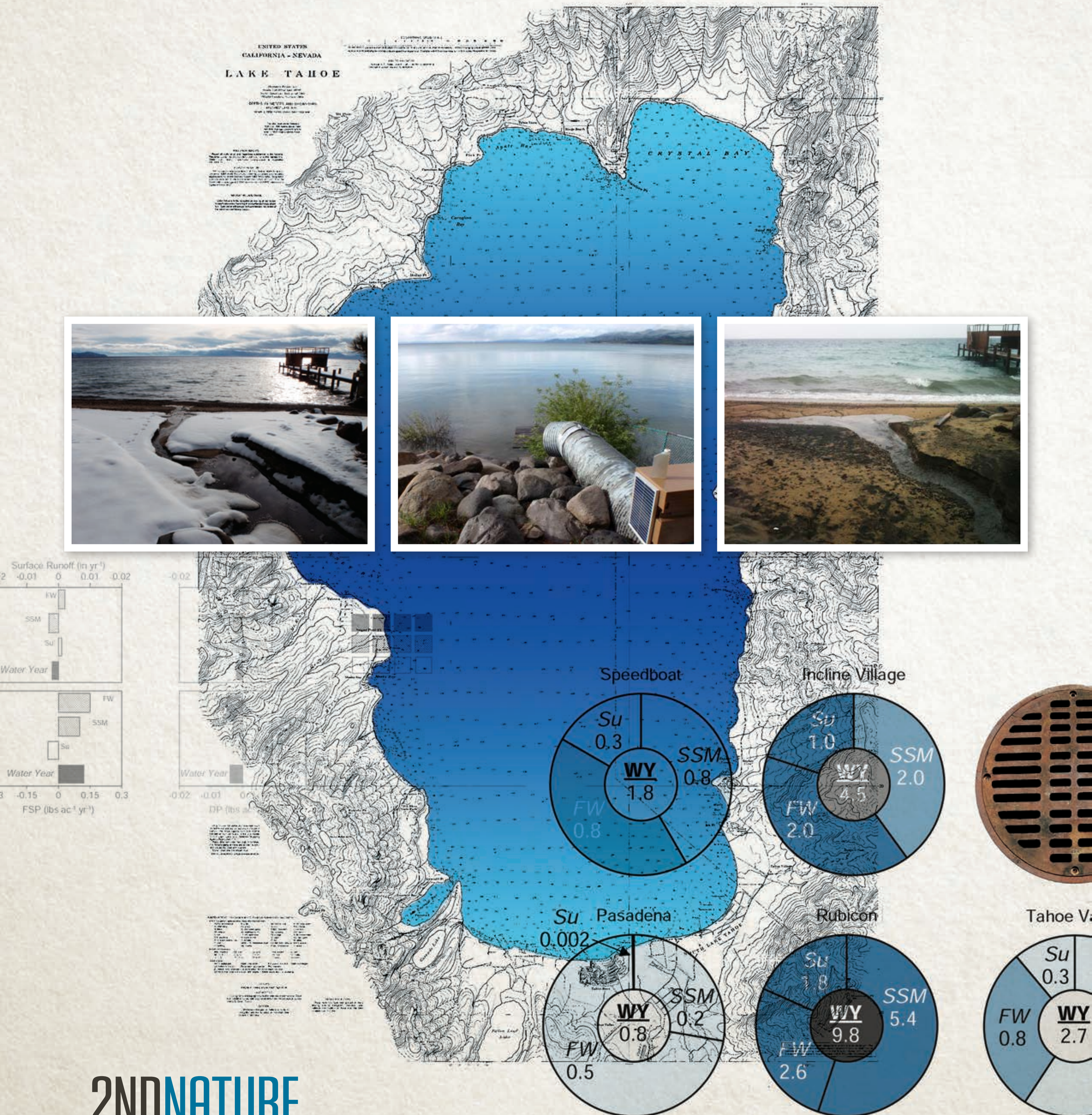
# ALIGNING STORMWATER MONITORING DATASETS WITH PRIORITY MANAGEMENT QUESTIONS

**DECEMBER 2014**




2NDNATURE
ecosystem science + design

# Aligning Stormwater Quality Datasets with Priority Management Objectives

Technical Guidance
December 2014

Developed by:


2NDNATURE
ecosystem science + design

2NDNATURE, LLC
**www.2ndnaturellc.com**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## LIST OF KEY ACRONYMS AND TERMS

| | |
|---|---|
| BMP | Best Management Practices; Actions taken to control pollutants associated with stormwater runoff. |
| CEC | Characteristic Effluent Concentration; Represents the effluent concentration typically achieved by a stormwater treatment BMP in PLRM dependent upon the type of BMP specified. |
| DQO | Data Quality Objectives; A 2011 document that outlines the RSWMP purpose, goals, and analytical approach for the analytes of concern in the region. |
| EIP | Environmental Improvement Program; Program, comprised of over 50 federal, state, and local agencies, launched in 1997 to implement the Regional Plan of restoring and protecting Lake Tahoe. |
| FSP | Fine Sediment Particle; Mass fraction of TSS concentration <16μm. |
| FW | Fall/Winter season; Time from October 1 through February 28. |
| LRWQCB | Lahontan Regional Water Quality Control Board; California regulatory agency overseeing the Tahoe Basin TMDL implementation. |
| LTIMP | Lake Tahoe Interagency Monitoring Program; Long-term monitoring program to measure nutrient and sediment input from a portion of Lake Tahoe's 36 streams. |
| MOU | Memorandum of Understanding; Stormwater regulatory agreements between NDEP and Nevada jurisdictions |
| MS4 | Municipal Separate Storm Sewer System; Permitted conveyance system that includes post-construction performance standards and effluent limitations that implement approved TMDLs for impaired waterbodies. |
| NDEP | Nevada Division of Environmental Protection; Nevada regulatory agency overseeing Tahoe Basin TMDL implementation. |
| NPDES | National Pollutant Discharge Elimination System; Permitting program that controls water pollution by regulating point sources that discharge pollutants into public waters. |
| P | Pollutant of concern; Either FSP, TN, TP, DN, or DP. |
| PLRM | Pollutant Load Reduction Model; Tool for Tahoe Basin urban stormwater community to estimate pollutant load reductions associated with catchment-scale water quality improvement actions. |
| RSWMP | Regional Stormwater Monitoring Program; A cooperative program of Tahoe Basin Agencies and the Tahoe Science Consortium. |
| SAR | Scientific Assessment Report; A collaboratively produced report that summarizes the current (as of 2014) of knowledge regarding stormwater monitoring conducted in the Tahoe Basin over the last decade. |
| SNPLMA | Southern Nevada Public Lands Management Act; Key funding source of this research. |
| SSM | Spring Snowmelt season; Time from March 1 through May 31. |
| Su | Summer season; Time from June 1 through September 30. |
| SWMM | Storm Water Management Model; EPA-developed dynamic rainfall-runoff simulation model used for single event and long term (continuous) simulation of surface hydrology quantity from primarily urban/suburban areas. |
| SWQIC | Storm Water Quality Interagency Committee; Involved in the urban stormwater treatment component of the EIP to identify, build, improve, deliver, and evaluate the effectiveness of stormwater quality improvement projects. |
| SWT | Stormwater Treatment Facility; Treatment BMP designed to reduce urban stormwater volumes and/or pollutant concentrations from a concentrated stormwater discharge path. |
| TMDL | Tahoe Basin Total Maximum Daily Load; Implementation plan that establishes pollutant load reduction allocations for urban stormwater to improve Lake Tahoe clarity. |
| TN | Total Nitrogen; Sum of nitrate-bound, nitrite-bound, ammonia-bound, and organically- |

| | |
|---|---|
| | bound nitrogen in a known volume of water. |
| TP | Total Phosphorous; Sum of all phosphorous compounds, although primarily orthophosphate, in a known volume of water. |
| TRPA | Tahoe Regional Planning Agency; Leading agency to preserve, restore, and enhance the environment of the Lake Tahoe region. |
| TSS | Total Suspended Sediment; Mass of sediment contained in a known volume of water. |
| USGS | United State Geological Survey; Funding source of this research. |
| WRCC | Western Regional Climate Center; Repository for historical climate data and information. |
| WY | Water Year; Time from October 1 through September 30. |

**List of Units**

| | |
|---|---|
| ac | acres |
| ac-ft | acre-feet |
| d | day |
| g | grams |
| i | instantaneous |
| in | inches |
| lbs | pounds |
| L | liters |
| mg | milligrams |
| mo | month |
| MT | metric tons |
| s | second |
| ssn | season |
| yr | year |

| *Variable* | Units | Description |
| --- | --- | --- |
| $A$ | acre | catchment size |
| $[P]_i$ | mg $L^{-1}$ | instantaneous pollutant concentration |
| $P_i$ | g $s^{-1}$ | instantaneous pollutant mass load per second |
| $\overline{P}_i$ | g $s^{-1}$ | average instantaneous pollutant mass load per second |
| $P_d$ | g $d^{-1}$ | pollutant mass load per day |
| $[P]_d$ | mg $L^{-1}$ | daily pollutant concentration |
| $P_{FW}$ | MT $ssn^{-1}$ | pollutant mass load per FW |
| $P_{SSM}$ | MT $ssn^{-1}$ | pollutant mass load per SSM |
| $P_{Su}$ | MT $ssn^{-1}$ | pollutant mass load per Su |
| $P_{WY}$ | MT $yr^{-1}$ | pollutant mass load per WY |
| $PPT_d$ | in $d^{-1}$ | inches of precipitation per day |
| $PPT_{mo}$ | in $mo^{-1}$ | inches of precipitation per month |
| $PPT_{FW}$ | in $ssn^{-1}$ | inches of precipitation per FW |
| $PPT_{SSM}$ | in $ssn^{-1}$ | inches of precipitation per SSM |
| $PPT_{Su}$ | in $ssn^{-1}$ | inches of precipitation per Su |
| $PPT_{WY}$ | in $yr^{-1}$ | inches of precipitation per WY |
| $Q_i$ | cfs | instantaneous cubic feet of discharge per second |
| $\overline{Q}_i$ | cfs | average instantaneous cubic feet of discharge per day |
| $Q_d$ | cf $d^{-1}$ | volume of discharge per day |
| $Q_{FW}$ | ac-ft $ssn^{-1}$ | volume of discharge per FW |
| $Q_{SSM}$ | ac-ft $ssn^{-1}$ | volume of discharge per SSM |
| $Q_{Su}$ | ac-ft $ssn^{-1}$ | volume of discharge per Su |
| $Q_{WY}$ | ac-ft $yr^{-1}$ | volume of discharge per WY |
| $TB_i$ | ntu | instantaneous turbidity |

| Unit surface runoff and pollutant mass loads | | |
| --- | --- | --- |
| $U\text{-}P_{mo}$ | lb $ac^{-1}$ $mo^{-1}$ | pollutant mass load per acre per month |
| $U\text{-}P_{FW}$ | lb $ac^{-1}$ $ssn^{-1}$ | pollutant mass load per acre per FW |
| $U\text{-}P_{SSM}$ | lb $ac^{-1}$ $ssn^{-1}$ | pollutant mass load per acre per SSM |
| $U\text{-}P_{Su}$ | lb $ac^{-1}$ $ssn^{-1}$ | pollutant mass load per acre per Su |
| $U\text{-}P_{WY}$ | lb $ac^{-1}$ $yr^{-1}$ | pollutant mass load per acre per WY |
| $predU\text{-}P_{mo}$ | lb $ac^{-1}$ $mo^{-1}$ | predicted unit pollutant mass load |
| $residU\text{-}P_{mo}$ | lb $ac^{-1}$ $mo^{-1}$ | residual unit pollutant mass load (precipitation adjusted) |
| $U\text{-}Q_{mo}$ | in $mo^{-1}$ | unit inches of surface runoff per month |
| $U\text{-}Q_{FW}$ | in $ssn^{-1}$ | unit inches of surface runoff per FW |
| $U\text{-}Q_{SSM}$ | in $ssn^{-1}$ | unit inches of surface runoff per SSM |
| $U\text{-}Q_{Su}$ | in $ssn^{-1}$ | unit inches of surface runoff per Su |
| $U\text{-}Q_{WY}$ | in $yr^{-1}$ | unit inches of surface runoff per WY |
| $predU\text{-}Q_{mo}$ | in $mo^{-1}$ | predicted unit surface runoff |
| $residU\text{-}Q_{mo}$ | in $mo^{-1}$ | residual unit surface runoff (precipitation adjusted) |

| *Variable* | Units | Description |
|---|---|---|
| $CEC_{DB\text{-}FSP}$ | mg L$^{-1}$ | CEC for dry basin fine sediment particles |
| $CEC_{DB\text{-}TN}$ | | CEC for dry basin total nitrogen |
| $CEC_{DB\text{-}TP}$ | | CEC for dry basin total phosphorous |
| $CEC_{DB\text{-}DN}$ | | CEC for dry basin dissolved nitrogen |
| $CEC_{DB\text{-}DP}$ | | CEC for dry basin dissolved phosphorous |
| $CEC_{MF\text{-}FSP}$ | | CEC for media filter fine sediment particles |
| $CEC_{MF\text{-}TN}$ | | CEC for media filter total nitrogen |
| $CEC_{MF\text{-}TP}$ | | CEC for media filter total phosphorous |
| $CEC_{MF\text{-}DN}$ | | CEC for media filter dissolved nitrogen |
| $CEC_{MF\text{-}DP}$ | | CEC for media filter dissolved phosphorous |
| $CEC_{TV\text{-}FSP}$ | | CEC for treatment vault fine sediment particles |
| $CEC_{TV\text{-}TN}$ | | CEC for treatment vault total nitrogen |
| $CEC_{TV\text{-}TP}$ | | CEC for treatment vault total phosphorous |
| $CEC_{TV\text{-}DN}$ | | CEC for treatment vault dissolved nitrogen |
| $CEC_{TV\text{-}DP}$ | | CEC for treatment vault dissolved phosphorous |
| $CEC_{WB\text{-}FSP}$ | | CEC for wet basin fine sediment particles |
| $CEC_{WB\text{-}TN}$ | | CEC for wet basin total nitrogen |
| $CEC_{WB\text{-}TP}$ | | CEC for wet basin total phosphorous |
| $CEC_{WB\text{-}DN}$ | | CEC for wet basin dissolved nitrogen |
| $CEC_{WB\text{-}DP}$ | | CEC for wet basin dissolved phosphorous |

# 1 EXECUTIVE SUMMARY

This reseach developed specific recommendations to align urban stormwater monitoring datasets with priority TMDL, EIP and other water quality implementation and management questions in the Tahoe Basin. The Tahoe Basin stormwater community has a need to generate multi-year stormwater quality datasets that are capable of: 1) evaluating trends in urban pollutant loading over time as a result of water quality improvement management actions and 2) informing priority needs of the stormwater tools used by the TMDL program. The Regional Stormwater Monitoring Program (RSWMP) is intended to oversee how stormwater data is obtained, managed and reported to address these needs. The recommendations herein provide technical details and guidance to link the site specific datasets obtained with how they will be analyzed and reported such that the results can be used to meet these priority management questions.

The development of these technical recommendations required relevant and applicable datasets upon which the research team could test various statistical approaches, identify the collective reporting metrics and create the recommended results summaries. Given that no such datasets currently existed, the research team utilized available tools and existing data to create reasonable, but hypothetical, datasets upon which the iterative development of the data analysis and reporting formats could be conducted. The creation of tangible example datasets was critical to this research to provide the context and opportunities from which the process, techniques and final recommendations could be generated. Due to the fabrication of the data contained herein, it must be realized that none of the absolute results are in any way representative of measured or even hypothesized results or findings related to Tahoe stormwater quality. The value of this research is the definitions, guidance and processes provided, which translate the datasets to be generated for two high priority objectives into meaningful and easily interpretable results. In addition, the recommended data analysis and reporting techniques were identified such that they could be consistently and cost-effectively implemented by resource agency staff who are not necessarily statistical experts.

*OBJECTIVE 1. Provide the data necessary to evaluate if collective urban water quality improvement actions are effective at reducing pollutant loading to Lake Tahoe over time.* The data required to achieve this objective is long-term consistent stormwater volumes and pollutant concentrations on sub-hourly timescales from a collection of representative urban catchment outfalls. The recommended data analysis and reporting approach includes standardized annual site status metrics to summarize the seasonal and annual stormwater monitoring results for each water year. The annual site status summary includes site meta data, respective year climatic context and site results in a format that is easily comparable across sites and directly applicable for subsequent stormwater quality trend analyses(Figures 6-8). In order to isolate the signal of management actions from climatic drivers that inherently influence the measured stormwater volumes and pollutant loads, techniques are defined to constrain the precipitation variations over monthly, seasonal, and water year time scales. Long-term seasonal and annual trends in precipitation-adjusted stormwater unit runoff and pollutant loads are recommended to evaluate if decreasing trends are detected across sites and over time. The statistical significance of the trends is evaluated at the 90% confidence interval with standardized reporting formats (Figures 9-11) to easily document the magnitude, direction, and confidence for each season and the water year. General considerations are provided to minimize sampling variability, thereby maximizing confidence that the differences in data across sites and over time are the result of management actions and less dependent on hydrology and/or sampling differences.

*OBJECTIVE 2. Collect the necessary stormwater data to inform and improve the characteristic effluent concentrations (CECs) for the Pollutant Load Reduction Model (PLRM), which are representative of common and functioning stormwater treatment (SWT) facility types in the Tahoe Basin*. The data recommended to achieve this objective is a collection of treated effluent pollutant concentrations sampled across a range of event types, magnitudes and durations from multiple respresentative BMPs of the same type. A large number of disparate BMP effectiveness studies have been conducted throughout the Tahoe Basin over the past decade; however, minimal data is available from BMPs that have been consistently maintained in acceptable condition (TRCD et al. 2014, 2NDNATURE and nhc 2012). In order to appropriately inform PLRM CECs, the monitoring must be conducted on a series of maintained BMPs that are operating within the acceptable range of performance. The recommended experimental design includes 3 years of measured effluent concentrations from 3 specific BMPs of the same type (e.g., wet basin, dry basin, etc.) to generate a single measured recommended CEC (mg/L) for that BMP type for each pollutant ($CEC_{BMP-P}$). This approach is recommended because it is expected to provide a reasonable spatial and temporal distribution of treated effluent concentrations for priority BMP types, while meeting the central assumptions of PLRM algorithms. The data management, analysis and reporting formats recommended (Figure 16) are relatively simple, repeatable and easily interpreted by managers, funders and other relevant stakeholders.

# 2 INTRODUCTION

The critical pollutants impairing the clarity of Lake Tahoe are fine sediment particles (FSP <16μm) and nutrient species (nitrogen and phosphorous). The primary source of these pollutants has been linked to urban land use activities (LRWQCB and NDEP 2010). Significant resources are being, and will continue to be, expended to implement sustained and effective actions to reduce pollutant loads to the Lake from urban areas. A fundamental assumption is that should pollutant loading be reduced and sustained, a commensurate improvement in lake clarity would occur. The ideal scenario for the Lake Tahoe Total Maximum Daily Load (TMDL), the Environmental Improvement Program (EIP) and other water quality improvement programs would be to generate multi-year stormwater quality datasets in the future that: 1) demonstrate a decreasing trend in urban pollutant loading over time as a result of water quality improvement management actions and 2) inform and improve the stormwater tools used by the TMDL program. Load reductions as a result of actions would justify the central hypothesis of the TMDL, and stormwater tools would guide land owners and jurisdictions to prioritize locations where water quality improvements will be most effective. This would result in reductions in pollutant loading to the Lake and identification of specific actions that are effective year after year.

This research was funded by a grant awarded by the USDA Forest Service Pacific Southwest Research Station using South Nevada Public Land Management Act (SNPLMA) Round 12 funds. The intention is to guide TMDL program managers and provide recommendations on how to specifically align urban stormwater monitoring datasets with the priority TMDL implementation and management questions. Since the initial development of this effort in 2011, additional relevant research has been completed (e.g., 2NDNATURE and NHC 2014) and the data quality objectives have been further refined by steering and technical teams. Reflecting the current thinking of stormwater monitoring priorities, the two goals and objectives addressed herein are:

1. Provide the data necessary to evaluate if collective urban water quality improvement actions have been effective at reducing pollutant loading to Lake Tahoe over time. This involves obtaining stormwater data to document urban pollutant loading status and trends. The establishment and maintenance of multi-year urban catchment outfall monitoring stations should achieve this goal and simultaneously meet MS4 and MOU permit monitoring requirements for California and Nevada.

2. Collect the necessary stormwater data to inform and improve stormwater tools, specifically the Pollutant Load Reduction Model (PLRM). The priority data to be addressed are the characteristic effluent concentrations (CECs) for PLRM, which are representative of common and functioning stormwater treatment (SWT) facility types in the Tahoe Basin.

The research and results documented herein provide guidelines for the technical process to manage, synthesize, analyze, and report stormwater data to meet these objectives. The field collection methods for stormwater data were not considered in this research, as it is likely that these techniques will change over time. Should these data analysis and reporting methods be adopted and implemented by resource managers, we have included Technical Guidance so that data analysts can follow and complete the procedures.

## 2.1 RESEARCH RELATIONSHIP TO RSWMP

The development and implementation of the Regional Stormwater Quality Monitoring Program (RSWMP) was initiated prior to funding of this research and the complete vision of the program is expected to be completed in 2016. RSWMP is intended to fill the critical urban stormwater data collection and reporting need to address a myriad of management objectives. This research presents recommendations for consideration by the RSWMP steering committee for the data reporting formats and guidance to perform the analyses to achieve the two priority RSWMP objectives as of 2014. Collecting stormwater data to track stormwater quality over time and directly inform the stormwater tools supporting the TMDL requires a strong experimental design and consistent technical approach to data collection, management, analysis and reporting. The RSWMP monitoring program must also be fiscally achievable on a short and long term basis, which was strongly considered through the development of the recommendations herein.

The proposal for this research was originally submitted in 2011 and was driven by the 2011 Data Quality Objective (DQO) recommendations for RSWMP (Heyvaert and Reuter 2011). The objectives include: (1) define the technical approach for compiling stormwater monitoring results to assess and improve TMDL stormwater tools to better represent observed land use condition, BMP function, or catchment seasonal and annual hydrology and water quality; (2) compare pollutant load reductions predicted by the Pollutant Load Reduction Model (PLRM) (NHC et al. 2009) to measured estimates of load reductions; and (3) integrate measured stormwater quality data from multiple catchment monitoring sites to determine stormwater quality trends over time and evaluate the effectiveness of specific water quality improvement activities. As stated above, these RSWMP objectives have since been revised and were re-prioritized in 2014. The research conducted and reported herein addresses two (1 and 3) of the three RSWMP objectives.

## 2.2 POLLUTANT LOAD REDUCTION MODEL

The PLRM provides Tahoe Basin resource managers with a tool to compare stormwater quality improvement alternatives in an urban catchment based on predicted load reductions for pollutants of concern to Lake Tahoe clarity. The desktop estimation tool combines SWMM (Storm Water Management Model) hydrology with a customized water quality module to predict the average annual pollutant loads from the outfall of a mixed land use catchment (NHC et al. 2009a). The continuous simulation model uses local 18-year historic meteorological datasets (WY1989-WY2006) to generate urban hydrology and pollutant loading and provide average annual loads at the catchment outlet for 6 pollutants of concern (total suspended solids [TSS], fine sediment particles [FSP], total nitrogen [TN], dissolved inorganic nitrogen [DIN], total phosphorous [TP], and soluble reactive phosphorous [SRP]). A variety of user inputs are required to represent the modeled urban catchment, including physiographic characteristics, land use distribution and condition, hydrologic source controls, and design characteristics of stormwater treatment BMPs.

The PLRM estimates pollutant concentrations in urban catchments using two primary water quality algorithms: characteristic runoff concentrations (CRCs) and characteristic effluent concentrations (CECs). CRCs are representative average runoff concentrations expected from a specific land use and associated land use condition, while CECs represent the average treated outflow concentrations for stormwater treatment BMPs (SWT) commonly used in the Tahoe Basin. The PLRM Model Development Document (NHC et al. 2009a) identifies the need to obtain Tahoe specific land use and SWT data to evaluate the appropriateness of the CRC and CEC algorithms and estimation approaches included in the initial version of PLRM. The prioritization of CEC improvments by the RSWMP program was due to a number of factors; (1) there is a high expectation that stormwater treatment systems (SWT) can improve stormwater quality, (2) there are a large number of SWTs that have been installed throughout the Basin over the past 2 decades; (3) there is currently a limited amount of Tahoe specific treated effluent data that can inform the CECs for the specific SWT types modeled in PLRM that have been maintained at an acceptable condition.

## 2.3 REPORT ORGANIZATION

Section 2 provides an introduction to this research, and its context within the larger Lake Tahoe TMDL implementation and evaluation, including the relationship to RSWMP.

Section 3 discusses the research objectives and research approach. The research objectives reflect the final objectives selected in 2014.

Section 4 describes the research methods and the datasets used and/or created to address the priority objectives.

Sections 5-10 provide the reporting, sample collection, and technical guidance for the 2 priority objectives. Specifically, sections 5-7 focus on Objective #1: Status and Trends, while Sections 8-10 address Objective #2: CECs.

- Reporting (Sections 5 & 8) defines the key concepts and terms relevant to each objective. In this section, the research team recommends methods for data analysis, noting important assumptions regarding data collection, specified tabular outputs, as well as site specific and basin wide graphical summaries.
- Monitoring and Management Considerations (Sections 6 & 9) provides recommendations for sampling and managing data in a consistent, basin wide format that emphasizes minimizing sample error and extraneous long term data collection and management costs.
- Technical Guidance (Sections 7 & 10) provides a more detailed description of the rationale of the calculations and metrics, an explanation of the specific statistical techniques used and a statistical resources guide for the software used in the status and trends analysis.

Section 11 describes the limitations associated with the research presented herein, and recommended next steps towards improving the Lake Tahoe TMDL program.

Section 12 is the literature cited throughout this report.

Appendix A provides a description of the statistical techniques employed in this research effort.

Appendix B provides specific guidance for plotting data using Grapher software as seen in the Figures throughout this report.

# 3 PROJECT OBJECTIVES AND RESEARCH APPROACH

The goal of this research is to provide specific recommendations for data management, analysis, and reporting of priority stormwater quality datasets now and into the future. The research team has been involved with objective refinement by RSWMP over the course of this research and has used this involvement to generate specifically applicable guidance and recommendations for RSWMP implementation. The formal process for vetting and adopting these recommendations into RSWMP will follow this research as a separate effort, undertaken by Tahoe Resource Conservation District and supporting scientific advisory group, technical advisory committee and steering committee.

## 3.1 RESEARCH APPROACH

A wide array of previous stormwater monitoring efforts in the Tahoe Basin have collected data without a clear understanding of how the parameters and data will be used to address the study objectives. This lack of foresight leads to an unfocused experimental design and extraneous data collection. In addition, all too often critical data collection opportunities necessary to meet the study objectives are overlooked, resulting in costly data gaps. The desired vision for RSWMP is a sustainable long-term program that provides data to inform critical water quality improvement programs and potential future adjustments. The use of standardized protocols will provide consistency for this basin wide effort and align the data obtained with end uses, while minimizing extraneous costs. This research is intended to provide the complete thinking from monitoring to annual reporting such that the purpose, format and resolution of each data point obtained can be clearly linked to the desired objective for which the data was collected.

The following steps were implemented by the team to complete this research effort:

1. Identify priority objectives and specific monitoring components through coordination with the Tahoe stormwater community
2. Identify example datasets that align with objectives and can be used test and select the technical data analysis techniques and reporting formats
3. Recommend data management, analysis and reporting formats to communicate datasets relevant to each objective;
4. Identify data collection and data management considerations to streamline protocols;
5. Develop concise Technical Guidance to perform the recommended protocols.

## 3.2 PROJECT OBJECTIVES

The purpose of this research is to provide relevant and useable technical guidance to the Tahoe stormwater community for management and reporting of multi-year stormwater datasets. In order to ensure that the recommendations were aligned with future data needs, the research effort was developed through collaboration and partnership with the Stormwater Quality Interagency Committee (SWQIC) and the RSWMP. The recently completed RSWMP Scientific Assessment Report and refined 2014 RSWMP objectives were also relied upon heavily (TRCD et al. 2014).

Two specific high priority objectives were selected by the research team for full technical guidance development.

**OBJECTIVE 1: Tracking of urban stormwater pollutant loading status and trends.**

**OBJECTIVE 2: Inform PLRM CEC values for common and well maintained stormwater treatment facilities in the Tahoe Basin.**

The recommended site specific data and associated formats are noted for each objective (Table 1). These outputs and formats are independent of the data collection technique used. This research does not provide guidance as to how the site specific datasets are obtained (i.e., sampling and data collection methods) but rather is focused on the translation of these site specific datasets to inform the supporting water quality improvement programs in the Tahoe Basin over time. This research focuses on how the data are managed, analyzed and reported in a manner that can be easily interpreted by the Tahoe Basin water quality community and specifically resource managers.

**Table 1.** Recommended site-specific data fields for each RSWMP objective.

| Objective | Metadata | Time Series Data Fields | Notes |
|---|---|---|---|
| OBJ 1: Status and Trends | Catchment characteristics | Daily discharge, $Q_d$ (cf $d^{-1}$)<br>Daily pollutant* concentration, $[P]_d$ (mg $L^{-1}$)<br>Daily pollutant load, $P_d$ (g $d^{-1}$)<br>Daily precipitation, $PPT_d$ (in $d^{-1}$) | Daily discharge, pollutant concentration and daily pollutant mass load for one year at each site.<br><br>Regionally or locally representative daily precipitation. |
| OBJ 2: SWT CECs | BMP Type<br>Catchment characteristics | Measured pollutant* concentration, [P] (mg $L^{-1}$) | Treated SWT effluent sampled over many event types, durations, magnitudes to represent a range of water year types. |

*P (pollutant) can be FSP, total nitrogen (TN), total phosphorous (TP), dissolved nitrogen (DN), dissolved phosphorous (DP), etc.

The third RSWMP objective explicitly written into the proposal for this funding was to validate PLRM simulated estimates on monthly time scales. The challenges, limitations and extensive complexity of PLRM validation processes have been well documented by recent research (2NDNATURE and NHC 2014). The continued use of public dollars to complete PLRM validation on these time scales was recently deprioritized by the RSWMP advisors. In lieu of these findings, any additional technical guidance to validate PLRM and how the results would be used to improve the PLRM is not included in this research effort.

# 4 RESEARCH DATA AND METHODS

For each of the objectives discussed herein, relevant datasets were needed to test the applicability of different technical methods, statistical tools, and reporting formats. Since the intent of this research is to guide future collection and data analysis, complete datasets of multi-year urban stormwater runoff and pollutant loads or effluent samples from maintained SWTs do not currently exist. The research team compiled and/or created testable datasets, which are described below. While the datasets do not contain a comprehensive set of all priority pollutants, the recommended approach was tested on two water quality parameters for each objective. We assert that the recommended approaches can be consistently applied across all pollutants.

In addition, all of the graphical data displayed in the Figures 1-17 were developed using the propriety software, Grapher. Download and plotting information for Grapher is provided in Appendix B.

## 4.1 DATASETS USED

### 4.1.1 STORMWATER EFFLUENT SAMPLE DATA

Objective 1 requires a multi-year discharge and pollutant concentration dataset in order to evaluate the best methods for consistent data management and reporting over the next several years (Table 1). Extensive efforts were made to obtain existing long-term stormwater data through coordination with UC Davis, the Desert Research Institute (DRI), SWQIC, the Tahoe Regional Planning Agency (TRPA), and the United State Geological Survey (USGS). However, adequate datasets were not identified. Even though urban stormwater monitoring efforts have been prevalent in the Tahoe Basin for over a decade, no specific catchment or BMP effluent has been consistently monitored for more than three years (2NDNATURE 2006, TRCD et al 2014). Therefore, the research team had to create a reasonable long term urban stormwater dataset upon which the analyses techniques could be tested and defined.

The ideal urban stormwater dataset encompasses at least two decades of monitoring and represents a range of intermittent discharge conditions, discharge magnitudes and pollutant concentrations. In order to achieve this, the research team used the PLRM and associated Storm Water Management Model (SWMM) platforms to create a hypothetical but realistic 36-year hourly discharge and FSP concentration dataset for the Pasadena Catchment in the City of South Lake Tahoe (CSLT) (Figure 1). The Pasadena Catchment is a low gradient, residential catchment that directly discharges to the Lake. A water quality improvement project was implemented by CSLT within the catchment in 2011. Improvements included the installation of pervious pavement road shoulders, increased residential BMP implementation, improved road conditions, and the installation of a treatment vault and media filter SWT. The catchment has been previously monitored during Lake Tahoe TMDL development in early 2000s, and was re-instrumented in 2009 by 2NDNATURE. The 2009 effort resulted in high resolution monitoring in order to (1) initiate the potential multi-year continued monitoring by RSWMP (which continues in 2014) and (2) compare measured volumes and pollutant loads to PLRM estimates during a single water year (2NDNATURE and NHC 2014). 2NDNATURE and NHC developed and revised the PLRM model to ensure that it best represented the current catchment conditions to the best extent possible. As a result of this effort, a well-vetted detailed PLRM model of Pasadena Catchment for both baseline (2004) and existing (2011) conditions was available to 2NDNATURE.


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**Figure 1:** Pasadena Catchment, South Lake Tahoe.

Feet
0 125 250 500
N

In order to compare to the collection of continuous discharge and a pollutant concentration before and after a known improvement action, the research team generated hourly datasets for two 18-year simulations. Each 18-year simulation was post-processed in SWMM. The first simulation was for the baseline 2004 condition and the second was of the 2011 improved condition (Figure 2). FSP was the chosen pollutant to align with the previous PLRM development and validation (2NDNATURE and NHC 2014). As customary with PLRM, the same precipitation and temperature inputs were used for each 18-year simulation. As expected, the modeled reduction in site discharge and FSP loads from YR 1-18 and YR 19-36 is visually evident in Figure 2.

### 4.1.2 STREAM SAMPLE DATA

Stream data from existing long-term sites maintained by the Lake Tahoe Interagency Monitoring Program (LTIMP) were also reviewed and selected. The statistical techniques and reporting formats were performed on measured stream datasets to test that the methods developed using the simulated stormwater datasets were applicable to actual field data. The basin-wide LTIMP stream monitoring dataset was reviewed to identify two stations with the longest continuous records of discharge with regular and consistent sampling for at least one pollutant. The two stations selected were the USGS gages on Trout Creek and Edgewood Creek with over 30 and 20 years of data, respectively (Figure 3). The majority of the records include continuous 15 min discharge with regular monthly sample collection for total suspended solids (TSS).

### 4.1.3 BMP CEC DATA

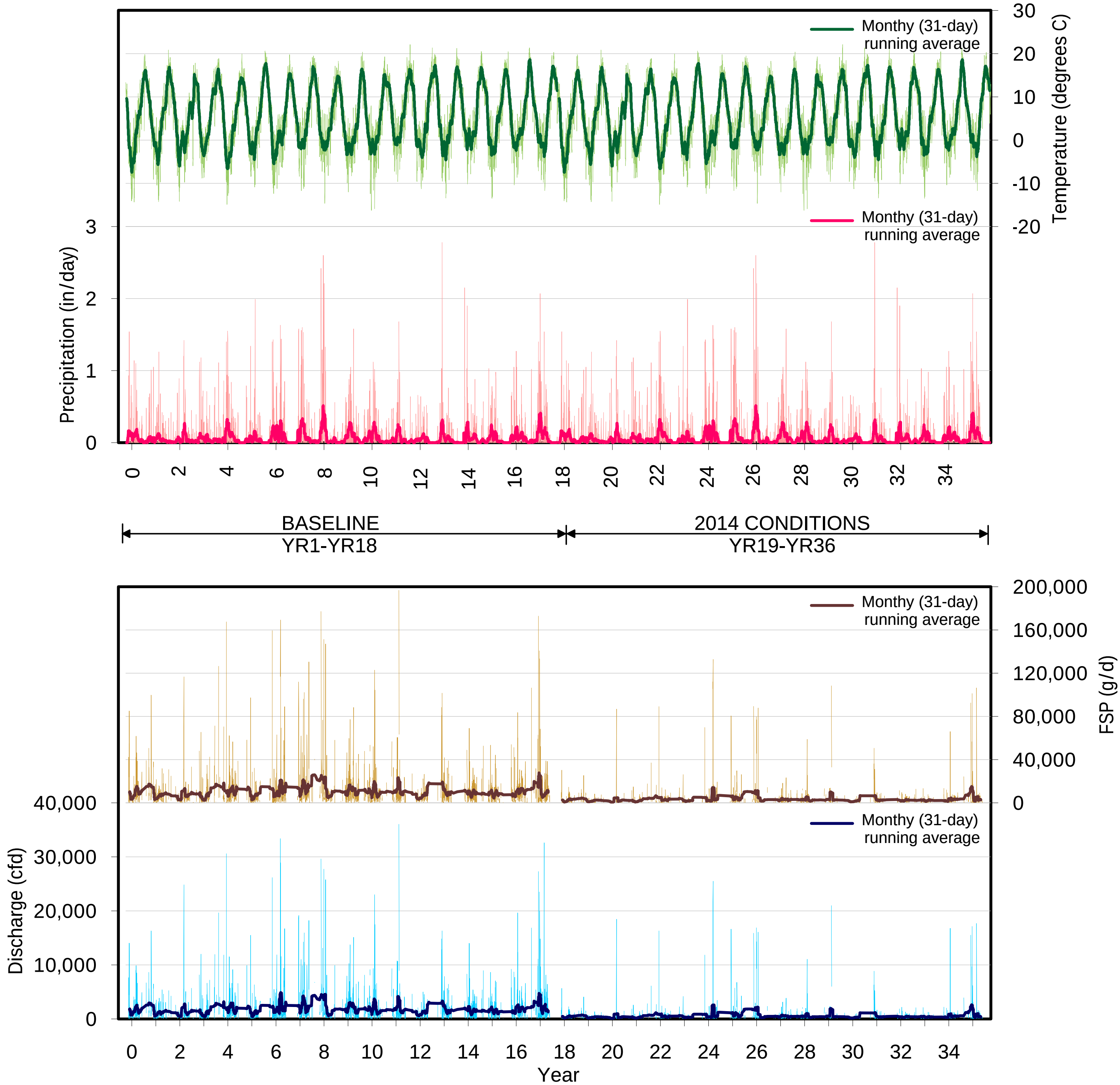
Objective 2 requires a SWT effluent dataset that can directly inform PLRM. Over the recommended years of monitoring, measured effluent concentrations will be grouped based on BMP type (e.g., wet basin, dry basin, media filter) (see Table 1). Two primary conditions must be met to the extent practical in order to accurately relate field data with PLRM simulations: (a) effluent data must represent a range of water year types and (b) BMPs must be regularly maintained in acceptable condition. It is important that the field dataset contains measurements during wet, dry, and average years because PLRM estimates are driven by an 18-year meteorological dataset that characterizes a wide range of precipitation variations. It is also important that BMPs are actively maintained because PLRM assumes that the BMPs are treating stormwater (i.e., reducing pollutant loads) in a manner consistent with the modeled design parameters for the life of the simulation.

In order to evaluate the best methods to determine the characteristic effluent concentrations for specific BMP types, the Basin wide effluent dataset was evaluated to select the BMP type with the longest record of field data. A review of the entire dataset revealed that wet basin FSP and TP effluent measurements had the longest record with 113 and 81 measurements, respectively. Other supplementary data sources were considered, including the national BMP Stormwater database (www.bmpdatabase.org). However, it was determined that the datasets available for the Tahoe Basin were sufficient to address and evaluate the data management and data analysis recommendations.

### 4.1.4 PRECIPITATION DATA

The intent of Objectives 1 and 2 is to evaluate the effectiveness of management actions over time. However, urban stormwater concentrations and loads are heavily influenced by natural climatic variability, making the isolation of the signal due to management actions more challenging. For example, snowy

# PLRM Simulations




TOP: Air temperature and precipitation from 1989-2006 used to run both PLRM simulations.

BOTTOM: Results from two PLRM simulations of Pasadena Catchments (South Lake Tahoe) graphed as daily FSP load and daily discharge time series.

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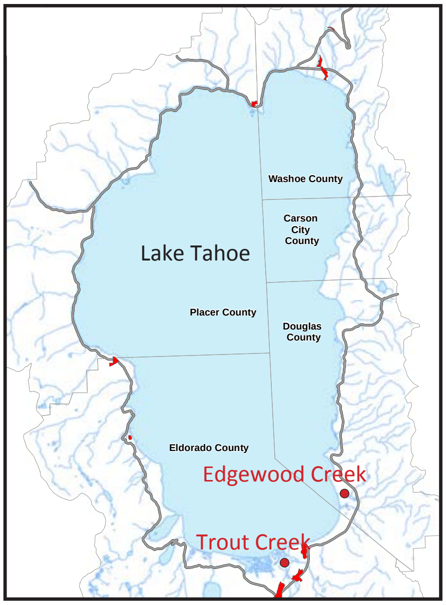
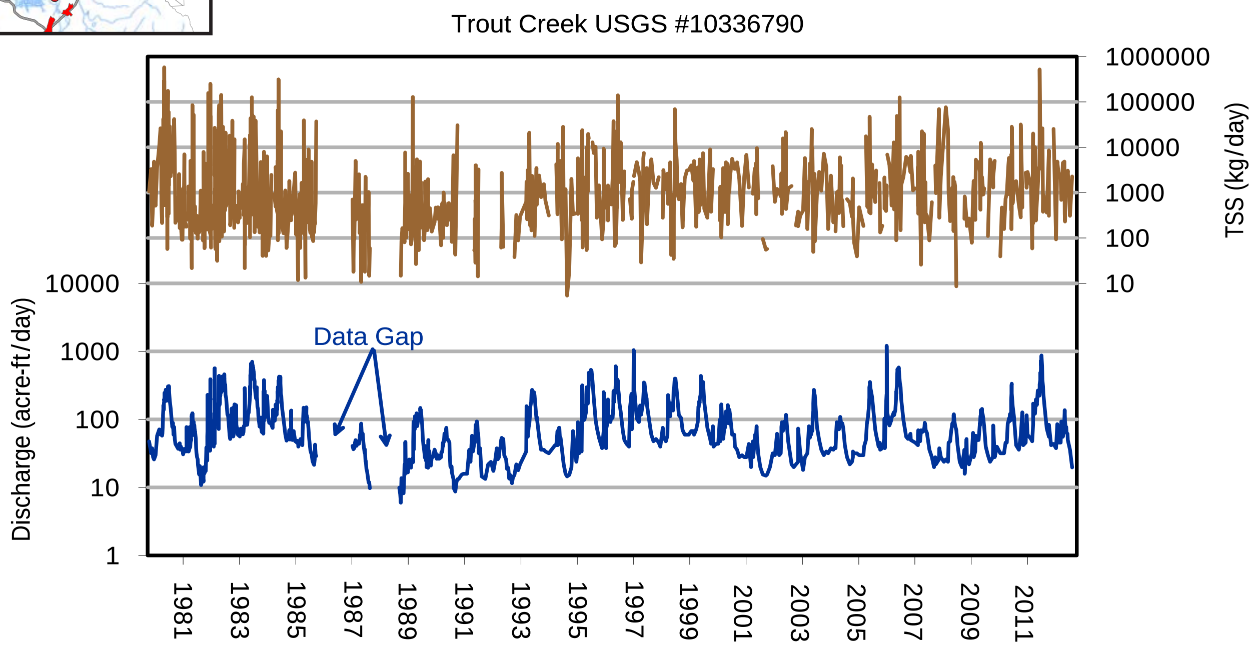
PLRM MODELED URBAN CATCHMENT OUTFALL TIME SERIES

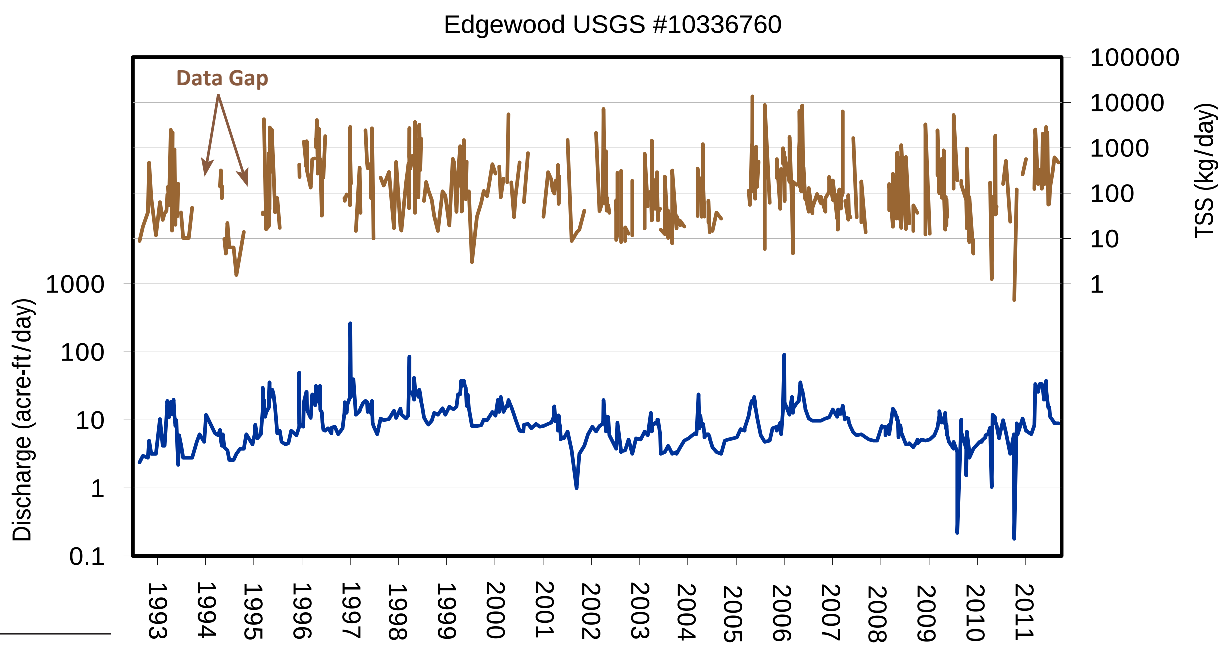
FIGURE 2




# Measured LTIMP Datasets

Selected LTIMP discharge and TSS datasets used to test statistical analyses to detect pollutant loading trends.

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2NDNATURE LLC
TEL: 831.426.9119
FAX: 831.426.7092
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AVAILABLE LONG TERM LTIMP DATASETS

FIGURE 3

winters tend to require more abrasive road applications to treat icy roads, which in turn is likely to generate higher total and fine sediment loads on surface streets. These larger winters also result in greater runoff and stormwater volumes. Thus, it is necessarily to evaluate stormwater and effluent data within a relevant climatic context and report and include precipitation variability (see Table 1). The recommended precipitation dataset to determine water year and seasonal types is the long term Western Regional Climate Center (WRCC) station located in Tahoe City (gage #48758; www.wrcc.dri.edu). The rationale for recommending this site is as follows:

- It is a consistently maintained met station with a dataset that spans over 100 years.
- The extensive record permits application of a frequency analysis. A detailed frequency analysis of the local precipitation patterns would yield consistent seasonal results such that a wet winter would be consistently defined for Tahoe City and South Lake Tahoe, even if the relative precipitation totals for each location vary.
- Categorization of season and water year types based on precipitation totals is representative of the next 5 years. The frequency analysis can be easily updated each decade and thus accommodate shifts in regional precipitation patterns due to climate change.
- It can serve as a reference to track precipitation differences across years in the future.
- There is high likelihood this station will continue to be operated and the data readily available for the next two decades.
- The data is reliable, consistent and can be obtained with no site operation and maintenance costs to data users.

## 4.2 DATA ANALYSIS AND REPORTING DEVELOPMENT

A variety of data analysis and reporting techniques were evaluated to recommend a customized process to align stormwater monitoring data with the RSWMP objectives. A detailed documentation of the testing sequences conducted to arrive at the final recommendations would be extensive and was deemed unnecessary. However, an overview and rationale of the general approaches tested are provided to illustrate that a consistent and automated procedure was prioritized. The next sections provide the reporting formats, sample collection considerations, and the technical guidance to leverage collection data and meet the priority objectives.

# 5 OBJ 1: STATUS AND TRENDS ANNUAL REPORTING

**Are urban stormwater volumes and pollutant loads discharging to the Lake decreasing over time as a result of effective management actions?**

This is the critical question for which consistently collected and properly analyzed stormwater monitoring data can address in the future. In addition, these stormwater datasets will meet annual jurisdictional MS4 permit requirements as well as provide the information necessary to evaluate the collective effectiveness of the actions implemented in urban areas under the EIP, the TMDL, BMP retrofit program for private lands, and other associated programs.

Six urban outfall sites have currently been selected by RSWMP as priority sites to monitor over the next several years and to directly address the question posited in Objective 1. These sites were selected because they: a) discharge directly to the lake, b) are relatively evenly distributed spatially around the Basin, c) represent a range of justisdictional practices, and d) many of the sites have been previously monitored, providing an opportunity to leverage institutional knowledge and experience to reduce site instrumentation trial and error, and associated costs. The next three sections of this report (Sections 5, 6, and 7) are devoted to guiding managers and analysts to address Objective 1 and to evaluate the effectiveness of the monitoring program.

We have divided the techniques into annual status and interannual trend reporting. The term *status* is used to report the total seasonal and annual discharge volumes and pollutant mass loads for a single year, a requirement in the MS4 Phase II California permits (LRWQCB 2011). The annual results are managed and reported in a format that allows and facilitates multi-year trend analyses once the length of the dataset is sufficient. The term *trends* is used to report the inter-annual changes in seasonal and water year unit discharge volumes and unit pollutant mass loads. Understanding the effectiveness of management actions independent of climate variability is critical for both status and trends, and is considered in Section 5.1. Recommendations for site specific data analysis and basin wide graphical comparisons for status and trend reporting are outlined in Section 5.2 (status) and Section 5.3 (trends) and are intended for use by program managers, funders and the public.

## 5.1 PROVIDING CLIMATIC CONTEXT

A primary objective of the long term urban catchment outfall monitoring is to measure urban runoff and pollutant load changes as a result of water quality improvement actions. However, urban stormwater runoff is a product of both management actions and natural climate variability. In order to isolate the signal of management actions from climatic drivers that inherently influence the data, it is important to consider the stormwater datasets in a climatic context. Precipitation variations over monthly, seasonal, and water year timescales are used to place the water quality data into this hydrologic framework. The selected seasons each represent a 3-5 month time interval (Table 2) and are the designations defined in the CA MS4 permits and NV MOU.

**Table 2.** Seasonal designations as defined in the NPDES permit.

| Season | Start | End | # of days |
|---|---|---|---|
| Fall/Winter | October 1 | February 28 | 151 |
| Spring Snowmelt | March 1 | May 31 | 92 |
| Summer | June 1 | September 30 | 122 |

The seasonal and water year categorizations are reported in the status sections and monthly precipitation totals are directly used to adjust priority status metrics for the trend analysis.

## 5.2 STATUS REPORTING FORMATS

Status reporting was developed to compare water quality metrics in a standardized way between sites around the Basin for any given year. The metrics are expected to: a) collectively summarize each site and water year results, b) provide values that are expected to be sensitive to effective management actions, c) allow result comparisons across catchments and over time, and d) be relatively simple to consistently generate year after year. For status reporting, seasonal and water year types (e.g., very dry, dry, average, wet, very wet) are defined based on a frequency analysis using the Tahoe City gage (Figures 4 and 5).

We recommend that the data necessary for each urban catchment outfall site is obtained and reported in a specified format as an annual status report (Figure 6). This annual status report for each site includes site location and key catchment characteristics (A), monitoring techniques (B), the total snow and precipitation context of the year relative to the historic record (C), the monthly Q and pollutant loads for the year relative to the historic record (D), and a collection of seasonal and annual volume and pollutant metrics that summarize the monitoring results for the specific year (E).

*All of the results presented in Figure 6 are based on the hypothetical stormwater dataset generated for the Pasadena Catchment and do not represent expected or even assumed monitoring results for this site.*

*% Runoff*: The % runoff is expressed as the fraction of rainfall that is exported from the catchment as stormwater runoff. It is anticipated that effective actions to disconnect impervious surfaces and recharge rain volumes on private parcels will directly decrease the % runoff over time in urban catchments. This metric can be compared over time at a single catchment and between catchments for a single year.

*Total Q:* The total seasonal (ac-ft $ssn^{-1}$) and annual discharge (ac-ft $yr^{-1}$) volumes are reported for each site, a specific reporting requirement of the MS4 Phase II permit.

*Unit Surface Runoff:* The unit surface runoff (in $time^{-1}$) is the total discharge volume (ac-ft $time^{-1}$) divided by the catchment size (acres) with appropriate unit conversions from feet to inches. Unit surface runoff is the discharge metric used in the trend analysis.

*Total Pollutant Mass Load:* The total seasonal (MT $ssn^{-1}$) and annual (MT $yr^{-1}$) pollutant mass loads are reported for each site, a specific reporting requirement of the MS4 Phase II permit.

*Unit Pollutant Load*: The unit pollutant mass load (lb $ac^{-1}$ $time^{-1}$) is the total pollutant mass load (MT) divided by the catchment size (acres) with appropriate unit conversions from metric tons to pounds. Unit surface runoff is the pollutant load metric used in the trend analysis.

Annual compilation of the RSWMP status and trend monitoring network for the existing sites across the Tahoe Basin can be summarized using a regional map display (Figure 7 with key provided in Figure 8). Hypothetical data is used to illustrate the visual power to readily compare the unit surface runoff and unit FSP loading rates measured across all 6 status and trends sites during a specific water year. *Data for all sites except Pasadena, which is based on PLRM model simulations, were fabricated to define the reporting formats and illustrate them.* A similar map is recommended for all additional nutrients monitored at the respective urban catchment outfall stations.

## Tahoe Basin Fall/Winter Precipitation Classification

| Year Type | Season Type Recurrence Interval (years) | Fall/Winter (Oct-Feb) (in/yr) | | Annual PPT Exceedance Probability (%) | n |
|---|---|---|---|---|---|
| | | Lower (in/yr) | Upper (in/yr) | | |
| Very Dry | 11 | | 11.41 | > 91 | 9 |
| Dry | 4 | 11.42 | 16.25 | > 67 | 26 |
| Average | 3 | 16.26 | 25.53 | > 33 | 35 |
| Wet | 4 | 25.54 | 36.61 | > 10 | 24 |
| Very Wet | 10 | 36.62 | | <10 | 10 |
| Long-Term Average Seasonal Precipitation = 22.01 in/yr | | | | | |
| Water Year Record = 1911 - 2014 | | | | | |

## Tahoe Basin Spring Snowmelt (SSM) Classification

| Year Type | Season Type Recurrence Interval (years) | SSM (March-May) (in/yr) | | Annual PPT Exceedance Probability (%) | n |
|---|---|---|---|---|---|
| | | Lower (in/yr) | Upper (in/yr) | | |
| Very Dry | 12 | | 2.91 | > 91 | 9 |
| Dry | 4 | 2.92 | 5.18 | > 67 | 26 |
| Average | 3 | 5.19 | 8.39 | > 33 | 35 |
| Wet | 4 | 8.40 | 13.49 | > 10 | 25 |
| Very Wet | 10 | 13.50 | | <10 | 10 |
| Long-Term Average Seasonal Precipitation = 7.42 in/yr | | | | | |
| Water Year Record = 1910 - 2014 | | | | | |

## Tahoe Basin Summer (Su) Classification

| Year Type | Season Type Recurrence Interval (years) | SU (June -Sept) (in/yr) | | Annual PPT Exceedance Probability (%) | n |
|---|---|---|---|---|---|
| | | Lower (in/yr) | Upper (in/yr) | | |
| Very Dry | 12 | | 0.34 | > 91 | 9 |
| Dry | 4 | 0.35 | 0.91 | > 67 | 26 |
| Average | 3 | 0.92 | 2.32 | > 33 | 35 |
| Wet | 4 | 2.33 | 3.93 | > 10 | 25 |
| Very Wet | 10 | 3.94 | | <10 | 10 |
| Long-Term Average Seasonal Precipitation = 1.81 in/yr | | | | | |
| Water Year Record = 1910 - 2014 | | | | | |

Tahoe City gage (#48758) operated by the Western Regional Climate Center; Elevation: 6230 feet; http://www.wrcc.dri.edu

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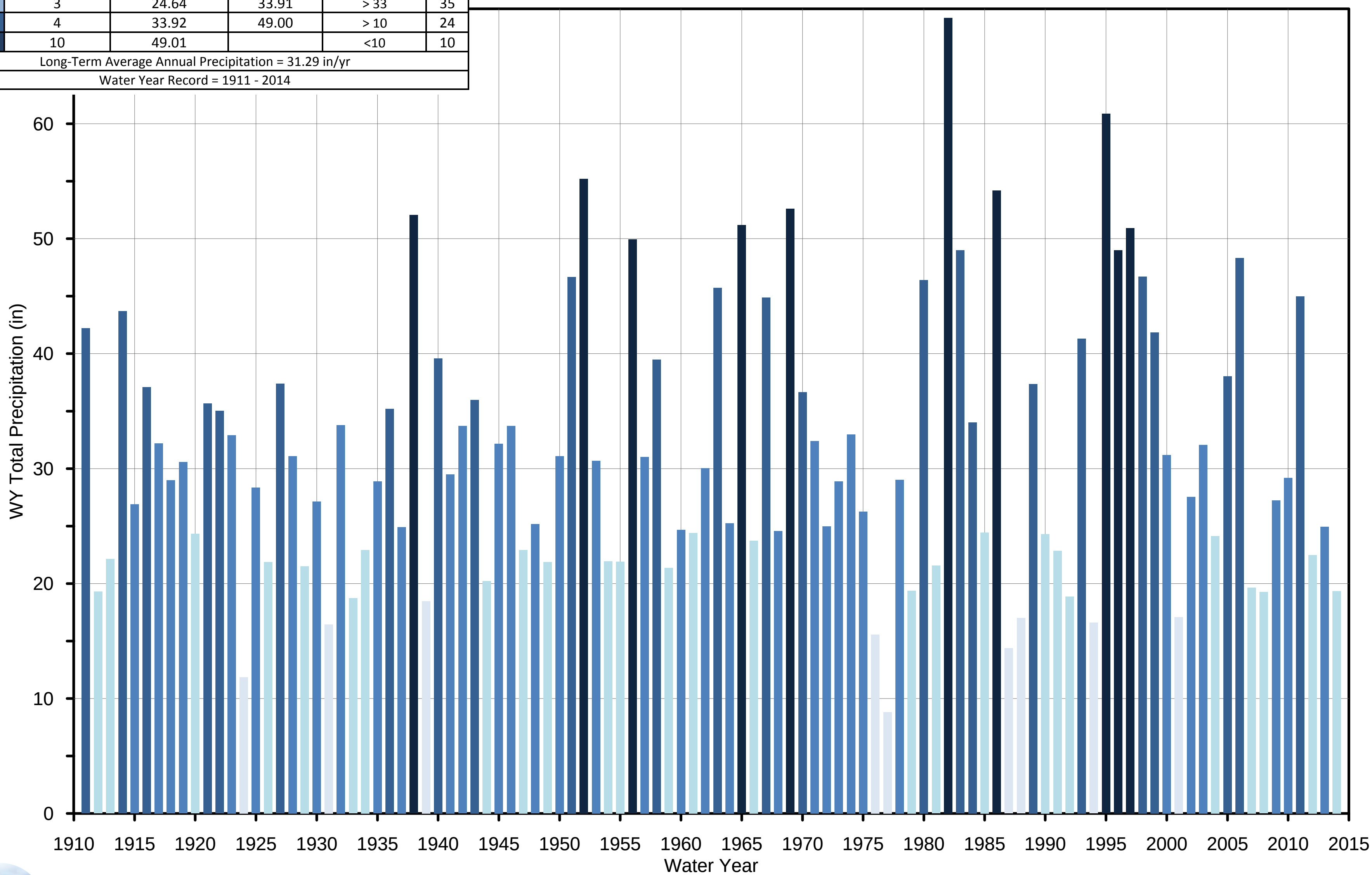
SEASONAL PRECIPITATION CLASSIFICATION - TAHOE CITY

FIGURE 4

| Year Type | WY Type Recurrence Interval (years) | Annual Precipitation (in/yr) | | Annual PPT Exceedance Probability (%) | n |
|---|---|---|---|---|---|
| | | Lower (in/yr) | Upper (in/yr) | | |
| Very Dry | 11 | | 18.60 | > 91 | 9 |
| Dry | 4 | 18.61 | 24.63 | > 67 | 26 |
| Average | 3 | 24.64 | 33.91 | > 33 | 35 |
| Wet | 4 | 33.92 | 49.00 | > 10 | 24 |
| Very Wet | 10 | 49.01 | | <10 | 10 |
| Long-Term Average Annual Precipitation = 31.29 in/yr | | | | | |
| Water Year Record = 1911 - 2014 | | | | | |

## Tahoe Basin Water Year Classification




Tahoe City gage (#48758) operated by the Western Regional Climate Center; Elevation: 6230 feet; http://www.wrcc.dri.edu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WATER YEAR CLASSIFICATION - TAHOE BASIN

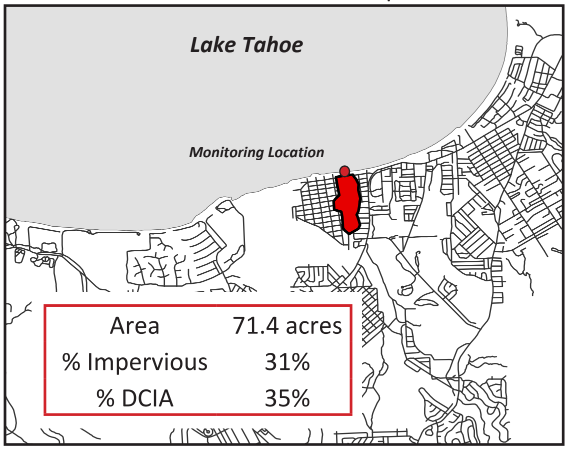
FIGURE 5

# Annual Urban Catchment Outfall Monitoring Status

Water Year 2020 (October 2019-2020)

Pasadena Catchment, City of South Lake Tahoe

A. Site Location Map

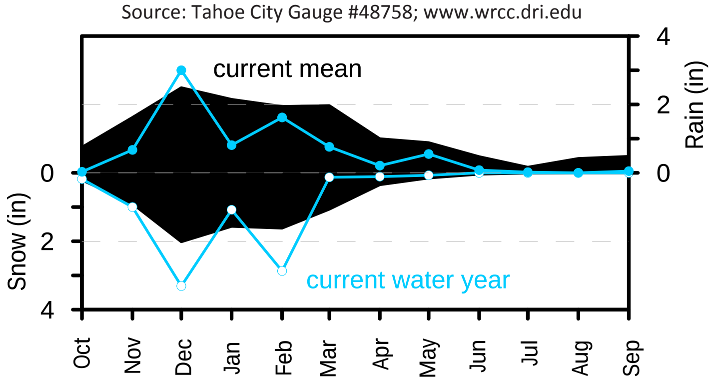



B. Monitoring and Measurement Data Collection

| Parameters | Technique | Instrument/Method |
|---|---|---|
| Q | Stage and H Flume | ISCO 730 Bubbler |
| FSP | Turbidity sensor Regression equation | FTS-DTS-12 Eq. 3.5 (DRI and 2N, 2014) |
| TN | Autosampler | ISCO 6712 |
| TP | | |

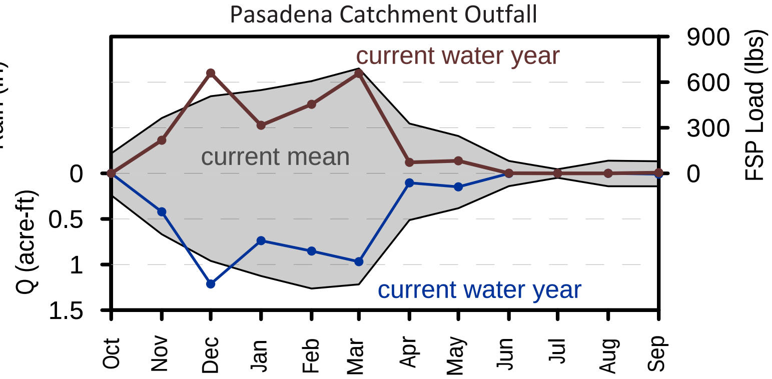
C. Monthly Rain and Snow Summary

Source: Tahoe City Gauge #48758; www.wrcc.dri.edu




D. Monthly Q and FSP Load Summary

Pasadena Catchment Outfall




E. Surface Runoff and Pollutant Load Metrics

| | Pasadena Catchment | Units | WY 2020 | Units | F/W | SSM | Su |
|---|---|---|---|---|---|---|---|
| | Data Completeness | % | 100 | | 100 | 100 | 100 |
| | Duration no flow | % | 62.6 | % | 40.4 | 52.2 | 97.5 |
| | WY/season type | | V.Dry | | Dry | V. Dry | V. Dry |
| | Precipitation *(PPT)* | in yr$^{-1}$ | 16.6 | in yr$^{-1}$ | 14.6 | 1.8 | 0.2 |
| Q | % runoff | % | 4.5 | % | 3.7 | 11.4 | 0.83 |
| Q | Surface runoff *(U-Q)* | in yr$^{-1}$ | 0.75 | in ssn$^{-1}$ | 0.54 | 0.21 | 0.002 |
| Q | Total Q *(Q)* | ac-ft yr$^{-1}$ | 4.46 | ac-ft ssn$^{-1}$ | 3.22 | 1.22 | 0.01 |
| FSP | FSP unit loading rate *(U-FSP)* | lbs ac$^{-1}$ yr$^{-1}$ | 34.5 | lbs ac$^{-1}$ ssn$^{-1}$ | 23.1 | 11.4 | 0.07 |
| FSP | Total FSP load *(FSP)* | MT yr$^{-1}$ | 1.12 | MT ssn$^{-1}$ | 0.75 | 0.37 | 0.002 |
| TN | TN unit loading rate *(U-TN)* | lbs ac$^{-1}$ yr$^{-1}$ | | lbs ac$^{-1}$ ssn$^{-1}$ | | | |
| TN | Total TN Load *(TN)* | MT yr$^{-1}$ | | MT ssn$^{-1}$ | | | |
| TP | TP unit loading rate *(U-TN)* | lbs ac$^{-1}$ yr$^{-1}$ | | lbs ac$^{-1}$ ssn$^{-1}$ | | | |
| TP | Total TP load *(TP)* | MT yr$^{-1}$ | | MT ssn$^{-1}$ | | | |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SITE STATUS SUMMARY

FIGURE 6

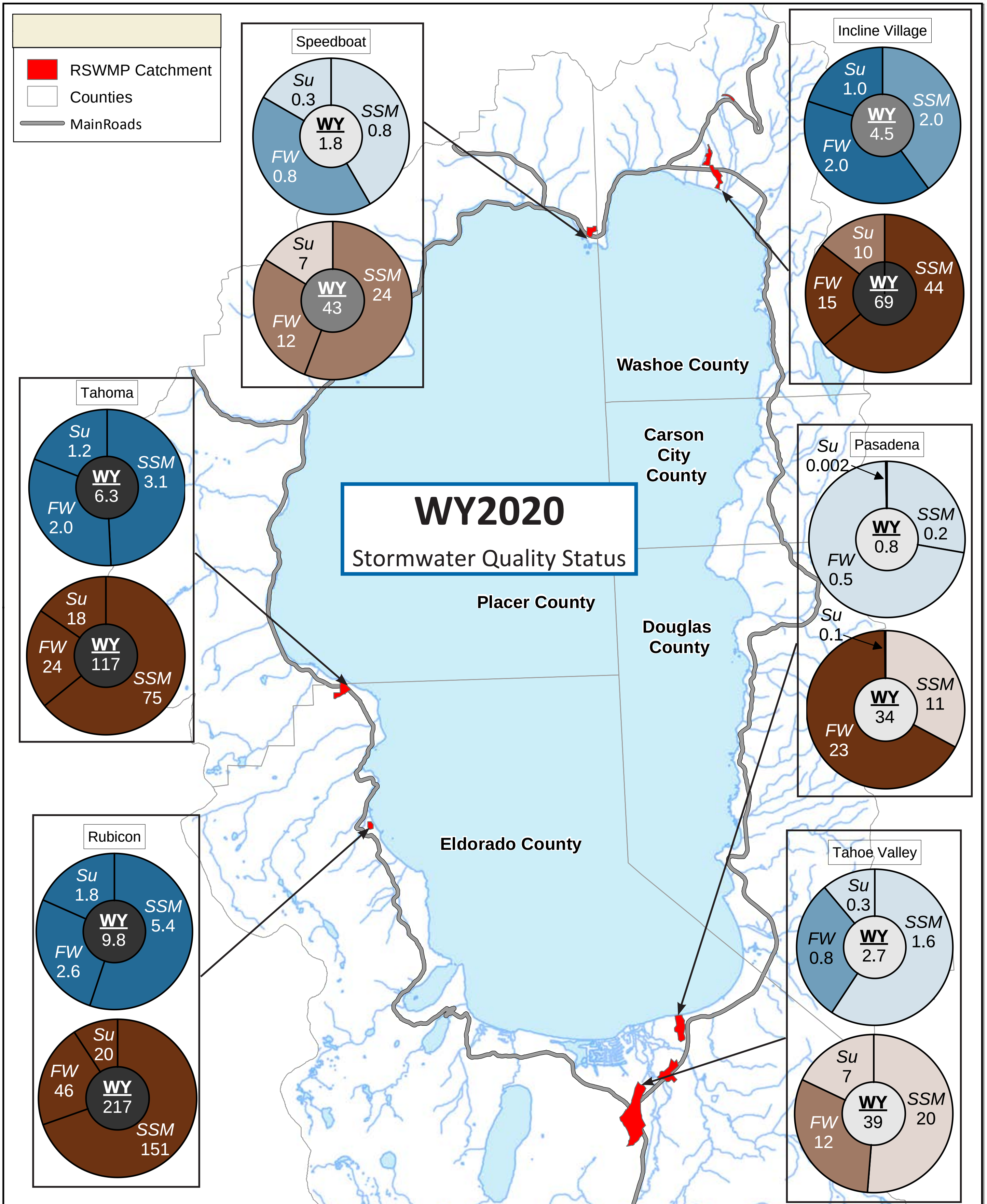


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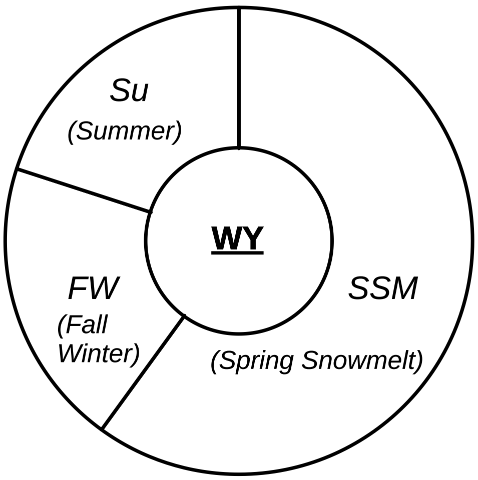
FIGURE 7. **WY2020**
Regional stormwater status summary. Urban catchment runoff volumes and FSP loads. Runoff reported as in yr$^{-1}$ or ssn$^{-1}$. FSP loads reported as lbs ac$^{-1}$ yr$^{-1}$ or ssn$^{-1}$.

Miles
0 0.75 1.5 3
1 in = 3 miles
N

# Key for urban catchment outfall pollutant annual status maps

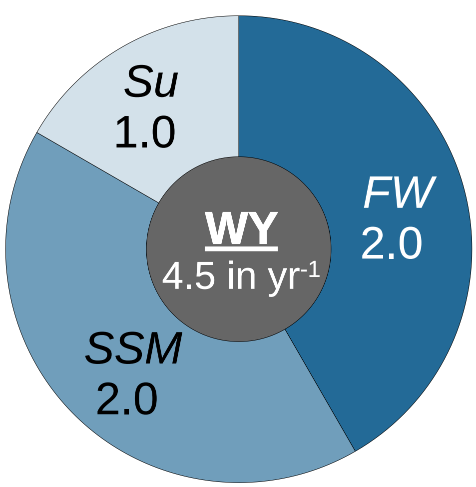
*GRAPHIC GUIDE: Unit runoff and pollutant loading rates are directly comparable across sites and over time. The values for unit surface runoff are given below in inches per year for the WY and in inches per season for each season. Unit pollutant loads values are given in pounds per acre per year or per season. The seasonal contributions sum to the water year totals displayed in the center, and the size of each seasonal pie wedge is proportional to its contribution to the water year total. Available data was used to reasonably estimate the basin wide average annual values for each parameter and are shown in the table below.*




Parameter Averages by Water Year and Season

| | Water Year | FW | SSM | Su |
|---|---|---|---|---|
| | (in $yr^{-1}$) | (in $ssn^{-1}$) | (in $ssn^{-1}$) | (in $ssn^{-1}$) |
| **Surface Runoff** | 4.0 | 0.8 | 2.4 | 0.8 |
| | (lbs $ac^{-1}$ $yr^{-1}$) | (lbs $ac^{-1}$ $ssn^{-1}$) | (lbs $ac^{-1}$ $ssn^{-1}$) | (lbs $ac^{-1}$ $ssn^{-1}$) |
| **FSP Load** | 50 | 10 | 30 | 10 |
| **TN Load** | TBD | | | |
| **TP Load** | | | | |

| Water Year (in $yr^{-1}$ or lb $ac^{-1}$ $yr^{-1}$) | Surface Runoff Season (in $ssn^{-1}$) | FSP Load Season (lb $ac^{-1}$ $ssn^{-1}$) | TN Load Season (lb $ac^{-1}$ $ssn^{-1}$) | TP Load Season (lb $ac^{-1}$ $ssn^{-1}$) |
|---|---|---|---|---|
| < 20% of average | < 20% of average | < 20% of average | < 20% of average | < 20% of average |
| +/- 20% of average | +/- 20% of average | +/- 20% of average | +/- 20% of average | +/- 20% of average |
| > 20% of average | > 20% of average | > 20% of average | > 20% of average | > 20% of average |




*EXAMPLE: WY surface runoff was within 20% of the defined average. Fall/Winter runoff was over 20% of the seasonal average, Spring Snowmelt runoff was within 20% of the average and Summer runoff was below 20% of the average.*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Based on the estimated unit surface runoff and unit pollutant load for the urban catchment, categorical determinations were defined to simplify spatial comparisons for each year of record (see Figures 7 and 8). Three categories were identified to show if the measured surface runoff and pollutant loads were above, below, or within 20% of the basin-wide average. This categorization allows for quick visual comparison between catchments across the Bain. The average values were informed by existing urban catchment monitoring data (2NDNATURE and NHC 2014; LRWQCB and NDEP 2010), available PLRM baseline modeling results (2NDNATURE and NHC 2011; NHC 2012) and best professional judgment. Once 3 to 5 years of status monitoring is available for urban catchment outfall sites, it is recommended that the average seasonal and annual unit surface runoff and unit pollutant loads be evaluated and revised. In the example dataset shown in Figure 7, the Tahoma and Rubicon catchments have unit surface runoff and pollutant loads that are >20% relative than the Basin average for all seasons and the water year. Tahoe Valley has average or below average unit surface runoff and pollutant loads for the year 2020.

## 5.3 TREND REPORTING FORMATS

The ability to compare seasonal and annual trends in urban catchment discharge volumes and pollutants loads requires several years of consistent monitoring at multiple urban catchment outfalls around the Lake. For each site monitored, the initial trend analysis of the seasonal and annual volumes and pollutant loads is recommended after 3 years of consistent data is available. The first 3 years can be used as the baseline for which to compare all subsequent years, as long as the years represent a range of water year types. Definitive trends will be difficult to discern with confidence until at least 5 years of consistent data exists for a specific site. The reporting, analyses, and data management recommendations provided herein are universal for all status and trends sites and associated data collection techniques, making these recommendations directly applicable to any status and trend sites added to the monitoring network in the future.

The recommended reporting format of an urban catchment outfall monitoring trend analysis is presented in Figure 9. Figure 9 includes general information about the site (A and B), the time series of monthly stormwater runoff and pollutant loading data obtained (C), the results of trend analyses (D and E), and a simple summary statement. The analysis used to quantify the site trends includes an adjustment for natural precipitation variability. The metrics in Figure 9 were selected so that they can be compared between catchments and over time. *Data for all sites, except for Pasadena which is based on PLRM model simulations, were fabricated and do not reflect the reality or expectations.* For the purposes of this research, it is assumed that the continued data collection and data management of the selected urban catchment outfalls will be achieved for decades to come.

*Independent Variable:* Monthly precipitation is the independent variable used to predict urban catchment seasonal and annual runoff volumes and pollutant loads due to the significant influence precipitation has on urban runoff and water quality. Monthly resolution was selected because it allows for reasonable data management over multiple years and but also provides sufficient resolution so that statistically significant trends can be identified with only a few years of monitoring.

*Adjusted Variable:* Monthly unit surface runoff and unit pollutant mass load is adjusted for monthly precipitation. As stated above, monthly resolution was selected because it allows for reasonable data management over multiple years and but also provides sufficient resolution so that statistically significant trends may be identified with only a few years of monitoring.

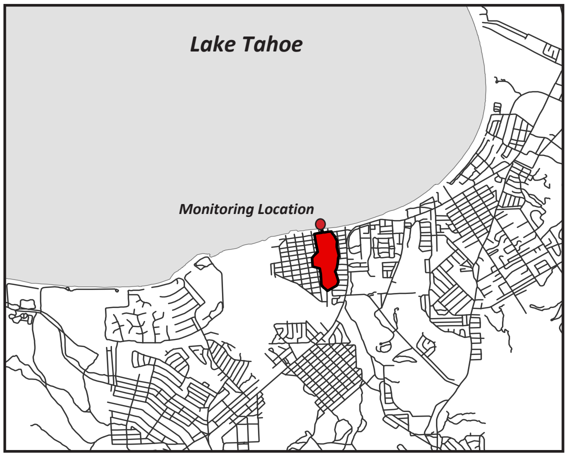
*Regression Equation:* Best-fit equation that is used to describe the relationship between monthly precipitation and unit surface runoff, *U-Q*, or unit pollutant mass load, *U-P*. The equations are site specific

# Urban Catchment Outfall Monitoring Trends

Monitoring interval: 1984-2020

Pasadena Catchment, City of South Lake Tahoe

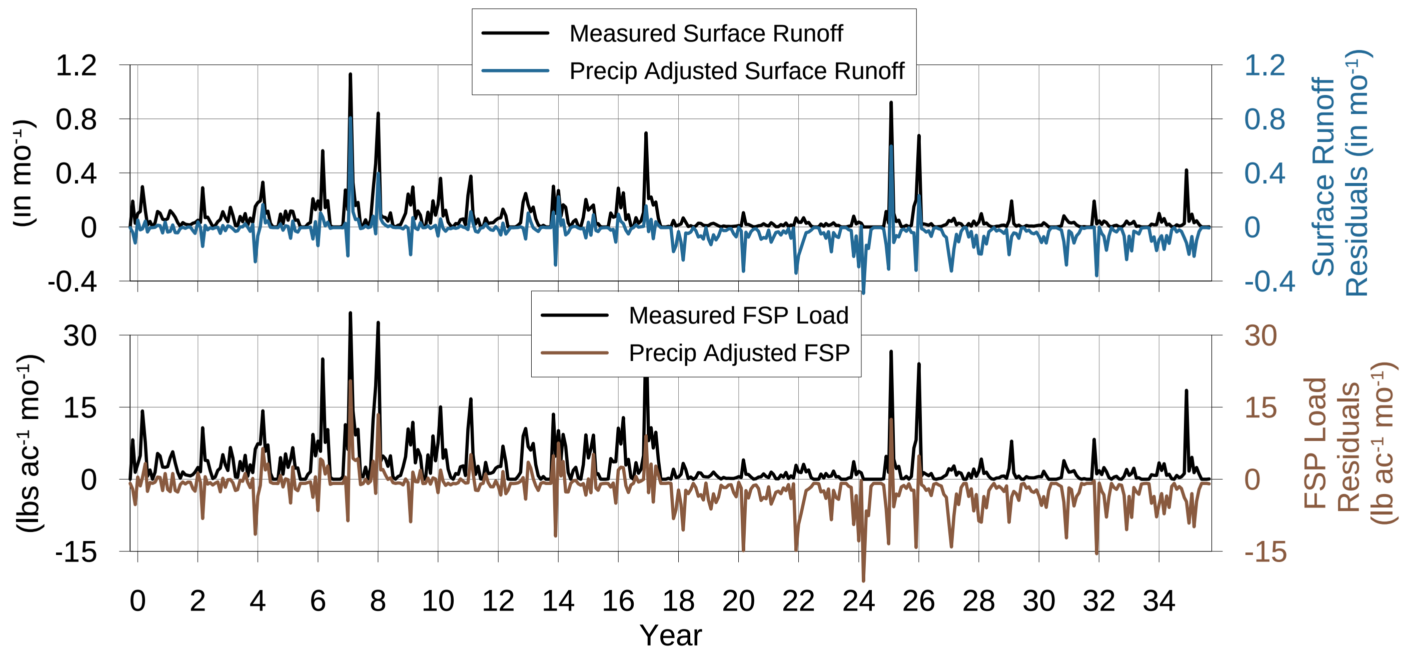
A. Site Location Map



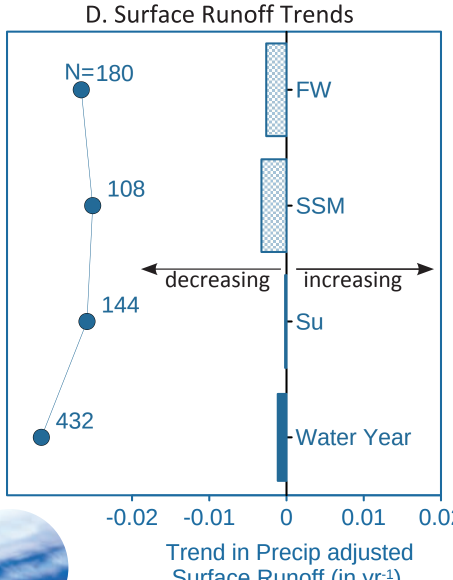

B. Precipitation and flow adjusted variables and equations for Q and FSP loads

| Adjusted Variable (units) | Independent Variable (units) | Regression Equation |
|---|---|---|
| Q (in $mo^{-1}$): FW and Su | Precip (in $mo^{-1}$) | Q = 0.0444*Precip + 0.0049 |
| Q (in $mo^{-1}$): SSM | | Q = 0.0499*Precip + 0.028 |
| FSP (lbs $ac^{-1}$ $mo^{-1}$): FW and Su | | FSP = 1.85*Precip + 0.86 |
| FSP (lbs $ac^{-1}$ $mo^{-1}$): SSM | | FSP = 2.05*Precip + 2.19 |

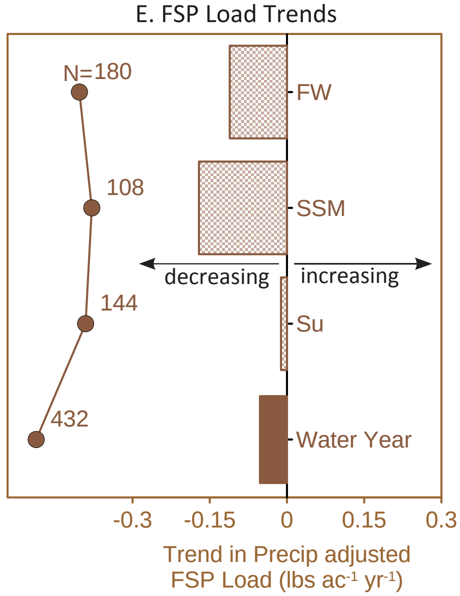
C. Timeseries of Surface Runoff and Pollutant Loads




D. Surface Runoff Trends




E. FSP Load Trends




*All water year and seasonal surface runoff and FSP loads show statistically significant decreasing trends over the 36 years of record. An average decreasing trend in FSP loading of 0.05 lbs $ac^{-1}$ $yr^{-1}$ has been measured at the Pasadena Catchment as a result of cumulative effective water quality improvement actions.*

and should be conducted after the first 3 years of monitoring at each location. An equation for the SSM season is considered separate from FW+Su because runoff during SSM is primarily the result of meltwater and is not a direct response to precipitation on the surface.

*Precipitation Adjusted Unit Surface Runoff*: The unit surface runoff data that is corrected for natural climate variability. The magnitude and direction (positive or negative) of each adjusted value represents the relative deviation of the measured data from the best-fit equation.

*Precipitation Adjusted Unit Pollutant Mass Load*: The unit pollutant mass that is corrected for natural climate variability. Positive residuals indicate that the pollutant mass loads for the month were above the expected value based on the amount of monthly precipitation. Negative residuals suggest loading below the expected load for the given monthly precipitation.

The time series graphic in Figure 9C displays the monthly measured and the precipitation adjusted unit surface runoff and unit pollutant load for the available record. The trend analysis was conducted on the precipitation adjusted data to investigate whether surface runoff and pollutant loads are decreasing beyond climate variations. The statistical significance of the trends was evaluated at the 90% confidence interval. The magnitude, direction, and confidence of the resultant trends are provided for each season and the water year (Figure 9D and 9E). Figure 10 provides the recommended display of the trend results for the urban catchments network for the year of interest as a means to spatially summarize and compare the results across sites. A key to interpret the trend analysis is provided in Figure 11.

As illustrated in the example dataset provided in Figure 10, there may be a range for the magnitude, direction, and statistical significance in the interannual trends Basin wide. Overall, the intention is that % runoff, unit surface runoff, and unit pollutant loads are decreasing (i.e., have negative trends) over time. Using the example dataset for Pasadena, the precipitation adjusted unit surface runoff results indicate that trends for each season and the water year are statistically significant and decreasing. The unit surface runoff water year trend for the PLRM simulated data is 0.001 in $yr^{-1}$ or extrapolated to a net decrease of 0.25 acre-ft of surface runoff over the hypothetical 36-year dataset. Similar decreasing trends are shown for unit pollutant mass loads and the FSP mass load decreasing trend results extrapolate to a net reduction of 450 lbs during the SSM season. These types of calculations can be conducted for each catchment over the time interval of interest.

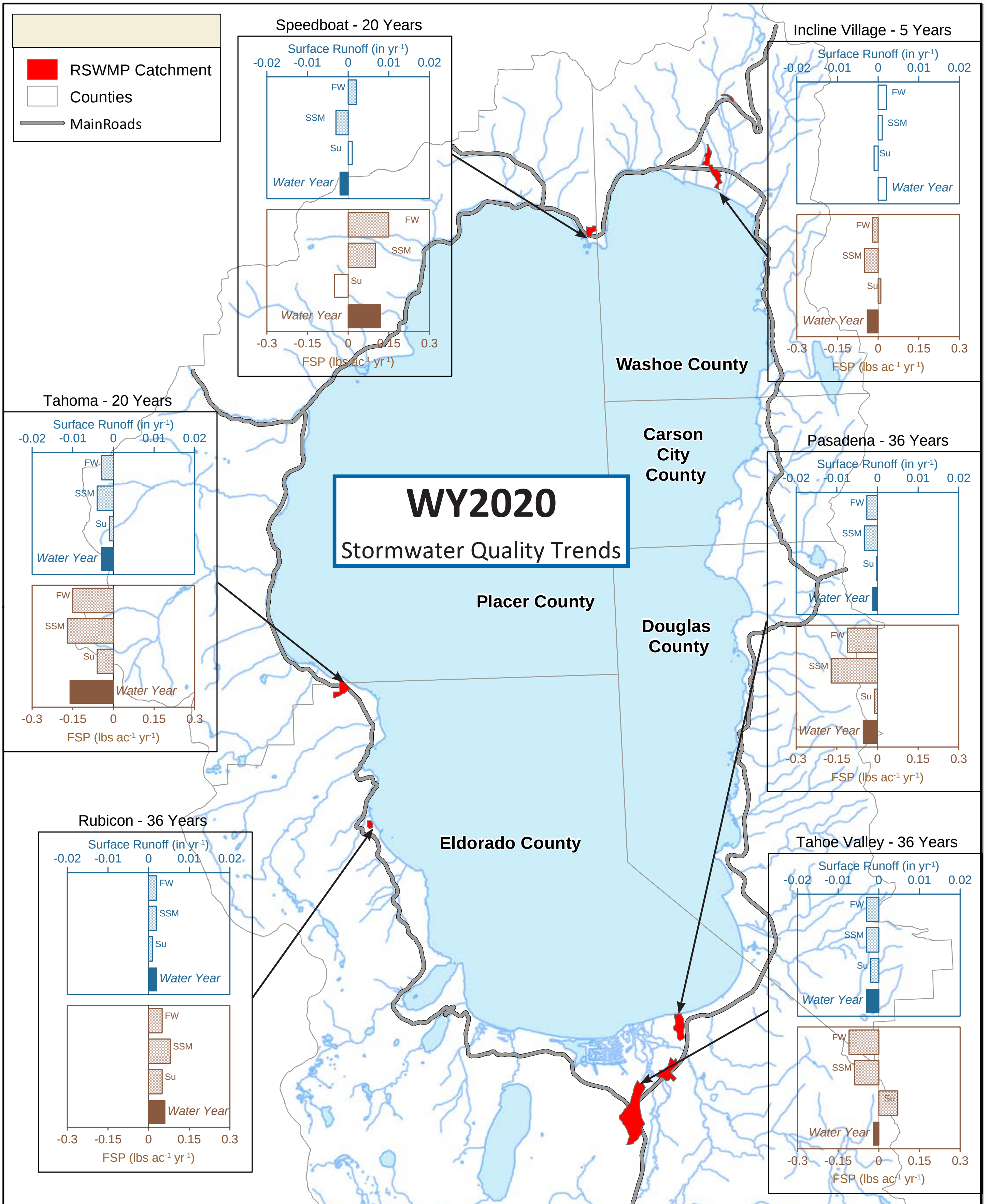



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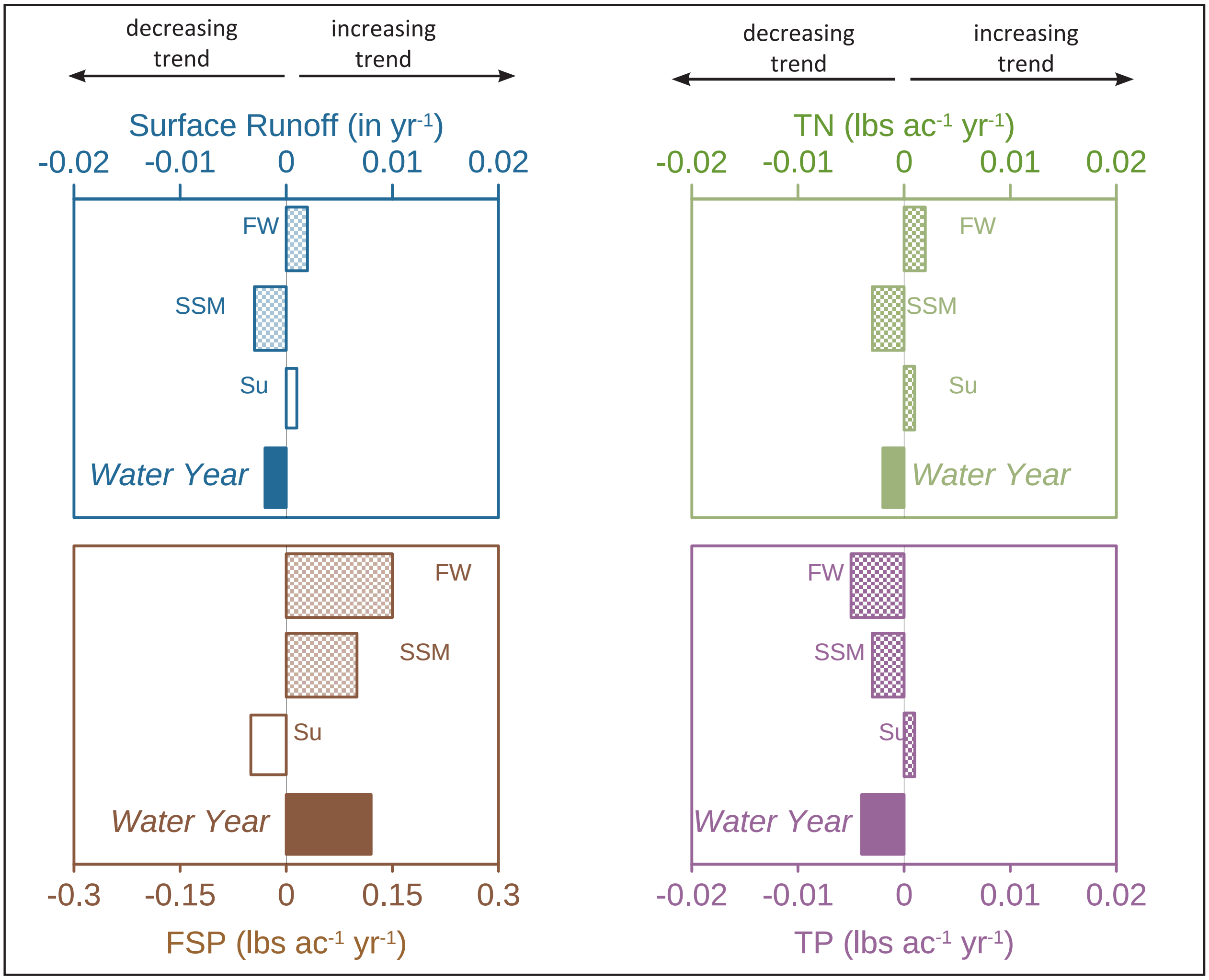
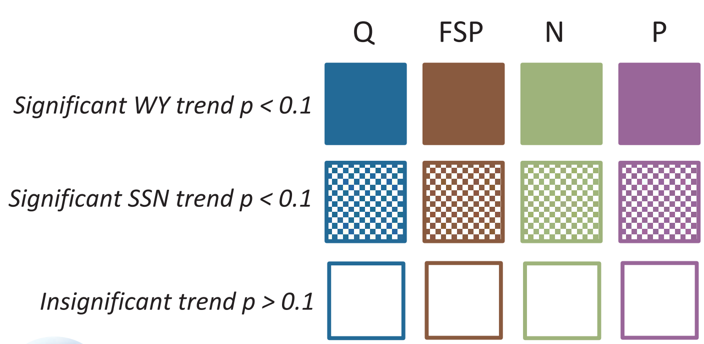
FIGURE 10. **WY2020**
Urban surface runoff and FSP load trends for status and trend monitoring stations. Runoff (blue) reported as inches $ssn^{-1}$ or $yr^{-1}$ and FSP (brown) reported as lbs $ac^{-1}$ $ssn^{-1}$ or $yr^{-1}$.

# Key for urban catchment outfall pollutant trend maps

*GRAPHIC GUIDE: Seasonal and interannual trends in unit runoff and pollutant loads are directly comparable across sites and over time. The values for surface runoff are given in inches year$^{-1}$ (in yr$^{-1}$) for surface runoff and pounds per acre per year for pollutant loads (lbs ac$^{-1}$ yr$^{-1}$). The magnitude, direction, and statistical significance of the trend is presented for the water year and three seasons by parameter. Available data was used to reasonably estimate the values for each parameter.*




*EXAMPLE (upper left): Surface water runoff displays a statiscally significant decreasing trend of 0.002 inches of runoff per year over the duration of the dataset. The summer surface runoff data suggests a negligible and insignificant increasing trend.*


DESIGNED BY
2NDNATURE LLC
TEL: 831.426.9119 FAX: 831.426.7092
www.2ndnaturellc.com

# 6 OBJ 1: STATUS AND TRENDS MONITORING AND DATA MANAGEMENT CONSIDERATIONS

This section is devoted to providing considerations for monitoring and data management so that Objective 1 can be addressed in an efficient and consistent manner. There are two primary sources of variability introduced to stormwater data that can confound our ability to achieve Objective 1. One source is precipitation variability, which is explicitely addressed in the trend data analysis approach. The second source is sampling variability or error. There are a variety of monitoring considerations that can be incorporated into the data collection process that will improve the chances of detecting statistically significant trends. The sampling considerations are prioritized to improve the chances that basin wide trends can be detected with the minimal number of years. Thoughtful and consistent data management protocols is also an important component to ensure that collected data is reliably and efficiently managed.

## 6.1 MONITORING CONSIDERATIONS

An array of data collection techniques, instruments, analytical protocols and sampling methods are available to obtain the data necessary to report urban catchment outfall data and quantify seasonal and annual stormwater volumes and pollutant loads. All of the sampling options for both discharge and pollutant concentrations vary in cost, required technical expertise, complexity and potential temporal sampling resolution. The purpose of this research is not to review, recommend or define the data collection methods, but rather provide clear guidance and recommendations on the data management formats and step wise procedures to translate the obtained data into the recommended standardized reporting formats. The definition and acceptance of such a standardized process could provide great focus and consistency for urban outfall catchment monitoring performed into the future. The recommended formats described herein have the potential to improve communication and ensure that the data obtained will address the critical questions of stormwater volumes, status, and trends in the Tahoe Basin over many years to come.

The primary site specific data required to achieve the recommended status and trend reporting formats (regardless of sampling methods) are: $Q_d$, discharge in cubic feet per day (cf $d^{-1}$), $[P]_d$, daily pollutant concentration in mg per liter (mg $L^{-1}$), and $P_d$, pollutant mass load in g per day (g $d^{-1}$). With proper unit conversions, the relationship between these three variables is:

$$Q_d * [P]_d = P_d$$

Whatever the discharge and pollutant concentration monitoring techniques selected, it is strongly recommended that a complete water year record of discharge and pollutant concentration time series is generated. These annual time series datasets are then managed in a customized database and are combined with other catchment metadata or regional precipitation data to generate all of the metrics, graphics and results as presented in the site and regional summaries (see Figures 6-11).

There are five critical sampling considerations at a specific urban catchment outfall site, discussed below.

**Maximize sampling precision**: The primary purpose of evaluating stormwater volume and pollutant loading trends in urban stormwater runoff is to determine the collective effectiveness of water quality improvement actions implemented on urban lands in the Tahoe Basin. All measurement techniques of stormwater discharge and pollutant concentrations will include some level of inaccuracy, imprecision, periods of data gaps, and other challenges to obtain and report at accurate seasonal and annual volumes and pollutant loads at the specific site of interest. As the desire for accurate, continuous records of volumes and loads increases, the cost per site can also increase exponentially. It is recommended that cost effective techniques are used to obtain site specific hydrology and pollutant concentrations, which allow for the consistent and precise determination of daily *Q* and *[P]* as accurately as possible.

Given the objective that the data should ultimately be used to evaluate the effectiveness of management actions over time, the research team argues that precision and consistency of the data obtained is more important than accuracy. The sampling error, or deviation from the true value, will never be known due to the costs and sampling challenges associated with stormwater monitoring, and funding limitations. It is critical that the data collection methods minimize sampling noise and are sampled at sufficient temporal frequencies, so that statistically significant trends as a result of management actions can be quantified. The directional relationship between sample size and each these variables is summarized in Table 3 below:

**Table 3.** Influential parameters on sample size distributions

| Parameter | Parameter description | Relative change in parameter | Relative change in number of samples | Description of parameter and number of samples relationship |
|---|---|---|---|---|
| Error | Magnitude of deviation from known value | Increase | Decrease | For a large difference, fewer samples are needed to confirm large difference |
| Noise | Standard deviation | Increase | Increase | For a large standard deviation, more samples are needed to confirm that the distributions are similar |
| Power | Sureness of detection (1-$\beta$) | Increase | Increase | When $\beta$ increases from 0.8 to 0.9 (80% to 90% power), more samples are need because power increased |
| Significance Level | Probability that the null hypothesis is true ($\alpha$) | Increase | Decrease | When $\alpha$ increases from 0.05 to 0.1 (95% to 90% confidence level that the null hypothesis is not true), fewer samples are needed because % confidence level is lower |

By implementing techniques that maximize sampling precision and minimize variability in the data due to sampling error, we directly increase our confidence that any differences in the data obtained over time is due to management actions or hydrologic differences and not variability or error associated with generating the daily Q and [P] values. By implementing consistent data collection and data management techniques across sites, confidence that differences in the seasonal and annual volume and loading values across sites are not the result of sampling error is gained. Similarly, site selection criteria that avoid site characteristics that make precise discharge or pollutant concentration monitoring challenging, such as backwater, unstable cross sections, dilution, vandalism, etc., should be a priority.

When sampling error is minimized, the power to detect a statistically significant trend in water quality is relatively higher with proportionally fewer samples. Alternatively, when the ratio of the error to the standard deviation is smaller, detection power decreases and more samples are required. Decreasing the standard deviation or noise in the data will improve the ability to determine statistically significant trends when fewer years of monitoring data are available. Efforts to keep sampling error low over the short term will likely be more cost-effective over the long term.

**Obtain high resolution hydrology**: Urban stormwater runoff is highly intermittent with long durations of no discharge. Without a discharge sampling program that can adequately capture this variability, extrapolation of intermittent measurements of discharge to quantify seasonal and annual volumes will include a significant amount of sampling error. Per the recommendations above, discharge data obtained on 15 min intervals are recommended to capture most runoff events, without significantly increasing instrument maintenance or data management costs with too frequent measurements. Given the episodic nature of discharge, sub-hourly hydrology will minimize error and at the same time increase the power and confidence level of the dataset as a result of increased sample size.

**Daily pollutant concentration estimates**: High resolution pollutant concentration monitoring can be cost prohibitive. At the time of this research, a strong and consistent empirical relationship has been documented between turbidity and fine sediment particle (FSP < 16um) concentrations using hundreds of paired stormwater samples (2NDNATURE and DRI 2014). No such low cost, high resolution sampling options or proxies for other priority pollutants (N and P species) have been identified at this time. When discrete event sample collection is used to obtain periodic measures of the pollutant concentrations in stormwater, it is strongly recommended that a concise, repeatable and standardized method be defined such that the [P] obtained from the sampled events can be applied to the remaining runoff discharges that were not directly sampled. Standardized approaches that apply the [P] obtained for each sample or sampled event, to the other unsampled events using the high resolution hydrology datasets will best preserve the quality and frequency of sample collection technique employed. This methodology will also increase the power and confidence level of the dataset, while minimizing sampling variability over time and across sites.

**Consistent long term monitoring**: We anticipate that a minimum of 5 years of data collected over a range of water year types is necessary to demonstrate a statistically significant trend in catchment volumes and pollutant loads. Additionally, a sustained commitment to reducing pollutant loads is required to meet both the Clarity Challenge (approximately 24 meters of clarity within 15-20 years) and the TMDL numeric target (29.7 meters of clarity in 65 years). To demonstrate the implementation of effective management actions in support of the TMDL, consistent monitoring at the same locations over many years is required and is therefore a key principle of RSWMP development.

**Rigorous and well documented field QA/QC procedures**: The reliance on automated field instrumentation is necessary to obtain high resolution datasets. Such instruments require continued calibration and maintenance, and data loss or calibration drift are a common challenge. Instrument drift can increase the noise in the dataset as well as jeopardize efforts to minimize sampling error. The value of field QA/QC procedures to continually obtain manual measurements, the value of calibrating instruments across the range of Q and [P] conditions at a site, and the ability to fill in data gaps using field procedures cannot be understated.

## 6.2 DATA MANAGEMENT

The recommended data analysis procedures necessary to generate all of the metric values presented in Figures 6 and 9 assume the site specific datasets obtained from urban catchment outfalls and meteorology stations are managed consistently in a customized database format. Regardless of data collection techniques, the recommended data management fields and units for each urban catchment outfall site and meteorology station will allow relatively simple and consistent analyses of these time series datasets. These metrics will be used to summarize both the annual status and interannual trends at each site. It is recommended that any data gaps during data collection are resolved by recreating the missing data using reasonable and consistent approaches such that each site's annual time series is complete (see 2NDNATURE and NHC 2014 for more discussion on data gap correction). These are the recommended data management fields for the Status and Trend objective.

**Table 4a.** Urban catchment outfall site metadata fields

| **Urban Catchment Outfall (UCO)<br>Site Metadata Fields** | | | | | | |
|---|---|---|---|---|---|---|
| UCO Site ID | Jurisdiction ID | WY | Drainage area (ac) | % IMP | % DCIA | WY Initiated |
| | | | | | | |

**Table 4b.** Urban catchment outfall time series data fields

| **Urban Catchment Outfall Time Series Data Fields** | | | | |
|---|---|---|---|---|
| UCO Site ID | Date (mm/dd/yyyy) | Q (cf $d^{-1}$) | $[P]_d$ (mg $L^{-1}$) | $P_d$ (g $d^{-1}$) |
| | | | | |

**Table 4c.** Meteorology station site metadata fields

| **Meteorology Station Site Metadata Fields** | | | | |
|---|---|---|---|---|
| MET Site ID | owner (weblink) | Jurisdiction ID | Elevation (AMSL; ft) | WY Initiated |
| | | | | |

**Table 4d.** Meteorology station data fields

| **Meteorology Station Data Fields** | | | | | |
|---|---|---|---|---|---|
| MET Site ID | Date (mm/dd/yyyy) | $PPT_d$ (in $d^{-1}$) | Mean Daily Air Temp (ºC) | Min Daily Air Temp (ºC) | Max Daily Air Temp (ºC) |
| | | | | | |

The database can be customized to consistently and automatically generate the desired annual metrics collectively used to document the measured stormwater quality status at each site at the completion of each year. The calculations for all metrics are included in the Technical Guidance.

# 7 OBJ 1: STATUS AND TREND TECHNICAL GUIDANCE

The arrival at the recommended metrics, analysis and reporting formats herein was a highly iterative process requiring continued evaluation of the methods to best and efficiently achieve the objective. In this section, we describe the recommended approach and provide the supporting rationale and justification for why the specific approach, formats and analyses were selected. The intended users of this guidance are analysts responsible for translating the annual datasets into the desired reporting formats and graphics. All of the status calculations can be conducted in typical data management software such as MS Excel or automated through custom database queries in MS Access. The appropriate trend data formats can be managed in Excel and imported into a statistical software package to complete the analysis each year. All of the variables, units and descriptions are provided in List of Variables located at the front of this document.

## 7.1 STATUS METRIC CALCULATIONS

A primary goal of the status metrics is providing a standardized set of evaluation criteria that is independent of catchment characteristics and can thus be compared across the Basin and over time. The metrics below represent those selected by the research team to best evaluate the status of an urban catchment each year. Part of this standardized process is "unitizing" the surface runoff and pollutant loads so that comparisons of seasonal and total runoff volumes and pollutant loads are relative to the size of the catchment. Previous research (2NDNATURE and NHC 2014) evaluated if standardizing volumes and loads relative to impervious area or %DCIA (directly connected impervious area) improved comparisons. It was determined that impervious area and %DCIA did not improve comparisons and instead complicated comparisons because impervious area and %DCIA are more difficult to calculate and can change over time as a result of independent land use actions. Thus, standardizing surface runoff and pollutant loads relative to total catchment size is the recommended approach.

For status metrics, seasonal and water year type definitions were created using reasonable recurrence intervals to bracket average precipitations totals and to categorize extreme (very wet and very dry; see Figures 4 and 5) with a less than 10% probability of occurring. The threshold definitions recommended in this analysis were previously used in 2NDNATURE and NHC, 2014. The total amount of precipitation in a season or water year is assumed to be an important factor that influences the relative magnitude of both surface runoff and pollutant loads. Including the season and water year type in the annual status reports provides this climatic context to the data obtained.

*Inches of precipitation over time ($PPT_{mo,\ ssn,\ or\ WY}$):* The monthly, seasonal, and water year precipitation totals are determined for each site. Seasonal and water year precipitation totals are reported in the annual status metrics table and used to determine the season and water year types. Precipitation totals per month are used in the trend analysis to adjust surface runoff and pollutants loads to natural variations.

$$PPT_{mo} = \sum_{First\ day\ of\ month}^{Last\ day\ of\ month} PPT_d$$

$$PPT_{FW} = \sum_{Oct\ 1}^{Feb\ 28} PPT_d$$

$$PPT_{SSM} = \sum_{Mar\ 1}^{May\ 31} PPT_d$$

$$PPT_{Su} = \sum_{Jun\ 1}^{Sept\ 30} PPT_d$$

$$PPT_{WY} = \sum_{Oct\ 1}^{Sept\ 30} PPT_d$$

*Volume of discharge per day ($Q_d$):* The volume of discharge per day is determined by taking the average, including times of no flow ($Q_i$ = 0), of the instantaneous discharge measurements, $Q_i$, over each day and multiplying by the number of seconds in a day.

$$Q_d = \overline{Q_i} \times 86400$$

*Conversion of turbidity ($TB_i$) to FSP concentration ($[FSP]_i$):* The conversion of instantaneous turbidity to [FSP] should be conducted using equation 3.5 in 2NDNATURE and DRI, 2014. The equation provided below summarizes the empirical relation between turbidity and [FSP] (Figure 2.3C, 2NDNATURE and DRI 2014). It is possible to calculate a more accurate estimate of [FSP] based on region and month of sample collection, but for this Basin wide analysis, the extra effort and complexity required to obtain the next level of accuracy may not outweigh the simplicity of using one equation that can be universally applied to all sites and seasons.

$$[FSP]_i = 0.34 * TB_i\hat{}1.07$$

*Pollutant mass load per day ($P_d$):* The pollutant mass load per day, $P_d$, is determined by converting the instantaneous pollutant concentration, $[P]_i$, to a pollutant loading rate, $P_i$, using the instantaneous discharge, $Q_i$. The daily rate is calculated by taking the average, including zeros, of the loading rate over each day and multiplying by the number of seconds in a day.

$$P_i = Q_i \times [P]_i \times 0.0283$$

$$P_d = \overline{P_i} \times 86400$$

*Pollutant concentration per day ($[P]_d$):* The daily pollutant concentration, $[P]_d$, is determined by dividing the daily pollutant loading rate, $P_d$, by the daily discharge, $Q_d$, with appropriate unit conversions between grams and milligrams and liters and cubic feet.

$$[P]_d = P_d \div Q_d \times 35.31$$

*Volume of discharge per season or water year ($Q_{ssn\ or\ WY}$):* The total seasonal and annual volumes are reported for each site, a specific reporting requirement of the MS4 Phase II permit. The volumes are determined by summing the daily volumes for each season with appropriate unit conversions from cubic feet to acre-feet.

$$Q_{FW} = \sum_{Oct\ 1}^{Feb\ 28} Q_d \div 43560$$

$$Q_{SSM} = \sum_{Mar\ 1}^{May\ 31} Q_d \div 43560$$

$$Q_{Su} = \sum_{Jun\ 1}^{Sept\ 30} Q_d \div 43560$$

$$Q_{WY} = \sum_{Oct\ 1}^{Sept\ 30} Q_d \div 43560$$

*Pollutant mass load per season or water year ($P_{ssn\ or\ WY}$):* The total seasonal and annual pollutant loads are reported for each site, a specific reporting requirement of the MS4 Phase II permit. The total loads are determined by summing the daily loads for each season and converting from grams to metric tons.

$$P_{FW} = \sum_{Oct\ 1}^{Feb\ 28} P_d \div 10^6$$

$$P_{SSM} = \sum_{Mar\ 1}^{May\ 31} P_d \div 10^6$$

$$P_{Su} = \sum_{Jun\ 1}^{Sept\ 30} P_d \div 10^6$$

$$P_{WY} = \sum_{Oct\ 1}^{Sept\ 30} P_d \div 10^6$$

*% Runoff*: The % runoff is expressed as the fraction of rainfall that is exported from the catchment as stormwater runoff. It is determined by dividing the seasonal or water year volume of discharge measured at the catchment outfall, *Q*, by the product of the seasonal or water year precipitation (in) and the catchment area, *A*, with proper unit conversions. Because this metric is independent of catchment size, it can be compared between catchments across the Basin and over time.

$$\%\ Runoff = 100 \times (Q_{ssn\ or\ WY} \times 12) \div (PPT_{ssn\ or\ WY} \times A)$$

*Unit inches of surface runoff over time (U-Q):* The unit inches of surface runoff over time is a metric that provides a way to compare surface runoff volumes between catchments and over time. The unit surface runoff is the volume of discharge over time, *Q*, divided by the size of the catchment, *A*, with proper unit conversions. Because this metric is independent of catchment size, it can be compared between catchments across the Basin and over time.

$$U\text{-}Q_{mo} = Q_{mo} \div A \times 12$$

$$U\text{-}Q_{ssn} = Q_{ssn} \div A \times 12$$

$$U\text{-}Q_{WY} = Q_{WY} \div A \times 12$$

*Pollutant mass load per acre over time (U-P)*: The mass of the pollutant loads over time provides a way to compare pollutants loads across catchments for the same seasons and water years. It is determined by the total pollutant mass load, *P*, divided by the size of the catchment, *A*, with proper unit conversions to pounds per acre over time.

$$U\text{-}P_{mo} = P_{mo} \div A \times 2204$$

$$U\text{-}P_{ssn} = P_{ssn} \div A \times 2204$$

$$U\text{-}P_{WY} = P_{WY} \div A \times 2204$$

## 7.2 TREND CALCULATIONS

Trend analyses are conducted to directly address the question: *Are surface runoff and pollutant loads to the Lake decreasing over time as a result of effective management actions*? The recommendations below were developed to provide a repeatable format by which urban catchment outfall data can be managed to feasibly evaluate this question over time. The approach was designed to achieve the following: (a) provide a feasible and repeatable process that maximizes the temporal resolution of datasets obtained; (b) minimize user time and complexity associated with data management and data analysis for a user that is likely not a statistician; (c) allow reliable comparisons of trends across urban catchments of different sizes and attributes; and (d) can be compiled into repeatable data outputs and reporting formats that can be easily interpreted by natural resource managers.

The trend analysis can be completed in three steps and each step is elaborated on below:

1. Plot monthly timeseries

2a. Adjust measurement data to natural precipitation variability using best fit equations

2b. Adjust measurement data to natural precipitation variability using LOWESS regression

3. Conduct trend analysis

### 7.2.1 PLOT MONTHLY TIME SERIES

Determine the monthly precipitation, unit surface runoff, and unit pollutant loads and plot the timeseries for each metric (see Figure 9C). It is recommended that these metrics have been stored in the database.

### 7.2.2 ADJUST MEASUREMENT DATA

Urban catchment outfall runoff and pollutant loading data is adjusted for natural climatic variability using a reliable and representative precipitation monitoring dataset for each urban catchment outfall included in the network. A variety of met stations exist in the Tahoe Basin that monitor and report daily precipitation, or precipitation can be monitored directly by the managing agency. Regardless of the data source, surface runoff and pollutant loads are adjusted on a monthly basis using the total amount of precipitation that fell in the corresponding month to complete the trend analyses. Effective analyses to correct for the influence of precipitation are critical to increase our confidence that a decreasing trend in urban runoff volumes and pollutant loads is a result of effective actions, not confounded by climatic variations. Precipitation data is also used to calculate the seasonal and annual % runoff from the catchment, a metric value that is expected to decrease with effective management actions of reducing stormwater volumes.

Both stormwater volumes and pollutant loading are sensitive to the amount of monthly precipitation, with wetter months typically generating more runoff. In addition, land management practices that result in variations of anthropogenic pollutant source applications can increase stormwater pollutant loads, such as road abrasive applications, which will also vary in response to total winter precipitation totals. The rationale for determining trends on seasonal and water year timescales is based on the assumption that trend evaluations are potentially more powerful by grouping data that are seasonally similar. The 3-5 month time interval (see Table 2) is thought to be long enough to smooth pollutant fate and transport variations on daily or weekly time steps, yet short enough to reasonably adjust for data gaps or other sampling issues that could introduce error into the results. Should instrumentation or sampling issues result in data loss or other QA/QC issues, the use of seasons may minimize the loss of an entire WY of data and still allow trend analyses using the remaining 2 seasons for that year.

#### Best-fit equations versus LOWESS regression

The trend analysis is conducted on the unit runoff, *U-Q,* and pollutant loads, *U-P*, to provide meaningful and comparable outputs across sites and over time. Two types of regressions were considered for the process of removing the influence of precipitation on unit surface runoff and pollutant loads: (a) Best-fit equations and (b) LOWESS regression. Best-fit linear equations are the simplest form for explaining a relationship between two variables and should be used whenever possible. If the relationship between precipitation and the parameter of interest has a greater $r^2$ value when an exponential or logarithmic equation is used rather than a linear equation, then the equation with the greatest $r^2$ value should be used. LOWESS regression should be applied when a linear, exponential, or logarithmic function does not describe the data well, such as when $r^2$ values are less than 0.5. LOWESS regression cannot be completed in Excel and for this study it was completed in Minitab software. A more detailed description of the LOWESS function is described in Appendix A.

## Best-fit equations

When using best-fit equations, unit surface runoff and pollutant loads are adjusted for natural precipitation variability in three steps:

a. determine a best-fit equation between monthly precipitation and the parameter of interest,
b. calculate the predicted value using the equation of the best-fit relationship,
c. calculate a residual value for each predicted value.

To determine the best-fit equation between monthly precipitation and the parameter of interest, use a scatterplot to display the data and select the trendline (e.g., linear, exponential, logarithmic) that best fits the data (Figure 12). Display the equation of the regression and the $r^2$ value. This step can be completed in Excel or other graphing software. Linear best-fit equations should be prioritized for simplicity of calculation. For linear equations, follow this format where *m* is the slope and *b* is the y-intercept:

$$\text{FW and Su: } predU\text{-}Q_{mo} = m * PPT_{mo} + b$$

$$\text{SSM: } predU\text{-}Q_{mo} = m * PPT_{mo} + b$$

$$\text{FW and Su: } predU\text{-}P_{mo} = m * PPT_{mo} + b$$

$$\text{SSM: } predU\text{-}P_{mo} = m * PPT_{mo} + b$$

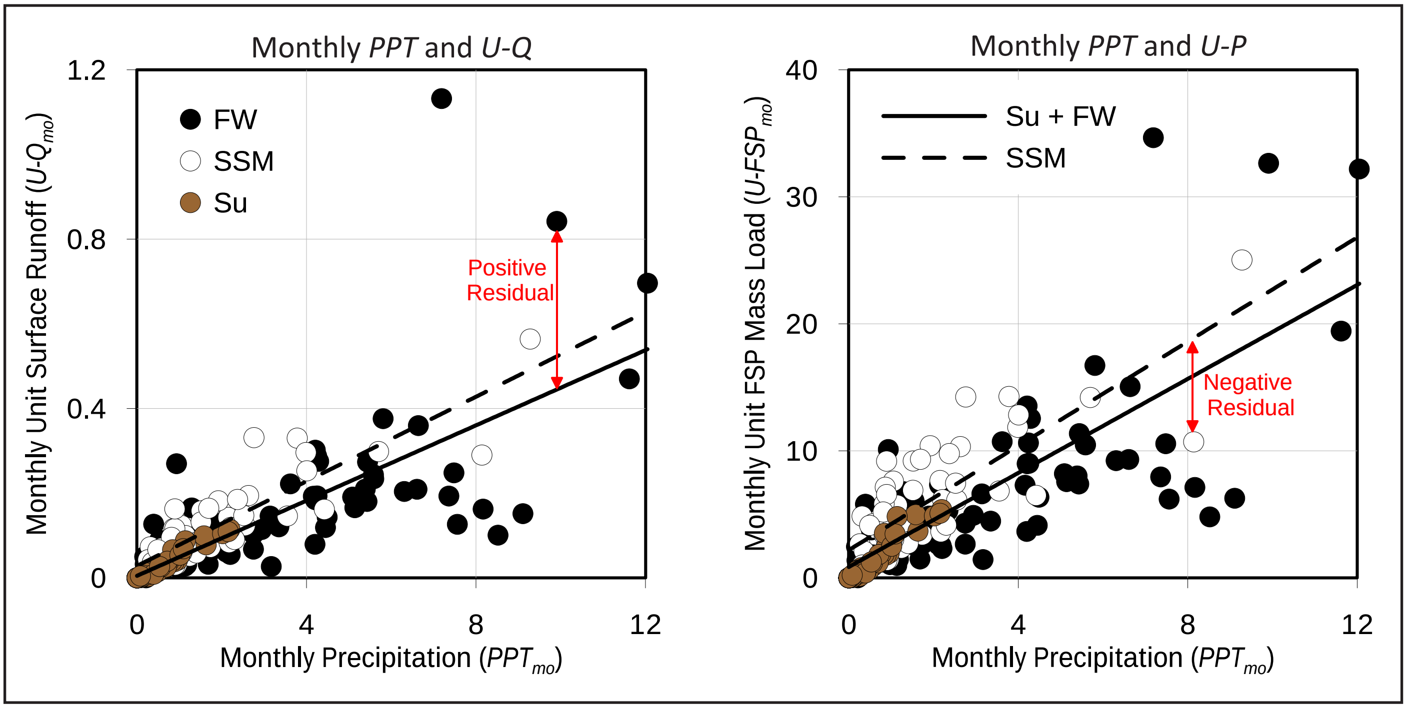
Next, determine the difference between the predicted and the measured data. This difference is the precipitation-adjusted unit surface runoff or unit pollutant load. The following equation describes how the residuals are calculated:

$$residU\text{-}Q_{mo} = U\text{-}Q_{mo} - predU\text{-}Q_{mo}$$

$$residU\text{-}P_{mo} = U\text{-}P_{mo} - predU\text{-}P_{mo}$$

# Step 2 of Trend Analysis: "Calculate the Residuals"
# PLRM Data and Linear Regression

## A. Establish best fit line




## B. Use equation of lines to determine predicted value

$$predU\text{-}Q_{mo} = m * PPT_{mo} + b$$

| Predicted Variable | Independent Variable | Season | Slope (m) | Intercept (b) | $r^2$ |
|---|---|---|---|---|---|
| $U\text{-}Q_{mo}$ | $PPT_{mo}$ | FW+Su | 0.0444 | 0.0049 | 0.59 |
| | | SSM | 0.0499 | 0.028 | 0.76 |

$$predU\text{-}P_{mo} = m * PPT_{mo} + b$$

| Predicted Variable | Independent Variable | Season | Slope (m) | Intercept (b) | $r^2$ |
|---|---|---|---|---|---|
| $U\text{-}P_{mo}$ | $PPT_{mo}$ | FW+Su | 1.85 | 0.86 | 0.64 |
| | | SSM | 2.05 | 2.19 | 0.64 |

*Best-fit lines and equations can be determined using typical data management software such as Excel and can also be computing using plotting software such as Grapher.*

*Predicted values are calculated using the measured monthly precipitation.*

## C. Calculate the residuals

$$residU\text{-}Q_{mo} = predU\text{-}Q_{mo} - U\text{-}Q_{mo}$$

$$residU\text{-}P_{mo} = predU\text{-}P_{mo} - U\text{-}P_{mo}$$

*To adjust the data for precipitation variability subtract the measured value from the predicted value.*

The predicted values and the associated residuals are stored as a timeseries in the formats recommended in Table 5. The predicted values and the associated residuals should be stored in the database. The residuals are used in the trend analysis.

**Table 5.** Precipitation adjustment of measured data

| **Trend Analysis – Precipitation adjustment on measured data** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Date (mm/yyyy) | $PPT_{mo}$ | $U\text{-}Q_{mo}$ | $U\text{-}P_{mo}$ | $predU\text{-}Q_{mo}$ | $predU\text{-}P_{mo}$ | $residU\text{-}Q_{mo}$ | $residU\text{-}P_{mo}$ |
| | | | | | | | |

## LOWESS regression

If the $r^2$ value is less than 0.5 for linear, exponential and logarithmic relationships, then use LOWESS regression. LOWESS regression is unique in that it does not provide an equation. Instead, when conducted in recommended Minitab software, the method automatically provides a predicted and residual value for each $PPT_{mo}$ and $U\text{-}Q_{mo}$ or $U\text{-}P_{mo}$ pair (Figure 13). Minitab software is licensed software that can be purchased and downloaded here:

http://www.minitab.com/en-us/products/minitab/features/?WT.srch=1&WT.mc_id=SE003691

Macros included in the Practical Stats package for Minitab should be also downloaded online or obtained from 2NDNATURE in order to complete the analysis. Open a new Minitab project and in a blank worksheet, store the data shown in Table 6. Cells cannot be left blank. If there is an unmatched pair of data (e.g., a flow measurement without a pollutant load), then a * should be entered into a blank cell. The unmatched pair will not be included in the analysis.

**Table 6.** Recommended data fields for determining LOWESS fits and residuals in Minitab

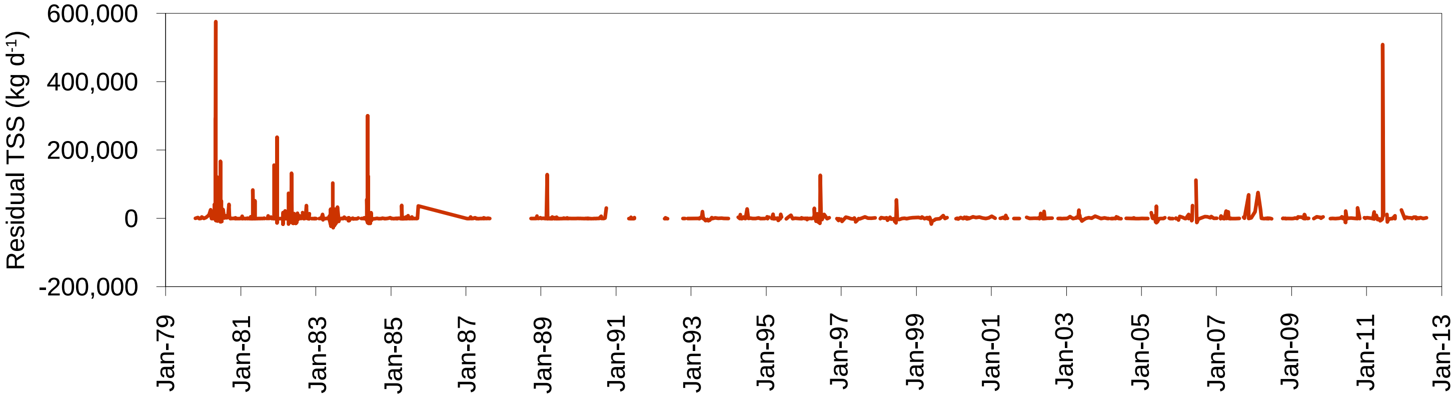
| C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
|---|---|---|---|---|---|---|---|
| Date (mm/yyyy) | Monthly Precip (in $mo^{-1}$) | Monthly Data *U-Q* (in $mo^{-1}$) | Monthly Data *U-P* (lb $ac^{-1}$ $mo^{-1}$) | *LOWFIT U-Q* | *LOWRES U-Q* | *LOWFIT U-P* | *LOWRES U-P* |
| User input | User input | User input | User input | *blank* | *blank* | *blank* | *blank* |

To complete LOWESS regression, the command line will be used to execute the function (Figure 14). To activate the command line prompt in Minitab, under Editor, click on Enable Commands. As an example, to compute and store the LOWESS fit and residuals for *U-Q* follow these steps:

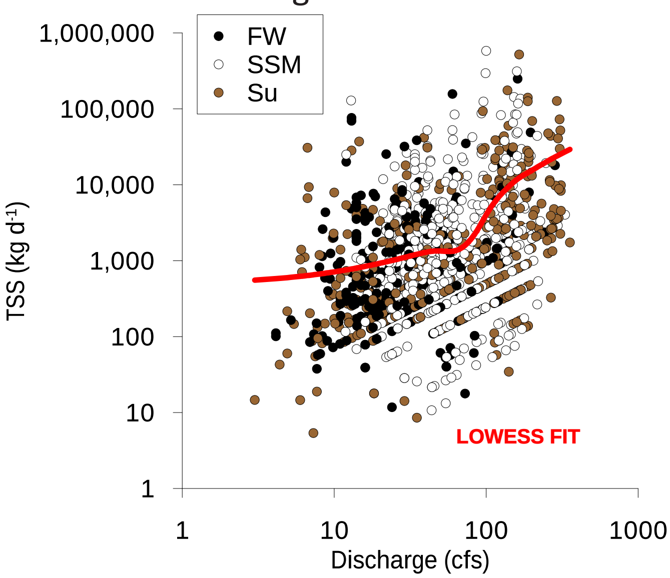
- Corresponding to the table headers in Table 6, type the following at a command prompt:
  - %lowres c3 c4 c5 c6
  - While c3 and c4 are populated by the user, the lowres function will automatically populate c5 and c6 with the LOWESS fit and the LOWESS residuals.
- Copy the LOWFIT and LOWRES data from Minitab and paste into Excel. To improve the look of the graph, use the copied Excel data and plot in Grapher (see Appendix B).
- Store the predicted values and the associated residuals in the database as formatted in Table 5.

# Trend Analysis: “Calculate the Residuals”
# LTIMP Data and LOWESS Regression

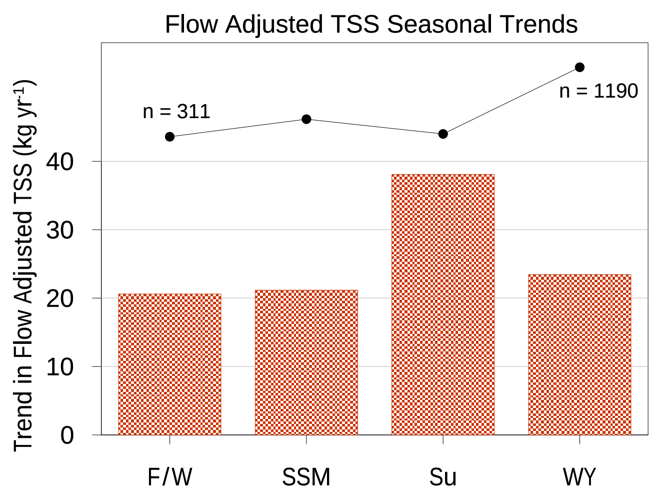
A. Plot of the residual timeseres




B. Discharge vs. TSS and LOWESS Fit




C. Interannual Trends



A screenshot that captures the data organization and command line execution to conduct LOWESS regression on the LTIMP data is provided in Figure 14.

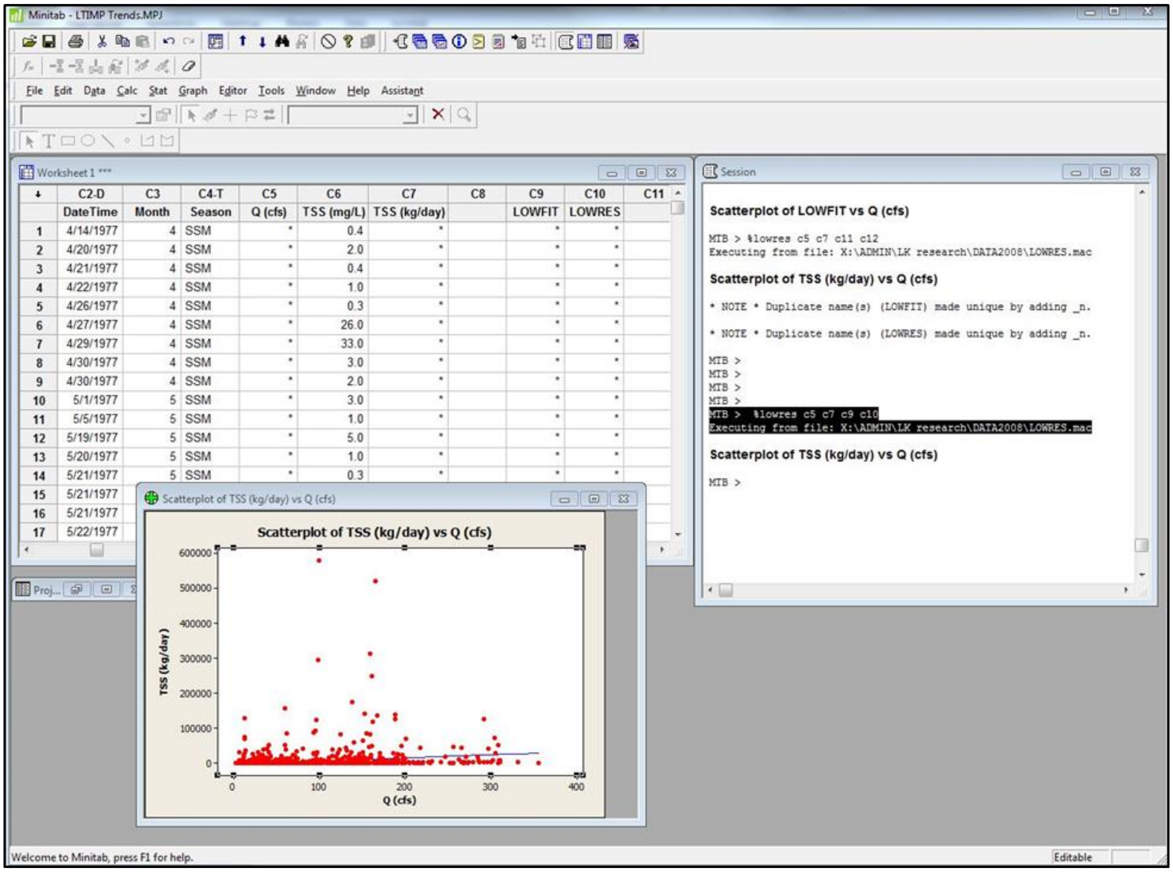


*Figure 14. Screenshot for data organization, command line execution, and automatically generated graphic for LOWESS regression in Minitab 16.*

## 7.2.3 CONDUCT TREND ANALYSIS

The technique used to conduct the trend analysis on the monthly precipitation adjusted data is a seasonal Mann-Kendall analysis. A more detailed description of the technique and the manner in which it corrects for any remaining seasonality in the data should it exist, is described in Appendix A. The results of seasonal Mann-Kendall analysis includes an estimate of the interannual trend (e.g., inches of surface runoff per year) for each season or year and a confidence level of the slope.

Interannual trends by season are conducted in the recommended software, Minitab, by copying the information parts of the data stored in Table 6 and pasting in a Minitab worksheet. The step by step instructions to complete the season Mann-Kendall test in Minitab are as follows:

- Make a table of the results as shown in Table 7:

**Table 7.** Recommended data inputs for seasonal Mann-Kendall trend analysis in Minitab

| C1 | C2 | C3 | C4 |
|---|---|---|---|
| Date (dd/mm/yyyy) | Monthly Data *residU-Q* (in $mo^{-1}$) | Monthly Data *residU-P* (lb $ac^{-1}$ $mo^{-1}$) | Season (FW, SSM or Su) |
| User Input | User Input | User Input | User Input |

- All rows must be completely filled (missing values are denoted by *)
- Use the SEAKEN macro, and unit surface runoff as an example, type the following at a command prompt:
  - %seaken c1 c2 c4 (these correspond to the table headers shown in Table 7)
  - The output will include an estimate of the slope and significance for the individual seasons and the overall value. This output will be displayed in the Session Window as shown in Table 8:

**Table 8.** Data outputs for seasonal Mann-Kendall results in Minitab

| Row | SEA2 | N_SEA | S_TAU | TAU_A | Z_S | P_VALUE | INTERCEPT | SLOPE |
|---|---|---|---|---|---|---|---|---|
| 1 | FW | *output* | *output* | *output* | *output* | *output* | *output* | *output* |
| 2 | SSM | *output* | *output* | *output* | *output* | *output* | *output* | *output* |
| 3 | Su | *output* | *output* | *output* | *output* | *output* | *output* | *output* |
| | | N_ALL | S_ALL | TAU_ALL | Z_ALL | PVAL_ALL | SEAINTER | SLOPE |
| 1 | Overall | *output* | *output* | *output* | *output* | *output* | *output* | *output* |

  - A screenshot that shows the data organization and the command line execution for the seasonal Mann Kendall trend analysis is provided in Figure 15.
- Copy the "Data Display" data as shown in Table 8 from the session window and paste in Excel.
  - The most important columns are N_SEA (number of data points), P_VALUE (statistical significance, <0.01 is greater than 90% significant, and the SLOPE (trend of the data per day).
- The units of the slope are provided per day. To determine the annual rate, multiply the slope by 365 to obtain the trends per year.
- Using the data copied from Minitab to Excel, create a horizontal bar chart in Grapher (see Appendix B) to display the seasonal and interannual Mann-Kendall trends.

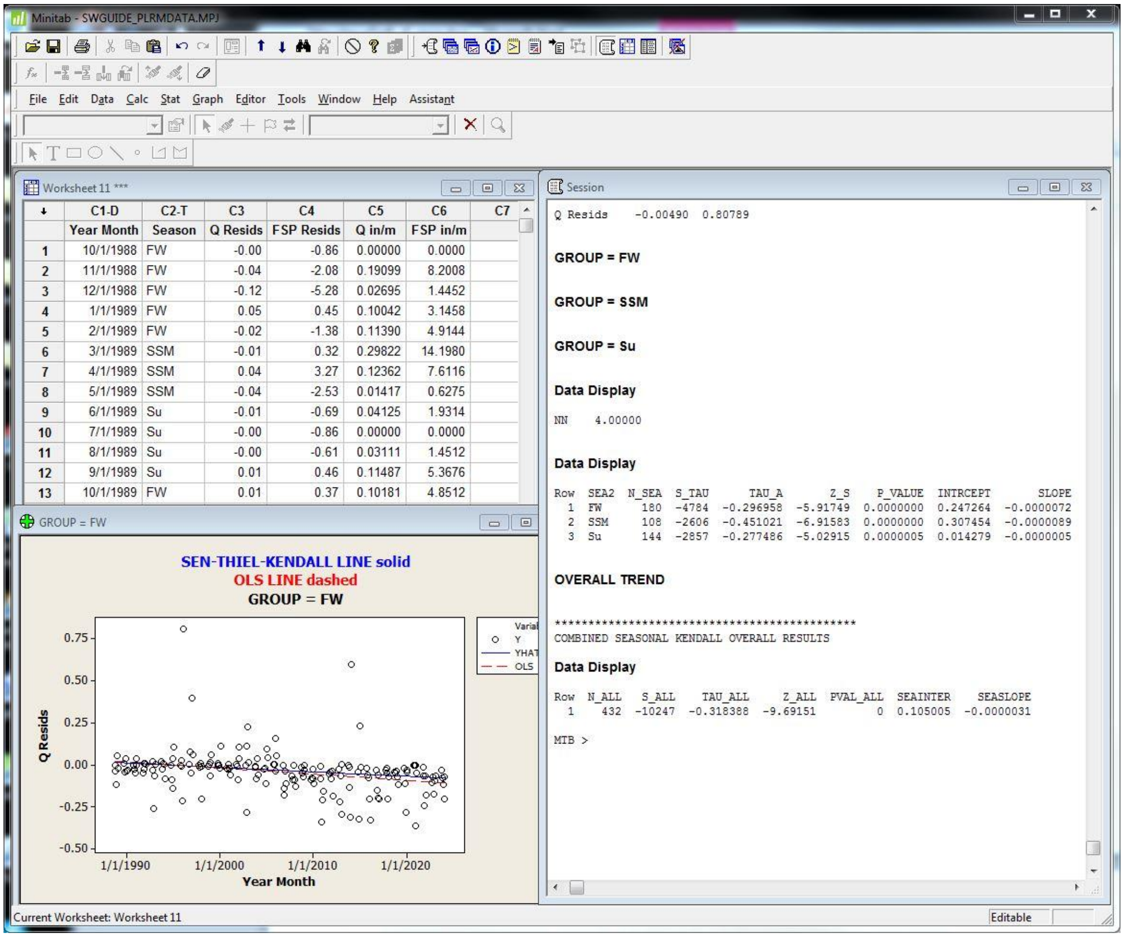



*Figure 15. Screenshot for data organization, command line execution, and automated graphic for seasonal Mann Kendall trend analysis in Minitab 16.*

# 8 OBJ 2: CEC ANNUAL REPORTING

**What are the average annual characteristic effluent concentrations (CECs) for well-maintained priority BMP types modeled in PLRM?**

This objective has been confirmed as a priority RSWMP Objective (*Steering committee meeting November 2014*) and is a critical data gap to inform and improve the stormwater tools supporting the Lake Tahoe TMDL. This objective can be achieved by a focused approach that samples the treated effluent of BMPs of the same type that have been recently maintained and are verified to be performing in an acceptable condition throughout the monitoring period.

The recommended experimental design includes 3 years of measured effluent concentrations from 3 specific BMPs of the same type to generate a single measured recommended CEC (mg/L) for a specific BMP type for each pollutant ($CEC_{BMP-P}$). This approach is recommended because it is expected to provide a reasonable spatial and temporal distribution of treated effluent conditions of priority BMP types over a feasible, cost effective time interval. The focused and concise approach of a discrete 3 year monitoring effort for a single BMP type provides a discrete monitoring effort that can be easily packaged for funding solicitations.

There are two central assumptions in the PLRM CEC algorithms that must be considered when monitoring BMPs. First, PLRM runs an 18-year simulation that includes a range of water year types. Therefore, the implementation over 3 consecutive water years is assumed to likely capture a reasonable range of event and water year types expected in the Basin. Second, PLRM assumes that the BMPs are treating stormwater (i.e., reducing pollutant loads) in a manner consistent with the modeled design parameters for the life of the simulation. Therefore the selected BMPs must be well-maintained throughout the monitoring to appropriately inform the model.

The priority BMP types modeled in PLRM where Tahoe specific monitoring of well-maintained BMPs is needed includes:

- media filter
- dry basin
- wet basin
- treatment vault

The pollutants modeled in PLRM for each BMP type for which CEC values would be valuable include:

- fine sediment particle concentrations (FSP < 16 um)
- total nitrogen (TN)
- total phosphorous (TP)
- dissolved inorganic nitrogen (DIN)
- soluble reactive phosphorous (SRP)
- total suspended solids (TSS)

Recommendations for site specific data analysis and graphical summaries of the CEC datasets are outlined below.

## 8.1 CEC REPORTING

Similar to the intent of Status and Trends reporting, the purpose of CEC reporting is to provide an efficient and clear way to disseminate information on the location of monitoring efforts, influential factors on the data measured, and the primary results of the monitoring effort. The intended audience of the final results reporting includes program managers, funders and the public. These standardized reporting documents can be used as a reference point for future PLRM simulations. The reporting format to convey the recommended CEC analyte concentrations and to summarize the 3 years of effluent data obtained for each BMP type is presented in Figure 16. The results presented in Figure 16 include FSP (mg/L) and TP (m/L) concentrations measured at three wet basins. The key information included in this annual summary were specifically selected so that a user can confirm the location of the monitoring sites, obtain important site characteristics, as well as understand the range of concentrations measured at the site. Annual progress reports will follow the same format, populating the information and data graphics where data is available until the 3-year data collection effort is complete, upon which the data is analyzed and the CEC recommendations generated.

*A. Characteristic Effluent Concentrations*: The result of Objective 2 is to determine a single recommended CEC for each priority pollutant. Both the value and the 90% confidence interval around that value are reported.

*B. Site location map*: Display the spatial distribution of the sites around the Basin.

*C. Site characteristics:* Site characteristics that might influence the analyte concentrations, such as impervious area and dominant urban land use are included. A higher distribution of high impact land uses (roads, CICU) and a greater density of impervious area may correspond to higher incoming pollutant loads, which may in turn affect the treatment capability of the BMP. Noting these differences may be important in interpreting future results and informing PLRM.

*D. Water year type, number of samples, and BMP RAM scores:* In order to obtain sufficient data to conduct the statistical analysis, the recommended annual sampling resolution is 66 samples per year. The total amount of annual precipitation, which is qualitatively described by the water year type, will likely influence the total number of samples obtained each year. The number of samples over and under the target is also reported.

BMP RAM tracks the condition of the BMPs and prioritizes maintenance efforts over time. It is expected that all newly installed BMPs will have a BMP RAM score of 5.0 and that the condition will decline over time. PLRM CECs are intended to represent BMPs maintained in acceptable condition, and the summary of BMP RAM scores by site and over time confirms the data obtained from the respective BMP meets this assumption.

*E. Effluent Data:* Box-Whisker plots are used to display the range of pollutant concentrations measured at each site. The median values are displayed and provide a context to compare the final recommended CEC values in Figure 16A.

*F. Bootstrapped Data*: The distribution of the bootstrapped medians is displayed to show the range of the estimated median values. The average of the 10,000 estimated medians is the recommended CEC value for each pollutant and is shown in the histograms as well as reported in Figure 16A.

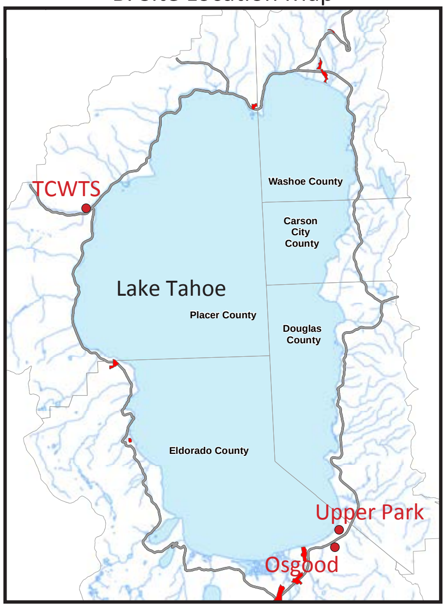
# Wet Basins: Characteristic Effluent Concentrations

Monitoring Years: 3 (2018-2020)

A. Characteristic Effluent Concentrations

| Pollutant | FSP (mg/L) | TP (mg/L) | TN (mg/L) |
|---|---|---|---|
| **Recommended CEC (boostrapped median)** | **15.0** | **0.082** | **TBD** |
| 90% Confidence Interval | 10.5 to 16.0 | 0.076 to 0.091 | TBD |

B. Site Location Map



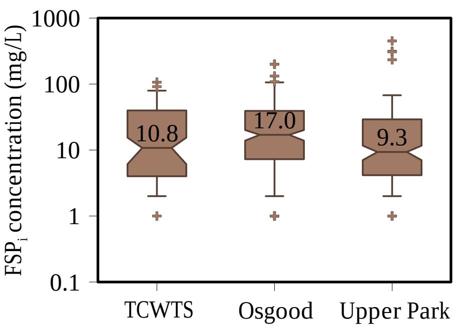

C. Site Characteristics

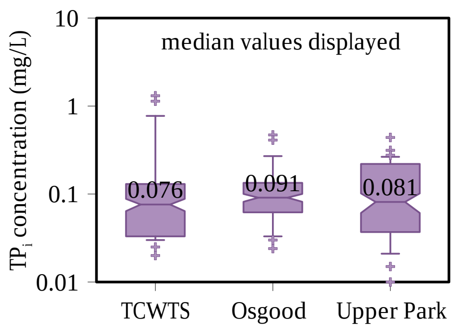
| Catchment | Jurisdiction | Area (ac) | % Imperv | Dominant Urban Land Use (% of total) |
|---|---|---|---|---|
| TCWTS | Placer | 281 | 42% | SFR; 16% |
| Osgood | CSLT | 341 | 23% | CICU; 27% |
| Upper Park | CSLT | 225 | 30% | SFR; 13% |

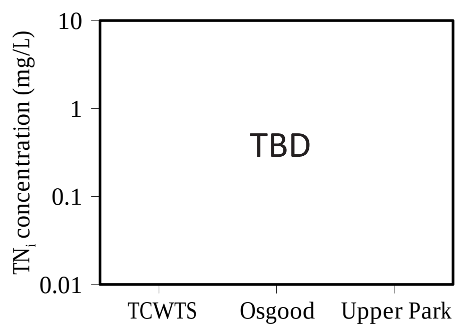
D. Water Year type, number of samples, and BMP RAM Scores

| Year | WY Type | Number of samples | # relative to target | Annual BMP RAM Scores | | |
|---|---|---|---|---|---|---|
| | | | | TCWTS | Osgood | Upper Park |
| 2016 | Ave | 66 | on target | 5.0 | 5.0 | 5.0 |
| 2017 | Wet | 70 | +4 | 4.3 | 4.2 | 4.5 |
| 2018 | Dry | 62 | -4 | 3.5 | 4.0 | 3.9 |

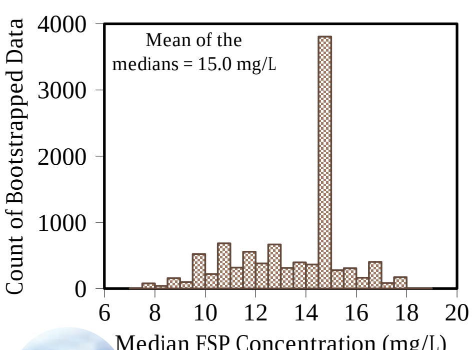
E. Effluent Data (WY16- WY18)

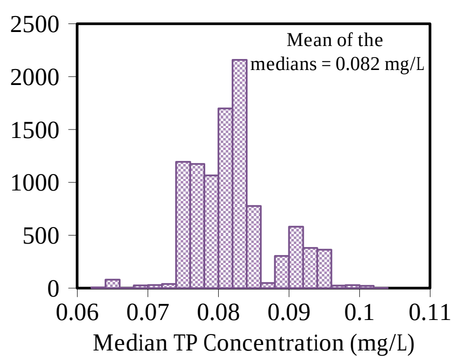


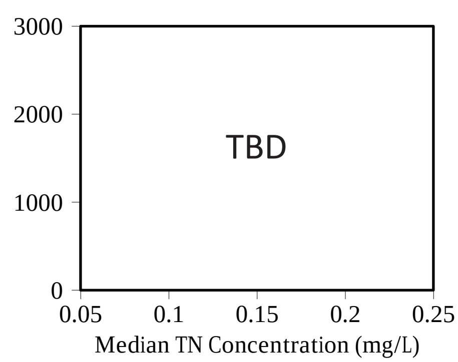




F. Bootstrapped Data




*Box-Whisker plots show the 25th, 50th, and 75th percentile (boxes) and the 10/90 (whiskers) percentile distributions of the measured data. The 50th percentile (the median) is labeled for each site. Bootstrapping was conducted for 10,000 iterations using the monitoring data. In each iteration, the median of the combined dataset (198 measurements sampled with replacement) was determined.*

# 9 OBJ 2: CEC MONITORING AND DATA MANAGEMENT CONSIDERATIONS

In order to focus future monitoring efforts and limit the amount of extraneous data collection, it is important to develop a clear SWT monitoring plan that best informs PLRM simulations of the Tahoe Basin. A significant amount of Treatment BMP monitoring has been conducted within the Tahoe Basin over the past 2 decades by a number of researchers, agencies and consultants (SH+G 2003; DRI 2004; CWS 2005; TERC 2005; 2NDNATURE 2006) but these disparate monitoring efforts were conducted for only a few years, the sampling techniques and pollutants evaluated varied, and the compilation and integration of these data to collectively evaluate BMP effluent quality has been challenging (2NDNATURE 2006 and nhc et al. 2009). Regardless, the greatest limitation of the past datasets to inform PLRM CECs is the fundamental assumption of PLRM modeling that treatment BMPs (i.e., SWTs) are maintained within the range of acceptable conditions. All documentation and reporting of past BMP effluent and performance monitoring have indicated that the subject BMPs did not exist in acceptable conditions at the time of data collection. 2NDNATURE and NHC 2012 obtained a limited amount of relevant data for existing dry basins and wet basins in the Tahoe Basin, however, none of the selected BMP sites had been recently maintained prior to the monitoring. There is currently no knowledge of any available and relevant effluent data for adequately maintained BMPs modeled in PLRM to inform CEC values.

We lay out and explain a series of monitoring and data management considers which, when incorporated to the extent possible, can inform PLRM inputs and ultimately provide more accurate simulations for BMPs in the Tahoe Basin.

## 9.1 MONITORING CONSIDERATIONS

There is a variety of instrumentation and sampling options available to obtain treated effluent samples from treatment BMPs. The recommendations and details of data collection are outside of the scope of this effort. However, a number of site selection and sampling considerations are provided below to guide future efforts.

**Recently and Well Maintained BMPs**: The critical sampling consideration for representative treated effluent BMP monitoring is the instrumentation of 3 recently maintained BMPs of the same type. This will require collaboration and coordination between the RSWMP research team and each jurisdiction responsible for maintenance of the selected BMPs. It is recommended that BMP RAM (www.tahoebmpram.com) is used to evaluate and track the condition of each of the BMPs included in the monitoring by completing field evaluations each May for the respective 3 consecutive water years studied.

**Treated Effluent Sampling**: Regardless of the sample collection technique, the site instrumentation must specifically sample the 'treated effluent' as defined by the specific PLRM inputs. SWT designs have both treated and bypass outflow orifices, where bypass outflow occurs when the capacity of the BMP has been exceeded and flows circumnavigate the BMP. Prior to instrumenting the outlets of treatment BMPs for effluent sampling, it is critical that the managers coordinate with the engineer and/or stormwater manager representing the jurisdiction to ensure only treated, and not bypass, effluent samples are collected. Equally important, the data collection technique should allow collection of samples throughout the range of treated discharges to characterize the pollutant concentrations in relation to the capacity of the BMP.

**Spatial Sampling Resolution**: For each BMP type, at least 3 specific BMPs should be monitored in a consistent manner. Three provides a range of characteristics while reducing the risk of exceeding funding availability. The population of BMPs of the same type may represent a range of expected pollutant loading rates, drainage areas, contributing land uses, configurations or capacity; however, the most important criteria is that the BMP is well-maintained. Jurisdictions are most likely to regularly maintain and annually assess BMPs that are included in their respective registered catchments and stormwater pollutant load reduction plans. These specific BMPs are likely best suited for inclusion in a CEC evaluation. Collaboration and coordination with responsible jurisdictions will result in a dual benefit: BMPs will be regularly maintained for monitoring and jurisdictions will meet annual regulatory inspection requirements.

**Temporal Sampling Resolution:** It is recommended that the effluent of 3 BMPs is sampled for 3 consecutive water years. This assumes that over the duration a reasonably representative range of event types, magnitudes, durations and intensities will occur and collectively will provide a reliable dataset from which to determine the average annual treated effluent concentrations. The evaluation of each water year type monitored (i.e., dry, average, wet) following the completion of the 3 years can inform if such a distribution was achieved and if additional monitoring to capture a range is needed. A reasonable distribution of event type sampling each water year that reflects the relative contribution to annual stormwater runoff and pollutant loading is recommended. Spring snow melt transports, on average, over 65% of the annual volumes and pollutant loads, flowed by winter rain, rain-on-snow, summer rain events. A reasonable approach may be a minimum of 4 spring snow melt events and 2 each of winter rain, rain on snow, and summer rain, resulting in an annual sample target of 66 samples, assuming an average of 2 samples per event.

## 9.2 CEC DATA MANAGEMENT

In order to maintain efficiency and clarity in CEC monitoring over the next several years, the database supporting the BMP CEC monitoring should manage the site-specific data from each unique BMP in the format summarized in Table 9. Regionally relevant daily precipitation data will be obtained and managed to complete the status and trend evaluations, and will include the seasonal precipitation totals and frequency analyses to report the season type for each season monitored as reported on Figure 10. Standardizing the annual dataset format allows future flexibility to revise and refine data collection methods as appropriate. It also provides the ability to optimize the day to day data collection techniques based on available resources.

Nutrient concentrations will be measured in the laboratory for each sample and turbidity will be measured in the sample bottle and then converted to FSP using the equations from 2NDNATURE and DRI (2014). The equation to convert turbidity (ntu) to FSP concentration (mg/L) is provided in Section 7 for Status and Trends. The same conversion can be used to convert turbidity to *[FSP]* for all CECs.

**Table 9.** Data fields and units for site metadata and annual BMP effluent monitoring. The Met Station ID will be related to Table 4c.

| **BMP Effluent Monitoring Site Metadata Fields** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| BMP Site ID | Jurisdiction ID | BMP Type | Drainage area (ac) | % IMP | Dominant urban land use type | Capacity stage (ft) | Treated outflow stage (ft) | METStation ID |
| | | | | | | | | |

| **BMP Effluent Monitoring Event Data Fields** | | | | |
|---|---|---|---|---|
| BMP Site ID | Date (mm/dd/yyyy) | Event type | Sample stage (ft) | $[P]_i$ (mg $L^{-1}$) |
| | | | | |

# 10 OBJ 2: CEC TECHNICAL GUIDANCE

The specific CECs (Table 10) for each BMP and pollutant will be determined using a statistical technique to estimate the median and the 90% confidence interval of the median. The bootstrapping method selected because it provides a robust estimate of the median and a confidence interval of the estimated median. By taking a representative subset of the measured data and computing the median of a new subset 10,000 times, each subset is representative of the measured data but the exact data distribution is slightly different between iterations. We recommend that the bootstrapping is conducted on the median, rather than the mean, of the measured data. Water quality data tends to have a large proportion of the measurements with low concentration and only a few measurements with high concentration. Using the mean of the dataset may skew the CEC estimate to high values even if those concentrations represented less than 10% of the data collected. Calculating the median would account for the significant number of low concentration measurements.

**Table 10.** CECs (mg $L^{-1}$) by BMP type and pollutant.

| | FSP | TN | TP | DN | DP |
|---|---|---|---|---|---|
| Wet Basin | $CEC_{WB-FSP}$ | $CEC_{WB-TN}$ | $CEC_{WB-TP}$ | $CEC_{WB-DN}$ | $CEC_{WB-DP}$ |
| Dry Basin | $CEC_{DB-FSP}$ | $CEC_{DB-TN}$ | $CEC_{DB-TP}$ | $CEC_{DB-DN}$ | $CEC_{DB-DP}$ |
| Media Filter | $CEC_{MF-FSP}$ | $CEC_{MF-TN}$ | $CEC_{MF-TP}$ | $CEC_{MF-DN}$ | $CEC_{MF-DP}$ |
| Treatment Vault | $CEC_{TV-FSP}$ | $CEC_{TV-TN}$ | $CEC_{TV-TP}$ | $CEC_{TV-DN}$ | $CEC_{TV-DP}$ |

The protocol for this technique was developed in the R statistical package. R is available for free download at: http://www.r-project.org/). The code to complete this analysis is provided in Figure 17 and conceptually, the protocol involves the following steps:

1. Organize all data for a single pollutant and a single BMP in one column (3 years of data).
2. Complete steps a to c 10,000 times (this is the standard bootstrapping technique):
   a. Sample, with replacement, the data using the number of measurements collected. Sample with replacement, also a standard for bootstrapping, refers to the process of picking one sample from the distribution and putting it back into the population before picking the second sample.
   b. Calculate the median.
   c. Store the median value.
3. Plot a histogram of 10,000 medians.
4. Calculate the mean of 10,000 medians – this is the recommended CEC for the specific BMP and priority pollutant, *(P)*.
5. Calculate the 5% and the 95% percentile of the 10,000 medians; this is the 90% confidence interval range for the pollutant concentration.

The protocol for the statistical bootstrapping to determine the CECs was developed in the R statistical package as well as the R-Studio software, which provides a user-friendly interface, http://www.rstudio.com/products/rstudio/download/.

- To execute the bootstrapping technique in R, make a table of the results in Excel following the format shown in Table 11 and save as a comma separated file, .csv.

**Table 11.** Recommended data input fields for bootstrapping in R-Studio.

| C1 | C2 | C3 |
|---|---|---|
| FSP | TP | TN |
| User Input | User Input | User Input |

# R bootstrap script to determine CECs

```
## READ DATA
CEC <- read.csv("filepath/filename.csv")

##LOAD SOFTWARE PACKAGES
library(ggplot2)
library(plyr)

##CREATE VARIABLES OF EACH ANALYTE
fsp <- na.omit(CEC$FSP)
tp <- na.omit(CEC$TP)

## DEVELOP FUNCTION TO FIND BOOTSRAPPED MEDIAN OF FSP
smedian <- function(n) {
  obs <- sample(fsp, n, replace = TRUE)
  median(obs)
}

simmedians <- raply(10000, smedian(N)) ##RUN BOOTSTRAP AND REPLACE N WITH LENGTH OF DATASET
qplot(simmedians, binwidth = 0.5) ##PLOT HISTOGRAM OF BOOTSTRAP RESULTS

mean(simmedians) ##DISPLAY AVERAGE OF THE BOOTSTRAPPED MEDIANS; COPY AND PASTE CEC VALUE
quantile(simmedians, c(0.05, 0.95), na.rm = TRUE) ##DISPLAY 90% CONFIDENCE INTERVAL COPY AND PASTE CONFIDENCE INTERVAL

hist <- hist(simmedians,breaks = 24) ##BIN THE BOOTSTRAPPED DATA FOR REASONABLY SIZED OUTPUT TO PLOT
hist_fsp <- cbind(hist$mids, hist$counts) ##OBTAIN THE MIDPOINTS AND COUNTS OF THE BINNED DATA

##save binned histograph data of bootstrapped medians
library(xlsx)
write.xlsx(hist_fsp, "filepath/hist_fsp.xlsx")
```

*Guide*

*a) Copy script into R Studio*

*b) Execute script line by line by entering Ctrl+Enter*

*c) Green text is commented text and "##" must preceed text to be read as user a comment in R. Comments are colored green automatically in R and are provided here to guide user the analysis conducted at each step.*

*d) Blue text is colored automatically in R studio.*

*e) The code above is to calculate a CEC for FSP. To computer for TP or any other analyte copy and replace FSP with TP.*

- Open R Studio and type in the code presented in Figure 17. In order to execute the code line-by-line, press CTRL+ENTER at each line.
- Copy and save the bootstrapped median and the 90% confidence interval into the CEC status reporting table (see Figure 16A).
- The Excel file saved at the end of the R routine contains the binned bootstrapped medians shown in Table 12 to plot the historgram shown in Figure 16F.

**Table 12.** Recommended data output fields for bootstrapping in R-Studio.

| Midpoint of bin | Count of Bootstrapped Medians |
|---|---|
| *R output* | *R output* |

- To improve the display, plot the binned count of bootstrapped medians using the bar chart functionality in Grapher (see Appendix B).

# 11 RESEARCH LIMITATIONS & NEXT STEPS

The guidance and analyses herein have been developed using example data created from modeled simulations or real-world data that does not meet all of the monitoring requirements necessary to achieve the stated RSWMP objectives. The absolute results presented in the reporting summaries are hypothetical and only for illustrative purposes to communicate the recommended formats and provide the necessary technical guidance to generate these reporting templates. The reporting formats and associated guidance to generate these summaries are expected to focus and improve communciations of Tahoe stormwater monitoring data in the future. Given that this research was conducted on fabricated datasets, there may be a number of unforeseen challenges associated with doing the analyses on real-world data.

Perhaps the greatest challenge may be the detection of improved stormwater quality in the Tahoe Basin over time. The achievement of obtaining datasets that demonstrate measureable decreasing trends in urban stormwater quality may prove challenging due to the timing of the initiation of a consistent stormwater monitoring program. Significant investment in water quality improvements have been made over the past 15 years. This investment has resulted in many changes in land use practices and extensive BMP implementation on public and private lands that occurred over the decade prior to the implementation of a consistent monitoring program. The ability to measure a detectable improvement in stormwater quality as a result of effective management actions likely would have been much stronger if the monitoring program had been initiated in the early to mid 1990s. This timing issue may result in a smaller signal by management actions on urban stormwater quality in the dataset obtained than if the monitoring had been consistently conducted over the past 2 decades.

The inititation of monitoring and the subsequent consistent reporting of results in standardized metrics will begin to define the range of stormwater runoff and pollutant loading rates throughout the Basin. This information will be invaluable toward understanding what is achievable across different jurisdictions, seasons, and water year types in the Tahoe Basin. These comparative results on seasonal and annual time scales across sites during the same monitoring intervals should be used to quantitatively define what effective stormwater management entails and this information should supplement the site trend analyses for the reasons explained above.

The ideal monitoring network would be much more spatially comprehensive than what is fiscally sutainable long term. Thus, the feasible urban catchment monitoring network maintained will possess spatial data gaps. It will be assumed the measured sites are reasonably representative of similar catchments under similar management. Tracking land management practices implemented in other similar (non-monitored) catchments in formats comparable to the monitored catchments may help address the questions of how applicable the measured results at the selected urban catchment outfalls are of the greater unsampled urban areas.

The inherent nature of stormwater monitoring and the associated desire to evaluate trends or define CECs requires many years of consistent data collection. This long time frame to complete the required monitoring and obtain results conflicts with the desire to evaluate the effectiveness of management actions and adjust practices and programs accordingly. The critical next step to this research is to implement and build the urban stormwater datasets necessary to address the priority management questions. The value of standardization and consistency in a continued stormwater monitoring program and its supporting data management structure cannot be understated. Insightful technical evaluations of the data results obtained and their implications to the TMDL, EIP, and BMP implementation and maintenance will be critical to continue to leverage the available dataset to inform programmatic decisions.

Lastly, stormwater monitoring is inherently dependent on the climatic conditions and resulting hydrology. While recommended timeframes are provided (3-5 years for trend analyses and 3 years for CEC calculation), the need to monitor a range of representative water year types cannot be overstated. Climate is the main uncontrollable driver in stormwater runoff, and will heavily influence the volumes and quality of the stormwater monitored. Understandably, there will be a desire to conduct analyses and finalize results in these minimum time frames; however, especially for informing PLRM, it is critical a range of water years are monitored to inform the average annual concentration values. The potential effects of climate change on the future stormwater fate and transport will also likely need to be considered as stormwater monitoring data analysis and interpretations are conducted in the future.

# 12 REFERENCES

2NDNATURE and Northwest Hydraulic Consultants. 2011. Placer County Stormwater TMDL Strategy. Final Technical Report. Prepared for Army Corps of Engineers, Sacramento District and Placer County. July 2011.

2NDNATURE and Northwest Hydraulic Consultants. 2012. Focused Stormwater Quality Monitoring to Inform Assumptions & Evaluate Predictive Capabilities of Existing Tools. Final Technical Report. Prepared for USFS Pacific Southwest Research Station. June 2012.

2NDNATURE and Northwest Hydraulic Consultants. 2014. Catchment-Scale Evaluation of Tahoe Stormwater Tools. Final Technical Report. Prepared for USFS Pacific Southwest Research Station. June 2014.

2NDNATURE, Desert Research Institute and UC Davis. 2014. Surrogate Indicators to Monitoring Fine Sediment Particles in the Tahoe Basin. *In Development*. Prepared for USDA Forest Service Pacific Southwest Research Station. Draft Final Report March 2014.

Cleveland, W.S. and Devlin, S.J. 1998. Locally Weighted Regression: An Approach to Regression Analysis by Local Fitting. *Journal of the American Statistical Association*, Vol. 83: 596-610.

CWS. 2005. Evaluation of Angora Meadows as a Filter for Nutrients. Center for Watershed Sciences, Aquatic Ecosystem Analysis Laboratory, UC Davis.

Desert Research Institute. 2004. Evaluation of Urban Runoff BMP Effectiveness through Assessment of Mechanical Treatment Technologies (Vaults) and Wetland Systems Employed at the Stateline Stormwater Project. Division of Hydrologic Sciences, Desert Research Institute. Prepared for the TRPA.

Heyvaert, A., and Reuter, J.E. 2011. Tahoe RSWMP Data Quality Objectives. Prepared for the Tahoe Regional Storm Water Monitoring Program (RSWMP).

Helsel, D. and Gilroy, E. (2008) Practical Stats: Make Sense of Your Data! Applied Environmental Statistics, Rutgers EcoComplex, Bordentown, NJ.

Helsel, D.R. and Hirsch, R.M (2002) Techniques of Water-Resources Investigations of the United States Geological Survey Book 4, Hydrologic Analysis and Interpretation. Chapter A3 Statistical Methods in Water Resources, U.S. Geological Survey.

Lahontan Regional Water Quality Control Board (LRWQCB) and Nevada Division of Environmental Protection (NDEP). 2010. Final Lake Tahoe Total Maximum Daily Load. November 2010. http://www.swrcb.ca.gov/rwqcb6/water_issues/programs/tmdl/lake_tahoe/docs/tmdl_rpt_nov2010.pdf

LRWQCB and NDEP. 2010. Final Lake Tahoe Total Maximum Daily Load. November 2010.

LRWQCB. 2011. Lake Tahoe Municipal NPDES Permit. December 2011. http://www.waterboards.ca.gov/lahontan/board_decisions/adopted_orders/2011/docs/r6t_2011_101a1.pdf

Lisbester, C. and Grimball, A. 2002. Performance of partial Mann-Kendall tests for trend detection in the presence of covariates. *Environmetrics*, 13: 71-84.

Loftis, J.C, MacDonald, L.H., Street, S., Iyer, H.K., Bunte, K., 2001. Detecting cumulative watershed effects: the statistical power of pairing. *Journal of Hydrology*, 251, 49-64.

Northwest Hydraulic Consultants (NHC), Geosyntec Consultants, and 2NDNATURE. 2009a. Pollutant Load Reduction Model (PLRM) Model Development Document. Prepared for the Tahoe Basin Storm Water Quality Improvement Committee. South Tahoe Basin, CA. October 2009. Complete documentation, user's manual, and tool available for download at http://www.tiims.org/TIIMS-Sub-Sites/PLRM.aspx

Northwest Hydraulic Consultants (NHC). 2009b. Pollutant Load Reduction Model (PLRM) User's Manual. Prepared for the Tahoe Basin Storm Water Quality Improvement Committee. South Tahoe Basin, CA. December 2009. Complete documentation and tool available for download at http://www.tiims.org/TIIMS-Sub-Sites/PLRM.aspx

Northwest Hydraulic Consultants (NHC), Geosyntec Consultants, and 2NDNATURE. 2010. PLRM Applications Guide. Prepared for the Lake Tahoe Basin Storm Water Quality Improvement Committee. South Lake Tahoe, CA. October 2010. http://www.tiims.org/TIIMS-Sub-Sites/PLRM/docs-downloads.aspx

Swanson Hydrology + Geomorphology. 2003. Assessment of Seasonal Pollutant Loading and Removal Efficiency of Detention Basins. Prepared for TRPA and U.S. EPA.

Tahoe Environmental Research Center (TERC) and U.C. Davis. 2005. Performance Assessment of the Coon Street Basin, Kings Beach, CA. Prepared for Placer County Department of Public Works.

Tahoe Resource Conservation District, Lahontan Regional Water Quality Control Board, 2NDNATURE, Desert Research Institute, and Northwest Hydraulic Consultants. 2014. Scientific Assessment Report. Prepared for the Regional Storm Water Monitoring Program.

United States Geological Survey (USGS). 2000. Trends in Surface-Water Quality During Implementation of Best Management Practices in Mill Creek and Muddy Run Basins, Lancaster County, Pennsylvania. USGS Fact Sheet 168-99. http://pa.water.usgs.gov/reports/fs168-99.pdf

# APPENDIX A

## STATISTICAL TECHNIQUES

Below are a collection of statistical techniques employed for this research to interpret stormwater monitoring data to meet the said objectives. These general descriptions are provided to supplement the rationale and value of these techniques toward data analysis.

**LOWESS**: The locally weighted regression model (LOWESS) was used to remove the fluctuation in surface runoff and pollutant loads over time due precipitation before tests for trends were performed. At each point in the dataset a low degree polynomial was fit to a subset of the data using weighted least squares. This process gives more weight to points near the point whose response is being estimated and less weight to points further away. LOWESS combines much of the simplicity of linear least squares regression with the flexibility of nonlinear regression by fitting simple models to localized subsets of the data. A smoothing coefficient (see Cleveland and Devlin, 1988) determines how much of the data is used to fit each local polynomial. Similar to the linear regression, the model residuals (difference between the LOWESS model and actual observed values) can be thought of as surface runoff or pollutant concentrations that have had the precipitation influence on their value removed. Thus, changes in these values over time represent a change in the system that are likely due to factors other than meteorologically driven variations.

**Mann-Kendall**: Since water quality data are commonly skewed and result in non-normal distributions of residuals (Hirsch et al. 1982), non-parametric procedures, such as the Mann-Kendall test, are often substantially more powerful with large sample sizes (e.g., Helsel and Hirsch, 1988). The statistic used, Kendall's Tau ($\tau$), is a rank correlation statistic that measures the strength of dependence between two variables. The test also handles missing values and values below the detection limit, which both occur in the stormwater datasets with some frequency. The value of $\tau$ is calculated by computing Kendall's S statistic, which is the number of matching ranks of two variables. If we consider two variables x and y, the total number of pairings of equal ranks possible between the two is n(n-1)/2. S is the difference between the number of matching pairs ($n_{mp}$) and the number of non-matching pairs ($n_{np}$):

$$S = n_{mp} - n_{np}$$

$\tau$ is related to $S$ by:

$$\tau = \frac{S_i}{n(n-1)/2}$$

(tau ranges from -1 to 1) The availability of streamflow data also permitted adjustments of concentrations data to account for changes over time that may be explained by hydrologic variability. Water quality constituents may have a direct or inverse relationship with streamflow discharge, or the relationship may be more complex and depend on antecedent hydrologic conditions, land use dependent activities, and watershed characteristics (USGS 2000). Removal of external or 'exogenous' sources of variability in water quality data can reduce the background variability to improve the ability to detect a change in water quality conditions. Lisbester and Grimball (2002) demonstrated that the inclusion of discharge as an explanatory variable in the Seasonal Mann-Kendall test substantially improved the power of the test. It can be beneficial to include streamflow as an explanatory variable even with weak correlations between streamflow and the water quality variable of interest, and the ability to detect change can increase non-linearly as the correlation increases (Loftis et al., 2001).

The seasonal Mann Kendall test (Hirsch et al., 1982) accounts for seasonality by computing the Mann-Kendall test on each season separately, and then combining the results. The overall Tau is a weighted average of 3 rank correlation coefficients, one of each season of the year included (SSM, F/W, Su). While Kendall's Tau is used to test the significance of the correlation with time, the Sen slope estimator is used to denote the magnitude of the change over time. It is computed using the method of Sen (1968) and has shown to be robust to outlying data points that may have an overly large leverage on the slope of a line using more traditional ordinary least squares (OLS) method. A slope was calculated for each season and the overall slope is the median of those slopes.

In order to determine the significance of Kendall's Tau, calculate the z-score:

$$Z = \frac{3(n_{mp} - n_{np})}{\sqrt{n(n-1)(2n+5)/2}}$$

Z values greater than 1.96 (1 standard deviation) represent 95% confidence that the slope is significant.

**Changepoint**: Changepoint analysis is capable of predicting multiple changes in the mean and variance of a dataset. Unlike estimating a single trend for a specified interval, changepoint can address if and when more than one change (in the mean or variance) occurred for a specified interval and with what confidence did the changes occur. However, changepoint only looks at step wise changes in the mean. It does not calculate non zero trends in the dataset. The research team determined that the seasonal Mann-Kendall trend analysis met all of the needs of Objective 1 and that a changepoint analysis would not be recommended due to the increased complexity and lack of additional high priority information.

**Bootstraping:** Bootstrapping is a statistical technique that can be used to unlock additional information in a measured dataset. In this study, boostrapping is used to estimate the statistical significance, or the confidence interval, around the median of the pollutant concentrations measured for a specific BMP type. The confidence interval is determined by resampling the measured data over and over, up to 10,000 times. Each time the dataset is resampled, the median of the dataset is calculated. After 10,000 iterations of resampling and calculating the median, a dataset of 10,000 medians exists and is used to conduct additional statistical test. The mean of the bootstrapped dataset (the 10,000 medians) is the most likely median of the original pollutant concentration dataset and the 0.05 and 0.95 percentiles of the bootstrapped dataset is the 90% confidence level around the most likely median.

# APPENDIX B

## GRAPHER SOFTWARE GUIDANCE

All graphics included in the figures for this report were made using proprietary software, Grapher, which is available for purchase and download at:

http://www.goldensoftware.com/products/grapher

Grapher has the capability to read data directly from data tables in Excel and create multiple graphics on a single page. In addition to the main window that displays the plot on an 8.5" x 11" worksheet, the Grapher interface includes an Object Manager, Property Manager, and Worksheet Manager to provide a user friendly framework to edit and modify charts in detail. Similar to Excel, Grapher charts work best when data of different types, and units, are stored in separate column. When a graph is created in Grapher, all the data saved in the specified Excel spreadsheet is uploaded to the Worksheet Manager in Grapher. Data can be edited in Grapher's Worksheet Manager, but, in practice, it is best to edit the worksheet directly in Excel, save changes, and then reload the data in Grapher. Editing, saving, and reloading can all be completed while both programs are open and in use. Basic shapes, arrows, and text boxes can also be added to charts.

Five different types of graphs were used in this report: line plot, scatter class plot, horizontal bar chart, doughnut plot, and box-whisker plot and are described below.

*Line plots:* These were used to display time series data (see Figure 2 and Figure 3). DateTime was stored in one column and the data of interest was stored in adjacent columns. All colors and line thickness can be edited directly in the Property Manager. The x-axis and y-axis length, data ranges, and spacing can also be placed at any interval specified by the user. Symbols can be added to the line plots by changing the symbol frequency. DateTime label format can also be specified exactly as desired by the user (e.g. mm/yyyy, MM-yy, dd/mm, etc.).

*Scatter class plots:* Scatter plots were used to display the relationship between and determine the best-fit line of $PPT_{mo}$ with $U\text{-}Q_{mo}$ (or $U\text{-}P_{mo}$) (see Figure 12). They function similar to line plots except that the symbol frequency is usually set to 1 and no line is used to connect the symbols. All aspects of editing colors, symbols are available in scatter plots. Fits (e.g., linear, exponential, logarithmic, etc.) can also be added to scatter plots. The fit statistics (the equation, $r^2$, etc.) can also be displayed and manually added in a text box to the graphic. The class functionality of the scatter plots requires a third column that categorizes the data. In this report, it provided a user-friendly way to display the data based on season – FW, SSM, or Su.

*Horizontal bar charts:* Horizontal bar charts were used to display the trend data (see Figures 9 and 10). Data from different sites should be stored in different columns and sorted by season type. Color and line characteristics can be modified, including replacing the labels of the axes with text instead of ordered numbers.

*Doughnut plots:* Doughnut plots were used to display the seasonal unit surface runoff or unit pollutant loading (see Figures 6 and 7). Data from different sites should be stored in different columns, so that one plot per site is generated. Based on the data in each column, the function generates a wedge for each season that scales in size to the contribution to the water year total. The color of each wedge and the center hole can be edited to represent the magnitude relative to the runoff or load. The data value of each was also added to each figure (see Figure B1).

*__Box-Whisker plots:__* Box-Whisker plots were used to display the distribution of CEC data for each analyte by site (see Figure 16). Data from each site are stored in separate columns.

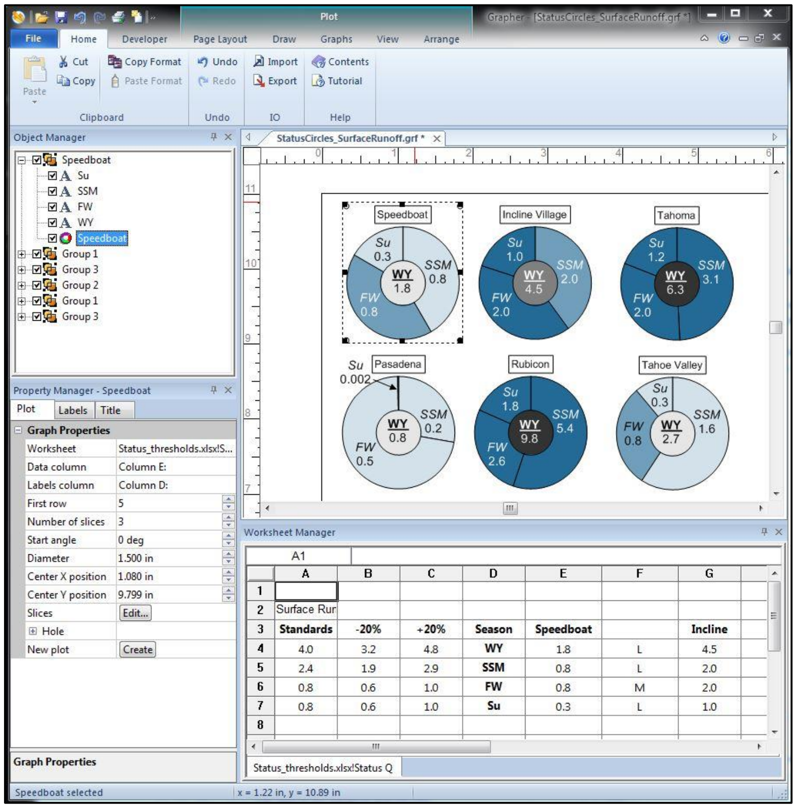



*Figure B1. Screenshot of the Grapher interface for the annual status unit surface runoff doughnut plots.*