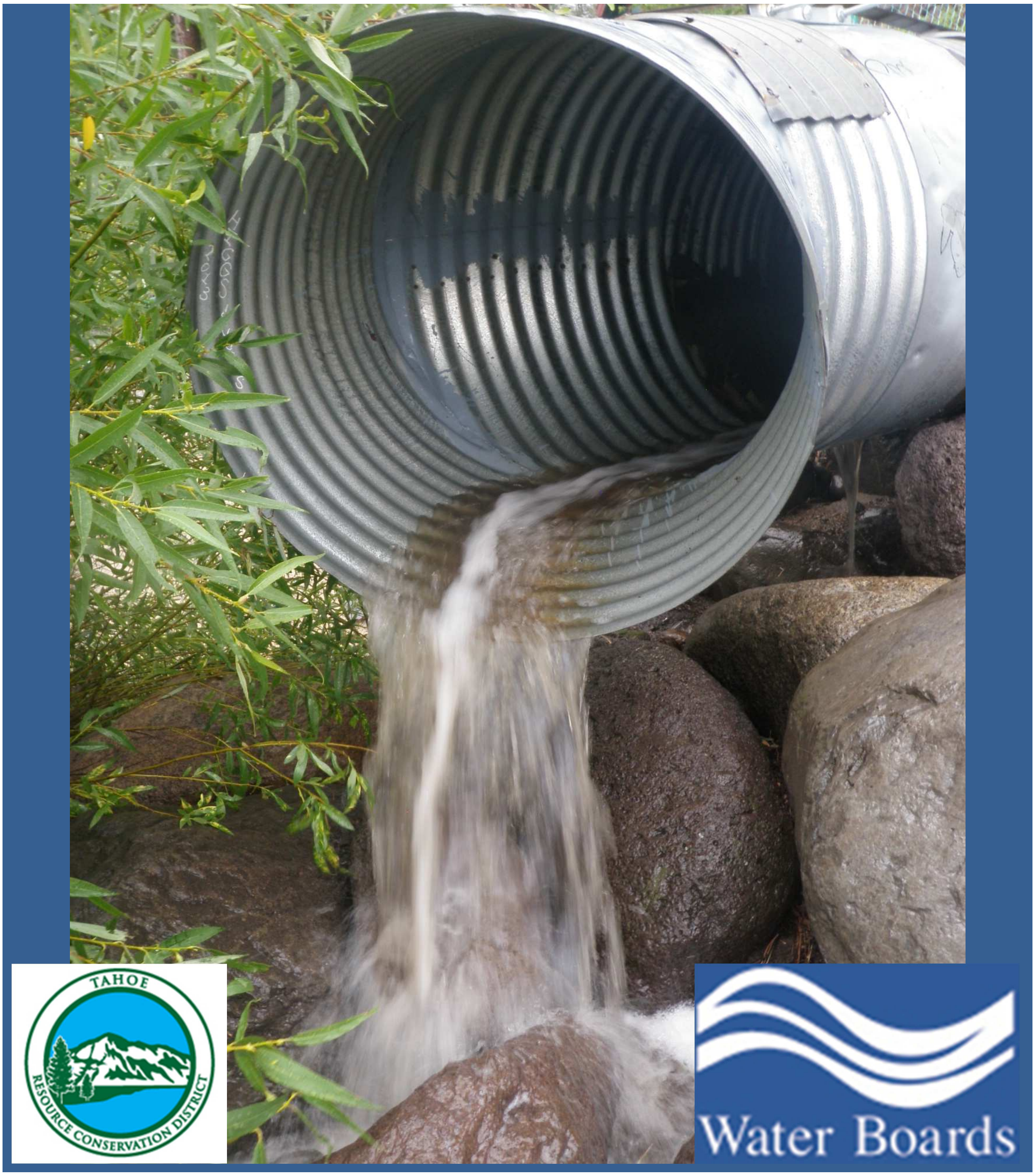

Scientific Assessment Report

A Stormwater Literature Review for the Regional Stormwater Monitoring Program in the Lake Tahoe Basin

August 2014

Regional Stormwater Water Monitoring Program

Scientific Assessment Report

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ACRONYMS

ARR	Assessment and Recommendations Report
ASCE	American Society of Civil Engineers
BMP	Best Management Practice
BMP RAM	Best Management Practice Rapid Assessment Method
CEC	Characteristic Effluent Concentration
CEDEN	California Environmental Data Exchange Network
CRC	Characteristic Runoff Concentration
DRI	Desert Research Institute
EIP	Environmental Improvement Program
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
FSP	Fine Sediment Particle (<16µm)
IMP	Implementers' Monitoring Program
Lahontan	Lahontan Regional Water Quality Control Board
LSPC	Loading Simulation Program in C++
LTIMP	Lake Tahoe Interagency Monitoring Program
NHC	Northwest Hydraulic Consultants
NTU	Nephelometric Turbidity Units
NURP	National Urban Runoff Program
PLRM	Pollutant Load Reduction Model
PP	Particulate Phosphorus
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
Road RAM	Road Rapid Assessment Method
RSWMP	Regional Storm Water Monitoring Program
SAG	Scientific Advisory Group
SAP	Sampling and Analysis Plan
SAR	Scientific Assessment Report
SWAMP	Surface Water Ambient Monitoring Program
SWMM	Storm Water Management Model
SWT	Stormwater Treatment
Tahoe RCD	Tahoe Resource Conservation District
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TRG	UC Davis Tahoe Research Group
TRPA	Tahoe Regional Planning Agency
TSS	Total Suspended Sediment
WY	Water Year

EXECUTIVE SUMMARY

The Scientific Assessment Report summarizes the current state of knowledge regarding stormwater monitoring conducted in the Tahoe Basin over the past decade and highlights relevant findings for consideration during the development and design of the Lake Tahoe Regional Stormwater Monitoring Program (RSWMP). The breadth of past stormwater monitoring conducted in the Tahoe Basin has greatly improved our knowledge of urban stormwater monitoring techniques, existing stormwater quality conditions, and informed the development and refinement of the stormwater tools supporting the TMDL and the Lake Tahoe Environmental Improvement Program. Section 3 overviews the range of different stormwater monitoring methods employed and how the successes and lessons can inform RSWMP data collection method selection and approaches. Section 4 provides a synthesis of relevant stormwater research approaches and findings that may be relevant to focusing the RSWMP objectives. Section 5 is the compilation of the available research into a collection of focused considerations to guide RSWMP design. These considerations documented in Section 5 will be vetted through both the RSWMP Scientific Advisory and Technical Advisory Groups used to inform the final Assessment and Recommendations Report that will solidify the long-term RSWMP objectives, data collection, data management and reporting approaches and priorities.

1 PURPOSE

The Scientific Assessment Report (SAR) has been developed collaboratively by the Tahoe Resource Conservation District (Tahoe RCD), the Lahontan Regional Water Quality Control Board (Lahontan), the TRPA, and the Scientific Advisory Group (SAG).

The purpose of this document is to summarize the current state of knowledge regarding stormwater monitoring, highlight relevant findings from past research, and establish overarching recommendations for stormwater monitoring to consider for the Lake Tahoe Regional Stormwater Monitoring Program (RSWMP), and inform the future RSWMP Assessment and Recommendations Report (ARR) . RSWMP supports a multitude of water quality improvement programs including the Lake Tahoe Total Maximum Daily Load (TMDL), Lake Clarity Crediting Program, Tahoe Regional Planning Agency (TRPA) Regional Plan, local jurisdictions stormwater programs, Environmental Improvement Program (EIP), and others. RSWMP objectives will be defined to address critical management needs. In order to achieve these objectives clear and consistent data collection, data management, data analysis, and reporting methods will be developed to support the Lake Tahoe TMDL adaptive management system.

The Lake Clarity Crediting Program provides a process to guide regulators and jurisdictions to prioritize, implement, and verify water quality improvement actions via a series of tools. The Pollutant Load Reduction Model (NHC et al 2009) is used to estimate the pollutant load reductions as a result of water quality improvements to an urban catchment. Two rapid assessment tools were also developed, Best Management Practices Rapid Assessment Methodology (BMP RAM) and Road Rapid Assessment Methodology (Road RAM) (2NDNATURE et al 2009 and 2010b, respectively), to verify that water quality improvements in a catchment are maintained annually to the registered conditions. In conjunction with RSWMP data collection and findings, the Lake Clarity Crediting Program will support management actions, inform the stormwater tools supporting the Lake Tahoe TMDL and provide information necessary for improving stormwater quality in the Tahoe Basin.

The Tahoe RSWMP was initiated with the development of three guidance documents, during the planning phase 2009—2011.

- Quality Assurance Project Plan (QAPP) v.1.4; Tahoe Regional Stormwater Monitoring Program; May 10 2011, A. Heyvaert, J. Reuter and R. Susfalk.
- Sampling and Analysis Plan (SAP) v1.4; Tahoe Regional Stormwater Monitoring Program; May 10 2011, A. Heyvaert, J. Reuter and R. Susfalk.
- Tahoe RSWMP Data Quality Objectives v1.4; May 10, 2011 A. Heyvaert and J. Reuter.

These documents outlined an integrated program focused on stormwater monitoring in the Tahoe Basin that could be implemented across jurisdictional boundaries to provide the information needed for both scientific and management purposes. That vision has evolved into the present RSWMP program, of which this report is the next step. Elements of the original monitoring design and organizational structure will change as this program is implemented to reflect funding realities, emerging management questions, and available monitoring opportunities.

2 SAR DEVELOPMENT APPROACH

The Tahoe RCD and RSWMP SAG members coordinated with local agencies, researchers and stormwater managers to identify available and relevant stormwater research conducted in the Tahoe Basin since the early 2000's. Final reports were compiled and reviewed to summarize past research in a simple tabular format, and the full list of references utilized are provided at the end of this document. Table 2.1 summarizes the general monitoring research objectives; the type of stormwater monitoring conducted; the key pollutants evaluated; and the applicability of the research to evaluate urban stormwater pollutant loading trends, treatment BMP effectiveness and inform the stormwater tools supporting the Crediting Program. Applicable site selection, data collection, data analysis, data management and reporting methods were synthesized to ensure techniques and lessons learned from past efforts are considered during the RSWMP design process. A concurrent effort by 2NDNATURE that includes potential data analysis and reporting recommendations for the RSWMP SAG to consider in the future RSWMP Assessment and Recommendations Report (ARR) is also included in the bibliography, but the results were not ready in time to be included in this synthesis.

3 SUMMARY OF PAST STORMWATER MONITORING METHODS

Considerable amounts of stormwater data have been collected and a variety of stormwater monitoring approaches have been used in the Tahoe Basin. RSWMP will leverage this experience to develop focused and standardized data collection, management, analysis, and reporting procedures that address existing questions related to stormwater management and research in the Tahoe Basin. Table 2.1 summarizes the 32 stormwater quality research efforts from 2001 to 2013 that are relevant to the development of objectives and design of RSWMP.

3.1 SITE TYPES

Past and current stormwater runoff research has been conducted on three primary types of monitoring sites in the Tahoe Basin: urban catchment outfalls, stormwater treatment BMPs, and highway runoff. Below is a summary of these site types and their purposes.

3.1.1 URBAN CATCHMENT OUTFALL MONITORING

Urban catchment outfall monitoring is conducted to sample the quality and quantity of stormwater runoff generated from developed land uses in the Tahoe Basin, and can be used to determine status and trends over time in a particular catchment. Most urban catchment outfalls receive runoff from a mixed land use drainage area. Figure 3.1 indicates the locations of the 28 known catchment outfall sites previously instrumented for water quality monitoring. This includes any *inlets* to stormwater treatment BMPs, as these monitored inlets can be considered the culmination point (or catchment outfall) of the urban drainage area contributing to the stormwater treatment BMP. Many of the existing sites were implemented to inform development of the Lake Tahoe TMDL land use pollutant loading analysis (Lahontan and NDEP 2010) or were instrumented to sample inflow to stormwater treatment BMPs for performance assessment. Most have included nutrient and total suspended sediment (TSS) analyses, and slightly more than half have included particle size distribution analyses to determine fine sediment particle (FSP, <16um) concentrations and loads. Some of the data resulting from past urban catchment outfall monitoring (e.g. Gunter 2005, NHC et al 2009) was used to determine the characteristic runoff coefficients (CRC's) used in the Pollutant Load Reduction Model (PLRM). Current and future catchment outfall monitoring will be used to detect pollutant load status and trends and provide quantification of urban pollutant loading to the Lake. The potential for previously monitored catchment outfalls should be considered during RSWMP future site selection whenever possible due to the cost-savings associated knowledge of site specific nuances and the insight of available data to inform expected hydrology and pollutant concentrations.

3.1.2 TREATMENT BMP EFFECTIVENESS MONITORING

Stormwater treatment BMP monitoring at inlets and outlets has been conducted to quantify effectiveness of reducing pollutant loads by comparing event or seasonal inflow/outflow volumes, pollutant concentrations or loads, and/or determination of characteristic effluent concentrations (CECs) used in the PLRM (NHC et al 2009). Typically, stormwater treatment BMPs accept runoff from mixed land use drainage areas, similar to urban catchment outfall sites. Figure 3.1 indicates the locations of all treatment BMP effectiveness sites previously monitored for water quality performance. The majority of treatment BMP effectiveness studies in the Tahoe Basin have been conducted on dry basins, wet basins, and treatment vaults (Table 3.1 for definitions). Past research has evaluated the performance of 12 dry basins, 5 wet basins, 4 treatment vaults, 2 infiltration basins or gallery features, and 3 cartridge filters. Although studies conducted on stormwater cartridge filter and infiltration basin BMPs have evaluated removal of total suspended solids, and total and dissolved nutrients (nitrogen and phosphorus), the research that specifically addresses effectiveness of these BMPs to remove FSP is very limited.

3.1.3 HIGHWAY RUNOFF MONITORING

Highway runoff monitoring has been conducted by a number of researchers to determine the quality of highway runoff, the effectiveness of road operations, validate PLRM road water quality algorithms, and inform the development of Road RAM. Monitoring has been conducted by Caltrans and NDOT at a number of sites that solely receive highway runoff to evaluate the effectiveness of pollutant source control BMPs (such as using alternative abrasive types, reducing abrasives applications, or increasing sweeping frequency) and treatment BMPs such as bed filters or media filters. A total of 15 highway runoff sites (Figure 3.1) have been instrumented to characterize pollutants resulting from road runoff, three with bed filter treatment and two with media filter treatment. Total and dissolved nutrients, turbidity, TSS, pH, and conductivity were measured in many of these studies since 2002, and all road related research conducted since 2008 has included FSP evaluations.

Table 2.1A: Compilation of urban stormwater research efforts from 2001-2013 relevant to RSWMP design

Monitoring Effort / Study Name	Lead Researchers	Relevance to…						Urban Catchment Monitoring			
			Inform TMDL Stormwater Tools							Urban Catchment	
		Urban catchment pollutant loading status and trends	PLRM	Road RAM	BMP RAM	Treatment BMP Effectiveness	Pollutant Source Control	Urban Meterology	Urban Catchment Hydrology	FSP, Turbidity	Nutrients, TSS, others
Detention Basin Treatment of Hydrocarbon Compounds in Urban Stormwater.	2NDNATURE 2006a					√		Others data	√		√
Water Quality Evaluations of a Fertilzed Turf Surface in the Lake Tahoe Basin (2002-2006); Incline Village Nevada.	2NDNATURE 2007					√	√	Others data	√		√
Water Quality Performance Evaluation of Park Avenue Detention Basins; South Lake Tahoe CA.	2NDNATURE 2008	√	√			√		Others data	√	√	√
Statistical Analysis of Data Obtained from an Incline Village Street Sweeping Effectiveness Study.	2NDNATURE 2012		√	√				Others data			
Tahoe stormwater quality data analysis and reporting guidance	*2NDNATURE in preparation 2014*	√	√			√		*WY context guidance*	*Urban catchment data analysis and reporting guidance*		
PLRMv1 Focused Stormwater Monitoring to Validate Water Quality Source Control and Treatment Assumptions	2NDNATURE and NHC 2010		√	√			√	Others data			
Focused Stormwater Quality Monitoring to Inform Assumptions and Evaluate Predictive Capabilities of Existing Tools	2NDNATURE AND NHC 2012a		√	√				Others data			
Pilot Catchment Validation Study: Lake Tahoe Basin	2NDNATURE AND NHC 2012b	√	√					Others data	√	√	
Infiltration BMP Design and Maintenance Study	2NDNATURE AND NHC 2013		√		√	√					
Urban catchment scale evaluation of Tahoe stormwater tools	*2NDNATURE and NHC in preparation 2014*	√	√	√				Others data	√	√	
Highway 267 Filter Fabric Sand Trap Pilot Study: 2004-2005 Interim Report. CTSW-RT-05-157.01.1	CALTRANS 2006	√				√			√	turb	TSS
Alternative Abrasives Study	*Caltrans in preparation*						√	Others data	√		
Delaware Sand Filter: Stormwater Monitoring in a Cold-Climate Region, Monitoring Season 2012-2013.	*Caltrans in preparation 2015*		√			√					
Nutrient and Sediment Production, Watershed Characteristics, and Land Use in the Tahoe Basin, California-Nevada. Journal of American Water Resources Association, 44(3): 754-770. June 2008	Coats et al 2008	√						√	√	√	√
Effect of Urbanization on the Suspended Sediment Loads from and Intervenening Zone of Lake Tahoe. Prepared for Tahoe Regional Planning Agency and California State Water Resources Control Board, 205j Grant. November 2001.	Dogrul et al 2001		SWMM						√	√	√
Rosewood Creek Monitoring Compendium, 2002-2010	DRI and NTCD 2010	√					√		√	√	Nutrients
Lake Tahoe Basin Stormwater BMP Evaluation and Feasibility Study. Prepared for Lahontan Regional Water Quality Control Board and Tahoe Research Group. July 2005	Geosyntec Consultants 2005	√	SWMM			√					
Subalpine, Cold Climate, Stormwater Treatment with a Constructed Surface Flow Wetland	Heyvaert el al 2006a	√				√			√	Turb	√
Monitoring Results Water Year 2003 Kings Beach Detention Basins	Heyvaert et al 2003	√				√		Others data	√	Turb	√
Efficiency Assessment of Stormwater Treatment Vaults in the Round Hill General Improvement District–Final Report	Heyvaert et al 2005	√				√		√	√	√	√
Brockway Project Area Stormwater Runoff and Characterization Study	Heyvaert et al 2008a	√						√	√	Turb	√
Upper Cutthroat Infiltration Testing and Stormwater Runoff Study	Heyvaert et al 2008b	√				√		√	√	√	√
Lake Tahoe Basin Stormwater Monitoring Report 2005-2007, Monitoring Seasons 2005-06 and 2006-07	NDOT 2007	√				√		√	√	turb	√
Homewood Phase 1 and 1A Water Quality Improvement Project Water Quality Monitoring Final Summary Report	NHC 2013	√					√	Others data	√	√	TSS
Effectiveness of Street Sweeping in Incline Village, NV	NTCD and DRI 2011		√	√							
Hybrid BMP Project	*NTCD and DRI in preparation*							Others data	√	Turb	
Burke Creek Monitoring Project Final Report	NTCD and NHC 2008	√							√	√	√
Lake Forest Stormwater Monitoring Report	NTCD and Placer County 2010	√						Others data	√	Turb	√
Lake Village Stormwater Investigation Final Report	NTCD and USFS 2009							Others data	√	√	√
Stormwater Runoff Water Quality Characteristics From Highways in Lake Tahoe, California	Regenmorter et al 2002	√				√		√	√	Turb	√
Land Use Based Stormwater Runoff Monitoring and Evaluation of BMP Effectivenebss in Lake Tahoe. Prepared for Tahoe Regional Planning Agency and California State Water Resources Control Board, 205j Grant. November 2001.	Reuter et al 2001	√	√			√		√	√	√	√
Analysis of Water Quality Monitoring Data from the Glorene and Eighth Erosion Control Project.	UCD and CSLT 2003	√						√	√		√

Table 2.1B: Compilation of urban stormwater research efforts from 2001-2013 relevant to RSWMP design

Monitoring Effort / Study Name	BMP Effectiveness Monitoring										Road Pollutant Sour		
	Treatment BMP Performance							Private Parcel BMP Performance			Road Operations Reporting	Road Condition Monitoring	Ro Run
	Wet/Dry Basin	Cartridge or Other Filter	Other BMP	Effectiveness Monitoring	O&M Evaluation	FSP, Turbidity	Nutrients, TSS, others	Infiltration	FSP, Turbidity	Nutrients, TSS, others			
Detention Basin Treatment of Hydrocarbon Compounds in Urban Stormwater.	√						√						
Water Quality Evaluations of a Fertilzed Turf Surface in the Lake Tahoe Basin (2002-2006); Incline Village Nevada.	√						√						
Water Quality Performance Evaluation of Park Avenue Detention Basins; South Lake Tahoe CA.	√					√							
Statistical Analysis of Data Obtained from an Incline Village Street Sweeping Effectiveness Study.											NTCD and DRI 2011 data		
Tahoe stormwater quality data analysis and reporting guidance	*SWT BMP performance data analysis and reporting guidance*												
PLRMv1 Focused Stormwater Monitoring to Validate Water Quality Source Control and Treatment Assumptions	√					√	√				√	√	
Focused Stormwater Quality Monitoring to Inform Assumptions and Evaluate Predictive Capabilities of Existing Tools	√					√					√	√	
Pilot Catchment Validation Study: Lake Tahoe Basin													
Infiltration BMP Design and Maintenance Study			√			√		√	√				
Urban catchment scale evaluation of Tahoe stormwater tools											√	√	
Highway 267 Filter Fabric Sand Trap Pilot Study: 2004-2005 Interim Report. CTSW-RT-05-157.01.1		√		√	√	Turb	TSS						√
Alternative Abrasives Study													√
Delaware Sand Filter: Stormwater Monitoring in a Cold-Climate Region, Monitoring Season 2012-2013.		√		√	√	√	√						
Nutrient and Sediment Production, Watershed Characteristics, and Land Use in the Tahoe Basin, California-Nevada. Journal of American Water Resources Association, 44(3): 754-770. June 2008													√
Effect of Urbanization on the Suspended Sediment Loads from and Intervenening Zone of Lake Tahoe. Prepared for Tahoe Regional Planning Agency and California State Water Resources Control Board, 205j Grant. November 2001.													
Rosewood Creek Monitoring Compendium, 2002-2010													
Lake Tahoe Basin Stormwater BMP Evaluation and Feasibility Study. Prepared for Lahontan Regional Water Quality Control Board and Tahoe Research Group. July 2005	√					√	√	√	√	√			
Subalpine, Cold Climate, Stormwater Treatment with a Constructed Surface Flow Wetland	√			√		Turb	√						
Monitoring Results Water Year 2003 Kings Beach Detention Basins	√			√		Turb	√						
Efficiency Assessment of Stormwater Treatment Vaults in the Round Hill General Improvement District–Final Report		√		√		√	√						
Brockway Project Area Stormwater Runoff and Characterization Study													
Upper Cutthroat Infiltration Testing and Stormwater Runoff Study			Infiltration Features	√		√	√						
Lake Tahoe Basin Stormwater Monitoring Report 2005-2007, Monitoring Seasons 2005-06 and 2006-07	√		Sediment Traps	√		Turb	√						√
Homewood Phase 1 and 1A Water Quality Improvement Project Water Quality Monitoring Final Summary Report													
Effectiveness of Street Sweeping in Incline Village, NV											√	√	√
Hybrid BMP Project			Rain Gardens (Infiltratin Basins)	√		√	TSS						
Burke Creek Monitoring Project Final Report													
Lake Forest Stormwater Monitoring Report	√			Pre, Post BMP installations		√	√						
Lake Village Stormwater Investigation Final Report			Private Parcel BMPs						√	√			
Stormwater Runoff Water Quality Characteristics From Highways in Lake Tahoe, California		√		√		Turb	√						√
Land Use Based Stormwater Runoff Monitoring and Evaluation of BMP Effectivenebss in Lake Tahoe. Prepared for Tahoe Regional Planning Agency and California State Water Resources Control Board, 205j Grant. November 2001.	√					√	√	√	√	√			√
Analysis of Water Quality Monitoring Data from the Glorene and Eighth Erosion Control Project.													

Figure 3.1: Known urban stormwater monitoring sites from research efforts 2001-2013.

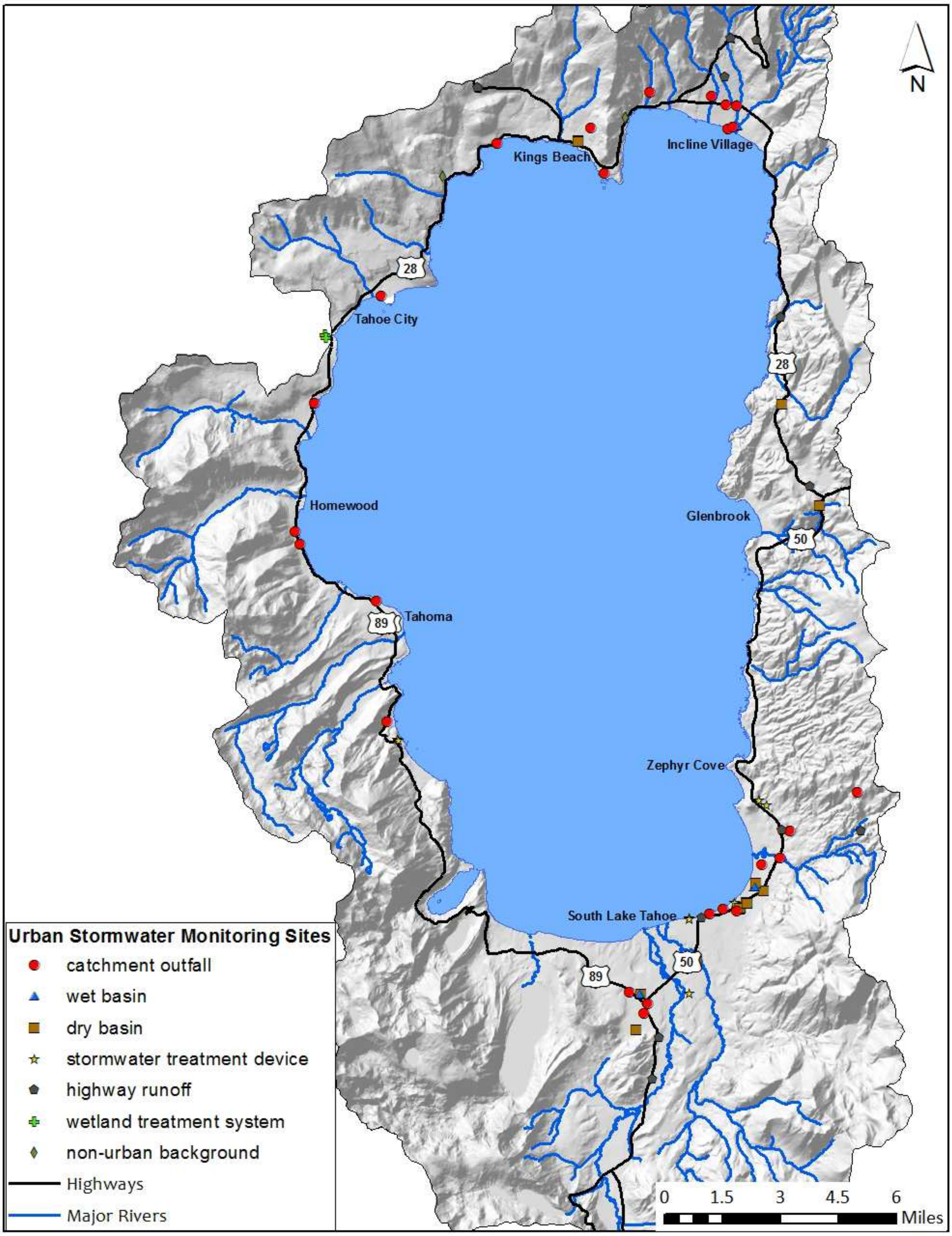

TABLE 3.1 Tahoe Treatment BMP Types as defined by BMP RAM (2NDNATURE et al 2009)			
Treatment BMP Type	**Other Names**	**Description**	**Processes relied upon for water quality treatment** **IN ORDER OF PRIORITY α**
Dry Basin	Extended Detention Basin, Dry Basin, Dry Pond, Detention Pond	• A constructed basin with riser outlets designed to detain stormwater runoff for some minimum time to allow particle and associated pollutant settling. Outflow occurs at the top of the water column and/or through drain holes at discrete depths. • Water quality improvements downgradient expected as a result of (1) volume reduction via infiltration due to high hydraulic conductivity of footprint soil, (2) effluent concentration due to residence time and particle capture. • Wetland and riparian vegetation species distribution is minimal to absent. Moderate distribution of grass and/or tree species likely and acceptable. • Stormwater is typically routed to the BMP and expected to be conveyed downgradient after treatment. • Typically a larger sized Treatment BMP type constructed in Lake Tahoe.	Infiltration Particle Capture *Conveyance* β
Wet Basin	Wet Pond, Retention Pond, Wetland Swale, Wet Extended - Retention Pond, Stormwater Wetlands, Constructed Wetlands	• A constructed basin with discrete inlet(s) and outlet(s) that detains runoff and has a persistent pool of surface water typically through the wet season and intermittently and/or consistently in the dry season. • Wet basin detention result in flow rate reductions, increased hydraulic residence times and particle aggregation and subsequent settling. Substrate is typically fine organic matter and silt making infiltration rates relatively low. Pollutant load reductions realized by particle capture and biogeochemical processes due to high vegetation presence. Annual stormwater volume reductions occur primarily by evapotranspiration. • High inundation frequency increases the vegetation density. Dominant vegetation is wetland species and can be supplemented with riparian species with very high densities. • Stormwater is typically routed to the BMP and expected to be conveyed downgradient after treatment. • Typically a larger sized Treatment BMP type constructed in Lake Tahoe. • Note that a wet basin does not include open types of wetland systems that do not have discrete inlets and outlets	Particle Capture Nutrient Cycling *Conveyance*

TABLE 3.1 Tahoe Treatment BMP Types as defined by BMP RAM (2NDNATURE et al 2009)

Treatment BMP Type	**Other Names**	**Description**	**Processes relied upon for water quality treatment** **IN ORDER OF PRIORITY α**
Infiltration Basin	Large-Scale Infiltration Feature	• Constructed basin with little to no treatment storage, meaning stormwater that continues downgradient has the same pollutant concentrations as introduced to the infiltration basin. • Highly permeable substrate designed to rapidly infiltrate significant volumes of stormwater into unsaturated zone. Pollutant load reductions realized due to significant volume reductions. • Vegetation distribution should be minimal, but preferably absent. • Stormwater is typically routed to the BMP and any excess stormwater is expected to be conveyed downgradient as bypass. • Typically a larger sized Treatment BMP type constructed in Lake Tahoe.	Infiltration *Conveyance*
Treatment Vault	Flow Separation Vault, Hydrodynamic Separators	• Flow-through confined space structure that separates sediment, debris and other particulate pollutants from the water volumes via various settling techniques. • Water quality improvements of stormwater continuing downgradient expected as a result of particle capture. No volume loss occurs due to impervious base, thus pollutant load reductions realized by concentration reductions due to particle capture. • Typically manufactured and proprietary structures. • Treatment BMP strategically placed in stormwater drainage path and treated water is conveyed downgradient • Typically a moderate sized Treatment BMP type constructed in Lake Tahoe.	Particle Capture *Conveyance*
Cartridge Filter	Proprietary Media Filter (e.g. Stormfilter®)	• Cartridge filters are contained within a confined space similar to treatment vaults. • Granular or media filter to remove fraction of stormwater pollutants. • The proprietary filter media type should be specifically selected to target removal of the pollutants of concern, resulting in downgradient stormwater concentration reductions. No volume loss occurs due to impervious base. • Treatment BMP strategically placed in stormwater drainage path and treated water is conveyed downgradient. • Typically a moderate sized Treatment BMP type constructed in Lake Tahoe.	Media Filtration *Conveyance*

TABLE 3.1 Tahoe Treatment BMP Types as defined by BMP RAM (2NDNATURE et al 2009)			
Treatment BMP Type	**Other Names**	**Description**	**Processes relied upon for water quality treatment** **IN ORDER OF PRIORITY α**
Bed Filter	Surface Sand Filter, Underground Sand Filter, Perimeter Sand Filter, Organic Media Filter	• Typically a settling/pretreatment basin followed by a filter bed (e.g., sand filter, activated alumina) with several feet of volume retention above the bed. Filtration is controlled by the rate of infiltration through the filter bed. • The capture of particles and pollutants is achieved via filtration of stormwater through an activated alumina, sand or other media type. • Hydraulically similar to infiltration basins except the runoff is filtered through the bed, collected into an under drain, and discharged to an outlet rather than being infiltrated to the local unsaturated zone. Little to no volume loss occurs. • Stormwater is routed to the structure or they may be strategically placed in an existing runoff path. • Typically a moderate sized Treatment BMP type constructed in Lake Tahoe.	Media Filtration *Conveyance*
Settling Basin	Concrete Forebay	• Structures typically placed at the inlet of other treatment BMPs to pre-treat inflowing stormwater and retain coarse sediment loads prior to stormwater entering subsequent Treatment BMP. • Load reductions are realized by concentration reductions. Minimal to moderate volume loss occurs. • Typically small to moderate sized Treatment BMP type constructed in Lake Tahoe.	Particle Capture *Conveyance*
Biofilter	Grass Swale, Grass Filter Strips, Vegetated Buffer Strips, Bioslopes	• A pervious substrate with dense vegetation coverage (>80%) to provide a concentration reduction by fixing nutrients via biological processes. Some infiltration may occur during inundation. • Typically constructed as pervious stormwater conveyance feature. • Small to moderate sized Treatment BMP type constructed in Lake Tahoe.	Nutrient Cycling Infiltration *Conveyance*
Infiltration Feature	Dry Well, Infiltration Trench, Roof Drip-Line, Rock-Lined Channel	• Land surface modified to sustain maximum infiltration rates, typically consisting of vertical excavation of native soils and filling with coarse drain rock or other highly permeable material. • Stormwater is typically not routed to infiltration features, but rather implemented to reduce volumes generated from adjacent impervious surfaces. • Small sized Treatment BMP type constructed in Lake Tahoe.	Infiltration *Conveyance*

TABLE 3.1 Tahoe Treatment BMP Types as defined by BMP RAM (2NDNATURE et al 2009)			
Treatment BMP Type	**Other Names**	**Description**	**Processes relied upon for water quality treatment** **IN ORDER OF PRIORITY α**
Porous Pavement	Porous Asphalt, Pervious Concrete, Porous Aggregate, Porous Asphalt, Grinding Shoulders, Modular Block	• Porous pavement consist of a durable, pervious surface overlaying a crushed stone base that stores rainwater before it infiltrates into the underlying soil. • Porous pavement can include an underlying reservoir to increase infiltration rates. • Local stormwater is typically not routed to a porous pavement surface, but rather constructed to minimize the volume of stormwater generated and routed downgradient from a previously impervious surface. • Footprint of Treatment BMP type can vary greatly, typically used for parking lots or other impervious surfaces.	Infiltration *Conveyance*
Sediment Trap	Vertical CMP, Catch Basin	• Typically constructed on site using low cost vertical corrugated metal (CMP) and trash rack placed in stormwater flow path to capture sediment, debris, coarse particles and associated pollutants in a deep (>5 ft) sump. • Minimal to no volume loss occurs due to vertical accumulation of road side particulates and relatively small footprint. • Typically located on road shoulder stormwater flow paths. • Small sized Treatment BMP type constructed in Lake Tahoe.	Particle Capture *Conveyance*
Conveyance BMP			
Drop Inlet	DI, Storm Drain, Culvert,	• Stormwater feature placed strictly to collect and convey stormwater. • A drop inlet that includes a sump to capture sediment is termed a **Sediment Trap**. • Typically connected to a culvert and provides no water quality benefit downgradient.	*Conveyance*

3.2 DATA COLLECTION

The type of data collected in past studies varies by project, notably dependent upon the objectives of the specific study, but data critical to stormwater monitoring includes nearby meteorology and site specific hydrology, and water quality samples analyzed for constituents of interest, namely sediments and nutrients. The following sections summarize data collection methods.

3.2.1 METEOROLOGY

The majority of past monitoring studies obtained meteorological data from external sources such as the Western Regional Climate Center, with sites maintained by the Desert Research Institute (DRI), and SNOTEL (snow telemetry) sites maintained by the Natural Resources Conservation Service. Few research studies installed and maintained a site specific weather station for the monitoring study. The distance from monitored sites to the nearest weather station varies significantly among the studies summarized in Table 2.1. Weather data was generally used to determine event, seasonal, and annual precipitation totals, as well as to characterize the monitoring period as relatively wet or dry compared to average meteorological conditions. In some instances, weather data was used to determine the annual rainfall-runoff response by calculating the runoff coefficient, which is a dimensionless value indicating the amount of runoff relative to the amount of precipitation in a catchment. These were used primarily to compare normalized runoff between sub-drainages in study areas and to rate the consistency of results between years (e.g., Heyvaert et al 2008a). Efforts that included generation of site and time specific PLRM models to compare to measured catchment volumes and loads utilized best available precipitation and temperature 10-minute data (2NDNATURE and NHC 2014).

3.2.2 HYDROLOGY

Stormwater hydrology monitoring has typically been conducted using series different types of techniques. Table 3.2 summarizes the types, equipment needs and primary advantages and disadvantages. Automated pressure transducers and data loggers installed in a controlled cross-section is a cost-effective technique to create reliable stage to discharge conversions. A series of controlled cross-section options are available and are typically selected based on site installation specifics. These options include a weir, culvert, flume, or stable open channel to calculate flows from a measured level and expected velocity (based on flume specifications or channel characteristics). Accurate stage to discharge conversion equation for the controlled cross section is critical to properly translate stage to measured discharge. Automated area velocity meters are also commonly used, typically in conjunction with automated sampling units. Water budget mass balance approach couples a topographic survey with continuous water level monitoring as a method to cost-effectively obtain reasonable water input and output rates for flow-through treatment BMPs. In all instances, periodic manual flow measurement techniques are recommended to QA/QC in-situ methods to monitor discharge. Each of these techniques has their own unique set of equipment needs, data resolution capabilities, and benefits under various site-specific constraints. Though equipment logging continuous hydrology is the most expensive to install and maintain, it is capable of obtaining the most accurate flow measurements.

Due to the variability and intermittent flow conditions of urban stormwater and the relative cost-effectiveness of obtaining hydrologic data on minute timescales, a number of past stormwater monitoring efforts have noted the benefit of high resolution site hydrology. The influence of hydrology on pollutant loads is significant, yet the cost of instrumenting and maintaining fairly accurate hydrologic stormwater monitoring stations is relatively low and

Table 3.2: Summary of stormwater hydrology monitoring techniques, typical past applications, and general advantages and disadvantages

Technique	Typical applications	Equipment needs	Advantages	Disadvantages
Area Velocity	Controlled cross section Weir, culvert, flume, or stable open channel	Area velocity sensor and accurate cross-sectional area calculations.	Theoretically the most accurate measure of site hydrology in the right type of application. Data measured in desired units, data transformation/calculations are less than other methods.	Not accurate if any backwater exists Precision sensitive to debris in runoff Higher field expertise to properly install and maintain.
Stage/Weir		Stage recorder, weir and accurate orifice calculations	Once site conditions are understood and stage to flow calculations are established and verified, can be cost effective long term stormwater hydrology method.	Weir orifice dimensions vary and establishing the correct translation from stage to discharge can be technically challenging. Rigorous QA/QC with manual measurement to verify flow estimates for the range of flow conditions are critical.
Stage/Flume		Stage recorder and flume	Pre fabricated flumes include flow equations and recommended installation procedures. Cost effective long term stormwater hydrology method.	Flume costs.
Stage/Manning's Equation		Stage recorder consistent open channel segment with accurate slope and area calculations per unit stage increase	Simple and relatively cheap site installation and data collection methods.	Appropriate use of equation to get accurate results in typical stormwater systems is challenging. Not accurate if any backwater exists.
Stage/Rating curve		Stable cross-section is critical and manual flow measurements over the range of flow conditions	Simple and relatively cheap site installation and data collection methods.	Typically used in stream systems. May be possible in small stormwater channel but need frequent manual measurement and stage observations over range of flow conditions. Flashy stormwater hydrographs make this challenging. Not accurate if any backwater exists. Can be challenging to get accurate results in stormwater, particularly for higher site flow conditions.
Water budgets (WB)	Quantify inflow and outflow hydrology for flow through treatment BMP types	Stage recorder and a topographic survey to accurately translate stage to storage volume.	Time series of storage volume using a single stage recorder can be used to quantify inflow and outflow hydrology. Cost effective long term hydrology monitoring technique for flow through BMPs.	Technical expertise to manage and analyze datasets appropriately is moderate, once trained. Material accumulation may change the stage to volume relationship over time, requiring intermittent resurveying of footprint.
Manual flow measurements	QA/QC of continuous equipment		Critical for regular QA/QC of stage recorders or velocity probes.	Unlike all other techniques, flow is discrete point in time and not continuous. Not good technique for site hydrology.

**The annual costs include the frequency of field visits and QA/QC procedures, equipment replacement and repair, the technical capability of data management and analysis personnel to QA/QC datasets and perform necessary calculations and generate the most accurate site hydrology given the limitations of the data collection technique.*

hydrology on minute time scales extends the water sampling opportunities to allow reasonable estimates of pollutant loads over time. To fully understand pollutant loading from stormwater, it may also be necessary to measure groundwater flux, but this has not yet been widely integrated into stormwater monitoring.

Regardless of the data collection technique, lessons from past effort support the critical need to frequently QA/QC field equipment to the extent possible. In addition to ensuring proper instrument operation, regular data downloads and spot measurements of stage or velocity (depending upon instrument type) and flow should be adequately conducted at every site visit. These field QA/QC procedures require field personnel to be onsite during events with frequent and regular calibration points each year that ideally capture the range of flow conditions experienced at the site, including periods of no flow. Standardized simple field logs are recommended for each site to document and track regular site visit actions, personnel, and any issues. The majority of research efforts have noted changes with instrument drift and/or failure as a result of the challenging freeze thaw conditions in Tahoe. These issues are best mitigated by frequent site visits during winter operation.

3.2.3 WATER QUALITY SAMPLING METHODS

Three primary stormwater sample collection techniques have been used in the Tahoe Basin continuous sampling using in-situ sensors and data-loggers, event targeted sampling and manual grab sampling. Continuous sampling techniques have been well developed using automated turbidity probes as a surrogate for FSP concentrations in the Tahoe Basin. No continuous sampling proxies have been well developed or used in the Tahoe Basin. Event sampling has been conducted using automated samplers (example http://www.dri.edu/lake-tahoe-watershed) and passive samplers (example Passive Sampling Methods). Manual grab samples by field personnel have also been used to obtain stormwater pollutant concentrations (example Water Board Sampling Methods). Table 3.3 summarizes the devices typically used for each technique, equipment needs and primary advantages and disadvantages of each method. Regardless of the method selected, regular verification of proper sampler operation and synchronized data recording prior to each targeted event to ensure that accurate and reliable data are being collected has been an essential component of all successful studies in the past.

Commercially available optical sensors for measuring continuous water quality parameters such as turbidity, nitrate, and Florence dissolved organic matter can provide a continuous dataset to supplement traditional grab, auto, or passive samples. These types of sensors have been used for decades in wastewater, coastal and oceanographic monitoring, but have more recently been implemented in freshwater studies nationwide (Pellerin et al 2013; Pellerin and Bergamaschi 2014). The biggest advantage of these optical sensors over traditional discrete sampling is that they provide a continuous data record and can therefore better capture the intermittent flow conditions thereby sampling the full range of pollutant concentrations over the hydrograph and improve estimates of pollutant loading. However, these optical sensors are subject to biofouling and require either manual or automated cleaning, as well as frequent field visits to ensure that the units are functioning properly. In addition, the application to Tahoe stormwater where nutrient levels are relatively low may be challenging. Periodic calibration and data QAQC should be performed when using these sensors (Pellerin et al 2013; Voichick and Topping 2014). To date, *in situ* continuous turbidity sensors are the only optical sensors that have been used for storm water monitoring in the Tahoe Basin (Heyvaert et al 2011, 2NDNATURE et al 2014).

Automated turbidity probes placed *in-situ* can provide a cost efficient alternative or supplement to water sample collection specific to estimating FSP concentrations. Available Tahoe stormwater datasets from multiple researchers have been compiled, analyzed, and used to recommend universal rating curves that convert

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Water budgets (WB)	Quantify inflow and outflow hydrology for flow through treatment BMP types	Stage recorder and a topographic survey to accurately translate stage to storage volume.	Time series of storage volume using a single stage recorder can be used to quantify inflow and outflow hydrology. Cost effective long term hydrology monitoring technique for flow through BMPs.	Technical expertise to manage and analyze datasets appropriately is moderate, once trained. Material accumulation may change the stage to volume relationship over time, requiring intermittent resurveying of footprint.
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**The annual costs include the frequency of field visits and QA/QC procedures, equipment replacement and repair, the technical capability of data management and analysis personnel to QA/QC datasets and perform necessary calculations and generate the most accurate site hydrology given the limitations of the data collection technique.*

stormwater or stream turbidity to FSP concentration (Heyvaert et al 2011, 2NDNATURE et al 2014). These studies document the use of turbidity as a sensitive and cost-effective proxy for FSP concentration. These same studies also suggest that site-specific rating curves should be pursued in selected cases as necessary to verify adequate fit with existing data and to improve the application of these relationships, for example with turbidity data above 800 NTU where existing data is sparse. Since turbidity measurements are influenced by particle concentration, size distribution and particle shape, it is possible for a water sample with different TSS concentrations to have the same turbidity measurements, which could confound the application of this technique at some locations (Voichick and Topping 2014).

Hand held turbidity units can provide cost-effective field QA/QC and calibration for the turbidity probes and can be used as screening tools in the field to determine if samples exceed the typical turbidity and FSP concentrations where current data gaps exist (approximately > 800 NTU; 2NDNATURE et al 2014). There currently are no well established relationships between turbidity and nutrient concentrations. With the current focus on nutrient input to Lake Tahoe and its effect on nearshore condition, it may be important to consider methods that effectively evaluate both nutrients and FSP.

Automated samplers (autosamplers) are versatile and can be used to discretely sample runoff events in the intermittent stormwater flow conditions. They consist of an area velocity sensor or stage recorder in a flume or weir, vacuum pump and sampling bottle unit that allow for flexible water sample collection applications in variable flow conditions. Autosamplers require technical oversight by trained field staff for both installation and ongoing operation to ensure the sampling scheme meets the site conditions and experimental design. Operator knowledge of the range of potential flow conditions to optimize the autosampler programming is essential as samples are taken at operator defined discrete flow or time intervals (for example: take a sample every 1000 cubic feet or take a sample every hour) that must be tailored to each site for the forecasted precipitation event type and expected intensity and duration. Typical sampling techniques using autosamplers in the Tahoe Basin include triggering sampling to begin at an operator defined stage and then samples are collected at discrete flow intervals in individual bottles throughout the hydrograph. Individual samples can then be composited on a flow weighted basis in the laboratory using a calculation template that adjusts for any modifications made to the program or sample collection interval in the field during the event. Often, one composite is made for the entire event, greatly reducing the analytical costs for sediment and nutrient analysis that would be associated with analyzing several water quality samples. This method allows for high resolution sampling and calculations of both FSP and nutrient loading over the entire duration of the sampled runoff event. It also allows for replicate manual samples (triggered through the autosampler) and grab samples (taken by dipping a bottle directly in the flow) to be taken concurrently during the event to compare to the individual samples (before compositing) for QAQC compliance. Lastly, this method enables the development of a robust turbidity to FSP rating curve using well-mixed aliquots from the individual samples before compositing. Although equipment and maintenance costs are generally greater than associated with other monitoring techniques, the inherent flexibility in sampling design with autosamplers, as well as the resolution and reliability of data produced, often justify this extra expense.

Passive samplers represent a simpler and inexpensive approach to event runoff sampling. Passive sampler installation requires topographic surveys adequate to define site hydrology and discharge characteristics that inform the technical conditions required for successful deployment. Installation of strategically vertically nested passive samplers can allow a series of discrete samples across the rising limb of the hydrograph. Passive samplers consistently sample at the same discharge throughout the monitoring allowing standardized data collection and analysis procedures to be defined to consistently apply the sample concentration datasets to other non-sample runoff volumes at the site. While the data is knowingly biased toward the surface of the runoff and first flush volumes, it is consistently biased in a manner that allows direct evaluation of changes in runoff concentrations at site sampled. Sampling limitations include the potential to miss peak flow and the inability to capture the falling limb or variable stage fluctuations.

Manual grab samples are primarily used to assess the general status of a particular sampling location at a particular time. This approach is simple to execute but is limited in its usefulness without associated flow data and on call field staff. All these methods have been used to estimate annual pollutant loads, especially if accompanied with continuous flow monitoring, and have been used to develop turbidity to FSP rating curves.

3.2.4 CONSTITUENTS OF INTEREST

A significant change in the focus of the pollutant of concern in stormwater runoff occurred following the limnological research by Swift et al 2006 that identified FSP as the primary cause of the mid-lake clarity decline in Lake Tahoe. Prior to 2006, a number of stormwater research efforts did not include FSP as a pollutant of interest. Given the focus of the Lake Tahoe TMDL and supporting Lake Clarity Crediting Program on FSP, and thus the relevance of FSP to RSWMP, this synthesis pays close attention to the past research that included FSP fate and transport in Tahoe stormwater. However, the importance of nutrient loading cannot be dismissed as it drives both mid-lake and nearshore conditions with respect to eutrophication. The growth of both suspended algae and periphyton (attached algae) are fueled by inputs of phosphorus and nitrogen. There is a potential to link stormwater monitoring to a nearshore status and trends assessment that would identify “hot spots” or drainages where the targeting of mitigation and restoration projects could yield important reductions in nutrient and sediment loading (Heyvaert et al 2013).

Once obtained, samples are submitted to an analytical laboratory for analysis of sediment and/or nutrient constituents. Prior to 2006, outside of monitoring for Lake Tahoe TMDL development (Heyvaert et al 2007), the compiled stormwater research had focused on TSS and total, dissolved and biologically available compounds of nitrogen and phosphorous. As mentioned above, FSP replaced TSS as the sediment constituent of concern due to the documented direct influence on mid-lake clarity (Swift et al 2006). FSP analyses have been conducted using 3 methods.

- **FSP# (number of particles < 16µm)** is a measure of the number of fine sediment particles in suspension and are the primary cause of lake clarity impairment. Sampling data analysis has been conducted using a particle counter or a particle size analyzer. All available FSP# analyses have been conducted by the University of California, Davis (UC Davis) or DRI and this technology is relatively costly or unavailable at most commercial analytical laboratories. UC Davis and DRI have released recommended equations to estimate the FSP# using the results of a particle size distribution analysis by volume that can be conducted by most commercial analytical laboratories (Heyvaert et al 2011). Reporting of FSP# concentrations and loads is typically in the billions or higher, making the comprehension of the concentrations, loads and load reductions in simple tabular formats challenging.

- **[FSP] (mass of particles < 16µm)** can be conducted by most commercial laboratories using the results of TSS and particle size distribution analyses, where the TSS value is multiplied by the % by mass of the sample < 16µm. The mass of the sample will be dominated by the coarser size fractions, where the FSP# will be dominated by the smaller size fractions (e.g., < 5µm).

- **Turbidity (NTU)** has been identified to be an extremely sensitive and cost-effective proxy for both FSP# and [FSP] in the Tahoe Basin (Heyvaert et al 2011, 2NDNATURE et al 2014). Turbidity data can be collected in-situ using handheld probes (e.g., Hach 2100P) or continuous sensors (e.g., FTS DTS-12).

While FSP and turbidity are known to have the greatest impact on mid-lake clarity, nutrient constituents affect both mid-lake and nearshore conditions. Biologically available dissolved nitrogen and phosphorus compounds specifically drive algal growth, and can exaggerate impacts from invasive species that can impact the quality of recreational experiences (an important economic driver in the Tahoe Basin). Total nitrogen and phosphorus attached to sediment also provide the basis for storage and release of bio-available nutrients; it is therefore important to reduce overall sediment delivery as well as the dissolved nutrients fraction when planning stormwater treatment BMP projects. Future projects should also consider nutrient contribution from groundwater inputs as stormwater infiltration is a common treatment strategy utilized by the TMDL.

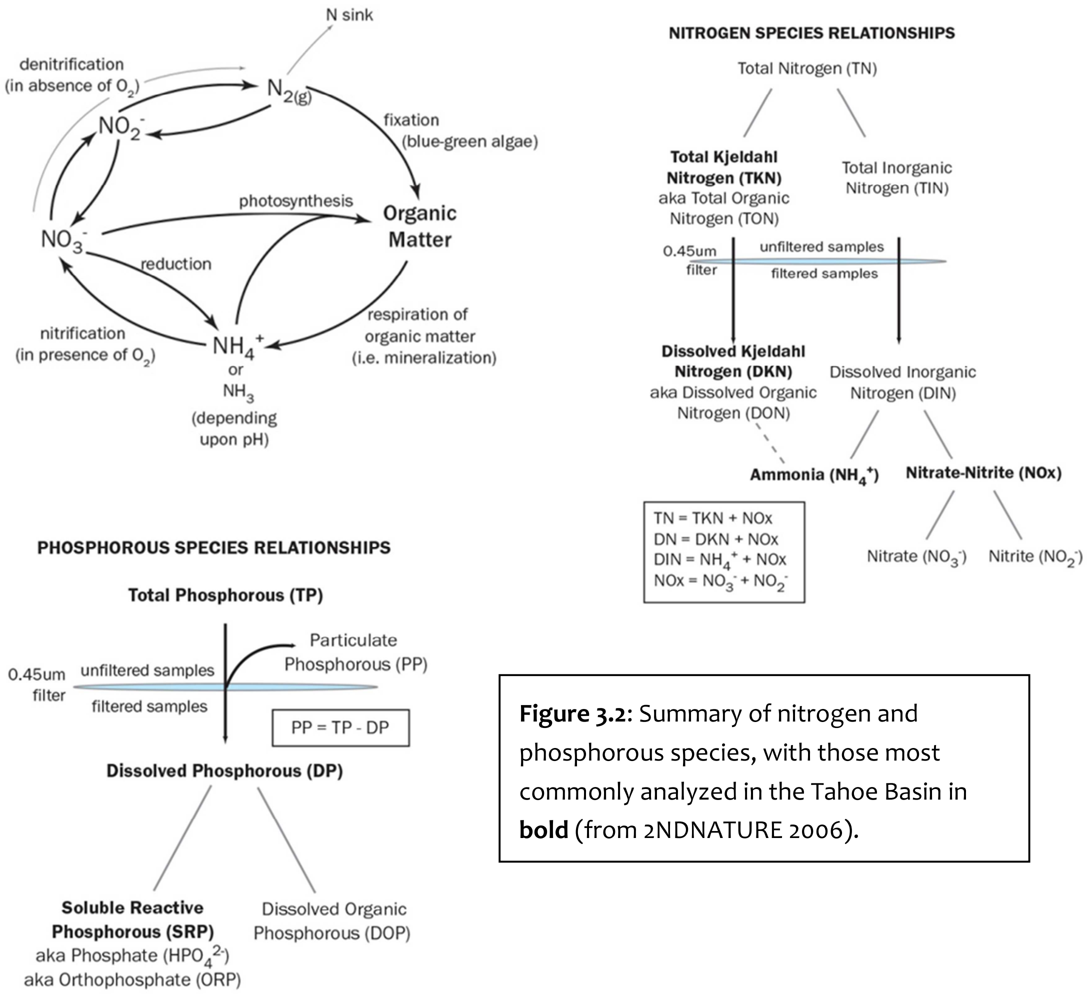


Figure 3.2: Summary of nitrogen and phosphorous species, with those most commonly analyzed in the Tahoe Basin in **bold** (from 2NDNATURE 2006).

Both phosphorus and nitrogen are measured in several forms. Phosphorus can be measured as total phosphorus (TP), total dissolved phosphorus (DP) or as soluble reactive phosphate (SRP). TP is a measure of the total amount of phosphorus in a sample, whereas DP represents the total dissolved fraction less than 0.45 microns. This fraction represents the total dissolved organic and inorganic fractions. The inorganic fraction is measured as SRP and is sometimes compared to orthophosphate (ortho-P). SRP represents the fraction of phosphorus that is immediately bioavailable to organisms for growth.Nitrogen can be measured as total nitrogen (TN), total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO3 + NO2), or ammonia-nitrogen (NH4). TN is similar to TP and is used to represent the total amount of nitrogen in a sample. TKN represents the fraction of TN that is bound up in its organic form. The remaining fractions, NO3 + NO2 and NH4 , represent the dissolved bioavailable forms of nitrogen. Figure 3.2 summarizes nitrogen and phosphorous species, with those most commonly analyzed in the Tahoe Basin in bold.

3.3 DATA MANAGEMENT

Available documentation varies in the amount of detail regarding data management and QA/QC procedures conducted by previous research. Many of the datasets generated for this collection of disparate monitoring efforts were likely managed in large spreadsheet programs such as MS Excel. DRI et al 2010 created a BMP water quality database to store BMP monitoring data generated in the Tahoe Basin in standardized formats. This database was designed in support of the RSWMP program, but was not funded for operation pending RSWMP implementation. It could be used as a preliminary framework for assembling existing data, or provide a starting place to for the RSWMP data management and reporting platform to be developed. 2NDNATURE and DRI have recently (2014) compiled an MS Access database of FSP samples collected from Tahoe stormwater that included discharge, turbidity, [FSP] and FSP #, but no such data compilation of past event hydrology or nutrient datasets exists. The existing RSWMP QAPP and SAP 2010 documents provide initial data management protocols, but a clear and complete link between data collection and ultimate use of data to meet Lake Tahoe TMDL management needs is not fully developed.

3.4 DATA ANALYSIS AND REPORTING

The consistency and level of detail regarding how raw values were used to calculate final water quality findings varies in past research. The majority of studies summarize general unit conversions, event hydrograph determinations, and pollutant load calculations, but specific equations and calculations are not always provided at the level of detail necessary for the report reader to repeat the data analysis methods used. Data analysis includes calculations, statistics and other technical dataset transformations.

Catchment outfall monitoring results typically reported event mean concentrations, and event, seasonal, annual, or monitoring duration volumes and pollutant loads. Quantification of treatment BMP effectiveness techniques also varied and included inflow and outflow concentration comparisons, event load reductions (both absolute and % reductions), or simply treatment BMP effluent concentrations. Given that each past study had a different set of specific research objectives, this inconsistency is not unexpected. Similarly, reporting formats of key findings and results vary as a result of each research effort having different experimental designs and specific needs of the data to address the key questions of the research.

One guiding principal of RSWMP is to ensure datasets inform both site-specific conditions and improvements, as well as provide directly comparable comprehensive data to improve our collective understanding the Tahoe stormwater regionally. Detailed guidance for all aspects of appropriate data analysis procedures to be performed on RSWMP datasets to meet stated objective is likely impossible, but a series of defined RSWMP calculations, output formats and statistical tools can provide great consistency to RSWMP data analysis and reporting in the future.

Similarly reporting formats of key findings and results vary as a result of each research effort having different experimental designs and specific needs of the data to address the key questions of the research. Consistency and clear linkages between RSWMP data collection and the reporting formats of the results will be critical to ensure a strong communicative power of RSWMP findings to a large array of audiences. Two current research efforts by 2NDNATURE and NHC (2014a, 2014b) are expected to provide some preliminary data analysis and data reporting recommendations for the RSWMP SAG to consider as the program design is completed.

4 RELEVANT FINDINGS

The team identified a number of reoccurring themes or relevant findings that should be noted and considered as RSWMP design and development continues. The findings are kept focused and brief, with the direct implications for consideration by the RSWMP design team to ensure stated RSWMP objectives are most effectively met.

4.1 TAHOE STORMWATER QUALITY CHARACTERIZATION

Coordinated stormwater runoff monitoring in the Tahoe Basin began with development of the Lake Tahoe TMDL, during which several water years (WY) of urban runoff hydrology and water quality data were collected at sixteen sites beginning in WY 2003. Results from Lake Tahoe TMDL development monitoring have been summarized in Gunter 2005, Coats et al 2008 and in the Lake Tahoe TMDL Technical Report (Lahontan and NDEP 2010). Prior to this, however, the best summary of Tahoe stormwater information was assembled in a report from GeoSyntec Consultants 2005 in which runoff and treatment BMP performance characteristics were evaluated based on preliminary modeling results from EPA SWMM 5 and a comparison with data from the ASCE International BMP Database. Subsequently, land use CRCs were developed for the PLRM.

The evolution of stormwater characterization at Tahoe is represented in the following series of tables, beginning with the initial compilation by GeoSyntec (Table 4.1), in which event mean concentrations (EMCs) are represented for selected nutrients (total phosphorus, total nitrogen, dissolved phosphorus, and nitrate-N) and for total suspended solids. This preliminary compilation was followed by analysis of data produced during the Lake Tahoe TMDL stormwater runoff monitoring program in WYs 2003 and 2004 (Table 4.2), which represented data collected as part of a coordinated monitoring program and considered additional land use types based on initial Tahoe Basin land use and land cover mapping produced in anticipation of the Lake Tahoe TMDL stormwater monitoring program (Luck et al 2002). Lake Tahoe TMDL stormwater data and the land use maps were then applied by TetraTech in development of a Loading Simulation Program in C++ (LSPC) watershed model for the Tahoe Basin. Additional data were obtained on primary road runoff constituent concentrations from Caltrans 2003 and NDOT 2004 reports. Taken together these data provided estimates of EMC values for primary road, commercial, mixed urban, high density residential and low density residential land uses. The TetraTech study approximated EMCs for additional land uses and then applied a 20 percent margin of safety augmentation on initial estimates for each land use to derive the final runoff EMCs (Table 4.3). Relative percentages of fine particles (<63 µm) in runoff were developed at this time for selected land uses from the Lake Tahoe TMDL stormwater data and the long-term Lake Tahoe Interagency Monitoring Program (LTIMP) stream data (Table 4.4).

Table 4.1: Summarized land use event mean concentrations (EMCs) from the Tahoe Basin BMP Evaluation and Feasibility Study (GeoSyntec Consultants 2005).

Land Use	Pollutant				
	TSS	TP	DP	TN	NO3
	mg/L	mg/L	mg/L	mg/L	mg/L
Commercial	178	0.542	0.114	2.364	0.203
Open Water	5	0.030	0.010	0.200	0.010
Recreation/Open Space	3	0.021	0.011	0.146	0.006
Residential	142	0.255	0.025	0.528	0.047
Transportation	1133	1.208	0.100	2.096	0.253

TSS - total suspended solids, TP - total phosphorus, DP - dissolved phosphorus,
TN - total nitrogen, NO3 - nitrate as nitrogen

Table 4.2: Land use comparison of TMDL stormwater EMCs, the National Urban Runoff Program (NURP) and Tahoe Research Group (TRG) projects from Gunter 2005.

	Median[1] EMCs in mg/L							
Land Use	Database	TKN	TP	TSS	NO2+NO3	NH4	TDP	SRP
Residential	TMDL	1.1	0.32	80	0.08	0.030	0.06	0.040
	TRG[1]	0.2	0.15	54	0.02			0.016
	NURP[2]	1.9	0.38	101	0.74		0.14	
	NSQD[3]	1.4	0.3	48	0.60		0.17	
Commercial	TMDL	1.6	0.48	156	0.10	0.055	0.04	0.028
	TRG	1.01	0.59	203	0.23			0.138
	NURP	1.2	0.20	69	0.57		0.08	
	NSQD	1.6	0.22	43	0.60		0.11	
Mixed urban	TMDL	1.4	0.61	161	0.13	0.041	0.06	0.040
	TRG							
	NURP	1.3	0.26	67	0.56		0.06	
	NSQD							
Natural/open/vegetated	TMDL	0.1	0.02	1	0.004	0.008	0.02	0.008
	TRG	0.1	0.03	1	0.002			0.011
	NURP	1.0	0.21	70	0.54		0.03	
	NSQD	0.6	0.25	51	60		0.08	

(1) TRG data are mean concentrations, from Reuter et al. 2001
(2) From U.S. EPA 1983
(3) From Pitt et al. 2004

Table 4.3: Derived EMCs for runoff by modeled land-use categories (mg/L) from the Tahoe TMDL Technical Report (Lahontan and NDEP 2010).

Land-use Name	TN	DN	TP	DP	TSS
Residential_SFP	1.752	0.144	0.468	0.144	56.4
Residential_MFP	2.844	0.420	0.588	0.144	150.0
CICU-Pervious	2.472	0.293	0.702	0.078	296.4
Ski_Runs-Pervious	0.360	0.132	0.120	0.038	270.7
Veg_EP1	0.164	0.011	0.034	0.029	14.0
Veg_EP2	0.164	0.011	0.034	0.029	37.6
Veg_EP3	0.164	0.011	0.034	0.029	100.9
Veg_EP4	0.164	0.011	0.034	0.029	270.7
Veg_EP5	0.164	0.011	0.034	0.029	726.6
Veg_Recreational	1.035	0.012	0.629	0.209	459.6
Veg_Burned	2.340	0.014	1.524	0.480	1015.2
Veg_Harvest	2.340	0.014	1.524	0.480	1015.2
Veg_Turf	5.475	0.450	1.463	0.450	12.0

Water_Body	0.000	0.000	0.000	0.000	0.0
Residential_SFI	1.752	0.144	0.468	0.144	56.4
Residential_MFI	2.844	0.420	0.588	0.144	150.0
CICU-Impervious	2.472	0.294	0.702	0.078	296.4
Roads_Primary	3.924	0.720	1.980	0.096	951.6
Roads_Secondary	2.844	0.420	0.588	0.144	150.0
Roads_Unpaved	2.340	0.014	1.524	0.480	1015.2

TN - total nitrogen, DN – dissolved nitrate with nitrite plus ammonium as nitrogen, TP - total phosphorus, DP - dissolved phosphorus, TSS - total suspended solids. SFP – single family pervious, MFP – multifamily pervious, CICU – commercial, industrial, communications and utilities, EP1 through EP5 – vegetated areas with increasing erosion potential, SFI – single family impervious, MFI – multifamily impervious.

Table 4.4: Percent fines by land-use and subwatershed as applied in the Lake Tahoe Watershed Model (TetraTech, 2007) from the Tahoe TMDL Technical Report (Lahontan and NDEP 2010).

Land-use Type	Land-use Name or Subwatershed	Runoff Fines Distribution		
		(< 63 µm)	(20 - 63 µm)	(< 20 µm)
Urban	Residential_SF	76.3%	40.6%	35.7%
Urban	Residential_MF	88.4%	30.7%	57.7%
Urban	CICU	85.4%	22.3%	63.1%
Urban	Roads_Primary	85.4%	22.3%	63.1%
Urban	Roads_Secondary	85.4%	22.3%	63.1%
Non-Urban	Third Creek	31.0%	21.5%	9.5%
Non-Urban	Incline Creek	67.0%	46.6%	20.4%
Non-Urban	Glenbrook Creek	80.0%	55.4%	24.6%
Non-Urban	Logan House Creek	75.0%	51.6%	23.4%
Non-Urban	Edgewood Creek	59.0%	41.2%	17.8%
Non-Urban	General Creek	29.0%	20.3%	8.7%
Non-Urban	Blackwood Creek	45.0%	31.4%	13.6%
Non-Urban	Ward Creek	47.0%	32.3%	14.7%
Non-Urban	Trout Creek	38.0%	26.3%	11.7%
Non-Urban	Upper Truckee River	44.0%	30.6%	13.4%

SF – single family, MF – multifamily, CICU – commercial, industrial, communications and utilities.

The original land use and land cover map produced by Luck et al 2002 was updated by TetraTech to address classification artifacts remaining from initial compilation and to add some additional categories, as shown in Figure 4.1. Then the relative contribution of pollutant loadings from various land classifications were derived from the calibrated Lake Tahoe Watershed Model, and these results (Table 4.5) were presented in the Lake Tahoe TMDL Technical Report. Paved roads were identified as a dominant source of both nutrients and fine sediment (<63 µm), which was notable considering their relatively minor representation in terms of total area and flow (runoff).

Figure 4.1: Land use types in the Lake Tahoe Basin (from TetraTech 2007).

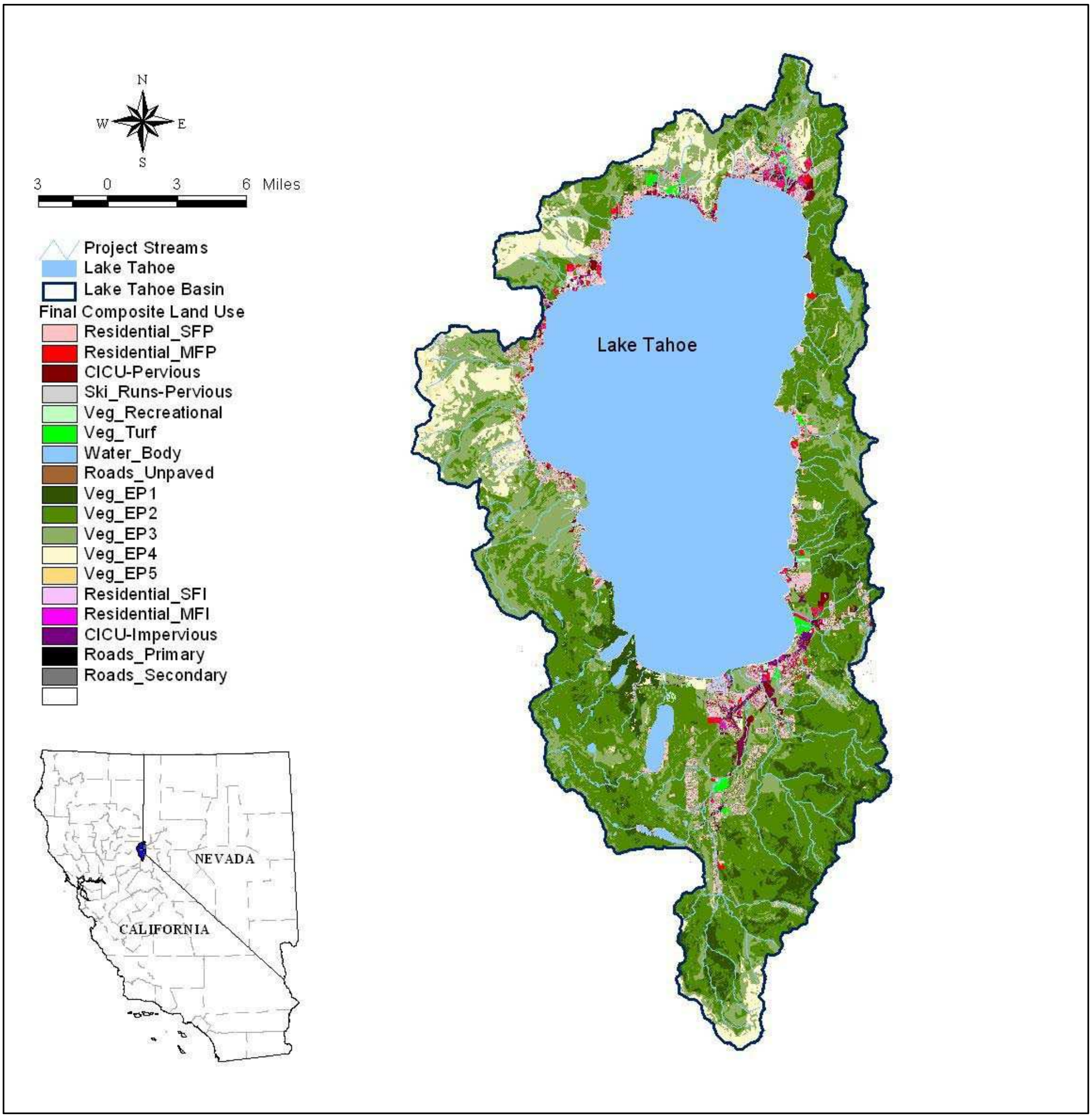


Table 4.5: Land use area distribution and percent contribution to the Lake Tahoe Watershed Model predictions (TetraTech unpublished) from the Tahoe TMDL Technical Report (Lahontan and NDEP 2010).

Land-use	Area	Flow	Upland TSS	Upland Fines (<63µm)	TN	TP
Residential_SFP	4.0%	3.8%	1.7%	2.3%	5.4%	7.5%
Residential_MFP	1.0%	0.9%	1.3%	1.9%	1.5%	2.2%
CICU-Pervious	0.9%	0.7%	1.3%	1.9%	1.0%	1.5%
Ski Runs-Pervious	0.5%	0.7%	4.1%	2.5%	0.6%	1.3%
Veg_EP1	5.7%	5.2%	0.1%	0.1%	2.3%	1.4%
Veg_EP2	46.3%	41.1%	4.0%	3.2%	20.9%	13.4%
Veg_EP3	26.1%	27.0%	17.6%	13.5%	16.4%	12.4%
Veg_EP4	8.9%	9.7%	33.1%	25.9%	6.4%	6.3%
Veg_EP5	0.2%	0.3%	4.0%	3.2%	0.2%	0.4%
Veg_Recreational	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%
Veg_Burned	0.2%	0.2%	1.0%	0.8%	0.4%	0.8%
Veg_Harvest	0.2%	0.2%	0.8%	0.6%	0.2%	0.5%
Veg_Turf	0.5%	0.4%	0.0%	0.0%	0.9%	2.0%
Water_Body	1.7%	n/a	n/a	n/a	n/a	n/a
Residential_SFI	0.9%	1.3%	2.0%	2.7%	7.6%	8.4%
Residential_MFI	0.4%	0.5%	2.3%	3.5%	4.8%	4.0%
CICU-Impervious	0.5%	0.7%	5.0%	7.4%	5.2%	5.3%
Roads_Primary	0.3%	0.4%	10.8%	16.2%	5.4%	12.2%
Roads_Secondary	1.3%	2.1%	8.6%	12.9%	20.2%	18.1%
Roads_Unpaved	0.2%	0.2%	2.0%	1.4%	0.4%	2.0%

Note: upland fines (<63 µm) were incorrectly identified (as >63 µm) in original report (Lahontan and NDEP, 2010). SFP – single family pervious, MFP – multifamily pervious, CICU – commercial, industrial, communications and utilities.

PLRM represents pollutant concentrations using CRCs, which were derived mainly from Lake Tahoe TMDL stormwater data analysis described above. CRCs are intended to be the average annual runoff concentration for a particular pollutant. CRCs vary based on PLRM inputs of land use and land use condition (2NDNATURE et al 2010a). Specifically, CRCs differ from individual concentration measurements and from EMCs because they are intended to represent the long-term annual average concentration as a result of an integration of all available seasonal data across many event types and magnitudes sampled. The default values for CRCs used by the PLRM are shown in Table 4.6 for parcel land use types with and without pollutant source controls. CRCs associated with roadway condition are more complex and discussed in detail in the PLRM Technical Development Document (NHC et al 2009).

Table 4.6: PLRM CRC values use for each urban land use with and without pollutant source controls, except roads (nhc et al. 2009).

Land Use	Land Use Condition	CRC Values (mg/L unless otherwise noted)					
	(Data Source)	TSS	FSP (% of TSS by mass)	TN	DIN	TP	SRP
SFR	Without PSCs (TMDL Existing Conditions Values)	56.4	20.3 (36%)	1.752	0.144	0.468	0.144
	With PSCs (TMDL Tier 1 Values)	39	14.0 (36%)	1.577	0.13	0.421	0.13
MFR	Without PSCs (TMDL Existing Conditions Values)	150	87.0 (58%)	2.844	0.42	0.588	0.144
	With PSCs (TMDL Tier 1 Values)	56.4	32.7 (58%)	2.56	0.378	0.529	0.13

Land Use	Land Use Condition	CRC Values (mg/L unless otherwise noted)					
	(Data Source)	TSS	FSP (% of TSS by mass)	TN	DIN	TP	SRP
CICU	Without PSCs (TMDL Existing Conditions Values)	296.4	186.7 (63%)	2.472	0.293	0.702	0.37
	With PSCs (TMDL Tier 1 Values)	204	128.5 (63%)	2.136	0.195	0.536	0.05
Veg_Turf	Without PSCs (nutrient values from 2NDNATURE (2007); sediment values from TMDL Existing Conditions)	12	4.3 (36%)	4.387	0.547	1.09	0.631
	With PSCs (nutrient values from 2NDNATURE (2007); sediment values from TMDL Existing Conditions)	12	4.3 (36%)	2.369	0.319	0.454	0.289

TSS - total suspended solids, FSP – fine sediment particles (<16 µm), TN - total nitrogen, DIN – dissolved inorganic nitrogen (nitrate with nitrite plus ammonium as nitrogen), TP - total phosphorus, SRP – soluble reactive phosphorus (approx. equivalent to dissolved phosphorus).

It is generally understood that stormwater constituent concentrations are log-normally distributed, and that flows can vary over a much greater range than is typical of constituent concentrations. Thus, emphasis must be placed on obtaining accurate flow measurements and producing reliable event hydrographs that inform analytic results derived from judicious stormwater sample collection. Given that stormwater monitoring and sample collection in the Tahoe Basin have been intermittent and not yet coordinated, outside of the stormwater program for Lake Tahoe TMDL development, it is impractical to provide a long-term assessment of status or trends for stormwater runoff, although RSWMP is intended, in part, to address this deficiency. In the meantime, it is informative to look at the history of precipitation in the Tahoe Basin to gain perspective on inherent variability that drives runoff volumes for PLRM and Lake Tahoe TMDL assessment, as well as the recent historical climate change that includes rising temperatures and earlier snowmelt. Since the early 1900's, precipitation has been increasing slightly (Figure 4.2) while snowfall has been decreasing (Figure 4.3), which will have implications for the evaluation of trends in stormwater monitoring and for management of stormwater infrastructure and BMPs. It may also be informative to look at the history of water quality in Lake Tahoe as an indicator of what is occurring throughout the watershed. The TMDL however, is focused on urban inputs as the primary pollutant source of concern at this time. Future coordination with the LTIMP, focused on Lake Tahoe tributaries, and the Near Shore Monitoring Program, would benefit the understanding of pollutant loading trends basin-wide

Figure 4.2: Time series of total annual precipitation at Tahoe City, CA. Red line is the linear best fit to annual data (from Kunkel 2014).

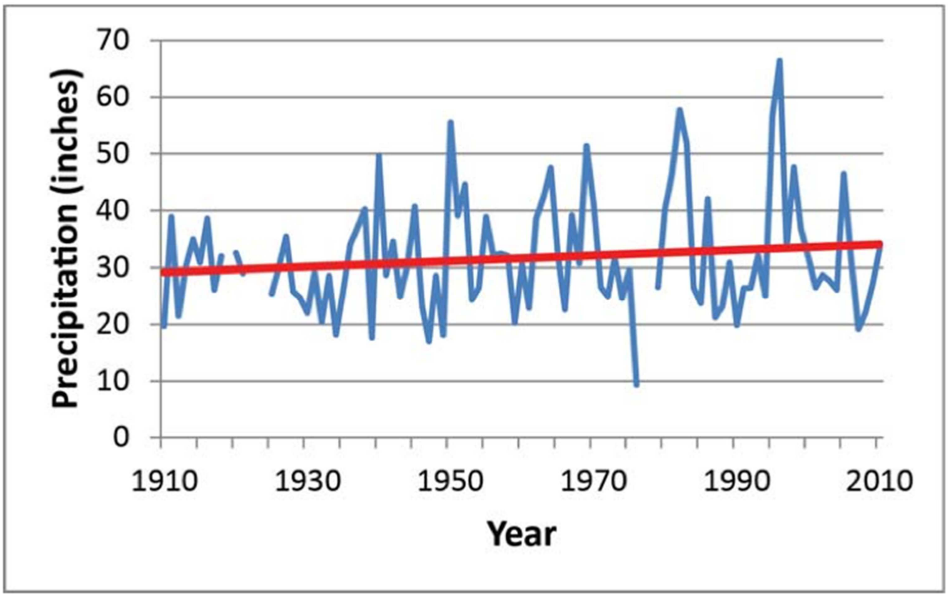
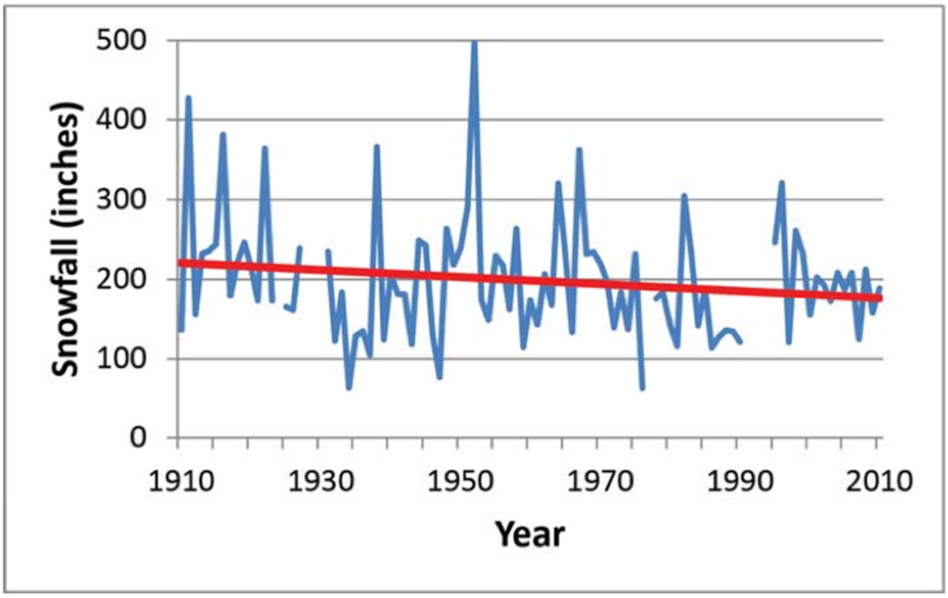


Figure 4.3: Time series of total annual snowfall at Tahoe City, CA. Red line is the linear best fit to annual data (from Kunkel 2014).



4.2 TAHOE STORMWATER BMP EFFECTIVENESS

The first attempt to compile Tahoe specific data on BMP performance was initiated by Reuter et al 2001 in a review of available data from different projects conducted as part of various studies from the 1980s through the 1990s. Performance assessment was based on percent reduction in constituent outflow concentration relative to inflow, with some limited information also available on load reductions. The primary BMP types represented in 19 studies fell into eight categories: detention basins (hydraulic retention in dry basins), ditch improvements, retention basins (extended retention in wet basins), revegetated areas, sediment traps, unspecified BMPs, wet meadows, and wetland basins (flow-through system with wetland vegetation).

While the overall mean efficiency for all BMPs combined in the Tahoe Basin appeared favorable (range for nutrient/sediment reduction was 3%-44%), there was considerable variability within each of the water quality constituents. Unfortunately, in most cases, the percent reduction by BMP class was indistinguishable statistically from no effect (i.e. zero percent reduction or increase), in part because case studies were sparse for most BMP types (n = 0–3) and variance was quite high. Reuter et al 2001 concluded that variance between studies would need to be reduced by focusing more studies on specific BMP types and reducing the differences in sampling, analysis and reporting techniques. The performance of Tahoe BMPs compared to similar BMP types in the ASCE National BMP Performance Database at that time showed relatively less effective treatment at Tahoe, which was credited to the limited number of Tahoe BMP performance assessments and to higher inflow concentrations overall in the national database.

A subsequent assessment of BMP performance was produced by GeoSyntec Consultants 2005 to evaluate the feasibility of project level and basin-wide BMP implementation and overall effectiveness of these BMPs at reducing urban runoff pollution to Lake Tahoe. Runoff and BMP modeling was conducted to evaluate theoretically achievable treatment, as well as to study size criteria and runoff water quality estimation. This project incorporated BMP data from the Reuter et al 2001 study as well as a few new sites from later reports. These data were compared to the ASCE BMP database in terms of achievable pollutant removal (Table 4.7) for common BMP types, including media filters, wetland basins, biofilters, wet ponds and dry ponds.

Table 4.7: Achievable percent reduction based mean effluent concentration of Tahoe Basin BMPs (from GeoSyntec Consultants 2005).

Constituents	Land Use Type						Lake Tahoe BMPs Mean Effluent Conc.	Achievable % Reduction					
	Undisturbed	Roadway	Industrial	Mixed Urban	Residential	Turf Grass		Undisturbed	Roadway	Industrial	Mixed Urban	Residential	Turf Grass
TSS	44	498	202	341	142	NA	79		84	61	77	44	NA
TP	28	878	800	295	325	866	153		83	81	48	53	82
DP	30	57	66	224	30	489	100				55		80
NO3	2	35	213	256	56	40	67			69	74		
NH4	3	156	212	41	35	53	14		91	93	66	60	74
TKN	140	2,443	4,995	NA	1,636	4,795	874		64	83	NA	47	82

TSS values are in mg/L and all other constituent values are in µg/L unless mentioned otherwise.
Cells highlighted green indicate that TRPA or LRWQCB Standard is exceeded
Cells highlighted orange indicate that BMP would likely not provide treatment for this parameter.

The authors concluded that all five BMP types could reduce TSS loads by around 70-80% (Figure 4.4), while enhanced treatment achievable through more effective design and management of individual BMPs could significantly improve treatment performance for phosphorus removal (Figures 4.5 and 4.6). Model estimates indicated that nitrate-N would be one of the most difficult constituents to treat given its high solubility, and that load reductions would most likely be achieved through volume reductions from evapotranspiration and infiltration (GeoSyntec 2005). A targeted two year sampling at the inlet and outlet of a dry basin for FSP treatment removal efficiency documented consistent but small reductions in both sample concentration and loads as a result of BMP interactions (2NDNATURE 2008).

A third assessment of BMP performance at Lake Tahoe (2NDNATURE 2006) evaluated stormwater constituent reductions for detention basins (Table 4.8), for constructed wetland, wet basin, and natural meadow treatments (Table 4.9), as well as for mechanical vault and trap treatments (Table 4.10). It was concluded that detention basins generally reduce effluent EMCs for TSS, total Kjeldahl nitrogen (TKN), and particulate phosphorus (PP), but were not effective at reducing dissolved nutrients at relatively low influent concentrations. On the other hand, data suggest that constructed wetlands and wet basins may be effective for removal of both particulate and soluble nutrients, as well as TSS. Mechanical treatment devices were generally similar to detention basins in terms of pollutant reductions, with comparable efficiency for TSS and particulate nutrients, but limited or highly variable removal efficiency for the soluble nutrients and in some cases increased effluent concentrations of nitrate+nitrite (as NOx-N). A set of recommendations provided for future assessment studies included emphasizing hydrologic characterization, conducting pre-project monitoring, identifying BMP monitoring objectives, and implementing scientific peer-review of monitoring plans. Important elements of performance assessment reporting were demonstrated in outline form.

Table 4.8: Detention basin quantitative comparisons of average study inflow concentrations and reported EMC percent reductions for relevant studies (from 2NDNATURE 2006).

INFLOW N SPECIES CONCENTRATION (ug/L)	TN	TKN	NOx-N	NH4-N
Coon Street (TERC 2005)	5085	4124	961	98
Northwood Basin (SH+G 2003)	1229	1056	173	11
Eloise Basin (SH+G 2003)	2301	2132	170	44
INFLOW P SPECIES CONCENTRATION (ug/L)	TP	PP	DP	SRP
Coon Street (TERC 2005)	1629	1480	149	116
Northwood Basin (SH+G 2003)	321	264	57	48
Eloise Basin (SH+G 2003)	955	898	57	23
INFLOW TSS SPECIES CONCENTRATION (ug/L)	TSS			
Coon Street (TERC 2005)	481			
Eloise Basin (SH+G 2003)	239			
Northwood Basin (SH+G 2003)	105			
N SPECIES % EMC REDUCTION	TN	TKN	NOx-N	NH4-N
Coon Street (TERC 2005)	Y	65	66	29
Northwood Basin (SH+G 2003)	Y	7	65	-13
Eloise Basin (SH+G 2003)	Y	13	-51	-5
P SPECIES % EMC REDUCTION	TP	PP	DP	SRP
Coon Street (TERC 2005)	89	Y	53	77
Northwood Basin (SH+G 2003)	Y	64	13	-7
Eloise Basin (SH+G 2003)	Y	56	-41	-31
TSS SPECIES % EMC REDUCTION	TSS			
Coon Street (TERC 2005)	94			
Eloise Basin (SH+G 2003)	72			
Northwood Basin (SH+G 2003)	68			

TN – total nitrogen, TKN – total Kjeldahl nitrogen, NOx-N – nitrate plus nitrite as nitrogen, NH4-N – ammonium as nitrogen, TP – total phosphorus, PP – particulate phosphorus, DP - dissolved phosphorus, SRP – soluble reactive phosphorus, TSS – total suspended solids. Y: metric not provided in this report, X: metric justifiably not provided

Figure 4.4: Comparison of average annual TSS loads for project level BMP treatment (from GeoSyntec 2005).

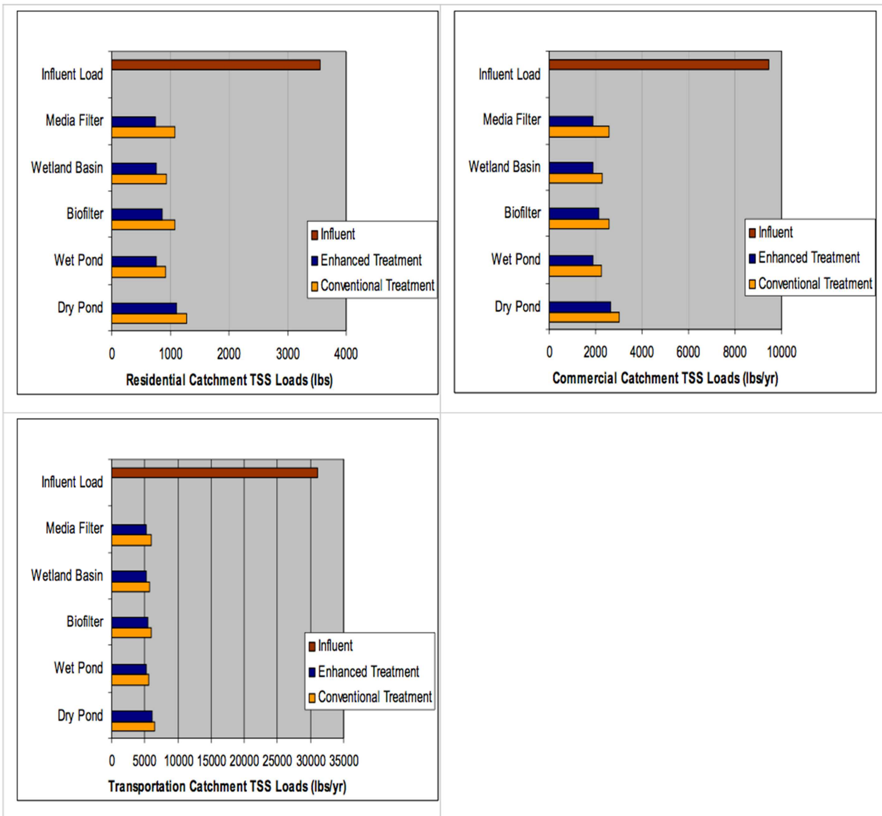


Figure 4.5: Comparison of average annual total phosphorus loads for project level BMP treatment (from GeoSyntec 2005).

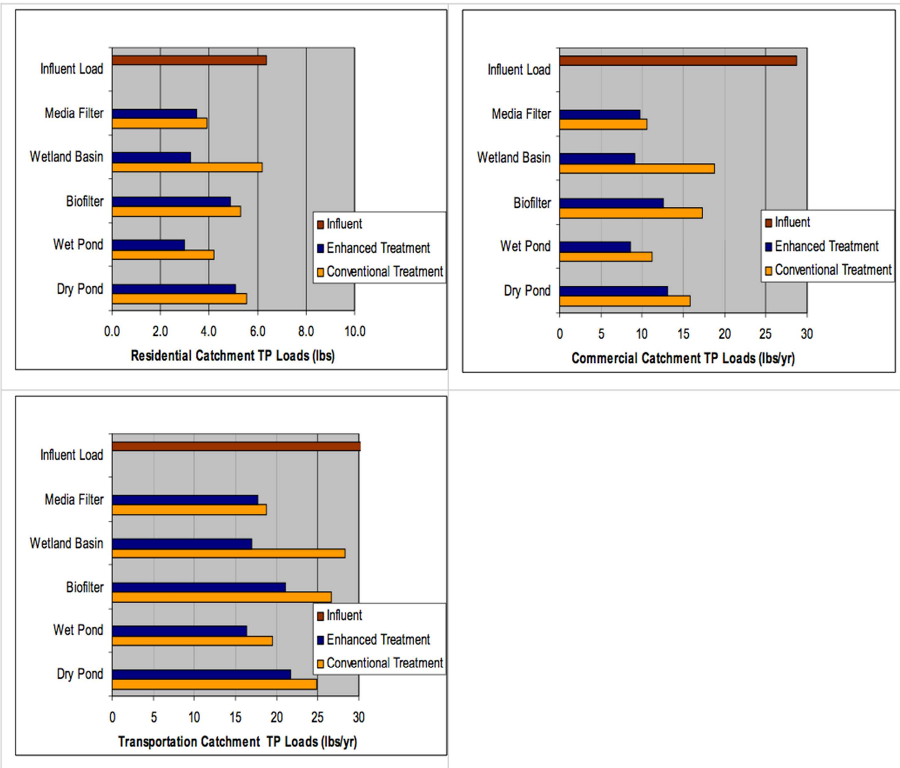


Figure 4.6: Comparison of average annual dissolved phosphorus loads for project level BMP treatment (from GeoSyntec 2005).

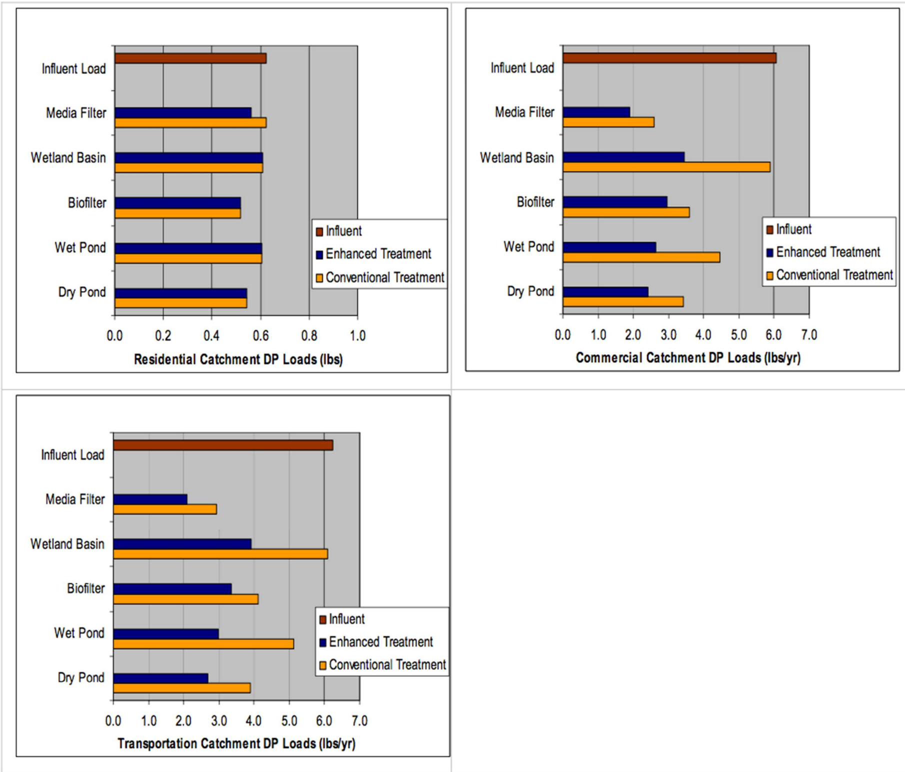


Table 4.9: Constructed wetland, wet basin and natural meadow quantitative comparisons of average study inflow concentrations and reported EMC percent reductions for relevant studies (from 2NDNATURE 2006).

INFLOW N SPECIES CONCENTRATION (μg/L)	TN	TKN	NOx-N	NH4-N
Tahoe City Wetland (TRG 2005)	1966	1214	722	47
Village Green Pond (SH+G 2003)	6604	6404	200	468
Angora Meadow (URS 2003)	954	796	Y	Y
INFLOW P SPECIES CONCENTRATION (μg/L)	TP	PP	DP	SRP
Village Green Pond (SH+G 2003)	1433	607	826	730
Tahoe City Wetland (TRG 2005)	542	X	139	112
Angora Meadow (URS 2003)	230	Y	Y	Y
INFLOW TSS SPECIES CONCENTRATION (μg/L)	TSS			
Tahoe City Wetland (TRG 2005)	120			
Village Green Pond (SH+G 2003)	X			
Angora Meadow (URS 2003)	Y			

N SPECIES % EMC REDUCTION	TN	TKN	NOx-N	NH4-N
Village Green Pond (SH+G 2003)	49	47	96	93
Tahoe City Wetland (TRG 2005)	49	28	84	43
Angora Meadow (URS 2003)	33	24	NP	NP
P SPECIES % EMC REDUCTION	TP	PP	DP	SRP
Tahoe City Wetland (TRG 2005)	63	Y	57	66
Village Green Pond (SH+G 2003)	44	59	32	37
Angora Meadow (URS 2003)	77	NP	NP	NP
TSS SPECIES % EMC REDUCTION	TSS			
Tahoe City Wetland (TRG 2005)	74			
Village Green Pond (SH+G 2003)	X			
Angora Meadow (URS 2003)	NP			

TN – total nitrogen, TKN – total Kjeldahl nitrogen, NOx-N – nitrate plus nitrite as nitrogen, NH4-N – ammonium as nitrogen, TP – total phosphorus, PP – particulate phosphorus, DP - dissolved phosphorus, SRP – soluble reactive phosphorus, TSS – total suspended solids.
Y: metric not provided in this report, but could be calculated if additional data analysis were performed.
X: metric justifiably not provided in the report because it was not the purpose of the investigations.

Table 4.10: Mechanical structure BMP quantitative comparisons of average study inflow concentrations and reported EMC percent reductions for relevant studies (from 2NDNATURE 2006).

INFLOW N SPECIES CONCENTRATION (ug/L)	TN	TKN	NOx-N	NH4-N
Stormceptor® STC 900 (DRI 2004B)	5000	5000	300	NP
StormFilter® (2ND 2005C)	1629	1371	241	328
Jensen Vault (DRI & TERC 2005)	2456	2274	182	183
Vortechnic Vault (DRI 2004A)	7250	7070	180	130
Vortechnics Vault (DRI & TERC 2005)	1941	1794	148	35
Sediment Trap (DRI 2004B)	2560	2430	130	NP
CDS Vault (DRI & TERC 2005)	2227	2123	88	51
Sediment Basin (DRI 2004B)	2500	Y	Y	NP
INFLOW P SPECIES CONCENTRATION (ug/L)	TP	PP	DP	SRP
CDS Vault (DRI & TERC 2005)	636	510	126	99
StormFilter® (2ND 2005C)	363	258	105	83
Vortechnics Vault (DRI & TERC 2005)	872	769	97	75
Vortechnic Vault (DRI 2004A)	380	Y	Y	70
Stormceptor® STC 900 (DRI 2004B)	1050	960	90	50
Jensen Vault (DRI & TERC 2005)	479	373	106	41
Sediment Trap (DRI 2004B)	1080	1030	50	30
Sediment Basin (DRI 2004B)	600	Y	Y	Y
INFLOW TSS SPECIES CONCENTRATION (ug/L)	TSS			

Stormceptor® STC 900 (DRI 2004B)	1000			
Sediment Trap (DRI 2004B)	784			
Vortechnics Vault (DRI & TERC 2005)	680			
Sediment Basin (DRI 2004B)	600			
StormFilter® (2ND 2005C)	241			
CDS Vault (DRI & TERC 2005)	226			
Jensen Vault (DRI & TERC 2005)	120			
Vortechnic Vault (DRI 2004A)	115			
N SPECIES % EMC REDUCTION	TN	TKN	NOx-N	NH4-N
Stormceptor® STC 900 (DRI 2004B)	21	21	65	NP
CDS Vault (DRI & TERC 2005)	11	8	-15	-4
Sediment Trap (DRI 2004B)	Y	11	-20	NP
Vortechnics Vault (DRI & TERC 2005)	1	17	-26	15
StormFilter® (2ND 2005C)	13	23	-33	45
Vortechnic Vault (DRI 2004A)	Y	83	-33	46
Jensen Vault (DRI & TERC 2005)	36	42	-77	22
P SPECIES % EMC REDUCTION	TP	PP	DP	SRP
Stormceptor® STC 900 (DRI 2004B)	25	Y	40	51
StormFilter® (2ND 2005C)	45	57	16	15
Sediment Trap (DRI 2004B)	26	Y	-1	14
CDS Vault (DRI & TERC 2005)	-4	Y	3	10
Vortechnics Vault (DRI & TERC 2005)	17	Y	7	9
Vortechnic Vault (DRI 2004A)	55	Y	Y	-14
Jensen Vault (DRI & TERC 2005)	52	Y	-10	-33
TSS SPECIES % EMC REDUCTION	TSS			
StormFilter® (2ND 2005C)	80			
Vortechnic Vault (DRI 2004A)	60			
Jensen Vault (DRI & TERC 2005)	58			
Vortechnics Vault (DRI & TERC 2005)	35			
Sediment Trap (DRI 2004B)	35			
Stormceptor® STC 900 (DRI 2004B)	31			
CDS Vault (DRI & TERC 2005)	11			

TN – total nitrogen, TKN – total Kjeldahl nitrogen, NOx-N – nitrate plus nitrite as nitrogen, NH4-N – ammonium as nitrogen, TP – total phosphorus, PP – particulate phosphorus, DP - dissolved phosphorus, SRP – soluble reactive phosphorus, TSS – total suspended solids.

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

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

From available data average annual characteristic effluent concentrations (CECs) were developed for the types of stormwater BMP types modeled in PLRM (NHC et al 2009). Given the sparse available data to determine average annual CECs most values were taken from the National BMP Database (Table 4.11). Subsequent focused data collection efforts to refine PLRM CEC values using Tahoe specific data have resulted in recommended revised FSP CECs for dry basins and wet basins in particular (2NDNATURE and nhc 2012b).

Table 4.11: Recommended CEC values by stormwater treatment (SWT) type (NHC et al 2009).

SWT Type	Pollutant of Concern						Primary Reference
	FSP (mg/L)	TSS (mg/L)	SRP (mg/L)	TP (mg/L)	DIN (mg/L)	TN (mg/L)	
Dry Basin	25	25	0.05	0.16	0.12	1.1	LRWQCB and NDEP 2008
Wet Basin	10	10	0.04	0.1	0.1	0.95	nhc and Geosyntec 2006
Bed Filter	13	13	0.04	0.14	0.68	1.5	nhc and Geosyntec 2006
Cartridge Filter	13	13	0.04	0.14	0.68	1.5	nhc and Geosyntec 2006
Treatment Vault	48	48	0.09	0.18	0.28	1.42	LRWQCB and NDEP 2008

4.3 TREATMENT BMP MAINTENANCE

The primary processes relied upon by treatment BMPs in the Tahoe Basin to treat urban stormwater are infiltration, particle settling, nutrient cycling, and media filtration (2NDNATURE et al 2009). Appendix A, Table 3.2 is the summary of the treatment BMP types, defined by the processes they rely upon to treat stormwater and the physical characteristics of each. Appendix A, Table 3.1 suggests over 20 relevant research efforts were conducted to quantify the effectiveness of one or more of these treatment BMP types to remove sediment and nutrient species, and nearly all of the research was conducted on unmaintained treatment BMPs. Thus, many findings include recommendations to repeat efforts following adequate and continued maintenance on the subject treatment BMP(s). Additionally, the majority of these studies was conducted prior to 2006 and did not include FSP as a constituent of concern, but contain a significant amount of data regarding nutrient and total sediment removal efficiencies.

The general findings from studies addressing nutrient and total sediment treatment are:

- Treatment BMP types that detain stormwater can effectively settle particles and provide consistent load reductions for TSS, TN and TP as a result.
- The ability to definitively measure treatment BMP effectiveness to provide consistent dissolved nutrient load reductions was tainted by the lack of BMP effectiveness monitoring on properly maintained BMPs in the Tahoe Basin.

The post 2007 studies that focused on FSP suggest the following:

- Volumes that are detained and infiltrated can effectively remove FSP loads by depositing them on the surface soils of the treatment BMP. However, an extensive study on treatment BMP performance as a function of FSP loading found extremely rapid declines in infiltration rates as a result of FSP accumulation forming a clay layer at the soil surface (2NDNATURE and NHC 2013).
- Paired sampling of inlet and outlet sampling at a wet basin showed slight but consistent FSP concentration reductions over a 2 year study (2NDNATURE 2008). Wet basins contain large amounts of wetland vegetation and other researchers have documented that FSP aggregated on emergent vegetation is extremely effective (Andrews et al 2011).
- FSP treatment via BMPs that rely on particle settling (such as Treatment Vaults) is likely not very effective due to the very low settling velocities of these particles in suspension.
- While not widely tested to date, it is likely that media filtration systems can effectively filter FSP in stormwater, though the higher the FSP loading rate the more rapidly the filters would likely clog and performance would decline without adequate maintenance.

RSWMP BMP monitoring conducted to inform PLRM CECs should only monitor BMPs that are actively maintained during the study, with targeted data collection to inform basin managers on how to optimize maintenance for specific BMP types. The pairing of BMP effectiveness monitoring with verification of acceptable BMP function using standard field verification protocols to confirm condition (such as BMP RAM) is recommended. BMP RAM (2NDNATURE et al 2009) was developed following a review and compilation of available treatment BMP types implemented in the Tahoe Basin that were/are implemented to improve stormwater quality via treatment (2NDNATURE 2006b). To date there does not exist reliable long-term pollutant load reduction monitoring of a well maintained dry basin, which is one of the more common stormwater treatment BMP types in Tahoe, and likely will be included in many jurisdictions' pollutant load reduction plans.

Should RSWMP BMP effectiveness data be used to evaluate the sensitivity of BMP RAM observations to adequately track the decline in performance of a specific BMP type over time, it is recommended that monitoring be consistently conducted from BMP installation (or adequate maintenance) to some future point of measured performance failure where the BMP is no longer providing the acceptable pollutant load reductions intended. This quantitative point of failure should be defined prior to data collection initiation and data analysis and interpretations must consider the role seasonal and annual hydrology will play on measured pollutant load reduction variability over time. A long-term dataset of paired BMP RAM observations and adequate BMP effectiveness monitoring could provide critical insight to the adequacy of BMP observations and associated recommended BMP RAM observation threshold values for the respective BMP type. Given the distribution of wet and dry basins in the Tahoe Basin, it is recommended that such a paired study be conducted on a set of three specific wet or dry basins initially.

4.4 DETECTING POLLUTANT LOADING TRENDS

Previous research efforts were conducted for a range of different objectives and study questions, but there are two common themes:

1. Pollutant loads and associated absolute measures of load reductions (mass/time) are significantly influenced by event, seasonal and annual hydrology and weather. In addition to hydrologic variability having a strong influence on measured pollutant loads, wetter Tahoe winters typically correlate to larger and more frequent snow storms. These wetter winters correlate to significantly more volume and associated watershed erosion, as well as frequent application of road abrasives to paved roadways, which is a significant source of FSP to urban stormwater. RSWMP needs to identify and incorporate data collection, data analysis, and data reporting techniques to constrain this natural variability in order to evaluate if pollutant load reductions are detectable as a result of effective management actions.
2. Long-term (decade scale) consistent stormwater monitoring datasets are required to obtain the necessary data to evaluate pollutant loading trends. Within the breadth of stormwater monitoring conducted in the Tahoe Basin, consistent monitoring at a single site conducted beyond three continuous years is uncommon. The identification, instrumentation and monitoring of sites over a decadal time period is critical to obtain the data adequate to detect load reduction trends.

One intention of establishing and committing to long-term monitoring sites is to detect pollutant loading trends as a result of effective water quality improvement actions. To achieve this, the changes in water quality characteristics, influenced by effective management actions, has to be as significant as possible. Both natural variation and sampling variability will result in measured differences in data over time, and the ability to detect a load reduction trend, if one exists, is increased in locations and at times when we expect the signal from management actions to exceed the signal from hydrologic differences or noise due to sampling error. In order to increase the likelihood of detecting a change in water quality as a result of effective actions, should one exist, the RSWMP will select sites using targeted sampling approach rather than random probability sampling. The targeted monitoring of urban catchments will commence with sites where current/existing pollutant loading is relatively elevated, where the local jurisdiction intends to implement actions to achieve significant load reductions over time, and where other factors such as excessive seasonal base flow conditions will reduce the likelihood that natural or sampling variability will not dilute the water quality signal of management actions.

A current research effort (2NDNATURE 2014) is exploring the application of data analysis techniques on available long term water quality datasets to provide recommendations for RSWMP design team to consider. One recommended technique is the categorization of water year and season types using readily available weather parameters and a simple best fit regression model (linear, exponential, LOWESS, etc) to adjust the measured volumes/loads for seasonal weather patterns. This adjustment for weather patterns will remove differences due to weather and allow a comparison of the future measured volumes/loads (years 10-20) to volumes/loads measured earlier in the program (years 1-5) to evaluate trends. Seasonal Mann Kendall or change point analyses are additional statistical tests to evaluate if trends in pollutant loads in long term continuous datasets can be statistically identified after constraining daily seasonal and annual variability.

4.5 ROAD OPERATIONS AND CONDITION

Paved road pollutant source monitoring has been the focus of a number of recent stormwater research efforts based on two key findings:

1. Paved roadways generate the greatest amount of FSP per unit area in the Tahoe Basin (Lahontan and NDEP 2010; 2NDNATURE et al 2010b, Kuhns et al 2010), and
2. Road operations focused on water quality improvement have been identified as the most cost-effective pollutant load reduction strategy to reduce the source of FSP to urban stormwater (Lahontan and NDEP 2008; 2NDNATURE and NHC 2011). (Little research on the effectiveness of improved road operations on nutrient load reductions has been conducted to date.)

PLRM FSP catchment loading is highly sensitive to road conditions, and the associated algorithms have been extensively verified with road specific monitoring using a customized portable simulator (2NDNATURE et al 2010a and 2010b). Current urban catchment monitoring efforts are evaluating data collection, analysis and reporting techniques to test the sensitivity of urban catchment FSP loading on road conditions (2NDNATURE et al 2014 *in prep*) and these results are expected to provide potential guidance to RSWMP. To date, there are no adequate datasets to directly link road condition to measured catchment outfall pollutant load due to the lack of necessary temporal and spatial resolution of road condition monitoring paired with simultaneous long-term downslope catchment outfall pollutant load monitoring. While adequate paired road condition tracking may not be feasible in all RSWMP urban catchments, a focused and committed road condition monitoring program in a selection of urban catchments could provide the necessary data to evaluate the sensitivity of urban catchment pollutant loads on road conditions.

Road RAM (2NDNATURE et al 2010b) is a simple field assessment and data management tool to predict the FSP CRC from a 10,000 sq ft road segment at time of observation. These methods however, do not currently predict CRC estimates for nitrogen and phosphorus, a limitation that could be addressed by understanding the range of N and P concentrations on roadways and incorporating these scales in the RAM tool scoring rubric in the future.

4.6 COMPARING PLRM ESTIMATES WITH MEASURED STORMWATER DATA

PLRM is a water quality planning tool designed to predict average annual runoff volumes and pollutant loads. The hydrologic approach used in PLRM provides a model structure that can predict runoff volumes and pollutant loads at the time scales important to the Lake Tahoe TMDL (i.e. average annual). PLRM is a simplified and constrained version of the more complex SWMM model, and PLRM simplifications mean that users have minimal ability to refine modeled estimates of peak flows or the shape and timing of the stormwater hydrograph on event timescales. In addition, simulating PLRM catchments for the same time period as measured data requires modeling in SWMM itself. Therefore, a series of refinements are necessary in SWMM to generate modeled estimates to compare to the measured water quality data at the urban catchment outfall.

Catchment scale PLRM validation efforts have recently been completed (2NDNATURE and NHC 2014). Overall, the results of the research suggest that PLRM models can perform reasonably well on the seasonal and annual time scales, as intended based on the objectives of the model design. However, the model can have notable discrepancies in predicted runoff volumes and pollutant loads at the event time scale, especially during periods of snow hydrology when the model is dependent on accurate inputs of temperature data to predict snow accumulation and melt, or when complex drainage conditions are present in the monitored catchment, such as a baseflow component (2NDNATURE and NHC 2014).

Based on the lessons learned from the research, below are a number of model and data requirements to adequately compare PLRM estimates with observed stormwater volumes and pollutant loading data from an urban catchment outfall. As the compilation of the requirements below suggest, the generation of reliable data to conduct reasonable comparisons between measured and modeled data is complex and time intensive. Future efforts to conduct such comparisons must clearly understand the intended purpose of the comparisons and the potential value and use of the results.

- **Site selection.** PLRM developers made a number of design decisions that simplified or automated algorithms to streamline use of the tool and reduce data input. The simplifying assumptions have produced a tool that most PLRM users find relatively easy to use, but can complicate efforts to represent the catchments accurately. All sites will inherently be more complicated than what can be represented and modeled in PLRM, and it is important to understand the effects these issues will have on the comparisons to measured data.
- **Accurate and representative weather data of the monitored site**. The critical weather parameters to generate high resolution site-specific PLRM estimates are accurate precipitation and temperature data that correspond with the timing of stormwater monitoring. Results of the monitoring study show that weather stations in the vicinity of the study area, but not located directly in the study area, produced data that did not adequately predict events that were a mixture of rain and snow. The establishment, operation and maintenance of representative weather stations within the drainage are essential, particularly during the winter when small local temperature variations determine if precipitation falls as snow or rain, if modeled and measured datasets are intended to be compared. Additionally, convective summer storms are often too localized for anything but proximate precipitation monitoring. Correlations and analyses for events with a mixture of rain and snow may be improved in future monitoring efforts by including representative and distributed pavement temperature monitoring along with air temperature monitoring.
- **High-resolution (10-minute) predicted stormwater runoff volumes and pollutant loads must be generated**. These predictions must be completed in SWMM, and supporting spreadsheets, not in the PLRM interface that the Tahoe stormwater community is accustomed to using. Guidance by the PLRM developers to complete event-based SWMM estimates can be found in 2NDNATURE and NHC 2014. However, users not familiar with SWMM may have difficulty critically evaluating model outputs to ensure they are reasonable.
- **Accurate and representative physical representation of the drainage catchment of the monitored urban outfall.** Catchment area, distribution of directly connected impervious area (DCIA), treatment BMPs, and flow routing through the stormwater system, including bypass, diversions, and flow splits, all must be understood and accurately represented in the model.

- **Reasonable representation of land use CRCs at time of stormwater monitoring.** Several large-scale, flow-through stormwater treatment BMP types are modeled in PLRM. The stormwater volumes 'treated' by the treatment BMP are assigned a characteristic effluent concentration (CEC), which is a static value. The default PLRM CECs may not be representative of the actual treatment BMP performance if (1) the physical configuration of the BMP in PLRM is not accurate; (2) the BMP has not received adequate or regular maintenance; or (3) inflow pollutant concentrations are misrepresented in the model. Treatment BMP CEC representation can be improved or calibrated using effluent sample collection representing the range of event types and flow conditions that occurred at the site during the duration of monitoring.
- **Accurate observed high resolution discharge data.** Equally as important to proper catchment representation in PLRM, the measured discharge dataset must be as accurate as possible. This requires reliable equipment and frequent and detailed field visits to calibrate instruments, conduct accurate manual depth, flow or other relevant measurements, and ensure site operation is as continuous as possible. While most techniques used to measure catchment outfall or treatment BMP hydrology is continuous (see Appendix A, Table 3.3) the data QA/QC value of being onsite during as many as possible larger runoff events cannot be overstated. It is impossible to validate the continuous hydrologic model outputs if the observed hydrology data is not as accurate as possible. While SWMM should not be run at hour timescale or finer, comparisons of predictions and observed data on these timescales are appropriate to visually verify event hydrograph timing and relative magnitude generally align, SWMM is a model based on an empirical representation of a natural system and hydrologic validation is only expected to be valid at the event, monthly, seasonal or annual scale.

The PLRM water quality module was developed in 2009, using available but limited FSP land use and treatment BMP effluent water quality data. A series of recent stormwater research efforts (2N and NHC 2010a and 2012a) have been conducted to evaluate PLRM algorithms used to estimate land use pollutant generation concentrations (i.e., CRCs), treated stormwater effluent concentrations (i.e., CECs), and effective infiltration rates of stormwater treatment BMPs and road shoulders. The general findings and recommendations are:

- Paved road CRCs contained within PLRM were determined to represent the range and distribution of road way FSP CRCs that existed in the Tahoe Basin in 2009-2011. No changes to the PLRM FSP road CRC range or values were recommended.

- Treatment BMP CECs in PLRM were obtained from the National BMP Database and include data collected outside the Tahoe Basin. Passive sampling techniques were used to obtain a large dataset of treated effluent concentrations from a collection of wet and dry basins over 2 years within the Tahoe Basin. The results suggested the PLRM CECs for these BMP types monitored were lower than observed concentrations and modifications were recommended. To date, focused CEC data to inform PLRM algorithms do not exist for cartridge filters, and the issue of lack of treatment BMP maintenance prior to monitoring makes the results potentially difficult to apply to PLRM in a manner that will appropriately predict performance with and without adequate treatment BMP maintenance.

4.7 TURBIDITY AS A FSP PROXY

Direct measurements of FSP concentrations in terms of FSP mass ([FSP]; mg/liter) and total of number of FSP particles (FSP#; number/liter) can be cost prohibitive. 2NDNATURE and DRI recently compiled available stormwater FSP data to evaluate and provide recommendations for reliable methods to estimate FSP concentrations using cost-effective surrogate measurements (2NDNATURE et al 2014). A series of multi-parameter linear regression models were systematically tested to identify the most powerful cost-effective metrics that predict and convert FSP concentrations, both by mass and number of particles. Turbidity was identified as a reliable proxy to predict FSP concentrations at urban stormwater sites in the Tahoe basin with small improvements in statistical power if regional location and month of sample collection are included in the conversion. The use of both in-situ and hand held turbidity as proxies for FSP are recommended within RSWMP. Targeted stormwater sample submission to an analytical laboratory to quantify FSP concentrations (both mass and count) is recommended when field turbidity is greater than 800 NTU to fill data gaps and improve model prediction for highly turbid stormwater. RSWMP sampling design can leverage these findings to reduce site-specific monitoring costs for FSP.

5 CONSIDERATIONS FOR RSWMP FROM PAST EFFORTS

The following is a summary of the relevant findings and lessons learned from past research to be incorporated, as appropriate, into the RSWMP Assessment and Recommendations Report (ARR). The ARR will formalize the RSWMP objectives, guiding principles and the necessary site selection criteria, data collection priorities, data management structures, data analysis techniques and reporting formats, in addition to the programmatic structure and annual funding expectations.

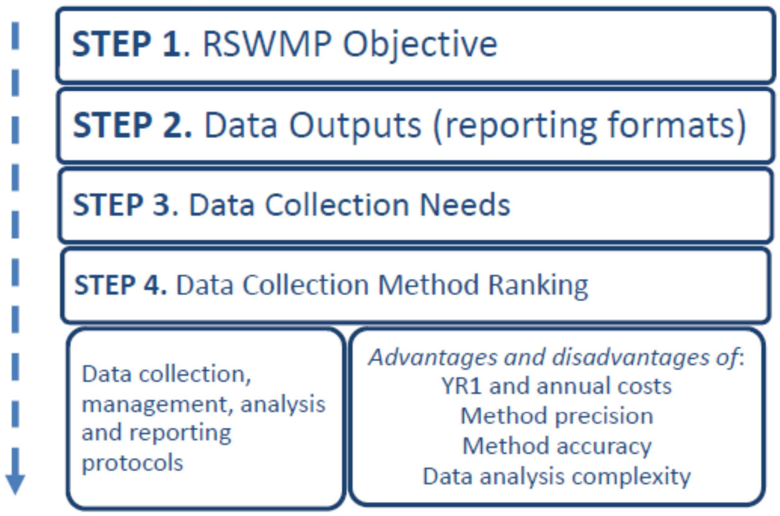
5.1 PROGRAMMATIC DEVELOPMENT CONSIDERATIONS

The breadth of past stormwater monitoring conducted in the Tahoe Basin has greatly improved our knowledge of urban stormwater monitoring techniques, existing stormwater quality conditions, and informed the development and refinement of the stormwater tools supporting the TMDL and Lake Clarity Crediting Program. However, the past research efforts have also resulted in a large amount of disparate water quality datasets that may have addressed specific research questions, but are not easily compiled and integrated to address the critical management questions of the long-term effectiveness of water quality improvement actions on reducing stormwater pollutant loading to the lake. In addition, past monitoring on Treatment BMP effectiveness has provided limited actionable information on how to inform design specifications and optimal maintenance schedules by the responsible parties to focus limited resources to ensure existing BMPs provide the intended water quality benefits over time., A clear articulation of what collected field data will be used for, what the final data outputs will be, and how they will be integrated into the final results, analyses, or conclusions is valuable for informing experimental design.

Given these past challenges, RSWMP objectives should directly inform the effectiveness of stormwater water quality improvement actions implemented on catchment and decadal scales. These management questions likely include evaluating and tracking the effectiveness of management actions to sustainably reduce urban stormwater pollutant loading to the lake and evaluating and optimizing the effectiveness of priority BMPs that are commonly implemented to achieve pollutant load reductions. The clear integration and evaluation of PLRM, Road RAM and BMP RAM into RSWMP objectives in a manner that could inform tool improvements and alignment with measured datasets is a long-term goal should be considered with adequate funding.

Figure 5.1 summarizes the recommended top down programmatic development steps for RSWMP. The guiding principal that will drive the actual tasks implemented under RSWMP each year will be driven by the available funding. As the development of the program is conducted, a vision of the potential range of available annual funding will be critical. RSWMP objectives (STEP 1) should be defined in manner that clearly links priority management actions to the expectation of RSWMP datasets compiled over the years to come. The required data outputs,minimum data quality or precision, and reporting formats (STEP 2) desired from the monitoring sites and associated network should be explicitly identified and linked to ensure the objectives are being addressed by the data outputs. Data outputs and associated reporting formats should include the units of measure and time intervals reported to address the specific management questions. Data outputs could include seasonal and annual pollutant loads from an urban catchment outfall to track urban pollutant loading status and trends. The intended use of these data outputs to directly address the specific management question by the data should be explicitly documented. The prioritization of the pollutants to be included in each RSWMP objective will guide the RSWMP implementers to make resource allocation decisions in the future as available funding fluctuates. By clearly defining the desired data output formats and clearly articulating how these outputs will be used and analyzed to address management questions, the identification of the data collection needs (STEP 3) and associated preferred site specific data collection methods (STEP 4) become much clearer and focused. RSWMP implementation would benefit from clear guidance and detailed protocols for each data collection need (STEP 3) and associated prioritized methods (STEP 4) to obtain the necessary raw data, manage and analyze it into the desired data reporting formats. The method prioritization process should consider first year and recurring annual costs, method reliability, method precision, data analysis complexity and level of accuracy needed to meet the respective RSWMP objective.

Figure 5.1. RSWMP top down programmatic development steps recommended to guide the completion of the RSWMP Assessment and Recommendations Report.



An explicit decision making process for the annual RSWMP design will ensure future available funding is allocated in a manner that achieves the programmatic priorities year to year. Through the development of the ARR, detailed costs and data output needs will be used to guide the prioritization of RSWMP objectives and the associated monitoring network given a range of potential annual funding conditions in the future.

5.2 URBAN OUTFALL MONITORING CONSIDERATIONS

To evaluate the collective effectiveness of water quality improvements to reduce urban stormwater pollutant loading to the lake, RSWMP should target catchments that discharge directly to the lake or tributary streams. The selection of urban outfalls where intensive and committed water quality improvements are planned by the local jurisdictions are expected to have higher pollutant load reduction signals over time due to management actions. An urban outfall water quality monitoring design that will have the highest power to detect pollutant load reductions as a result of management actions will maximize sampling precision and define consistent and reasonable techniques to adjust the resulting catchment pollutant loading data for natural hydrologic variability (i.e. wet verses dry years). Based on past stormwater monitoring and research, a number of RSWMP considerations regarding data collection for long-term consistent regional monitoring are provided:

- **Continuous hydrology**: Given the intermittent and variable flow conditions of urban stormwater, site instrumentation that allows cost-effective and reliable data to estimate site discharge on 10 or 15 minute time scales is recommended. Stage recorders with data loggers installed in a stable cross-section have been successfully used by many. The conversion of stage to discharge will require appropriate calculations given the method used to control the cross-section (e.g. weir, flume, culvert, etc). Instrument drift and other potential issues that result in data gaps have been common and can be minimized by regular and well documented field QA/QC procedures, including manual discharge measurements over the range of discharge conditions experienced at the site.

  Continuous meterology: Much of the variability in stormwater runoff with respect to annual and seasonal runoff volumes and pollutant loads can be accounted for by the variability in annual and seasonal precipitation. Meteorological stations that record precipitation and temperature on 10 or 15 minute time scales located in the urban area in close proximity to the stormwater monitoring site and are regularly maintained and quality checked is recommended. Convective summer storms are too localized for anything but proximate precipitation monitoring, and small localized temperature fluctuations can determine whether precipitation falls as snow or rain in the winter. Hourly data that includes precipitation and temperature are critical to more representative PLRM estimates.
- **Pollutant concentrations:** The TMDL pollutants of concern are FSP, TN and TP. DN and DP are critical to nearshore clarity issues. Continuous and event based sampling techniques should be considered by RSWMP urban outfall monitoring.
  - **Continuous concentration sampling:** Given the variability in pollutant concentrations in urban stormwater, site instrumentation that allows cost-effective and reliable pollutant concentration data on 10 or 15 minute time scales is recommended. No continuous sampling method has currently been implemented or well tested in the Tahoe Basin for nutrient species, but scientists outside the basin have successfully used optical sensors to measure continuous nitrate (Pellerin et al 2013, 2014). Investigations of automated probes to measure nitrogen concentrations must first evaluate if the available techniques can reliably detect and measure the relative low levels of total nitrogen (typically < 3 mg/L) and nitrate (< 0.1 mg/L) in Tahoe stormwater. Turbidity has been documented as a reliable surrogate for FSP concentrations and particle number and regional rating curves have been developed for Tahoe stormwater to reliably convert turbidity to FSP (2NDNATURE and DRI 2014). The confidence in the rating curve should be improved by supplemental data when turbidity exceeds 800 ntu. Continuous turbidity can be reliably measured using automated probes and data loggers on 10 or 15 minute time scales. Instrument drift and other potential issues that result in data gaps have been common and can be minimized by regular and well documented field QA/QC procedures, including manual turbidity measurements over the range of turbidity conditions experienced at the site.
  - **Event concentration sampling:** Event sampling is recommended over manual grab sampling techniques to ensure targeted and consistent sample collection with respect to each event hydrograph and discharge conditions. Two different sampling techniques have been developed and implemented in the Tahoe Basin to sample stormwater runoff events; automated samplers and passive samplers. Each have advantages and disadvantages regarding costs, sampling

precision, and data management and analysis needs that should be explored by the RSWMP SAG prior to recommending the preferred event concentration sampling methods for RSWMP. Both techniques require site visits and instrument preparation prior to targeted event sampling and immediate return to site following sample collection to implement site QA/QC procedures and prepare and submit samples to the laboratory.

5.3 CONSIDERATIONS FOR RSWMP TO INFORM PLRM

PLRM is a water quality planning tool designed to predict average annual runoff volumes and pollutant loads for use by Tahoe stormwater engineers and managers. PLRM is the recommended tool by the Lake Clarity Program to estimate the potential pollutant load reductions associated with collective water quality improvements in urban catchments. Given this role, there is a strong desire by the stormwater community to better understand the performance, limitations and opportunities to inform the PLRM. A series of recent research conducted by the developers of PLRM have identified and implemented a series of data collection and model development efforts to address these desires by the stormwater community (2NDNATURE and NHC 2010a, 2012a, 2012b, 2014). The relevant considerations during RSWMP design from the primary recommendations from these collective research efforts are summarized below.

- PLRM CECs (characteristic effluent concentrations from stormwater treatment BMPs) were initially determined using Tahoe specific data. Site specific and cost effective data collection, data analysis and data reporting protocols have been developed to sample the effluent from stormwater treatment BMPs in the basin to inform the PLRM algorithms. RSWMP should consider prioritizing long-term CEC monitoring from a variety of prevalent stormwater treatment BMP types (namely media filters, dry basins, wet basins, treatment vaults) to directly inform PLRM CEC revisions that reflect Tahoe specific data. To date, no data exists on a well maintained Tahoe stormwater treatment BMP.

- The PLRM version available to the Tahoe stormwater community includes a number of design simplifications or automated algorithms from the more complex SWMM model to streamline use of PLRM for the intended user group and to reduce data input needs. Intensive and costly efforts were undertaken to develop PLRM models to simulate urban pollutant loading on 10 minute time intervals to compare to measured runoff and FSP loading data for three urban catchments for 1 year of data for one pollutant (2NNDNATURE and NHC 2014). The results of the model calibration exercise and comparison to measured pollutant loads suggest that PLRM models can perform reasonably well on the seasonal and annual time scales, as intended based on the objectives of the model design. However, the general recommendation is that the generation of comparable and representative PLRM estimates to measured data is time consuming, complicated, and not a trivial undertaking to ensure the model represents the catchment sampled to the best extent possible.

5.4 BMP EFFECTIVENESS MONITORING CONSIDERATIONS

While an extensive number of treatment BMP effectiveness studies have been conducted in the past, minimal effectiveness data is available from *well-maintained* BMPs of any type. Traditional studies of flow through BMP effectiveness include continuous inflow and outflow hydrology, paired with event based water sampling and analysis for the array of typical sediment and nutrient species. The results from these two-three year monitoring efforts results in detailed event, seasonal and annual load and % reductions for the pollutants evaluated. These studies have resulted in a significant amount of snapshot water quality performance data for the specific BMPs evaluated, but the results have proven challenging to extrapolate to other similar BMP types or provide managers with applied guidance to directly inform siting, design, construction, and most importantly, treatment BMP maintenance over time.

RSWMP needs to be cognizant of these challenges and ensure any BMP effectiveness monitoring undertaken adequately addresses these applied needs. One consideration for RSWMP BMP effectiveness monitoring is the use of treatment BMP effectiveness monitoring to evaluate the sensitivity of BMP RAM observations to adequately track the decline in performance of a specific treatment BMP type over time. A long-term dataset of paired BMP RAM observations and quantitative BMP effectiveness pollutant load reduction monitoring could provide critical insight to the adequacy of BMP RAM observations and provide invaluable empirical data to improve the recommend threshold values for the respective treatment BMP type. Such an approach would also allow a direct means to apply the knowledge and data obtained to inform design, maintenance intervals and performance from one BMP to others of the same type. Selection of BMP types and pollutants evaluated should consider those prevalent in Tahoe Basin and the pollutants these types are expected to treat.

5.5 PROTOCOL DEVELOPMENT

The ability for the RSWMP program to be consistently and cost-effectively implemented over time will require detailed and standardized protocol development that can guide the best guide decisions by program implementers. Clear and consistent documentation of data outputs and reporting formats for each RSWMP objective will provide the desired data outcomes from the obtained datasets. Sampling design protocol to assure minimum data quality objectives are met will then guide the RSWMP implementation team to implement the day to day tasks to achieve the data outcomes. Below are a series of RSWMP considerations for site selection criteria, site monitoring techniques, and consistent and standardized data management and data analysis approaches gleaned from past research.

Site selection considerations:

- Focused and explicit site selection and optimal sampling network criteria should be developed for each RSWMP objective.
- Sites previously instrumented should be considered when new stations are to be added to the network due to the potential cost-effectiveness of reoccupying previously monitored sites and the knowledge of site nuances that can prove challenging when monitoring is initiated for the first time.
- Sites where stormwater hydrology monitoring is challenging (i.e. backwater, steep slopes, etc) may result in reduced sampling precision and increased noise due to hydrologic sampling error. In addition, sites with base flow inputs can dilute the urban land use or the treatment BMP performance signal.
- Given that annual funding availability will ultimately drive the definition of the sustainable RSWMP monitoring program, a targeted sampling approach should be preferred over random sampling to ensure both the site specific information as well as the comprehensive network distribution best achieve RSWMP objectives.

Site monitoring considerations:

- An array of sampling methods are available and well documented that can be selected to achieve any of the potential RSWMP objectives. The documentation of a clear prioritization and supporting rationale for the available methods to meet a specific data collection need should be considered by RSWMP. Such documentation may reduce subjectivity and inconsistencies in data collection efforts as the program proceeds.

- Instrumentation and equipment are continually evolving and RSWMP implementers should continue to evaluate new available technology that may more cost-effectively meet specific RSWMP data collection needs.
- The evaluation of different sediment (TSS, particle size distributions and associated bin size ranges) and nutrient (total, dissolved, inorganic, etc.) species provide different information regarding stormwater quality. Each constituent adds analytical, data management, data analysis and data reporting costs that must be considered with a clear alignment between addressing management questions and sampling design prior to inclusion. RSWMP design should consider providing guidance on the prioritizing constituents to be evaluated for each RSWMP objective.

Many load reduction strategies will rely on maintenance to sustain the condition of roads and treatment BMPs. Accurately tracking the management actions in the monitored catchment (e.g., treatment BMP maintenance, road practices, amount of functional private property BMP implementation, etc.) will be critical to understanding changes in water quality. **Data management considerations**

A standardized data management structure, data formats, units and QA/QC reporting procedures should be comprehensively defined for RSWMP. The existing RSWMP QAPP and SAP 2010 documents provide initial protocols, but a clear and complete link between data collection and ultimate use of data to meet RSWMP objectives and associated management questions are necessary to ensure data is managed and stored in consistent and standardized formats. To the extent possible, RSWMP data should be compatible with other state wide water quality databases such as California Environmental Data Exchange Network (CEDEN) and State Water Resources Control Board Surface Water Ambient Monitoring Program (SWAMP).

Data analysis considerations

While not well documented, it appears that past research efforts used a variety of data analysis techniques to translate the raw datasets obtained in the field into the metrics, values and graphics used to document the stormwater quality research findings. To ensure comparable and consistent data outcomes, RSWMP should document recommended data analysis techniques to transform the raw datasets into the desired data outcomes necessary to address each RSWMP objective. The documentation of recommended standardized calculations, statistical tools, and graphical displays for each RSWMP objective would ensure consistent data management and transformation into formats able to communicate RSWMP results to large array of audiences.

6 NEXT STEPS: ASSESSMENT AND RECOMMENDATIONS REPORT

The above considerations will be used to inform the development of the ARR by the RSWMP SAG and vetted with Technical Advisory Committee (TAC). The ARR is expected to include, but not limited to, the following components:

1. Program structure including an organizational chart and partnering agencies and organizations.

2. RSWMP objectives and strategies to optimize program by recommending a range of method options and related costs to achieve long-term goals.

3. Clear documentation of annual data outputs and reporting formats, including data analysis techniques to ensure consistent and comparable generation of results to achieve each RSWMP objective. Prioritization of the pollutants of concern by RSWMP objective.

4. Documentation of the data collection needs to generate the required data outputs of each RSWMP objectives, associated recommended process and protocols to select sites and select site specific monitoring methods.

5. Recommended data management formats/structure and platform to ensure consistent and comprehensive RSWMP data management.

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