parts per billion (μg/L)
SD	Standard deviation
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen (ammonia plus organic nitrogen)
TN	Total Nitrogen
TON	Total Organic Nitrogen
TP	Unfiltered Total Phosphorus (e.g. total phosphorus)
TSS	Total Suspended Solids
μg/L	micrograms per liter (ppb)

Organizations

ASCE	American Society of Civil Engineers
EPA	Environmental Protection Agency
FS	USDA Forest Service
LRWQCB	Lahontan Regional Water Quality Control Board
OWP	Office of Water Programs, California State University Sacramento

SMRC	Stormwater Manager's Resource Center
SWRCB	California State Water Resources Control Board
TRG	Tahoe Research Group
UCD	University of California Davis
USACOE	U.S. Army Core of Engineers
USDA	U.S. Department of Agriculture

1 Introduction

This technical memorandum fulfills Task 2 for Agreement 03-495 between El Dorado County and the Office of Water Programs at California State University Sacramento (OWP) and their co-authors, which include Bachand & Associates and the University of California Tahoe Research Group (TRG). The following document provides 1) a review of current treatment Best Management Practices (BMP) in the Tahoe Basin and their potential effectiveness in removing fine particles and reducing low nutrient concentrations; 2) an assessment of the potential for improving the performance of existing BMP types through retrofitting or better maintenance practices; 3) a review of additional promising treatment technologies not currently in use in the Tahoe Basin; and 4) a list of proposal ideas for the purpose of addressing knowledge gaps in BMP design and performance.

2 Review of Current Treatment BMPs in the Tahoe Basin (Task 2a)

The section addresses Task 2a of the Agreement 03-495 between El Dorado County and OWP. It provides a review of current treatment BMP types in the Tahoe Basin and their potential effectiveness in removing fine particles and reducing low nutrient concentrations. BMP types currently in use are identified based upon readily available information. The evaluation of BMP effectiveness is based on an analysis of the national datasets on stormwater BMPs, a review of literature sources, and an understanding of the known removal mechanisms. It is not based upon a detailed examination of data sets in the Tahoe Basin. This section ends with a discussion of the potential of BMPs currently applied in the Tahoe Basin to meet Tahoe Basin regulatory requirements.

2.1 Pollutant Sources

Preliminary results from Heyvaert et *al.* (2004) summarize the most current key assessments of pollutant loading to the lake, identifying the pollutants of concern (PoCs) in the Tahoe Basin, and the different loading sources. This summary (Heyvaert et *al.*) provides the necessary background for developing BMP implementation strategies to remove the PoCs in the Tahoe Basin:

- **Pollutants of concern**
    - o Phosphorus (P) is considered to be the nutrient limiting algal growth in Lake Tahoe during most the year, though both nitrogen and P co-limit algal growth during the summer and autumn during periods of strong lake stratification.
    - o Lake Tahoe's clarit attenuation (Secchi depth) is due to light scattering and adsorption. About 50% of this attenuation is due to suspended inorganic particles, and about 30% is due to algae. The remaining 20% is due to adsorption and scattering by pur water and dissolved organics.
    - o Fine suspended sediments less than 10 µm, commonly defined as clays or fine silt (depending upon the classification system used), are the suspended inorganic particles that degrade water clarity as discussed above. These particles long remain in suspension because of the lake's great depth and long fetch.
- **Loading Sources**
    - o Atmospheric deposition, stream loading and direct runoff from intervening zones each contribute an equivalent 12 to 13 Million tons per year (MT/y) of total P.
    - o Atmospheric deposition and groundwater are nearly equivalent sources of soluble P (~5 – 7 MT/y), the more labile form of P (Table 2-1 from Heyvaert et *al.*, 2004).
    - o Atmospheric deposition contributes about 60% total N (Table 2-1 from Heyvaert et *al.*, 2004).
    - o Pollutant loading from different land uses tends to increase with land disturbance causing runoff from Residential, Commercial and Highway to oftentimes exceed current surface water discharge standards (Table 2-2 from Heyvaert et *al.*, 2004 and Caltrans 2003b). In some cases, a specie or subset of the PoC will exceed the surface water discharge standard. For instance, whereas total nitrogen is regulated, TKN alone exceeds the surface water discharge standard. Additionally,

> some of the resulting PoC concentrations will also exceed infiltration standards. This is the case with Highway runoff for which average TP concentrations exceed both the surface water discharge standard of 0.1 mg/L but also the infiltration standard of 1 mg/L.
>
> o Highways and roads serve as conduits for stormwater, increasing runoff volumes and velocities at downstream locations.
>
> o An estimated 75% of annual load of soluble reactive P (which is currently assumed as the bioavailable P), is mobilized by rain events while about 60% of ammonia and nitrate (which is assumed to be the bioavailable nitrogen) is mobilized by snowmelt (Strecker and Howell, 2003).
>
> o All particle sizes appear to contribute to P loading to the Lake but fine particle fraction of less than 63 µm (silts and clays) are typically not effectively targeted by many structural BMPs.
>
> o Whereas TSS is a measure of total suspended solids, turbidity is disproportionately affected also by colloids and fine particles. In the Tahoe Basin, the ratio between TSS and turbidity is approximately 1.4. The ratio is higher for untreated flow then for treated flow demonstrating that stormwater BMPs more effectively remove larger particle sizes. The ratio is also higher for urban areas as opposed to rural areas. This trend shows that land use disturbance increases the overall particle size of the solids in the stormwater runoff.

Other factors likely to contribute to pollutant loading besides disturbance and land use are variables such as slope, percent impervious area, and compaction. From the different sources, these factors affect both the pollutant concentrations as well as the flow variability, amplitude and event frequency. Heyvaert et al (2004) provides a more detailed review and analyses of pollutant sources to Lake Tahoe, as well as a useful discussion of selected issues important to basin and wetland function in the region.

Table 2-1. Estimated Sources of Pollutant Loading to the Lake
Table presents preliminary results characterizing stormwater pollutant loading to the Lake.
(From Heyvaert et *al.*, 2004.)

Source	Total N		Total P		Soluble P	
	$(MT/y)^2$	(%)	$(MT/y)^2$	(%)	$(MT/y)^2$	(%)
Atmospheric Deposition	234	60%	12.4	27%	5.6	33%
Stream Loading	82	21%	13.3	29%	2.4	14%
Direct Runoff[1]	23	6%	12.3	27%	2.4	14%
Groundwater	51	13%	6.8	15%	6.8	40%
Shoreline Erosion	1	< 1%	1.6	3%	na	na
Total (MT yr^{-1})	391		46.4		17.2	

Notes

1. From intervening zones between stream watersheds that transport COC's directly to the lake through ephemeral channels and culverts.

2. MT/y = metric tons per year.

Table 2-2. Estimate for selected pollutants from different land uses.
Shaded cells indicate where current surface water discharge standards are exceeded for specific PoC (e.g. TN, TP, TSS, turbidity). Darkly shaded areas show where the surface water discharge standard is for specific PoC that are regulated (e.g. TN, TP and turbidity). Lightly shaded areas show where particular specie for a PoC exceeds the surface water discharge standard. For instance, TKN alone exceeds the TN surface water discharge standard. In some cases, infiltration standards are also exceeded. The infiltration standard for TP is 1 mg/L and that standard is exceeded by Highway runoff, which has an average TP concentration of 1.21 mg/L. TSS is one measure for monitoring the discharge of solids. Turbidity is another metric and the relationship between TSS and turbidity depends upon the source. The data presented for turbidity is from Caltrans (2003b). In the Tahoe Basin, the TSS/turbidity ratio is approximately 1.4. The table presented is modified from Heyvaert *et al.*, 2004 (with data from Strecker and Howell 2003, ACOE 2003a, Reuter et *al.* 2001) and includes data from Caltrans 2003b.

Source [1]	Pollutants of Concern[3]						
	NO3-N (mg/L)	TKN (mg/L)	TN[2]	SRP (mg/L)	TP (mg/L)	TSS (mg/L)	Turbidity NTU
Surface Water Discharge Std			0.5		0.1		20
Runoff, undisturbed forested area	0.01	0.14	0.15	0.01	0.02	3	
Residential area runoff	0.05	1.41	1.46	0.03	0.26	431	464[4]
Commercial area runoff	0.2	2.16	2.36	0.14	0.54	178	503[5]
Highway runoff	0.25	1.84	2.09	0.11	1.21	1133	
Forested area groundwater	0.12	0.06	0.18	0.05	0.07	--	
Residential area groundwater	0.37	0.26	0.63	0.08	0.11	--	
Commercial area groundwater	0.51	0.16	0.67	0.09	0.12	--	
Recreational use area groundwater	0.42	1.26	1.68	0.07	0.1	--	
Precipitation at Tahoe	0.2	0.2	0.4	< 0.03	0.04	13	3.8

1. Groundwater NO_3-N includes nitrite, and groundwater TP represents total dissolved phosphorus as reported in ACOE (2003a).
2. Calculated value from the addition of nitrate and TKN.
3. Light shading shows that one specie of pollutant exceeds surface water discharge std. Dark shading shows that pollutant total (e.g. TP, TN, TSS) exceeds the surface water discharge standard.
4. Rural (Caltrans 2003b)
5. Urban (Caltrans 2003b)

2.2   Models for Nutrient and Fine Particle Cycling and Removal

Stormwater systems typically focus primarily on total suspended solids or turbidity removal and oftentimes the systems are designed to provide treatment to the maximum extent practicable. This non-quantitative approach does not usually require the discharger to meet numeric limits. Rather, it requires that the BMP have the capacity to treat an identified volume. For Tahoe, the requirement for the typical BMP is to treat the 20-year, 1-hour storm. This approach, which does not require performance data, makes it difficult to assess the effectiveness of a given BMP. In recent years, more effort in the Tahoe Basin has focused on collecting performance data for the different BMPs. However, this effort is fairly young, methodologies are not yet standardized, and there is not a single clearinghouse for the data, although the TIIMS is designed to ultimately serve this purpose. Moreover, the Tahoe environment complicates the issue of assessing performance. Widely variable temperatures, high precipitation and rainfall, steep terrain and

oligotrophic lake conditions all make this watershed atypical and makes any determination of effectiveness difficult.

Because of the lack of reliable performance data, increasingly strict requirements on PoC discharge, and the atypical environment in Tahoe, a first step we are using in this assessment is identifying nutrient and particle removal processes in the development of models that describe processing of the different PoCs. As we have discussed, the three primary PoCs in the Tahoe Basin are nitrogen, phosphorus and fine particles. This section presents three models to describe the cycling and transport of these PoCs. With these models, we identify processes with high potential to remove the PoCs and hope to identify BMP strategies and approaches for improved removal of PoC from stormwater runoff. This approach has been used to design treatment wetlands and develop accompanying BMPs to improve nitrate removal by the treatment wetlands (Bachand and Horne, 2000; Bachand, 1996) and is currently being implemented to develop BMPs to minimize dissolved organic carbon (DOC) and nutrient export from rice fields (CCWD, 2002). These models should help us better understand PoC processing and better predict which BMPs will be effective for removal of different PoCs and ideally aid in developing a strategy on their use in the Tahoe Basin.
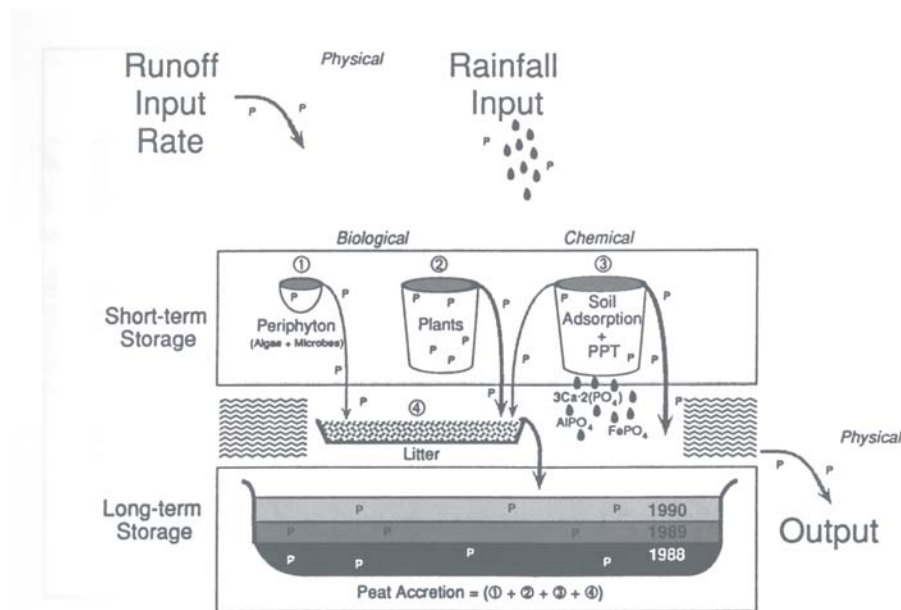
2.2.1 Phosphorus Cycling

Figure 2-1 from Richardson et *al.* (1997) presents the phosphorus cycle for a wetland environment. The short-term storage pools for phosphorus are periphyton (algae and microbes), plants and soil, with each of these pools successively larger. As wetlands age, these short-term pools approach capacity, progressively leading to less and less P removed from the water column. This scenario is well documented (Richardson et *al.*, 1997; Craft and Richardson, 1993; Qian and Reckhow, 1998). Long-term storage of phosphorus is then through burial of recalcitrant litter and sediments, and limited by the accumulation rates of these materials. Short-term storage can be increased by the addition of adsorptive materials which have higher P storage capacity than local sediments as well as through the addition of chemicals which result in precipitation. Both these chemical applications typically rely on iron, aluminum or calcium-based materials, as these materials have relatively high P adsorptive capacity and can form precipitates with P at certain pH conditions.

This wetland model applies fairly well to other systems as well because it includes all the P cycling and uptake processes:

- biotic uptake of P by periphyton, microbes and algae; and
- abiotic processes such as chemical adsorption, precipitation, settling and burial.

The predominance of each process depends largely upon the environment. For instance, in systems that dry out, periphyton will be reduced or eliminated and not provide short-term storage. Dry-down conditions will increase redox conditions in the sediments and this oxidized state will increase decomposition of recalcitrant litter beyond that level which occurs under flooded conditions. Reflooding will then lead to a short-term pulse of P being mobilized before biotic uptake and chemical adsorption again begin the short- and long-term storage processes.

Other processes are not clearly shown in this model. Periphyton (attached algae) and phytoplankton (floating algae) are a food source for zooplankton, which then are consumed by other small and large animals. Phosphorus is then cycled back into the system through necrosis or excretion. Additionally, soluble phosphorus can be released from the sediments through the decay of organic material and detritus. That being said, this model shows the sinks and their degree of importance well.

Figure 2-1. Phosphorus Cycle

This pollutant removal model is from Richardson et *al.* (1997) and describes aquatic phosphorus removal processes and sinks. The short-term sinks for phosphorus are periphyton, plants and soil adsorption and precipitation, with the capacity of the sink described by the bucket size. The long-term sink for P removal is burial through peat accretion or accumulation of inorganic sediments that have absorbed onto P or precipitated (PPT) with P. Phosphorus can be recycled back into the system through food web dynamic (e.g. necrosis, excretion) and microbial processes decomposing organic sediments and detritus.

2.2.2 Nitrogen Cycle

Figure 2-2 presents the nitrogen cycle for aquatic systems, modified from Horne and Goldman (1994). The figure clearly shows the nature of nitrogen cycling, with multiple processes transforming and recycling nitrogen back into the environment. Several microbial processes change nitrogen from one species to another: denitrification, nitrification, mineralization and assimilation. These processes ensure the bioavailability of nitrogen in natural systems.

In Figure 2-2, sources and sinks for nitrogen are shown as shaded areas. Nitrogen is introduced into aquatic systems through nitrogen fixation, atmospheric deposition and through runoff. In areas receiving anthropogenic nitrogen loading, nitrogen fixation is negligible, only occurring when nitrogen is limiting. Sinks for nitrogen include the formation of nitrogen gas and nitrogen oxide, the burial of recalcitrant litter, the volatization of ammonia gas, and through physical removal of macrophytes and algae. In aquatic systems without elevated pH levels, ammonia volatization is negligible. Stormwater treatment systems from developed regions tend to have relatively enriched nutrient conditions in their inflows and this is true in the Tahoe Basin as well (Table 2-2). In nitrogen enriched systems, the dominant processes for nitrogen removal are the sequential microbial processes nitrification and denitrification. Of these two reactions, nitrification is slower and oftentimes limits the reaction rates of both. Denitrification is dependent on a number of factors including anoxic conditions, temperatures sufficient for microbial processes to occur, available labile organic carbon, and delivery of nitrate to areas in which denitrification is occurring (Bachand, 1996).

In comparing this model with that for phosphorus, most nitrogen removed from the system will be lost as nitrous oxide and nitrogen gas. In comparison, phosphorus does not have a dominant gaseous phase and its ultimate removal is primarily through processes that lead to its burial in the sediments.

Not shown in this model are coagulation and precipitation effects. These processes are discussed in the later sections and technologies utilizing these processes are discussed in Task 3. Precipitation and coagulation effectively remove DOC, and this result should enhance the transport of dissolved organic nitrogen (DON) and particulate organic nitrogen (PON) to the sediments. Their ultimate removal will depend upon the recalcitrance of the formed precipitates and the microbial activity on these precipitates.
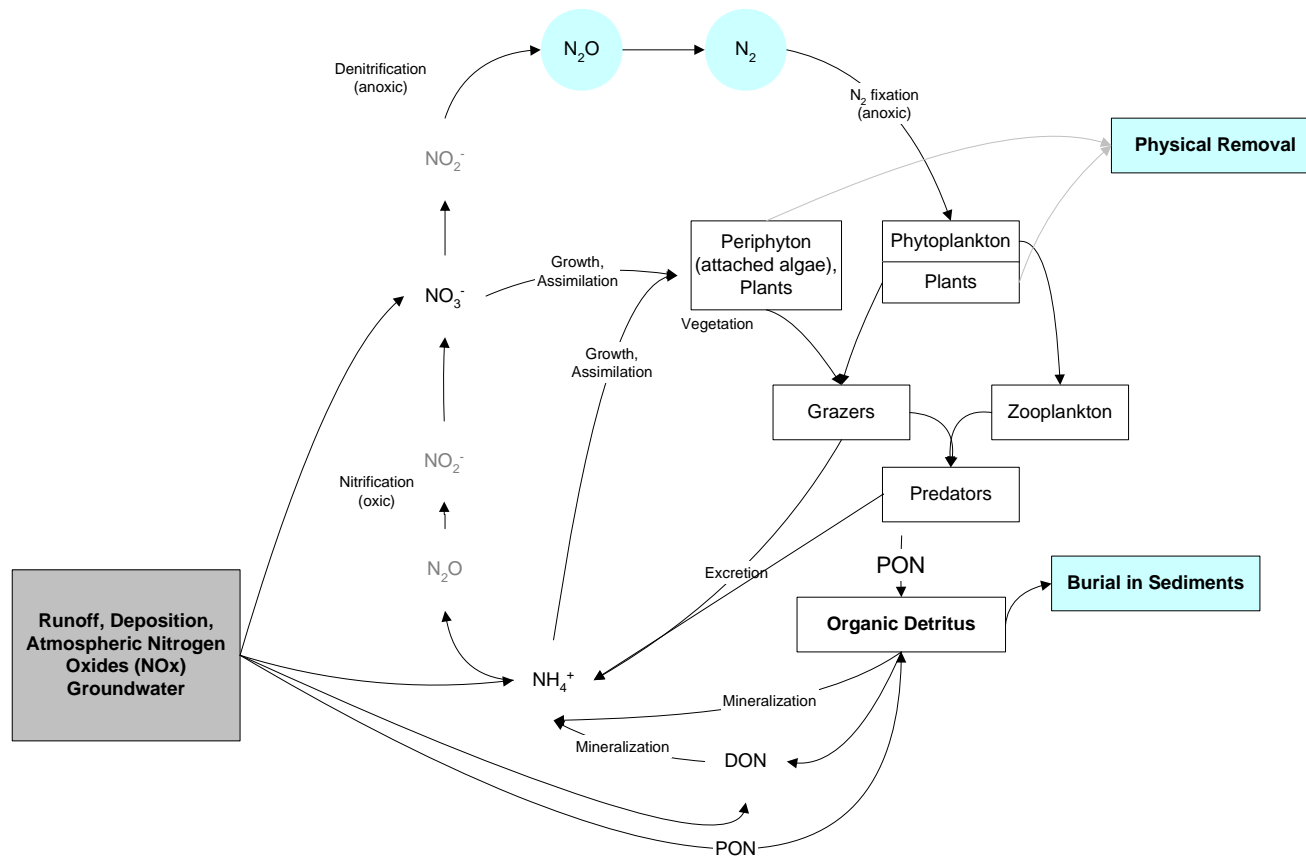
Figure 2-2.   Nitrogen Cycle

Figure 2 is modified from Horne and Goldman (1994) nitrogen model for freshwater aquatic systems. Sources and sinks for nitrogen are shown as shaded areas. Nitrogen is introduced into aquatic systems through nitrogen fixation, through runoff and atmospheric sources such as deposition and atmospheric nitrogen oxide (NOx). In areas receiving anthropogenic nitrogen loading, nitrogen fixation is negligible as it only occurs when nitrogen is limiting. Nitrogen can be removed through the formation of nitrogen gas and nitrous oxide as well as through incorporation into sediments or through physical removal of sediments or plants. Ammonia can be volatized but this occurs at pH levels atypical of most aquatic systems including stormwater wetlands and ponds. In typical aquatic systems, nitrification and denitrification is the dominant process removing nitrogen from the aquatic system.

2.2.3   Solids and Fine Particle Cycling

Figure 3 presents a model describing solids and fine particle cycling. Solids removal depends upon the form of the solid, whether dissolved or particulate, and, if particulate, the particle size. Coarse and medium size particles are removed relatively effectively through settling and filtration whereas fine particles are not. The importance of assessing particle size when assessing BMP performance has been demonstrated in a number of Caltrans studies. Caltrans (2001) showed that anywhere from around 6- 92% of particles in sand trap effluent were fine particles (< 63 µm). Caltrans (2002) found that double barrel sand traps removed about 55% of particles within the 0.5 to 300 µm range and that the majority of the particles removed fell in the 0.1 – 2 mm (100 – 2000 µm). In outflow from the Echo Summit and Tahoe Airport, the majority (in mass) of particles in the outflow ranged from approximately 2 to 31 µm; and particles ranging in size between 6 to 8 µm had the single highest mass. Thus, sand traps are more effective at removing medium and coarse grain particles, and not very effective at removing fine and very fine particles. For Lake Tahoe where fine particles are the primary factor reducing lake clarity, BMP assessments that do not characterize the size of the particles may not adequately address the critical treatment issues as they relate to lake clarity (Heyvaert et *al.*, 2004).   Thus, while monitoring of turbidity and/or total suspended solids (TSS) may be useful for meeting current infiltration and surface water discharge standards, that approach will likely be insufficient under the future TMDL.

Figure 2-3 shows that fine particles, especially those approximately 10 µm or less, will have enhanced settling and filtration through precipitation and coagulation processes.   Biotic processes may also be important in transporting fine particles to the sediments. Minshall et *al.* (2000) found the depositional velocities for fine particulate organic matter (FPOM) between 53 and 106 µm were much different than the fall velocity predicted by gravitational/hydrodynamic models, suggesting that other physical or biological characteristics may be important factors in controlling deposition and suspension of FPOM. Paul and Hall (2002) reported similar results in that transport distances necessary for very fine organic particle settling were similar; their results were confirmed by another investigation in which depositional velocities varied one order of magnitude from 0.06 and 0.87 mm/s for organic particles ranging in size from 0.45 to 106 µm. Based on Stokes Law, particles with this size range should have fall velocities that vary by over 5-orders of magnitude, from 0.000055 to 2.26 mm/s. These results suggest that other factors, such as filtering through hyporeic zones (the area of subsurface flow between the groundwater and the surface water flow) and filter-feeding or biofilm adhesion in the streambeds, are more important for settling of fine particulate organic matter (FPOM) than gravitational settling, turbulent mixing and near-bed shear stresses, basic elements of models that typically describe sediment transport in streams and rivers (Minshall et *al.*, 2000). These results are especially important in assessing particle cycling in Stream Environmental Zones (SEZs) as well as designing removal basins. Encouraging surface and subsurface flow exchange and interaction, and promoting biologically active systems should improve deposition of FPOM, thus reducing the load of fine particles to Lake Tahoe. In these types of systems, FPOM transport distance for a wide range of organic particles cannot be easily predicted though the presence of transient storage zones, water depth and channel velocity appear to be reasonable predictors of improved FPOM removal (Minshall et *al.*, 2000; Paul and Hall, 2002).

Other processes are also described in Figure 3 with implications on particle and solid removal processes. Biotic processes such as bioturbation and abiotic processes such as wind and wave energy can resuspend particles (Harter and Mitsch, 2003, James et *al.*, 2004). Macrophytes can help reduce these effects by dampening wave activity and wind shear (James et *al.*, 2004) and that has been found to improve settling as well (Barko and James, 1998). Macrophytes are likely to improve solids removal in other ways. Macrophytes increase grazing pressures on algae by providing protection of zooplankton from predators (Jeppesen et *al.*, 1998). Foodweb dynamics can incorporate fine organic particles that eventually transport them to the sediments. Ultimate particle or solids removal is burial or physical removal.
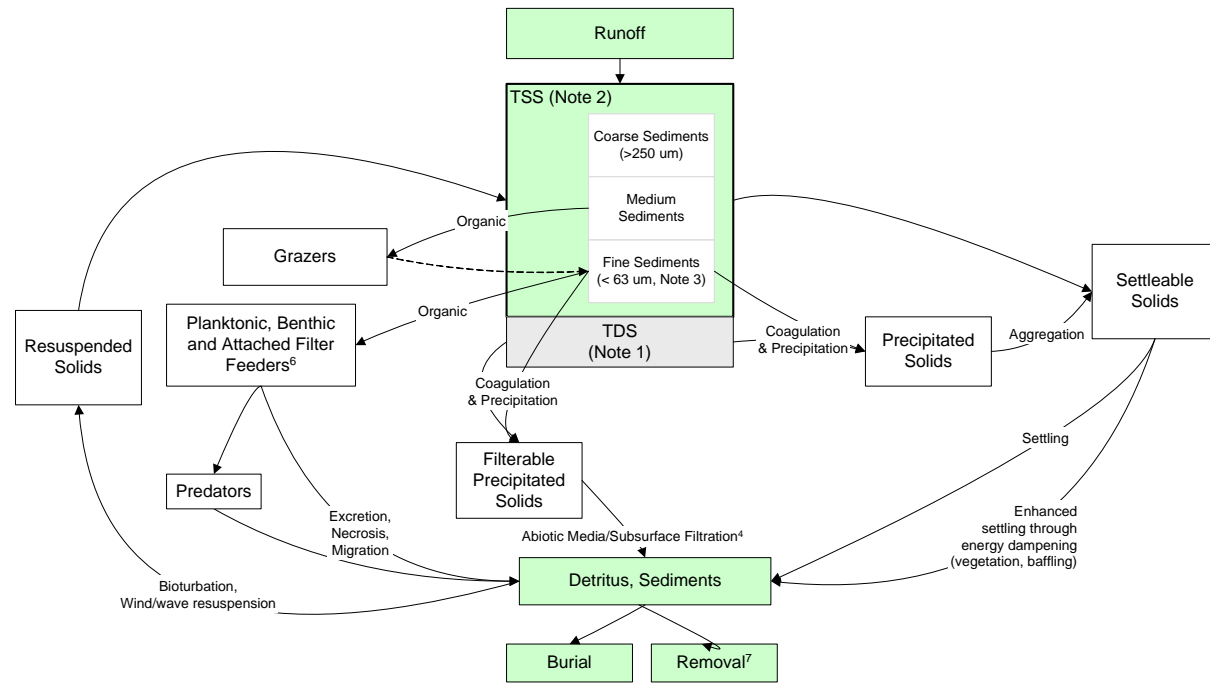
Notes:
1. TDS represents Total Dissolved Solids and refers to colloids and dissolved solids that pass through a filter of < 0.45, 1.2 or 1.5 um, depending upon the filter used.
2. TSS represents Total Suspended Solids and refers to non-filterables solids at the filter size used for TDS analysis (Note 1). Pre-filtering at a larger filter size such as 2 mm delineates a maximum particle size.
3. Includes clays, fine sands and silts (Heyvaert et al, 2004)
4. An example of subsurface filtering in natural streams is filtration resulting from surface/subsurface interactions in hyporeic sediments in transient stream zones (pools).
5. Filtration of large particles by impeding flow and particle movement.
6. Includes detrivores (crustacea), insect larvae, zooplankton, etc… (Horne and Goldman, 1994).
7. Physical removal by dredging, backflushing and other O&M methods.

Figure 2-3. Solids and Fine Particle Cycling and Removal

Solids removal depends upon their form (e.g. dissolved, particulate), and if particulate, the particle size. Coarse and medium size particles are removed relatively effectively through settling and filtration. Fine particles, especially those approximately 10 µm or less, do not settle rapidly or filter easily, requiring precipitation and coagulation to create settleable or filterable solids. Biotic processes can resuspend particles (bioturbation) as well as result in finer, less settleable, particles (grazing). Foodweb dynamics can incorporate fine organic particles that eventually transport them to the sediments. Ultimate particle or solids removal is burial or physical removal.

2.3   Current Treatment BMP Types in the Tahoe Basin

There is currently a large number of treatment BMPs used in the Tahoe Basin. Table 2-4 presents results of a qualitative survey identifying treatment BMPs sent to the local California Agencies (e.g. El Dorado County, Placer County, and the City of South Lake Tahoe) and to CSUS Office of Water Programs (OWP) representing Caltrans. The survey's purpose was to identify the predominant treatment BMPs implemented in the Tahoe Basin based on data from the California side, and to provide an estimate of their relative use. Data was provided by Placer County, the Office of Water Programs and the City of South Lake Tahoe.

From the surveyed agencies, hydrodynamic devices are by far the most numerous (>200) and widespread BMPs. These devices can be drain inlets with and without filters. In this survey, hydrodynamic devices included oil-water separators, centrifugal concentrators, sedimentation traps and drain inlets without filter media. They are used at the source, are very space efficient and generally remove most coarse particulates and trash from stormwater. Other BMPs that are relatively numerous (>20) and widespread include dry detention basins, infiltration basins, bioretention basins and water quality swales. Of these four BMPs, bioretention basins are not widespread, only being reported as being used by the City of South Lake Tahoe. BMPs that are less numerous (>10) but still in widespread use include vegetated filter strips, wet ponds and stormwater wetlands. Between eleven and fifteen wet ponds are being used by the City of South Lake Tahoe though the other two agencies do not report their usage. The BMPs with the least reported use (1 to 5) are media filters, infiltration trenches, porous pavement, and filtering drain inlet inserts. These relative distributions are assumed to be the same throughout the Tahoe Basin.

Table 2-3. Treatment BMPs in the Tahoe Basin
The listed BMPs are those reported in use in the Tahoe Basin. Drain inserts with and without media are defined as hydrodynamic devices and these include traps, oil-water separators and centrifugal concentrators. Many proprietary BMPs are categorized as hydrodynamic devices.

Best Management Practice (BMP)	BMP Description	Used in or by:				Estimated Usage
		City of South Lake Tahoe	Placer County	El Dorado County	Caltrans	
Treatment BMPS:						
Bioretention basin	Landscaped area that accepts water through a buffer zone or filter strip. It is a depression comprised of several layers; plants, mulch, soil, and sand bed. A pipe at the bottom conveys stormwater away. It is assumed that these basins do not include th	X				RN
Media Filter	Granular or membrane filters that remove pollutants by passing runoff volumes through peat, compost, geotextiles, or other porous media. Water is collected by underdrain.	X				LU
Dry Detention Basin	Basin that captures stormwater but completely dries between runoff events.	X	X		X	RN
Wet Pond or retention pond	Basin that retains a permanent pool of water between storms. Pond is generally deeper than a stormwater wetland. Generally requires a consistent baseflow or high groundwater table.	X				LN
Water quality swale (dry swale, wetland channel, grass channel)	Channels designed for slow water flow during runoff events. Wetland channels or grass channels are covered with wetland vegetation or grass-lined . They are shallow with gently sloping sides. May have underdrains.	X	X			RN
Grass Filter strip (biofilter strip, buffer strips)	Vegetated areas designed to accept sheet flow .	X	X			LN
Infiltration Basin	Basins that capture a given stormwater runoff volume and infiltrate it into the ground, transferring surface flow to groundwater flow	X	X		X	RN
Infiltration Trench (percolation trench or dry well)	A ditch filled with gravel or other porous media to facilitate the rapid percolation of runoff to groundwater. It is assumed that they do not include the use of adsorptive media.		X			LU
Porous pavement	Modular block or porous concrete, generally used in in lower traffic areas.		X			LU
Stormwater wetland[3]	Basin that retains a permanent pool of water between storms. Basin has varying depths, with 50% of its surface is covered by emergent wetland vegetation. Generally requires a consistent baseflow or high groundwater table.	X	X			LN
Drain Inserts without filters	Hydrodynamic devices that collect and direct flow and capture sediment. Some systems have porous bottom to allow some infiltration. Some have sediment removal tank followed by filters. Filters can vary with contaminant. Proprietary products exist.	X	X		X	MN
Drain Inserts with filters	Wastewater flows through set of filters contained within drain. Filters can vary with contaminant. Many available proprietary products that may not have been tried: Drop-In-Drain-Interceptor, Multi-Cell Filter, Raynfiltr, SeaLife Saver, StormFilter.	X				LU

2.4 An Evaluation of Treatment BMP Effectiveness for Nutrient and Fine Particle Removal

To assess the general effectiveness of treatment BMPs being implemented in the Tahoe Basin, we reviewed typical performance data from two datasets summarized in Tables 2-4 and 2-5. Table 2-5 shows median outflow concentrations and percent reductions based primarily on data from the National Pollutant Review Performance Database for Stormwater Practices (Winer 2000). Where possible, data gaps were filled in using the Stormwater Manager's Resource Center (SMRC) Fact Sheets (www.stormwatercenter.net).

In these datasets, several BMPs are considered, with many depending upon infiltration. There is no information on where effluent is measured for these infiltration systems such as porous pavement, infiltration trenches and infiltration basins. We assume that these concentrations are measured in the overflow of or runoff from these systems.

2.4.1 National Pollutant Review Performance Database for Stormwater Practices – Winer 2000

The data summarized on Table 2-4 is referred to here as the Winer dataset. This data shows median outflow concentrations and percent removal. Inflow concentrations are not provided in this dataset though a median inflow concentration for the dataset is estimated by calculations using the provided outflow and percent removal data. Shading is used to present the medians in terms of discharge standards. Light green shading shows that the median outflow data is at or below the infiltration concentration standard for the Tahoe Basin. Dark or blue shading is used to show that the median outflow data is at or below the surface water discharge standard.

2.4.2 International Stormwater BMP Database – ASCE/EPA

Table 2-5 shows average inflow and outflow concentrations and calculated percent pollutant removal based on raw data in the International Stormwater BMP Database (www.bmpdatabase.org). This data is referred to here as the ASCE/EPA dataset (ASCE and USEPA, 2005). We downloaded the event mean concentration (EMC) data from their dataset. For this dataset, we present mean inflow, mean outflow and calculated mean percent removal using paired inflow and outflow data. Mean percent removal data was determined by calculating the percent removal for each pair of inflow and outflow data and then calculating a mean for those values for each BMP type. We also present an aggregate percent removal which estimates percent removal based upon the mean inflow and outflow concentrations:

$$Aggregate\ \%\operatorname{Re}moval = \left(\frac{Mean\ Inflow - Mean\ Outflow}{Mean\ Inflow} \right)$$

Mean percent removal and aggregate percent removal are not going to be identical when the number of data points is greater than one. However, these values should be relatively similar. When they are very different, this may indicate inconsistencies in the data. We used a comparison of these two values to filter the data from this ASCE/EPA dataset.

Data provided from each dataset did not include all the same BMPs. The ASCE/EPA database did not provide data on several stormwater BMPs: infiltration basins, infiltration trenches and porous pavement. Hydrodynamic devices were included in the ASCE/EPA dataset. However, the data was limited and the exact hydrodynamic device was not specified. Because there are so many different hydrodynamic devices, each type with different performance characteristics, we did not include these devices in our analyses of this dataset.

We filtered the ASCE/EPA dataset by comparing mean percent removal and aggregate percent removal in order to determine inconsistencies in the data. There were a few examples where these two values were not similar. In the data presented in Table 2-5, we noted that TSS and ortho-P data for retention ponds caught our attention. For the ortho-P data, mean percent removal is -82% (an increase) whereas aggregate percent removal is 14.2%. For TDS data for retention ponds, mean percent removal is 11.1% whereas aggregate percent removal is 62.7%. Based upon these data, we reviewed the raw data and did not find any data that was clearly impossible for any of the data entries. So we kept the data as is.

However, we did filter one data point from this dataset based upon the above method. For media filters, the mean percent removal of TSS was negative (an increase in TSS) whereas the aggregate percent removal was positive. In reviewing the data, we found a single data point that was very inconsistent with the remaining 11 data points. For that data point, a ten times increase in TSS occurred through the filter. Based upon the other data points and our experiences with media filters, this increase we consider impossible. So we removed that data point from the dataset. Thus, Table 2-5 represents our analysis of the ASCE/EPA database using a subset of data:

- paired inflow and outflow data;
- not including hydrodynamic devices because of a lack of information on those devices;
- and filtering out a TSS data point for media filters based upon our assessment of its impossibility.

2.4.3 Comparing Databases

Both datasets have an indication of the number of data points used for their respective data summaries. For Table 2-4, Winer (2000) indicates where less than five data points were used. Thus for several BMPs shown, the data from Winer (2000) is sparse. For the ASCE/EPA dataset, we provide the number of data points.

In these two datasets, we looked at both achievable outflow concentrations and percent removal in the context of runoff concentrations in the Tahoe Basin and current surface water and infiltration discharge standards. In our analyses, we focused on removal of PoCs (e.g. phosphorus and nitrogen species, solids and fine particle removal) to the extent possible for the data supplied. These databases only include total suspended solids (TSS) data as opposed to turbidity data which provides a better assessment of the removal of colloids and fine particles. Achievable outflow concentrations are useful in assessing the lowest achievable concentrations that might be achieved using the BMP. The percent removal provides a measure of the load reduction. Both these values likely depend on the operating conditions and the inflow chemical and physical characteristics.

Table 2-6 provides a summary of Tables 2-4 and 2-5, presenting a comparison of data for similar treatment BMPs as provided by the two datasets. In Table 2-6, data provided by both datasets is shaded. The dark shading indicates the data from each dataset that is relatively similar. We defined this as both values provided being within 25% of their mean. This was applied to outflow concentration data and to percent reduction. The lightly shaded data represents data that was more dissimilar. Data that is not shaded was only provided by one of the datasets. From Table 2-6, we were able to compare data from these two datasets and develop a better understanding of the robustness and reliability of the data and the systems that were reported.

Table 2-7 is the final table we used to assess performance. For Table 2-7 we identified if each treatment BMP met the infiltration or surface water standard in the Tahoe Basin (e.g. Yes, No) and whether the provided (ASCE/EPA dataset) or calculated (Winer dataset) inflow concentration was initially above or below the Tahoe Basin infiltration or surface water discharge limit. This table qualitatively provides a rapid means to assess the likelihood that each treatment BMP will meet the discharge standards in the Tahoe Basin and whether that prediction is based more on initially low inflow concentrations or performance results.

Table 2-8 summarizes the relative performance of the treatment BMPs for which the national datasets provide information, and qualitatively rank their relative performance based upon reported values for load reduction and outflow concentrations, as well as on the reliability of the data.

Nitrogen

Based on the national datasets, the reported treatment BMPs with mean and median TN concentrations between 0.9 and 3.8 mg/L (Tables 2-4, 2-5 and 2-6) would meet Tahoe Basin infiltration standard (5 mg/L) for total nitrogen but fail the surface discharge standard (0.5 mg/L). For this reported data, TN percent removal ranges from -30% (a nitrogen increase) to 84%. The reported inflow concentrations for these datasets are similar but slightly higher than concentrations expected in runoff from undeveloped areas of the lake. Between the two datasets, some systems show similar results as indicated by the darkly shaded regions (Table 2-6). Dry basins and wet ponds have similar performance data between the two datasets as shown by the shading. These systems seem to achieve mean TN concentrations in the range of 0.9 – 1.3 mg/L, values which exceed the surface water discharge standard for the Tahoe Basin. Mean percent TN reduction ranges between 20 and 80%. Stormwater wetlands and water quality swales have performance data that differs between the two datasets. For the Winer (2000) dataset, stormwater wetlands perform nearly on par with the dry basins, wet ponds and wetland channels but in the ASCE database, they perform much worse.

For grass filter strips, infiltration basins, infiltration trenches, porous pavement and oil-grit separators, the data is sparser. Infiltration trenches, infiltration basins and porous pavement have similar percent removal for the data that is presented as is found for dry basins, wet ponds and wetland channels. However, the sparser data makes us less comfortable considering them as effective as these other systems for which there is greater data. Oil-grit separators, biofilters and centrifugal concentrators appear to be ineffective for TN removal.

Though mean and median nitrogen outflow concentrations meet infiltration standards for all the BMPs for which there is data (Table 2-7), the inflow is typically below those standards as well. Thus, from the available data, none of these BMPs seem to perform significantly better with regard to meeting regulatory concentration standards. If one is to access these systems from a load reduction perspective, as one would do when considering systems to meet TMDL requirements, many systems have an above average % removal: media filters, dry basins, wet ponds, wetland channels, infiltration basins, infiltration trenches and porous pavement (Table2 2-4 through 2-8). Wet ponds are considered the top performer with regard to load reduction of TN because data from both datasets support this conclusion and have similar data. Stormwater wetlands are considered a poor performer though the data is inconsistent with the data for wetland channels, a similar system. Factors affecting performance of the stormwater wetlands are discussed below.

TN removal data for each treatment BMP data can be broken down to organic and inorganic N. Nitrate and ammonia, the two main inorganic forms of nitrogen, are the most biologically available. The BMP's effectiveness at nitrate removal tends to be similar between the data sets (Tables 2-4 through 2-6). Mean nitrate concentrations in the inflow typically range from 0.38 to 1.11 mg-N/L (ASCE and EPA, 2005). All the BMPs generally achieve nitrate concentrations less than 0.65 mg-N/L and many achieve outflow concentrations below 0.3 and 0.4 mg-N/L. Media filters added nitrate to the outflow (-50% and -15% removal) and in general were the poorest at achieving low mean or median nitrate concentrations. The addition of nitrate is inevitable in these systems because organic nitrogen and ammonia is trapped during each filter cycle. Subsequent mineralization and nitrification result, leading to the leaching and export of nitrate during the next wetting period. Ammonia concentrations tend to be slightly lower in both the inflow and the outflow to the BMPs than nitrate concentrations. In the EPA/ASCE database, inflow ammonia concentrations range from 0.06 to 0.94 mg-N/L (Table 2-5). Mean outflow ammonia concentrations range from under 0.15 to up to 0.61 mg-N/L, though most mean outflow concentrations are less than 0.20 mg-N/L (Table 2-5). Thus, the different treatment BMPs seem to remove inorganic N though the exact amount is difficult to quantify from the data presented because of inconsistencies in the data and internal nitrogen cycling that occurs in these systems (Figure 2-2)

Organic nitrogen appears to make up the greatest fraction of inflow nitrogen to the BMPs. In the EPA/ASCE database, mean TKN inflow concentrations are generally in the range of 1.14 to 2.36 mg-N/L, with approximately 70 – 80% of that concentration as organic N. For those systems, TKN percent removal tends to be between 8 to 24%. Increases in organic nitrogen account for the total nitrogen increases reported for treatment wetlands. These increases may have been due to organic matter being flushed during high flow events that had accumulated in the basins between storms whether through deposition or plant growth, or the release of DON that had formed between storms during periods of drydown and oxidation. It is also possible these anomalies were due to sampling errors.

When considering the surface water discharge limit of 0.50 mg/L in the Tahoe Basin, several species of nitrogen may be a concern. In general, inorganic nitrogen (ammonia + nitrate) exceeds the N surface water discharge standard. Organic nitrogen also tends to exceed the N surface water discharge limit. Because of the complex nitrogen cycle, nitrogen moves between

the different species, both organic and inorganic, with the permanent removal sinks being burial of very recalcitrant material (as for phosphorus) and, more importantly, removal from the aquatic system through nitrification and denitrification.

In looking at these different BMPs, a few conclusions on performance can be made:

- Reported outflow concentrations from these systems are similar. More effective BMPs achieve TN concentrations in the 0.9 to 1.5 mg/L. Less effective systems achieve TN concentrations in the range of 1.7 to 3.8 mg/L. Some of these systems see an increase in TN which in part may be due to asynchronous sampling or the flushing of organics during storm events. Some increase in TN may also be due to the organic matter accumulation during and between storm events and then its flushing during subsequent storm events.
- Surface water discharge standards are unlikely to be met by any of these BMPs under typical conditions and configurations.
- The treatment BMPs are more likely to differentiate themselves in a TMDL environment under which load reduction is more important. Data suggests that several BMPs may be above average performers: media filters, dry basins, wet ponds, wetland channels, infiltration basins, infiltration trenches and porous pavement. Wet ponds seem the best choice for TN load reduction based upon the reliability of the data. Overall, TN removal is likely to be in the range of about 20 to 40%. The actual value will likely depend upon BMP operation, design and maintenance, and may be limited by the BMP's minimum achievable nitrogen concentration, or irreducible concentration.
- There may be a TN concentration that defines the lowest achievable level that can be achieved through treatment. This concentration is likely to exceed the surface discharge limit of 0.5 mg/L and we believe it will be in the range of 1 to 1.5 mg/L based on the data presented in these datasets.

Additionally, some important results may help address treatment strategies:

- Both organic and inorganic forms of nitrogen may prove problematic for meeting surface water discharge standards. Nitrate, an inorganic form, is highly mobile in soils and can cause subsurface plumes. Nitrate is also a very biologically available form of nitrogen and so if these plumes reach the Lake and nitrogen is limiting biological productivity in some way, this could be detrimental to lake clarity.
- Inorganic nitrogen can be removed from systems through nitrification/denitrification. In the Tahoe Basin, nitrate accounts for about 5 to 15% of the nitrogen load in the runoff and is the primary form of inorganic nitrogen in the runoff. Ammonia can form through mineralization of organic N that has transported with runoff and subsequently settled into a treatment BMP.
- Organic nitrogen can also be removed through nitrification and denitrification, though as discussed above mineralization will need to first occur to convert organic N to ammonia. Under oxic conditions, nitrification rates will likely be limited by mineralization rates (Figure 2-2). Under anoxic conditions throughout the BMP environment, nitrification will not occur and thus limit the organic N removal processes. However, if there are areas of both oxic and anoxic conditions within the BMP environment, then

mineralization rates will likely limit the subsequent processes of nitrification and denitrification, and thus control the rates organic N is removed from the system.

Phosphorus

The two datasets show similar results for TP removal. The Winer (2000) dataset suggests several conclusions that we discuss in this paragraph. For the Winer (2000) dataset, most BMPs achieve median TP concentrations in the range of 0.02 – 0.2 mg/L (Table 2-4). This includes bioretention and media filters, dry basins, wet ponds, water quality swales, porous pavement, stormwater wetlands, and Stormceptors[TM]. Where sufficient data is available to calculate a standard deviation (SD), the SD has a similar magnitude as the median value. Those BMPs achieving TP concentrations less than 0.2 mg/L, percent removal ranges between 35 and 65%. Oil-Grit separators and infiltration trenches perform the worst. According to Winer (2000), the media filters (including bioretention basins), and porous pavement reportedly meet the TP surface water discharge standard, though porous pavement has very few data points. The high standard deviations along with the relatively small samples sizes suggest that the outflow TP concentrations for the BMPs do not statistically differ significantly from each other, especially for those with outflow concentrations in the range of 0.1 to 0.2 mg/L. Thus, from this data set, media filters, dry basins, wet ponds, wetlands, water quality swales, porous pavement and some hydrodynamic devices likely have very similar performance for removing TP and achieving low TP concentrations in the outflow on average. Of these BMPs, stormwater wetlands, water quality swales and wet ponds had reportedly higher percent removal of SRP.

Results from the EPA/ASCE dataset suggest slightly different findings as discussed below. The EPA/ASCE dataset for the most part shows slightly higher outflow concentrations of TP. For these systems, mean outflow TP concentrations are in the range of 0.21 to 0.54 mg/L (Table 2-5). Percent removal is in the range of 7 to 45% for all systems except for biofilter strips which show an increase in TP of about twofold. The removal rates for each BMP are lower than found in Winer (2000). Wetlands, wetland channels and water wet ponds have the highest removal rates, ranging from about 20 to 45%. Reported mean outflow concentrations for these systems are above the surface water discharge limit, ranging from 0.21 to 0.57 mg/L. Dissolved organic phosphorus tends to be below the surface water discharge standard for these systems though wetland channels and wetlands were shown to sometimes add organic phosphorus, possibly due to flushing of organics during storm events with some of that possibly from the biological decomposition of vegetation.

These systems can be compared from both an effluent standard perspective and a load reduction perspective. All these systems show very similar outflow concentrations, which suggests that TP may be reaching an irreducible concentration for the treatment BMPs and, if so, this concentration is above the surface water discharge limit (Table 2-6). For the two datasets, many of the treatment BMPs met the TP infiltration standard (Table 2-7). However, only one of these BMPs had a mean inflow TP concentration above the infiltration discharge limit. So in these cases, treatment by the BMP was not a factor in meeting the infiltration limit. None of the BMPs achieved the surface water discharge limit. Thus, it seems unlikely these BMPs alone can meet the TP surface water discharge limit for the Tahoe Basin. From these results, we can identify which BMP will be more effective at meeting surface water discharge standards. Only the Oil-

Grit separator distinguishes itself from the others with the possibility of not meeting infiltration standards (Table 2-8).

From a load reduction perspective, water quality swales/wetland channels, wetlands and wet ponds seem to be the better performers (Table 2-8). Data from both datasets strongly suggest that these systems will have above average performance for TP removal. For these systems, load removal is expected to be in the range of 20 to 50%, depending upon the BMP type, its design and the inflow characteristics. Other systems may also do fairly well for TP removal, with data indicating above average TP removal: media filters, infiltration basins, infiltration trenches and porous pavement. Oil-grit separators, centrifugal concentrators, biofilter strips and dry detention basins are expected to have below average to poor TP removal rates.

In summary, the national database suggests the follow conclusions:

- When assessing the BMPs from an effluent standard perspective, the data suggest the different existing stormwater BMPs will be ineffective in meeting surface water discharge standards. The minimum mean TP outflow concentrations achieved are in the range of 0.1 to 0.2 mg/L (dry detention basins, media filters, wetland channels, and stormwater wetlands). The data suggests a minimum achievable (or irreducible) outflow concentration around 0.1 mg/L.
- From a load removal perspective, the more effective systems for P removal tend to be BMPs in which there is a biotic component: wetlands, wet ponds and wetland channels. Removal rates are expected to be in the range of 22 to 50%.
- Other BMPs may have above average performance from the load reduction perspective and these include media filters, infiltration basins, infiltration trenches and porous pavement. Oil grit separators, centrifugal concentrators, grass filter strips (biofilters) and dry detention basins are not expected to perform as well and some may perform badly.
- Total phosphorus that is incorporated in medium and coarse particles is likely to be removed more effectively by the reviewed BMPs than dissolved phosphorus or phosphorus incorporated with fines.
- There is insufficient data to assess the effectiveness of the different BMPs for ortho-P or dissolved organic P removal. Both these forms of P are more biologically available, with ortho-P the most biologically available.

From these results, some strategies on treatment can be suggested:

- Ortho- or soluble reactive P makes up about 10 – 25% of the total P in runoff from developed locations throughout the lake. This form of P is the most biologically available and most likely to affect lake clarity. It is also most affected by biotic processes. Dissolved organic phosphorus is less biologically available and so will be less affected by improving biotic processes. Thus BMPs that utilize biotic processes are more likely to remove these forms of P.
- Many of the biotic processes occur in the upper sediments (hyporeic zones) as well as at the sediment-water interface. Improving transport of P to those zones should improve performance.

Total Suspended Solids and Turbidity

The two national databases provide data on TSS removal. TSS includes particles of all sizes. According to this metric, many of the BMPs effectively remove particulates, removing from around 50% to over 80% TSS (Tables 2-4, 2-5 and 2-6).

TSS though is not a particularly good indicator of fine particles. Turbidity data is more likely to better represent the effectiveness of a system to remove fines and colloids as these are the particles that most affect turbidity values (Caltrans, 2003b). Turbidity data is available for systems in the Tahoe Basin and should be considered in the future when assessing the effectiveness of stormwater BMPs for fine particle removal.

However, from our understanding of turbidity in the Tahoe Basin, we are able to speculate on the effectiveness of the different stormwater treatment BMPs based upon the national datasets. Water quality data for the Tahoe Basin shows that the ratio of TSS to turbidity is about 1.4. For urban stormwater runoff, the ratio is higher than for rural stormwater runoff (~2.2 vs. 1.3, Caltrans, 2003b), indicating a greater proportion of larger particles in the urban stormwater as opposed to rural stormwater. The same is true for inflow to stormwater treatment BMPs as opposed to effluent. In the influent, the ratio is about 1.4 to 1.8 whereas in the effluent, it is about 0.9 to 1.1 (Caltrans 2003b).

If assuming a TSS/turbidity ratio of about 1.0 in the treated effluent from stormwater BMPs, as the Caltrans data suggests (Caltrans 2003b), then the TSS data presented in Tables 2-4 through 2-6 can be related to turbidity and we can use that relationship to estimate how well these systems will meet turbidity surface water and infiltration standards. Based upon that assumption, the outflow turbidity values can be estimated to be about 8 to 48 NTU for the different stormwater treatment BMPs.

In Table 2-8, we rate these BMPs for their likelihood to meet turbidity surface water and discharge standards. The surface water discharge standard for turbidity is 20 NTU. Based upon our analyses, we do not expect any stormwater treatment BMP to meet the surface water turbidity standard. This is based upon an analysis of the data in Tables 2-4 through Tables 2-6 as well as an understanding that turbidity values in Highway Runoff are expected to be quite high and a removal of over 90% will likely be needed to reduce turbidity values in the effluent to below 20 NTU. Based upon the data, we predict that these systems should be able to meet turbidity infiltration standards (Table 2-8).

We also have considered these systems from a load reduction perspective as will be needed when working in the TMDL regulatory environment. Media filters, wetland channels and stormwater wetlands are expected to have higher than average TSS removal, with removal rates ranging from 55% to 81%. Media filters are included in this group based upon data from OWP's assessment of this technology in the Tahoe Basin. Data suggests that wet ponds, filter strips, infiltration basins and porous pavement should also perform well, with removal rates in the range of 75 to 95%. However, the data is not as reliable for this latter set of BMPs so we have rated them lower in Table 2-8.

The results here suggest a number of conclusions:

- Current surface water turbidity standards will be difficult to meet for any of these stormwater treatment BMPs. Turbidity infiltration standards are likely to be met.
- No data exists in the datasets to assess the distribution of fine particles. Fine particles may become a focus of the TMDL though how the metric that will be used has not been determined at this time.
- A number of stormwater BMPs are expected to be able to achieve above average load reduction. Possible BMPs include media filters, wetland channels, stormwater wetlands, wet ponds, filter strips, infiltration basins and porous pavement. The data for media filters, wetland channels and stormwater wetlands is more robust. The other BMPs listed here will likely need more field testing to improve confidence in this conclusion.

2.5   Summary of Expected Performance for BMPs Currently in Use in Tahoe

As shown in Table 2-7, none of the BMPs are expected to be consistently better than others at meeting surface water discharge limits for all three PoCs: nitrogen, phosphorus and fine particles. However, we can still make some generalizations about performance of the different BMPs based upon the national data that has been presented and our analysis in the previous section. The different stormwater BMPs can be viewed in for two different regulatory environments: an effluent based regulatory environment and a TMDL based regulatory environment.

2.5.1   Effluent based regulatory environment – Expectations to meet current Tahoe Regulatory Standards

In looking at the national datasets, we can make some statements about the likelihood or potential of different BMPs that exist in or are planned for the Tahoe Basin to meet current Tahoe Regulatory standards. Overall, based upon a review of the national datasets, it appears the current treatment BMPs in the Tahoe Basin will have difficulty meeting the current N, P and turbidity surface water discharge standards. This conclusion is based upon several reasons.

First, the national datasets suggest that the minimum N and P concentrations are approached asymptotically, with a minimum achievable N concentration on the order of 1 mg/L and the minimum achievable P concentration on the order of 0.1 mg/L. Those minimum achievable concentrations suggested by the BMP databases are about 5 to 6 times higher than the concentrations from undeveloped areas in Tahoe. (Table 2-2). Based upon the data in the national databases, PoC concentrations in stormwater runoff in the Tahoe Basin (Table 2-3) seem to be of similar magnitude. For the developed areas in Tahoe, average TN is between about 1.4 and 2.4 mg/L, average TP is between 0.25 and 1.25 mg/L and average TSS is between 178 and 1133 mg/L (Table 2-3). Average inflow concentrations of TN are roughly between 0.9 and 2.4 mg/L, for TP roughly between 0.25 and 1.7 mg/L and for TSS between 60 and 200 mg/L (Tables 2-4 and 2-5). With the level of treatment appearing realistic for these BMPs (without some extreme actions), the outflow concentrations from these systems are likely to be similar to those concentrations that are reported in the national databases. These levels are typical of N and P concentrations for natural streams around the world. For natural streams around the world, typical inorganic N concentrations are around 1 mg/L and typical inorganic P concentrations are around 0.1 mg/L (Horne and Goldman, 1994).

Our conclusion that the BMPs will achieve an irreducible concentration for each PoC that is likely to be above the surface water discharge standards is supported by an exercise we conducted to predict what PoC concentrations might be achieved for the better performing BMPs if situated in the Tahoe Basin. Viewing Table 2-9, we took the 75% quartile, the median and the 25% quartile for load removal for each PoC for the more effective BMPs. The more effective BMPs are those that are rated a "1" or a "2" in Table 2-8. These BMPs are expected to have above average load reduction capabilities for the different PoC. Thus, we consider the resulting range to be a reasonable predicted performance range for well designed and effective stormwater BMPs.

From these predicted load removal rates, we estimated the maximum, average and minimum mean values for each regulated PoC (e.g. TN, TP, TSS and turbidity) for the three different types of runoff in the Tahoe Basin (e.g. residential, commercial and highway). This approach assumes that the treatment BMPs implemented in the Tahoe Basin will generally be above average performers relative to the national datasets. This assumption seems reasonable if BMPs are selected for the potential to be effective with regard to load reduction. Integrating these good removal rates with the typical inflow concentrations from Table 2-2, we estimated achievable mean PoC outflow concentrations (Table 2-9) for different runoff conditions in the Tahoe Basin. These concentrations achieved thus represent what we believe are the likely range of concentrations that can be achieved with effective stormwater BMPs. The removal rates used in this calculation are not necessarily what would be expected for the Tahoe Basin for all well performing BMPs. Instead, they reflect what we believe are a reasonable range of potential removal rates that can be achieved for a well performing BMP under fairly ideal conditions. Very low inflow concentrations, highly variable flows and other factors could compromise BMP performance.

Table 2-9 shows the results. Data shaded in blue represents inflow or outflow data that is below the current surface water discharge standard. Based upon that calculation, it appears that for all runoff types from developed areas (Table 2-2), TN, TP and turbidity surface water discharge standards are unlikely to be met. This table suggests that the current stormwater BMPs in the Tahoe Basin are likely to be inadequate for meeting TN, TS and turbidity surface water discharge standards. Infiltration standards are nearly always met for these stormwater BMPs.

Another way to assess these stormwater BMPs is through reviewing their performance as reported in the national datasets with regard to the PoC concentrations they achieved (Tables 2-4 through 2-6). This approach is more straight forward and seems reasonable given the similar concentrations of PoC between the Tahoe stormwater (Table 2-2) and the stormwaters described in the national datasets (Tables 2-4 through 2-6). Table 2-8 ranks the different stormwater BMPs based upon those data. Based on that analysis, the more effective BMPs are likely to meet infiltration standards for TN, TP and turbidit. This result is consistent with our predictions calculated in Table 2-9 and our earlier assessment of irreducible concentrations exceeding the current surface water discharge standards.

Thus, we conclude the different stormwater BMPs currently being implemented in the Tahoe Basin are unlikely to meet surface water discharge standards for TN, TP and turbidity, though

they are likely to meet infiltration standards. In general, all the BMPs are expected to perform similarly with regard to meeting TN and TP infiltration standards though some BMPs will be more effective at meeting turbidity infiltration standards.

2.5.2   TMDL based regulatory environment

In a TMDL based regulatory environment, we expect the BMPs selected will have more of an effect on meeting regulatory standards. Table 2-8 clearly shows for each PoC, there are a group of BMPs likely to be more effective. For TN removal, our analyses of the data and its reliability suggests that wet ponds are likely the most effective and that a number of other BMPs, including media filters, dry basins, wetland channels, infiltration basins, infiltration trenches, and porous pavement could potentially provide above average performance for load reduction. For TP, wet ponds, wetlands and wetland channels are expected to be the most effective for load reduction and several others including media filters, infiltration basins, infiltration trenches and porous pavement have potential to provide above average removal. For turbidity removal, media filters, wetland channels, and wetlands are expected to provide the greatest load reduction and others such as wet ponds, biofilter strips, infiltration basins, infiltration trenches and porous pavement may provide above average performance. Overall, media filters, wet ponds, wetland channels (water quality swales) and stormwater wetlands are considered the more effective stormwater BMPs based upon their overall predicted load reduction for each PoC.

2.5.3   Other issues

Other issues need addressing here. First, though TN and TP standards will be difficult to meet, biologically available P and N will likely be low in the outflow from better performing BMPs that have a biotic component, such as wetlands and wetland channels. These systems are likely to reduce the inorganic forms of nitrogen and phosphorus.

Wetlands seem to be the most likely of the BMPs for to add organics, and mostly in the form of organic N. This increase may result from the flushing of organics that have accumulated between storm events or an increase of algae occurring during the assimilation of inorganic N. As those characteristics do not show up with water quality swales/wetland channels, this characteristic may be mitigated by better design and management. In general, treatment wetlands remove nitrogen (Sartoris et al., 2000; Reilly et al., 2000).

Finally, infiltration basins and trenches may provide good performance with regard to the removal of TN, TP and TSS from surface waters. It is unclear from the dataset where outflow is measured and we assume it is from overflow. However, a problem with these infiltration systems is that the natural soils do not have good adsorptive properties so that phosphorus and nitrate entering through infiltration will eventually move through the subsurface to the Lake. This could result in a nutrient plume to the Lake which will eventually affect clarity.

Table 2-4. Performance Review for BMPs from National Pollutant Removal Performance Database (Winer, 2000).

Lightly shaded outflow values (in green) are at or below the infiltration standard. Darkly shaded outflow values (in blue) are at or below the surface discharge standard. Notes generally provide clarification on statistics used, the source of the data or the number of data points.

Best Management Practices	Outflow (mg/l) and Removal (%)	Total Nitrogen[12]		NO$_X$		Total Phosphorus[11]		Soluble Reactive Phosphorus (SRP)		Total Suspended Solids[10]		National Pollutant Removal Database for Stormwater Treatment[6]	SMRC Fact Sheets[13]	Notes
		Med	SD	Med	SD	Med	SD	Med	SD	Med	SD			
Infiltration Discharge Limits		5.0				1.0				NA				
Surface Discharge Limits		0.5				0.1								
Bioretention and Media Filter	Outflow	1.10		0.60		0.10	0.14	0.07		11.00		X		7
	%Removal	38	16	-14	47	59	38	3	46	88	23			
Dry Detention Basin	Outflow	0.86		NA		0.18		NA		28.00		X		4
	%Removal	25	16	4	23	19	13	-6	9	47	32			
Wet Pond or retention pond	Outflow	1.30	0.80	0.26	0.60	0.11	0.08	0.03	0.03	17.00		X		5
	%Removal	33	20	43	39	51	21	66	27	80	21			
Water quality swale (dry or wet swale, grass channel)	Outflow	1.10		0.35	0.27	0.19	0.15	0.09		14.00	19.00	X		
	%Removal	84[2]		31	49	34	33	38	46	81	14			
Grass Filter strip (biofilter strip)	Outflow	NA		NA		NA		NA		NA			X	2
	%Removal	NA		20		40		NA		84				
Infiltration Basin	Outflow	NA		NA		NA		NA		NA			X	2
	%Removal	55-60		NA		60-70		NA		75				
Infiltration Trench	Outflow	3.8		0.09		0.63		0.01		NA		X		2
	%Removal	42		82		100		100		NA				
Porous pavement	Outflow	NA		na		0.1		0.01		17		X		2
	%Removal	83		NA		65		10		95				
Stormwater wetland	Outflow	1.7	8.8	0.36		0.2	0.81	0.07	0.03	22	14	X		3
	%Removal	30	34	67	54	49	36	36	45	76	43			
Centrifugal Concentrators (Stormceptor)	Outflow	NA		0.27		0.02		NA		7.50		X		2
	%Removal			6		19		21		25				
Oil- Grit Separator	Outflow	1.9		0.2		0.41		0.05		48		X		2
	%Removal			47		-41		40		-8				

Reference: National Pollutant Removal Performance Database for Stormwater Treatment and SMRC Fact Sheets — Median[1], 1 St. Dev[14]

[1] Numbers in light green are at or below the infiltration standard. Numbers in blue are at or below the surface discharge standard.

[2] Data based on fewer than 5 data points

[3] Removal statistics include shallow marshes, extended detention wetlands, pond/wetland systems, and submerged gravel wetlands.

[4] Removal statistics include quantity control ponds and dry extended detention ponds.

[5] Removal statistics include wet extended detention ponds, multiple pond systems and wet ponds.

[6] National Pollutant Removal Performance Database for Stormwater Treatment Practices (Winer, 2000)

[7] NO$_X$ removal shown on table is for media practices as a whole; bioretention basins appear to perform better.   The median removal of NO$_X$ for bioretention basins in the NPR database is 16% . Davis et al. (1998) reports 38% removal of NO$_X$ for one study.

[8] For 150 foot long filter strip. 75 foot long filter strip had very bad removal rate. One study (Yu et al., 1992 via SMRC FS, 2005)

[9] Estimated based on data from land disposal of waste water. Assumed sized to treat 1" storm (Schuler, 1987 - via SMRC FS, 2005)

[10] Specific information on fine particles is not available.

[11] Specific information on ammonium is not available

[12] Specific information on total dissolved phosphorus is not available.

[13] Stormwater Manager's Resource Center, Stormwater Management Fact Sheets (SMRC FS), www.stormwatercenter.net,1/10/05.

[14] Standard deviation not reported when there are less than 5 data points.

NA - Data not available

Table 2-5. Performance Review for BMPs from International Stormwater BMP Database (ASCE and USEPA

		Reported Average Data from International Stormwater BMP Database Based Upon EMC Data[1,2,7]										
		Nitrogen (mg/L as N)					Phosphorus (mg/L as P)				Solids (mg/L)	
		NO$_3$	NH$_4$	TKN	TN	TON	Ortho P	DP	DOP	TP	TDS	TSS
Infiltration Discharge Limits					5.00					1		
Surface Discharge Limits					0.5					0.1		
Mean Residential Area Runoff		0.05		1.41			0.03			0.26		431
Mean Highway runoff		0.25		1.84			0.11			1.21		1133
Best Management Practice												
Biofilter	Inflow (mg/L)	0.60		2.36	0.97		0.08			0.24	69.19	71.22
	Outflow (mg/L)	0.48		1.67	**1.09**		0.28			**0.46**	83.96	23.54
	N[4]	10		7	4		9			13	7	12
	Mean % Removal[6]	4.4%		23.7%	-13.7%		-302.9%			-126.2%	-29.4%	56.4%
	Aggregate % Removal[6]	19.8%		29.2%	-12.2%		-258.2%			-92.4%	-21.3%	67.0%
Detention Basin	Inflow (mg/L)	1.06		2.10	1.38	0.86	0.29			0.44	82.68	101.17
	Outflow (mg/L)	0.85		1.87	**0.89**	0.38	0.26			**0.33**	85.19	37.20
	N[4]	6.00		5.00	1.00	1.00	6.00			7.00	2.00	8.00
	Mean % Removal[6]	13.0%		11.6%	35.4%	55.8%	1.3%			15.4%	-1.5%	54.5%
	Aggregate % Removal[6]	20.4%		10.7%	35.4%	55.8%	10.0%			24.9%	-3.0%	63.2%
Media Filter[5]	Inflow (mg/L)	0.65	0.94	2.10			0.17			0.25	52.42	66.69
	Outflow (mg/L)	0.80	0.61	1.81			0.16			**0.23**	67.33	24.69
	N[4]	10.00	7.00	9.00			9.00			11.00	9.00	11.00
	Mean % Removal[6]	-55.7%	31.0%	8.1%			-3.6%			6.8%	-28.4%	54.2%
	Aggregate % Removal[6]	-24.0%	35.1%	13.5%			3.7%			10.6%	-28.4%	63.0%
Retention Pond	Inflow (mg/L)	0.84	0.26	1.39	2.31	0.81	0.34	0.18	0.16	0.73	1005.77	135.00
	Outflow (mg/L)	0.57	0.17	0.95	**1.21**	0.68	0.29	0.07	0.07	**0.57**	375.13	25.60
	N[4]	4.00	9.00	11.00	6.00	6.00	3.00	6.00	8.00	19.00	6.00	20.00
	Mean % Removal[6]	29.2%	17.0%	18.7%	31.8%	21.8%	-82.4%	58.8%	41.5%	44.7%	11.1%	48.1%
	Aggregate % Removal[6]	32.2%	35.4%	32.0%	47.8%	16.9%	14.2%	62.4%	57.1%	22.4%	62.7%	81.0%
Wetland Basin	Inflow (mg/L)	0.45	0.22	1.14	1.97	0.58	1.34	0.11	0.08	0.28	145.74	64.21
	Outflow (mg/L)	0.41	0.19	1.45	**2.55**	0.78	0.70	0.12	0.10	**0.21**	115.15	29.33
	N[4]	3.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00	7.00	4.00	6.00
	Mean % Removal[6]	13.5%	1.5%	-28.4%	-27.7%	-37.2%	34.7%	-25.1%	-23.7%	22.7%	39.2%	64.4%
	Aggregate % Removal[6]	9.4%	14.7%	-27.1%	-29.5%	-34.9%	47.7%	-12.2%	-26.2%	25.3%	21.0%	54.3%
Wetland Channel	Inflow (mg/L)	0.38	0.06	1.70	1.89	0.53		0.12	0.04	0.31	149.30	142.40
	Outflow (mg/L)	0.30	0.15	1.36	**1.51**	0.31		0.11	0.05	**0.22**	124.30	58.44
	N[4]	3.00	1.00	2.00	3.00	1.00		3.00	1.00	3.00	1.00	3.00
	Mean % Removal[6]	17.7%	-157.5%	19.7%	19.9%	41.7%		-5.5%	-14.3%	26.0%	16.7%	62.0%
	Aggregate % Removal[6]	22.4%	-157.5%	19.7%	20.2%	41.7%		10.3%	-14.3%	27.9%	16.7%	59.0%

[1] Numbers in light green are at or below the infiltration standard. Numbers in blue are at or below the surface discharge standard.

[2] Inflow, outflow and removal are calculated from data available in the database. Only paired data was used in calculations.

[3] TN=Total N, TON = Total Organic N, DOP = Dissolved Organic P, DP = Dissolved P, TP = Total P

[4] N - number of data points for outflow concentrations

[5] Media Filter data was filtered to remove one inflow/outflow pair for which data was very inconsistent with other published data and OWP experiences at Lake Tahoe.

[6] Mean % Removal is the mean percent removal from the database. Aggregate % Removal = (Mean Inflow - Mean Outflow)/Mean Inflow. Both values should be similar. Greatly different values for these two parameters suggested inconsistent data.

2005) [7] For both nitrogen and phosphorus, have shown which species are at or below different surface water stds.

Table 2-6. Comparing Performance Data from the Winer and ASCE/EPA Databases.

Performance	Removal Data from National Pollutant Removal Database for Stormwater Treatment (Winer) and SMRC Fact Sheets						Average Removal Data from International Stormwater BMP Database (ASCE)					
	Best Management Practices	Median[1]					Best Management Practices	Average[1]				
		TN	NO$_X$	TP	SRP	TSS		TN	NO$_3$	TP	SRP	TSS
Outflow	Bioretention and	1.10	0.60	0.10	0.07	11.00	Media Filter		0.80	0.23	0.16	24.69
%Removal	Media Filter	38.0%	-14.0%	59.0%	3.0%	88.0%			-55.7%	6.8%	-3.6%	54.2%
Outflow	Dry Detention Basin	0.86		0.18		28.00	Detention Basin	0.89	0.85	0.33	0.26	37.20
%Removal		25.0%	3.5%	19.0%	-6.0%	47.0%		35.4%	13.0%	15.4%	1.3%	54.5%
Outflow	Wet Pond or	1.30	0.26	0.11	0.03	17.00	Wet Pond	1.21	0.57	0.57	0.07	25.60
%Removal	retention pond	33.0%	43.0%	51.0%	66.0%	80.0%		31.8%	29.2%	44.7%	58.8%	48.1%
Outflow	Water quality swale	1.10	0.35	0.19	0.09	14.00	Wetland Channel	1.51	0.30	0.22		58.44
%Removal		84.0%	31.0%	34.0%	38.0%	81.0%		19.9%	17.7%	26.0%		62.0%
Outflow	Grass Filter strip						Biofilter	1.09	0.48	0.46	0.28	23.54
%Removal	(biofilter strip)		20.0%	40.0%		84.0%		-13.7%	4.4%	-126.2%	-302.9%	56.4%
Outflow	Infiltration Basin						Infiltration Basin			NA		
%Removal		55-60		60-70		75.0%						
Outflow	Infiltration Trench	3.8	0.09	0.63	0.01		Infiltration Trench/Well			NA		
%Removal		42.0%	82.0%	100.0%	100.0%							
Outflow	Porous pavement			0.1	0.01	17	Porous Pavement			NA		
%Removal		83.0%		65.0%	10.0%	95.0%						
Outflow	Stormwater wetland	1.7	0.36	0.2	0.07	22	Wetland Basin	2.55	0.41	0.21	0.70	29.33
%Removal		30.0%	67.0%	49.0%	36.0%	76.0%		-27.7%	13.5%	22.7%	34.7%	64.4%
Outflow	Centrifugal		0.27	0.02		7.50	Hydrodynamic Device			NA		
%Removal	Concentrators	0.0%	6.0%	19.0%	21.0%	25.0%						
Outflow	Oil- Grit Separator	1.9	0.2	0.41	0.05	48						
%Removal		0.0%	47.0%	-41.0%	40.0%	-8.0%						

[1]Data summarize previous tables. Italics data shows redundant data reported for both datasets. Blue data shows values that were within 25% of the average between the two datasets (good agreement). Yellow shows values outside that range (poor agreement)

Table 2-7. Assessing BMPs likelihood to meet Current Discharge Standards

Discharge Std Met	Best Management Practices	Median Removal Data from National Pollutant Removal Database for Stormwater Treatment and SMRC Fact Sheets				Best Management Practices	Average Removal Data from International Stormwater BMP Database			
		Meet Discharge Limits	Inflow Above Discharge Limits?[2]	Meet Discharge Limits	Inflow Above Discharge Limits?[2]		Meet Discharge Limits	Inflow Above Discharge Limits?	Meet Discharge Limits	Inflow Above Discharge Limits?
		TN		TP			TN		TP	
Infiltration	Discharge Limit (mg/L)	5		1		Discharge Limit (mg/L)	5		1	
Surface		0.5		0.1			0.5		0.1	
Minimum	Typical Tahoe Runoff from Developed Areas	1.46		0.26		Typical Tahoe Runoff from Developed Areas	1.46		0.26	
Maximum		2.36		1.21			2.36		1.21	
Infiltration	Bioretention and Media Filter	Yes	*Below*	Yes	*Below*	Media Filter			Yes	*Below*
Surface		No	*Above*	No	*Above*				No	*Above*
Infiltration	Dry Detention Basin	Yes	*Below*	Yes	*Below*	Detention Basin	Yes	*Below*	Yes	*Below*
Surface		No	*Above*	No	*Above*		No	*Above*	No	*Above*
Infiltration	Wet Pond or retention pond	Yes	*Below*	Yes	*Below*	Wet Pond	Yes	*Below*	Yes	*Below*
Surface		No	*Above*	No	*Above*		No	*Above*	No	*Above*
Infiltration	Water quality swale	Yes	*Above*	Yes	*Below*	Wetland Channel	Yes	*Below*	Yes	*Below*
Surface		No	*Above*	No	*Above*		No	*Above*	No	*Above*
Infiltration	Grass Filter strip (biofilter strip)					Biofilter	Yes	*Below*	Yes	*Below*
Surface							No	*Above*	No	*Above*
Infiltration	Infiltration Basin					Infiltration Basin	NA			
Surface										
Infiltration	Infiltration Trench	Yes	Above	Yes		Infiltration Trench/Well	NA			
Surface		No	Above	No						
Infiltration	Porous pavement			Yes	Below	Porous Pavement	NA			
Surface				No	Above					
Infiltration	Stormwater wetland	Yes	*Below*	Yes	*Below*	Wetland Basin	Yes	*Below*	Yes	*Below*
Surface		No	*Above*	No	*Above*		No	*Above*	No	*Above*
Infiltration	Centrifugal Concentrators (Stormceptor)			Yes	Below	Hydrodynamic Device	NA			
Surface				Yes	Below					
Infiltration	Oil- Grit Separator	Yes		Yes	Below					
Surface		No		No	Above					

[1]Data summarize previous tables. Italics data shows redundant data reported for both datasets. Bold data represents similar performance reported for both data sets.

[2]Estimated based upon reported outflow and %removal data.

Table 2-8. Performance Summary Based Upon National Datasets

Best Management Practices	Ranking[4]							
	Discharge Concentration Standards / Effluent[1]				TMDL[2]			
	N	P	TSS	Turbidity[6]	N	P	TSS/turbidity	Total
Average % Removal by BMPs[5]					29%	26%	62%	
No Treatment	2	2/3[3]	1/3[3]	3	4	4	4	12
Bioretention and Media Filter	2	2	1/3[3]	2	2	2	1	5
Dry Detention Basin	2	2	1/3[3]	2	2	3	3	8
Wet Pond / Retention pond	2	2	1/3[3]	2	1	1	2	4
Water quality swale / Wetland channel	2	2	1/3[3]	2	2	1	1	4
Grass Filter strip / Biofilter Strip	2	2	1/3[3]	2	4	3	2	9
Infiltration Basin	2	2	1/3[3]	3	2	2	2	6
Infiltration Trench	2	2	1/3[3]	3	2	2	4	8
Porous pavement	2	2	1/3[3]	2	2	2	2	6
Stormwater wetland	2	2	1/3[3]	2	3	1	1	5
Centrifugal Concentrators (Stormceptor)	2	2	1/3[3]	2	4	3	4	11
Oil- Grit Separator	2	2/3[3]	1/3[3]	2	4	4	4	12
Comments	Most BMPs are expected to have insufficient removal rates to lower concentrations below surface water discharge limits.	Most BMPs are expected to have insufficient removal rates to lower concentrations below surface water discharge limits.	No Infiltration standards for TSS. For highway runoff, BMPs may have difficulty meeting surface water standards.	Estimated from TSS concentration data.	Inconsistencies between datasets confound ranking. Much removal of TN is probably due to removal of either inorganic N or particulate N.	Systems only give a "1" if data available from both datasets.	Media filter given a "1" based upon analyses of datasets and experiences in Tahoe.	

Notes

1. Effluent Rating: 1. Good potential to meet surface stds; 2. Good potential to meet infiltration stds; 3. Expected to be ineffective or insufficient data for determination

2. TMDL rating: 1. Data strongly suggests above average removal; 2. Data less strongly suggests above average removal (possibly due to inconsistencies in datasets); 3. Data suggests below average removal; 4. Insufficient data or expected to be very in

3. Depends upon runoff source

4. Rankings are based upon predicting performance for the expected PoC concentrations for Tahoe stormwater runoff.

5. Average is calculated from removal data for both datasets.

6. Turbidity is estimated from TSS based upon ratio shown by Caltrans between TSS and turbidity.

7. Total provides overall performance based upon summation of performance for each PoC

Table 2-9. Predicted Achievable Outflow Concentrations for Different Promising BMPs Currently Used in the Tahoe Basin.
Shaded regions represent inflow or predicted outflow data that is below the surface water discharge standard. Based upon our expectations for best possible removal rates for BMPs, predicted mean outflow concentrations of TN, TP and turbidity are expected to exceed the current surface water discharge standards.

		TN (mg/L)	TP (mg/L)	TSS (mg/L)	Turbidity (NTU)
Lake Tahoe Discharge Standards					
	To Infiltration	5.00	1.00		200
	To Surface Water	0.50	0.10		20
Predicted Load Reductions Based upon National Databases[1,5]					
	Lower quartile	32%	28%	59%	59%
	average	35%	48%	75%	75%
	Upper quartile	42%	64%	83%	83%
Predicted Outflow Concentrations for Different Runoff Sources[2,6]					
Residential area runoff		**1.46**	**0.26**	**431**	**464**
Predicted Outflow[6]	Maximum mean	1.00	0.19	176	189
	Average mean	0.95	0.14	108	116
	Minimum mean	0.85	0.09	75	81
Commercial area runoff		**2.36**	**0.54**	**178**	**503**
Predicted Outflow[6]	Maximum mean	1.61	0.39	73	205
	Average mean	1.53	0.28	45	126
	Minimum mean	1.37	0.20	31	88
Highway runoff		**2.09**	**1.21**	**1133**	
Predicted Outflow[6]	Maximum mean	1.43	0.87	462	
	Average mean	1.36	0.63	283	
	Minimum mean	1.21	0.44	198	

[1]Based upon averages or medians by category as reported by the two national databases.

[2]Shaded regions indicate where surface water quality standard met. Infiltration standard met by nearly for all predicted outflow concentrations

[3]Relative to the nitrogen standard

[4]Relative to the phosphorus standard

[5]Based upon runoff data shown in Table 2-2.

[6]Predicted outflow concentration is estimated by calculation maximum, average and minimum outflow concentrations for a specific type of runoff based upon the performance range for a given BMP.

3   Promising Technologies not used in the Tahoe Basin (Task 2c)

The section addresses Task 2c of the Agreement 03-495 between El Dorado County and OWP. It reviews additional promising treatment technologies not currently in use in the Tahoe Basin and includes an assessment of the state-of-the-art for each of these promising technologies. Of particular interest are whether or not the technologies can treat stormwater to below regulatory levels and whether the technologies are likely to remove fine particles, which contribute significantly to loss of lake clarity but are often not measured separately from TSS. These new technologies are listed and described in Table 3-1. In Table 3-1 we show if the technology incorporates chemical dosing of some form or adsorptive media. If it does incorporate chemical dosing, we show the chemicals that have been or can potentially be used.

3.1   Discussion of Removal Mechanisms

As we have discussed in the previous chapter, under an effluent based regulatory environment, the stormwater BMPs that are being implemented in the Tahoe Basin will likely have difficulty meeting surface water discharge standards for TN, TP and turbidity. These systems are inadequate for removal of fine particles and are unlikely to remove nitrogen and phosphorus to the regulatory levels. Under a TMDL approach, more emphasis will be placed upon load reduction rather than meeting effluent standards. In either case, improved removal of TN, TP and turbidity will aid the local governments in their goal of meeting regulatory standards.

By reviewing the models presented for nitrogen, phosphorus and particle cycling and removal, we are able to better understand the tools that are available for improving performance.

3.1.1   Turbidity and solids removal

Many of the current BMPs are not expected to sufficiently reduce turbidity concentrations, whether it is to meet concentration or load based discharge standards. We have earlier discussed that stormwater BMPs are more effective at removing medium and coarse particles rather than fines. This result is the reason that the TSS/turbidity ratio is different for inflow to and outflow from stormwater BMPs. In general, fines are not removed as effectively and some size classifications are probably not removed at all. In reviewing the model, methods to improve settling and filtering should improve performance with regard to the removal of fines:

- Energy dampening for improved settling and a reduction in resuspension through the installation of baffling or the growth of vegetation;
- Enhanced creation of filterable and settleable solids through coagulation and precipitation

3.1.2   Phosphorus removal

For phosphorus removal using the BMPs currently in place at Tahoe, Table 2-8 suggests systems that integrate biotic processes generally remove phosphorus more effectively. Figure 2-1 shows for the phosphorus cycle biotic processes are key to uptake and burial. When P is taken up by vegetation, some of the P will go into the less labile fraction of the vegetation and when the vegetation dies, that fraction will not be readily released but rather become buried over time.

Under flooding, decomposition can be further suppressed, further enhancing P removal through burial.

Two abiotic processes are also important: soil adsorption and precipitation. These two processes represent the largest short-term sink for phosphorus. Adsorptive substrates, like aluminum and iron based media, are likely to have enhanced adsorption of dissolved P and thus provide a removal mechanism for the dissolved constituents. Precipitation will remove dissolved P as well as enhance the settling rate of particulate P. Burial of the adsorptive media or precipitates potentially provides long-term P removal and a percent of this removal is irreversible.

Finally, enhanced settling will play a role in improving P removal. Some fraction of P entering the system will be associated with fine particles that do not settle well. Utilizing methods to improve settling as discussed earlier should improve P removal.

Thus, BMPs that promote improved P adsorption and precipitation, improve settling rates and/or include biotic processes will have more effective P removal.

3.1.3   Nitrogen removal

For nitrogen removal, Figure 2-2 suggests BMPs for which there are many biotic processes will have better nitrogen removal. The sequence of microbial processes, which include mineralization, nitrification and denitrification, represents the permanent removal of N from an aquatic environment through the formation of gaseous nitrogen forms. These processes dominate N cycling and removal, and are the key to the removal of inorganic N and a percent of organic N. Other removal processes are either physical removal of plants or sediments or burial in the sediments. Some litter when buried will not decompose when flooding is maintained and under these circumstances, burial represents a permanent sink. However, whether plants are physically removed or buried, the mass of biologically available N removed in this way will likely be only a fraction of that removed through the microbial processes.

Organic N, both dissolved and particulate, represent another specie of nitrogen. Microbial and biotic processes will be less effective in removing this less labile and less biologically available form of N. Only when inorganic N is exhausted from the system will the biotic community begin to utilize energy on this N source. Thus, methods to improve the removal of this N fraction need to focus on other processes such as improved settling and improved filtering.

Finally, one potential issue for N is its recycling back into the environment. Data from the national datasets suggest that stormwater wetlands export N back. This may be due to the accumulation of organics between storm events and then their export from the systems during storm events. Improved designs and maintenance practices may be a solution to this problem if it in fact exists for systems in the Tahoe Basin.

Table 3-1. New BMP Technologies Defined
BMPs listed are new to the Tahoe Basin, either undergoing some form of testing or not having been tested at all.

Name			Description	Coagulant			Fe, Al or Ca adsorptive media
				PAM	Chitosan	Al or Fe	
New, Field Testing[1]	Stormwater Treatment	Dual Media Austin Filter	Self contained system in which water passes through two media filters into a gravel underdrain. The first media is sand and the second media are adsorptive substrates such as an iron, aluminum, and/or calcium rich materials. The top sand layer clogs first and will be replaced more often than the second media. Water drains to underdrain system.				
New, Lab Tested	Stormwater Treatment	Passive Chemical Delivery[2]	Water flows over sock or log of chemical that passively dissolves and enhances coagulation and precipitation of fine particles. Two proprietary products are given as examples. Floc-Log is a semi-hydrated polyacrylamide blended block. Gel-Floc Sock is a fabric sock containing a flake form of chitosan, a cationic polymer. They can be used in conjunction with rock checks, drop inlets, storm drains, slope drains and upstream of other systems such as basins, wetlands and biofiltration systems.	X	X	X	
		Flow-through chemical treatment followed by settling[2,3]	Dosing of coagulant at inlet. Coagulant delivered in proportion to flow, turbidity and other parameters. To optimize results, may use injection pump that reads the charge associated with the water and adjusts the chemical dosage to match the charge. Removal occurs in downstream basin, wetland or filtration system.		X	X	
		Chemical-Filtration Systems[2]	Water is pumped from retention basin and injected with liquid chemical that will promote coagulation and precipitation of fine particles and nutrients. The water then flows through above-ground sand filters.		X	X	
		Ion Exchange[2]	Stormwater flows through a resin bed that removes contaminant ions from the stormwater and replaces them with other ions.				
		Sand Filter[2]	Granular filters that remove pollutants by passing runoff volumes through beds or pads of sand. Requires pretreatment which is typically a settling basin.				
New, Un-tested	Small-Scale Stormwater Treatment	Batch Chemical Treatment	Coagulant is added to pond or tank and mixed. May require extended settling time. May require polishing filter at discharge.		X	X	
		StormTreat Wetland Systems	9.5 foot diameter prefabricated device consisting of 6 sedimentation chambers and one constructed wetland. Water in wetland is directed through root zone. Can treat 1 to 5 gallons per minute. Need 2 systems per paved acre.				

	PAM land applications	Hydroseeding over soft armor (i.e., erosion control blankets, turf reinforced mats) using "soil specific" high chelating anionic PAM blends (e.g. Siltstop). These polymer blends act as tackifier/growth additive and improve soil conductivity. Florida, Wisconsin and other states use soft armor for high velocity flow, erosion control and increased water quality. Siltstop is recommended for use with Floclog because it promotes coagulation.	X			
	Electrocoagulation	Stormwater passes through charged metal plates, leading to destabilization and coagulation of suspended particles. Followed by settling. Does not use a chemically dosed coagulant but instead an electrically dosed ion acting as a coagulant.			(X)	
Stormwater Treatment	Flow-through treatment using electrical-coagulation system.	Electrical-coagulation system at retention pond/Vault outlet. Metal Plates are charged and sacrifice a metal ion. The metal ion is normally ferric or aluminum. Metal ion causes destabilization of suspended particles. The destabilization results in coagulation. Water is then directed to a clarifier, for coagulant settlement.				
	Non-Filtering Proprietary Drain Inlet Inserts	Many available proprietary products that may not have been tried: aquaShield SD-100, CLR Filter, Grate Inlet Skimmer Box, Grate Protector 1000 & Grate Protector 2000, HydroKleen, SIFT Filter, SormKlenz, Ultra-Urban Filter.				
	Passive chemical delivery with baffle grids	Treatment train described for use with Floc Log. Water treated by floc logs flows into baffle grid (made using jute woven mat) and particles adhere to the baffle grid panels. The addition of a high chelating anionic pam blend (such as the proprietary material "Siltstop") under and within the baffle grid panels is recommended to further encourage coagulation. This treatment train has been used and found to be effective in other areas of the country. It is possible that a similar treatment train would work for chitosan or alumina based products.	X	X	X	
	Proprietary Drain Inlet Inserts with Media Filters	Many available proprietary products that may not have been tried: Drop-In-Drain-Interceptor, Multi-Cell Filter, Raynfiltr, SeaLife Saver, StormFilter.				

1. Being field tested at Tahoe.

2. Tested by CSUS OWP at small-scale facility

3. Tested by UCD TRG, UCD CE and Bachand & Associates.

3.2   Tested Technologies

Five new technologies have been field or lab tested at Tahoe.   Results of these tests were described as part of Task 3. The technologies, and associated testing results, are briefly summarized below.

3.2.1   Dual Media (Adsorptive Media) Filter

Dual Media Filter is a system in which stormwater passes from a sedimentation basin, through a sand filter and then through an adsorptive media filter. Caltrans has conducted studies on the effectiveness of the adsorptive media filter for treatment of highway runoff. These tests were initially laboratory scale and field-scale testing is now ongoing. Caltrans has found that sedimentation followed by filtration through activated alumina may provide sufficient treatment to meet surface discharge limits.

Currently, two full-scale activated alumina filters are in operation and are being fully monitored. Caltrans plans to also investigate iron-based adsorptive media.   Potential problems that have been identified with the filters thus far include clogging, metal leaching, and pH alterations. It is expected that the dual media filter would perform similarly to the adsorptive media filters described above, except that the sand filter would remove particulates and therefore clog before the media filters. Disposal and replacement of the sand layer is assumed to be less costly than disposal and replacement of the adsorptive media.

Based upon our models (Figures 2-1 through 2-3) and our discussion in Section 3.1, we expect this technology will lead to improved removal of dissolved P. In Table 2-8, sand filters are considered amongst the more effective systems for TSS and turbidity removal. Careful selection of the media size should maintain and possibly improve removal of TSS and turbidity beyond that typical for media filters. Moreover, these dual media systems which utilize adsorptive media should move up a notch for P removal. N removal is not expected to be affected much.

Data suggests these systems will meet turbidity surface water discharge standards. This technology may help these media filter systems also meet surface water discharge standards for P.

3.2.2   Chemical Dosing and Settling

In Chemical Dosing and Settling, water is dosed with coagulant and then mixed; PoC removal occurs in a downstream settling basin. This process has been indirectly tested by Caltrans as part of treatment train studies performed at its small-scale test facility at the South Lake Tahoe Maintenance State ion in Meyers. The treatment train tested included chemical dosing of PASS-C, mixing, settling, filtering, and ion exchange columns. This is covered in more detail in Task 3.

These studies found that the majority of treatment was occurring in the chemical dosing, mixing and settlement phases (the Chemical Dosing and Settling phase) of the treatment train.   In fact, when dosing was followed by both fast and slow mixing, surface water requirements were met after settling was complete.

Chemical dosing and settling has potential to be included upstream of any pond system. One example for this approach is the Low Intensity Chemical Dosing (LICD) studies. These ongoing studies previously supported by Caltrans and currently supported by the Forest Service and the City of South Lake Tahoe are considering this approach in combination with wet ponds and stormwater wetlands. We expect this approach should improve the removal of particles, including fines, and the removal of dissolved and particulate P. Improved removal of particulate N may also occur. Laboratory tests suggest this technology will meet P and turbidity surface water discharge standards.

One variation of this technology is the use of ballast sand in the chemical dosing process. This variation improved settling rates and may be useful to reduce the footprint of a full-scale unit.

3.2.3   Ion Exchange

Ion Exchange is a treatment process in which stormwater flows through a resin bed that removes contaminant ions from the stormwater and replaces them with other ions. Ion exchange columns were the last component of a treatment train that was lab tested by Caltrans, which included chemical dosing of PASS-C, mixing, settling, filtering, and ion exchange columns. As discussed for Chemical dosing and Settlement, the stormwater in these tests met standards before reaching the Ion Exchange treatment phase. The ion exchange columns, which were treating relatively clean water, then removed some additional iron and nitrogen. Ion exchange columns have the capacity to remove the dissolved phases of phosphorus and nitrogen but do not remove particulates.

3.2.4   Sand Filters

In Sand Filters, PoCs in stormwater are removed as the water filters through a bed of sand. We assume that a settling basin precedes the filter and that water flows into drain pipes after leaving the filter. This technology is sometimes called an Austin sand filter.

Caltrans has tested this system and found that the effluent did not meet surface water limits for turbidity, phosphorus, nitrogen, and iron. Based upon our analysis of the national datasets, Caltrans' experience with these systems and our understanding of the processing and cycling of PoC (Figures 2-1 through 2-3), we believe modifications to these systems will not greatly improve N or P removal, nor the removal of turbidity and fines. This system does not utilize processes described in Section 3.1 that would help improve the removal of N, P or fines.

3.2.5   Passive Chemical Delivery

Passive Chemical Delivery occurs when the coagulant is contained in a form that allows it to passively dissolve in water, where it may enhance coagulation and precipitation. Passive Delivery Products are often formulated for particular water and soil chemistry of the treatment area in order to achieve optimal results (Applied Polymer Systems, 2004 & 2005; Natural Site Solutions, 2005; MacPherson 2002 & 2004). Currently available products are based on anionic polyacrylamide (PAM) and chitosan.

PAM "teabags" have been tested by Caltrans. For the PAM tests, PAM was passively dosed upstream of filters. Dosing was not easily controlled and clogging of the filter occurred presumably from overdosing. This is covered in more detail in Task 3. However, the results of

these tests were inconclusive. Another application of this approach is described by Macpherson et al. (2002) in which Gel-Floc chitosan socks were placed in a recirculation system and within pipes connecting ponds to reduce turbidity from turbid waters resulting from dredging at Tahoe Keys. Turbidity values were reduced two orders of magnitude with an average level meeting surface water discharge standards for the Tahoe Basin. A difficulty with this system was in controlling dosing, and water was oftentimes recirculated several times through the settling pond system until turbidity standards were achieved. This option is not available in many stormwater treatment BMPs in the Tahoe Basin.

Based on our models (Figures 2-1 through 2-3) and our discussion of the processes in Section 3.1, we believe Passive Chemical Delivery is potentially a promising technology. Coagulation and precipitation if done effectively would improve the removal of P, fines and particulate N. As power would not be required, this technology has broad application potential in areas where chemical dosing infrastructure is not available. However, there are real challenges with this approach. Primarily, important issues are dosing control and deployment strategies. This application approach may be appropriate for source control.

3.3   Untested Technologies

In Table 3-1, untested technologies are listed for general stormwater treatment and small-scale stormwater treatment. Stormwater treatment technologies that have not yet been tested at Tahoe include Electrocoagulation, Engineered Chemical Dosing and Filtration, and Passive Chemical Dosing and Baffle Grids.

3.3.1   Electro-coagulation

In Electro-coagulation (EC), stormwater passes through charged metal plates, leading to destabilization and coagulation of suspended particles (Water Tectonics, 2004). Electro-coagulation must be followed by a settlement phase for PoC removal.

EC may be an effective treatment for the removal of fine particles and associated nutrients. This expectation is because this technology focuses on destabilizing suspended particles similarly to chemical dosing. Research on this approach has shown that EC can achieve phosphate removal from synthetic waters from 50 to over 90% (Bektas et al., 2004); turbidity removal from a synthetic wastewater (using bentonite as a turbidity source) to less than 1 NTU for waters with initial turbidities of 112 and 52 NTU (Abuzaid et al, 1998); and outperform aluminum sulfate chemically-dosed systems for DOC removal in small-scale experimental EC systems (Jiang et al., 2002). This technology has been applied to construction site stormwater and groundwater cleanup. As with chemical dosing, this technology would require controls and instrumentation if it is found to be effective. However, implementation may not be anymore difficult and perhaps easier than chemical dosing as electro-coagulation dosing is power dependent and can be done within pipe reactors. In contrast, chemical dosing issues associated with chemical storage, dosing and handling may be tricky issues in the Tahoe climate. For both systems, a method to control dosing (through chemical application or applied power) will likely need to be developed. EC is currently under review by the Washington Department of Ecology. Turnkey stormwater treatment systems are now available and estimate operation and maintenance to cost between $3 to $5 dollars per 1,000 gallons of treated water (Stormwater Management, 2004). Applications for the turnkey system have typically been washwater and industrial water recycling. More

information is needed on the logistics of implementing this system including electrical requirements.

3.3.2   Engineered Chemical Dosing and Filtration Systems

Engineered Chemical Dosing and Filtration is a treatment train in which stormwater is dosed and mixed with coagulant, settled and then sent through a media filter which is back-flushed when necessary to clean the filter. Caltrans tested a similar system, chemical dosing (of PASS-C and PAM) with filtration and no backflushing.   They collected very little data and this is likely because of the filter clogging that plagued these studies. Surface water limits for phosphorus and turbidity were met inconsistently and nitrogen removal was limited. A more engineered approach, including optimal dosing and mixing, may lead to better performance and automatic backflushing of the filters may reduce clogging problems.

This approach is beginning to have widespread use in stormwater treatment from construction sites (MacPherson, 2004; Clearwater Compliance Services, 2004). We expect that this approach would improve removal of fines, phosphorus and particulate N. This prediction is based upon chemical dosing enhancing the creation of filterable and settleable solids from dissolved phosphorus and organic nitrogen species and from fine particles, which include particulate P and N.

This approach is likely to have similar filter clogging problems as was demonstrated in the Caltrans small-scale studies at the facility in Meyers. Unlike the Meyers tests, these systems will have a settling area. In addition, in these engineered turnkey systems the filters backflush the concentrate directly back to the upstream settling ponds. These turnkey systems typically dose based upon flow and turbidity. Research on chemical dosing by UCD, Bachand & Associates and the OWP show that turbidity has not been a good predictor of dosing level. Some turnkey applications are beginning to investigate chemical dosing control based upon outputs from Streaming Current Detectors. These issues are covered in more detail in Task 3.

3.3.3   Passive Chemical Delivery and Baffle Grids

Passive Chemical Delivery and Baffle Grids is a treatment train described for use with Floc Log (Applied Polymer Systems, 2004). Water flows by the floc logs, which release chemicals that cause fine particles and dissolved phosphorus and nitrogen in the water to coagulate. Areas of low flow velocity downstream of the log provide areas where settlement may occur. The water then flows through baffle grids or particle curtains. These grids and curtains are made using jute woven mat. The jute material of the baffle grids filter reduces velocities and enhance settling and filtration of the lighter floc that remains in suspension. The addition of a high chelating anionic PAM blend (such as the proprietary material "Siltstop") under and within the baffle grid panels may further encourage coagulation. This approach can be applied in a stream or basin as a treatment BMP. Similar approaches can be used for source control.

Data from Applied Polymer Systems (2004) suggest this approach can effectively reduce TSS. Data also suggest that about 60% of TP has been removed for lake treatment systems in Florida though the outflow levels reported are several times higher than the surface water discharge limits at Lake Tahoe. A similar approach may work for chitosan or alumina-based products.

This technology has promise for improving the removal of P, fine particles and particulate nitrogen.

3.3.4 Small-Scale Stormwater Treatment

Other technologies listed on Table 3-1 are for small-scale stormwater treatment. The two small-scale technologies are batch chemical treatment and prefabricated wetlands. Batch chemical treatment is a technology in which coagulants are added to a basin or tank containing stormwater, mixed, and then particulates are allowed to settle. The water is released after settling has occurred. This technology is likely to be used only in limited circumstances, such as for construction sites and the model predicts that it will remove fine particles and phosphorus. A StormTreat Wetland System is a proprietary device that consists of 6 sedimentation chambers and a constructed wetland. The system can process 1 to 5 gallons per minute, is expensive, and is likely to be an option for small sites only. Both of these small-scale treatments could potentially provide good treatment of the PoCs at Tahoe. Their performance is likely similar to systems using similar technologies.

4 Potential for Improving Existing BMP Performance through Retrofitting and Improved Maintenance (Task 2b)

The section addresses Task 2b of the Agreement 03-495 between El Dorado County and OWP. It assesses the potential for improving the performance of existing BMP types through retrofitting or better maintenance practices. This is a generic assessment and does not focus on individual sites.

4.1 Maintenance

Operation and maintenance is important to optimal performance of the BMPs. As part of its effort to operate, monitor and maintain BMPs in Los Angeles and San Diego counties, Caltrans established a standard maintenance plan to address operation and maintenance of all the different types of BMPs existing at Tahoe, except porous pavement and stormwater wetlands. This plan is attached as Appendix 1. The Caltrans plan was originally based on *Operation, Maintenance and Management of Stormwater Management Systems* (Watershed Management Institute and the United States Environmental Protection Agency, August 1997) in 1999 but has been reviewed and revised annually since. The plan sets out monitoring frequencies and indicators for required maintenance at the different types of BMPs. The document is mainly targeted at maintaining structural integrity, preventing sediment buildup, preserving appropriate flow characteristics (preventing short-circuiting), reducing mosquito breeding potential, and sustaining and trimming vegetation.

Similar information on BMP implementation and maintenance is available from other sources. In the Caltrans document *Storm Water Treatment BMP New Technology Report* of April 2004, technologies are discussed and maintenance suggested. Another document, *Planning Guidance for Implementing Permanent Storm Water Best Management Practices in the Lake Tahoe Basin (TIRRS, 2001)*, discusses guidelines for implementing BMPs and suggests maintenance activities. This document is a work in progress and as such does not provide consistent information for all technologies. Finally, Heyvaert et al. (2004) evaluated stormwater treatment basins at Lake Tahoe and recommended maintenance activities.

All these documents appear to rely upon nationally-based recommendations for maintenance and upkeep with the goal of keeping the system functional based upon a general understanding of the BMP and its treatment processes. Data relating performance to maintenance is generally not available.

The documents discussed in this section can serve as a good starting point for care of the Tahoe Basin BMPs but cannot be applied to Tahoe in their current form. Maintenance procedures need to take into consideration the climate, the volumes and characteristics of stormwater run-off in the Tahoe Basin, and the processes affecting particular PoCs in a stormwater treatment BMP. For instance, the Caltrans plan specifies maintenance and inspection frequencies that are appropriate for Southern California. Monitoring frequencies for the Tahoe Basin BMPs, which will process significantly more stormwater, may need to be increased. Also, as indicated earlier in this report, the biotic component of many of the BMPs is especially important in reducing

PoCs at the Tahoe Basin. Thus, it follows that vegetation management must be carefully undertaken to optimize this purpose at Tahoe.

For instance, the optimal operation of wet ponds and wetlands is a management concern that we identified but which is not addressed in these plans. Wet ponds and wetlands are very effective BMPs but in some instances they apparently have the potential to add organic phosphorus and nitrogen to the treated flow. We conjecture that this potential is due to drying, oxidation, and subsequent remobilization of nutrients upon reflooding. If this is correct, it is important to keep a water baseflow through the systems at all times to prevent drying. However, testing should be done to assess whether wetting/drying is a problem for these BMPs and to establish actions that can be taken to prevent nutrient remobilization. Another example for which management could be used to improve performance might be for improving denitrification rates. Denitrification can be carbon limited. Cutting vegetation at certain times prior to anticipated nitrogen inputs may create a pool of available carbon to enhance denitrification. Thus, the timing of vegetation cutting may impact performance with regard to removal of nutrients.

In summary, maintenance activities should focus on enhancing the processes most important to PoC removal within the BMPs. This approach to maintenance would go beyond a strict focus on functionality. Rather than asking the question of what is required to keep a system functional, questions can be asked on what processes are we trying to enhance and how different maintenance activities affect those processes.

Finally, even with maintenance activities that focus on creating more optimal processes rather than improving functionality, we do not know if performance of these systems will significantly improve. For some PoC removal processes, these systems may be relatively insensitive to these process-based maintenance activities and the level of performance improvement may be relatively small.

4.2   Retrofitting

Retrofitting some existing treatment BMPs may improve their performance. These retrofit activities can focus on two areas, improving hydrology and enhancing performance.

4.2.1   Hydrology

Appropriate hydrology such as the minimization of short-circuiting or the specification of water depths or wetting frequency is very important for effective operation of any stormwater treatment BMP. This consideration is important for treatment BMPs because without proper delivery of the stormwater, treatment cannot be accomplished effectively. Thus, consideration should be given to a number of important hydrologic issues.

The most important hydrologic issue is short-circuiting of flows. Short-circuiting leads to uneven distribution of stormwater for treatment in the BMP; shortened hydraulic retention times and thus shortened time for different biotic and abiotic processes to occur; and areas of unnecessarily high flows that compromise settling through a stormwater treatment BMP. Different BMPs will need different retrofit solutions to prevent short-circuiting.

Another hydraulic retrofit may relate to water control structures that can better control water depth or hydraulic retention time. For instance, for some current treatment basins and ponds in the Tahoe Basin, if they fill to their capacity for a given storm, the design does not allow for drainage from the basin rapidly enough for the basin to accommodate a second runoff event, if that event follows shortly thereafter. However, if structures are included to improve drainage, then the detention time for each storm is reduced, unless of course the storms follow each other so rapidly that the systems overflow. Thus, in considering systems, required detention times and drainage characteristics need to be considered and to optimize these two variables together may require more sophisticated water control structures.

Thus, better hydrologic control of some stormwater treatment BMPs, especially older BMPs, may improve their performance. For different treatment BMPs, different hydrologic concerns may need to be addressed. The BMPs most likely to benefit from hydrologic improvements would be non-proprietary systems such as ponds, swales, and stormwater wetlands.

4.2.2 Technology Retrofits

Opportunities exist to retrofit some existing BMPs with variations in the technologies discussed in the previous section. Depending upon the PoC targeted by a specific BMP, different retrofit strategies may be pursued. These retrofits are likely to generally fall in a few different categories which are listed below though other opportunities likely exist:

- Chemical Dosing Technologies to improve removal of phosphorus, fine particles and particulate nitrogen
    - Passive or Active
    - Chemical or electrical
- Adsorptive Media to improve adsorption of dissolved phosphorus and other dissolved organics
- Adsorptive Media to improve filtration of fine particles and particulate PoC
- Energy Dampening to improve setting and reduce resuspension of fines
    - Biotic (vegetation) or abiotic (grids, baffles)
- Implementation of biotic community (vegetation, microbial population) to improve uptake and processing of biologically available nutrients

These retrofit opportunities are likely most applicable to wet and dry basins, treatment wetlands and infiltration systems.

One example of an investigation of retrofit opportunities is being supported by the City of South Lake Tahoe and the U.S. Forest Service. They are sponsoring work by Bachand & Associates and U.C. Davis Tahoe Research Group to investigate a chemical dosing technology that can possibly be retrofitted to existing basins. In general, chemical additions that enhance coagulation, precipitation and/or adsorption can potentially be retrofitted to or combined with current stormwater treatment basins and treatment wetlands to improve performance. These modifications and retrofits could potentially greatly enhance the performance of a given treatment BMP. These performance improvements seem likely to occur for the removal of fine particles, phosphorus species and particulate N.

For any of these retrofit ideas listed above, more work is required for proof of concept before they can be implemented at full-scale. Performance questions will need to be addressed such as which PoC will be affected, what improvement in removal can be expected and will these retrofits enable the stormwater treatment BMPs to meet current surface water discharge standards. Some of these retrofits potentially may enable existing stormwater treatment BMPs in the basin to meet current surface water discharge standards for PoC and to improve load removal rates of PoC. This is possibly the case with chemical dosing in which early laboratory data suggests this technology may meet surface water discharge standards and if successful could have load removal rates much higher than the current non-retrofitted BMPs. This has been previously discussed in Section 3.1. Other retrofit technologies, such as utilizing adsorptive media, may have more limited retrofit potential but easier deployment may enable a broader range of strategies when considering opportunities in a TMDL environment. Finally, retrofit activities such as improving biotic activities in BMPs may help address the TMDL if biologically available P and N become regulatory targets.

However, not only do questions need to be answered with regard to performance but other questions such as those related to logistical and potential environmental issues or impacts need to be addressed. These issues need to be addressed through activities such as literature reviews and smaller-scale laboratory and field testing such as that which is underway for a number of technologies (Section 3.2).

4.3   Summary

Both improved maintenance and retrofitting may improve performance of stormwater treatment BMPs. Maintenance activities could focus on enhancing targeted processes to remove certain PoCs. Retrofit activities can be classified into those that improve hydrology and those that provide additional processes to remove PoCs through the use of complimentary advanced treatment technologies. Retrofit activities that improve performance include chemically-based methods such as adsorption and chemical dosing as well as methods to improve settling and increase biotic activity. The extent that performance will be improved by these different activities cannot be quantified at this time. We expect that performance improvements resulting from a process-based maintenance approach are likely to be less than those that can be achieved through retrofit activities. However, this expectation is not based upon any data analyses.

For any change in activity, whether it be a change in maintenance or a retrofit, data should be collected that can help quantify the change in performance that is resulting from that activity. Without data records that document the effects of these changes, expectations regarding improvements in performance will be mainly speculation.

5 Knowledge Gaps and Recommendations in BMP Design and Performance

The section addresses Task 2d of the Agreement 03-495 between El Dorado County and OWP. It provides recommendations to address knowledge gaps in BMP design and performance by providing proposal ideas that will aid agencies in specifying design standards and quantifying BMP performance for addressing storm water permitting and TMDL needs. These recommendations are not specific to El Dorado County but are for the Tahoe community.

This section describes the actions we recommend be taken by the Tahoe Basin community to aid with the development of treatment BMPs that will meet the Basin regulatory and pollutant reduction needs. These activities should progress concurrently with activities by state and federal agencies to develop the TMDL and efforts should be made that these two activities are developing complementary information.

5.1 Quantify Performance of Current and Future Stormwater Treatment BMPs in the context of meeting Current and Future Regulatory Needs.

Recommendation 5.1a. Standardize sampling and monitoring procedures at the Tahoe Basin.
The EIP program is supporting monitoring of treatment BMP effectiveness. BMPs funded through the EIP program and implemented by the City of South Lake Tahoe, Nevada Department of Transportation, El Dorado County, Placer County, the California Tahoe Conservancy and Caltrans are being now monitored (LRWQCB, 2002) . While a significant effort is being made to quantify the performance of these systems, it is important that the collected data are useful for assessing performance.

Sampling and monitoring data collected from treatment BMPs should be standardized so that BMP performance can be reliably assessed and compared, as was recently done with the Lake Tahoe TMDL Stormwater Monitoring Program and the Caltrans Tahoe Basin Stormwater Monitoring Program. Sampling and monitoring plans should collect similar data at similar frequencies. Issues to be addressed would include the appropriate parameters to monitor (such as TSS, turbidity or other metrics to assess fines); the role and methods for assessing toxicity; and statistical methods for data analysis.

The data collected for this purpose may not be the complete dataset for each BMP because specific BMP projects may have specific data collection goals. For instance, some BMP projects may focus on groundwater effects, ecosystem effects or other issues. However, for each collected dataset, there should be a subset of data useful in accessing BMP effectiveness in a standardized fashion. Overall research goals for assessing these BMPs should be developed with participation of scientific and regulatory agencies. This recommendation could be undertaken by the Working Group if it is formed (See Recommendation 5.2a). These research goals would then guide development of sampling and monitoring procedures and the results would likely have a greater potential of addressing current and future regulatory needs. The sampling and monitoring program should be implemented universally in the Tahoe Basin and the TIIMS database used for storing a database created for storing the universal data.

Recommendation 5.1b. Conduct necessary laboratory and field studies to predict the performance of the more promising existing stormwater treatment BMPs, retrofit activities, and promising BMP technologies. Better predictions of BMP performance are needed in the Tahoe Basin. These predictions are needed for local agencies to formulate deployment strategies to address the upcoming TMDL and to move forward on activities such as storm water permitting. These predictions are also needed by regulatory agencies to understand the load reduction and concentrations that can be achieved by the different stormwater treatment BMPs. Special emphasis should be made to understand and more accurately predict the performance of the more promising BMPs and to quantify the improvements in treating different PoC with different retrofit activities.

A first step in this process might be more in depth literature reviews and a more thorough analysis of the national datasets. But those efforts will only take this process so far (and not far enough) because the Tahoe Basin has a number of unique constraints and the national datasets do not adequately address the PoC for the Tahoe Basin. Thus, fundamentally this means further testing is needed in a number of areas:

- Table 2.8 ranks current BMPs in the Tahoe Basin based upon their potential to meet both effluent-based and TMDL-based regulatory requirements. In general, these current BMPs differentiate themselves mostly from each other in the TMDL-based assessment. Thus, current stormwater BMPs considered more promising in that ranking (for identified PoCs) should be further tested to better quantify their PoC removal performance for different stormwaters in the Tahoe Basin. Overall media filters, wet ponds, water quality swales (wetland channels) and stormwater treatment wetlands are considered the most promising current BMPs. However, certain BMPs are better for certain PoC and Table 2-8 ranks stormwater treatment BMPs for different PoC and different regulatory requirements.

- In addition to these current stormwater BMPs, promising new technologies should also be tested. These technologies are discussed in Section 3. Of these technologies, testing on some should continue and testing on others should begin. Those new technologies considered most promising are Dual Media (Adsorptive Media) Filters (3.2.1), Chemical Dosing and Settling (3.2.2), Passive Chemical Delivery (3.2.5), Electro-coagulation (3.3.1), Engineered Chemical Dosing and Filtration Systems (3.3.2), and Passive Chemical Delivery and Baffle Grids (3.3.3).

- Additionally, the effect of more promising retrofit activities needs to be determined. Potential retrofit activities are summarized in **Section 4.2** and include hydrologic and technology retrofits. These retrofits apply mainly to improving the performance of basins, wetlands and filtration systems. Technology retrofits that we believe should be further investigated include integrating chemical dosing systems and adsorptive media with current BMPs, implementing methods to improve energy dampening, and improving hydrology control and configurations of current BMPs. Additionally, encouraging biotic communities where possible such as in wetlands and wet basins should improve removal of biologically available N and P. The more promising retrofits should also be tested (see Recommendation 5.1c).

Testing discussed in this section should not fall on any one agency or group. This information will be critical in allowing local agencies to develop strategies to meet regulatory requirements and will provide regulators realistic targets for treating PoC.

Recommendation 5.1c. Survey current stormwater treatment BMPs being implemented by different agencies and identify retrofit opportunities for each agency. This document provides a list of potential retrofits ideas that could be applied to stormwater treatment BMPs, primarily basins, wetlands and infiltration areas. Each local agency has a unique distribution of current stormwater treatment BMPs and new projects under development. The retrofit activities most attractive to each agency will be those that will help meet regulatory requirements as well as those that are feasible and cost effective. Each agency should conduct a survey of their current treatment BMPs and include such information as identifying the locations of each BMP in the watershed, nearby current and future BMPs, the PoC targeted for that site based upon an assessment of land uses, and the cost and feasibility of implementing different retrofit ideas. With this information, each agency could identify which retrofit or technologies have the greatest potential in their watersheds and prioritize funding to develop or investigate those technologies accordingly (see Recommendation 5.1b).

Recommendation 5.1d. Investigate and better understand outflow and internal hydrologic control options available for managing hydrology in basins, infiltration systems and wetlands. There is a trade-off between detention time and frequency of draining. For the stormwater treatment basins and wetlands, hydrologic models need to be developed to better understand and identify the optimal hydrologic residence time for treatment, the likely frequency of storm events, and the outflow structure options that will most effectively meet those requirements. Additionally, hydrologic short-circuiting likely affects the performance of many of these systems, not only minimizing effective treatment time and area, but also leading to higher energy areas that promote resuspension and hinder settling. A better understanding of the biotic and abiotic features and hydrologic structures that can be used to better manage a basin or ponds internal flow distribution and energy dissipation is needed to ensure the basin and wetland BMPs are working optimally.

Recommendation 5.1e. Develop Watershed Model to Estimate Watershed Loads Under Different BMP Deployment Strategies. The Tahoe Basin is moving towards a TMDL regulatory requirement. The regulatory structure is evolving and the process will take many years. Until that time, agencies need to meet current regulatory requirements. In anticipation of the TMDL regulations, however, BMP projects should be planned and evaluated based not only on their ability to meet current standards but also on their potential usefulness within the upcoming TMDL framework.

Currently, a watershed model has been developed by TetraTech for the TMDL. A useful application of a watershed model would be to predict the different load exports for different BMP deployment strategies. This model could be used on specific watersheds throughout the Basin to enable local agencies to better develop BMP deployment strategies and more cost-effectively address PoC regulatory requirements. This watershed model may be an extension of

the current TetraTech model or, if that model is not particularly suitable for this purpose, then an alternate model could be developed.

From this model, cost-benefit analyses could be developed for different BMP deployment strategies and would include not only one-time capital costs for new BMPs or retrofit activities, but also ongoing operations and maintenance costs. A cost-benefit analyses needs to be done to put an economic number behind different strategies. Small-scale systems may be cost-effective for small-scale problems, but if the TMDL requires large-scale corrections to pollutant loading, then large-scale systems may become more cost effective. Part of this analysis should include an assessment of the revenues available to support long-term pollutant reduction activities.

Finally this model should include not only treatment BMPs but also source control BMPs. Source control has not bee discussed in this document but should aid local agencies with more cost effectively meeting their regulatory requirements. Integrating source control and treatment BMPs together under a unified strategy should make a more effective plan.

Recommendation5.1f. Support efforts to develop source control BMPs. As discussed in Section 5.1e, source control BMPs should enable more efficient and effective use of stormwater treatment BMPs. Some of the technologies discussed in this report could be used for source control: passive chemical treatment, adsorptive media. Agencies in the Tahoe Basin, including local agencies, should be actively promoting the development of these and other technologies to improve PoC source control.

5.2   Develop a More Coordinated Approach to Stormwater BMP Development and Implementation

There are various different groups working toward reducing PoC transport to Lake Tahoe. The work and responsibilities of these groups often overlap. Currently the majority of the work on advancing new BMP technologies has been conducted by the Tahoe Research Group/Bachand & Associates Team, and by the Office of Water Programs and Caltrans. These efforts have been loosely coordinated and for the most part seem to provide complementary data. However, a more coordinated approach is needed to guide stormwater BMP planning in the Tahoe basin and to optimize the effectiveness of new BMP technology and retrofit investigations.

Recommendation 5.2a. Promote the formation of a Stormwater BMP Working Group to Coordinate Stormwater BMP Research and Implementation. A working group should be formed analogous to LTIMP but which focuses on BMPs. This BMP Working Group (BMP-WG) would not be a dictating body but mainly a group to promote information-sharing and suggest standard implementation. It would provide a forum for frequent discussion of BMP research, development and deployment activities in the Basin and promote a more cohesive approach to this problem. The BMP Working Group should be composed of both science and agency representatives in the Tahoe Basin so that it can focus on not only the science issues of investigating BMPs but also the logistic issues of their implementation. This working group could be a subcommittee of the existing Storm Water Quality Improvement Committee (SWQIC) and should be created to provide a single place for consolidating all BMP research, implementations and actions. This working group could have a number of responsibilities:

- The BMP-WG should be involved in identifying research and implementation actions, and for securing funding for those actions through agreements with funding organizations. One joint activity that might be accomplished by this group would be coordinating proposals to EPA and other outside-the-membership agencies for funding.

- The BMP-WG could oversee and manage the development of a technical design manual for BMPs. As discussed in this document, there have been efforts to develop design standards in the Tahoe Basin. These guidelines could be part of the technical review by the Working Group. These standards should be consolidated into a single document that can provide guidance to the agencies implementing different BMPs. These guidelines should be updated as data validates or invalidates design features.

- *The* CalEPA recently held a conference on advances in stormwater treatment for construction sites. Similar conferences would be useful for applications in the Tahoe Basin. Over the last ten years, many advances have been made in stormwater treatment and as these systems have become more regulated, there is an increasingly useful dataset on some of these new technologies. These conferences, organized by the working group, could be held annually or biannually. They would both provide a way for the Tahoe community to better understand the state-of-the-art of treatment technologies and to help recruit stormwater professionals to test their systems in the Tahoe Basin. The BMP-WG could manage these conferences.

- A function of the working group should be to provide a forum for technical peer review of designs and implementation strategies. For the peer review, the committee should rely both on local experts as well as on national experts. This step would ensure better designs and continual progress towards more state-of-the-art approaches. The exact form of peer review would need to be determined (i.e., how peer reviewers are solicited, how items are submitted for peer review, whether peer review is in formal reports or less formal discussions).

Recommendation 5.2b. Better define PoC and Regularly Report Progress to Local Agencies.
An assessment of the effectiveness of a BMP cannot be made unless one understands what pollutants need to be removed. Currently, PoCs in the Tahoe Basin have been identified by the Regional Board as P and N species and fine particles (Heyvaert et al., 2004). These PoCs are indicated by but are not the same as the constituents that are monitored for regulatory purposes: TP, TN, TSS and turbidity. As the TMDL is developed over the next several years, we expect more emphasis will be placed on biologically available P and N species, and on fine particles, and that these changes are likely to change how the performance of any given BMP is measured. The effort to better define PoCs is in progress, supported by TMDL and EIP funding. Effective communication between state regulators and local agencies is needed to ensure that the progress of TMDL development is regularly reported to local agencies. This will allow local agencies to better meet current regulatory needs and transition in the future towards a TMDL regulatory environment.

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Appendix 1. Office of Water Programs Memorandum on Caltrans Maintenance Experience