URBAN CATCHMENT MONITORING TO EVALUATE TAHOE TMDL TOOLS

Prepared by 2NDNATURE and NHC // FINAL REPORT // JUNE 2014

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Catchment-Scale Evaluation of Tahoe Stormwater Tools

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LIST OF KEY ACRONYMS AND TERMS

A&T Tool	TMDL Accounting & Tracking Tool; Data management tool that stores, tracks and reports credit information and load reduction achievement over time in association with the Crediting Program.
Baseline	Baseline Condition; Conditions present during TMDL baseline period, Oct 1, 2003 – May 1, 2004.
BMP RAM	Best Management Practice Maintenance Rapid Assessment Methodology; Tool for Tahoe Basin urban stormwater community to determine relative condition of an urban stormwater BMP.
CEC	Characteristic Effluent Concentration; Represents the effluent concentration typically achieved by a stormwater treatment BMP in PLRM dependent upon the type of BMP specified.
CICU	Commercial/Industrial/Communications/Utilities; Land use designated in Tahoe Basin TMDL.
CRC	Characteristic Runoff Concentration; Representative concentration for a pollutant of concern in runoff from a specific land use and associated land use condition in PLRM.
Credit	Lake Tahoe Clarity Credit; Related to pollutant load reductions and used to evaluate progress towards TMDL.
Crediting Program	Lake Tahoe Clarity Crediting Program; Tahoe Basin program that defines system to track and evaluate pollutant load reductions and related credits within context of TMDL by urban catchment.
DCIA	Directly Connected Impervious Area; Impervious surfaces draining through a direct hydraulic connection to a surface water drainage system.
Existing	Existing Condition; Conditions present during the development of this Strategy Report, Oct 1, 2010 – May 1, 2011.
FSP	Fine Sediment Particle; Mass fraction of TSS concentration <16µm.
LRWQCB	Lahontan Regional Water Quality Control Board; California regulatory agency overseeing Tahoe Basin TMDL implementation.
MFR	Multi-Family Residential; Land use designated in Tahoe Basin TMDL.
NDEP	Nevada Division of Environmental Protection; Nevada regulatory agency overseeing Tahoe Basin TMDL implementation.

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.
Road RAM	Road Rapid Assessment Methodology; Tool for Tahoe Basin urban stormwater community to determine the condition of impervious road surfaces.
Road Risk	PLRM term that incorporates road characteristics to describe relative risk of pollutant generation and transport downslope from impervious road surfaces.
SFR	Single Family Residential; Land use designated in Tahoe Basin TMDL.
SNPLMA	Southern Nevada Public Lands Management Act; Key funding source of this research.
SRP	Soluble Reactive Phosphorous; Also known as orthophosphate, it is the dissolved inorganic fraction of total phosphorous that is biologically available to primary producers.
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.
TMDL	Tahoe Basin Total Maximum Daily Load; Implementation plan that establishes pollutant load reduction allocations for urban stormwater to improve Lake Tahoe clarity.
TSS	Total Suspended Sediment; Mass of sediment contained in a known volume of water.
UPC	Urban Planning Catchment; A contiguous area containing urban land uses with runoff draining to a surface water body. Any single square foot of land is included in only one urban catchment
WQIP	Water Quality Improvement Project; Typically a suite of improvements (pollutant source control, hydrologic source control, and stormwater treatment facilities) implemented within an urban catchment to reduce the pollutant loading to surface waters.

1 EXECUTIVE SUMMARY

The Lake Tahoe TMDL (LRWQCB and NDEP 2010) and supporting Lake Clarity Crediting Program (LRWQCB and NDEP 2009) are guiding water quality improvements within urban areas to reduce urban pollutant loading and ultimately improve the clarity of Lake Tahoe over the next 30 years. A series of stormwater tools have been developed to support the Crediting Program to estimate the load reductions of urban water quality improvement actions (i.e., Pollutant Load Reduction Model (PLRM); NHC et al. 2009) and verify these improvements are adequately maintained (Road Rapid Assessment Methodology (Road RAM), 2NDNATURE et al. 2010; BMP Rapid Assessment Methodology (BMP RAM), 2NDNATURE et al. 2009). Given the role of these tools in the Crediting Program, there is a clear desire by the stormwater community to better understand the performance, limitations and opportunities to improve these tools. The Regional Stormwater Monitoring Program (RSWMP) is being developed to obtain consistent long-term stormwater datasets to inform tool improvements, as well as provide datasets that will ultimately demonstrate if the collective water quality improvement actions have resulted in sustained reductions of urban stormwater pollutant loading to the Lake. The development of a standardized and consistent approach to urban outfall monitoring for sediment and nutrient pollutants of concern is currently being defined by RSWMP, and it was the intent of this research to inform RSWMP development to the extent possible.

A number of urban stormwater data collection, data analysis and reporting recommendations have been generated to guide the design and implementation of RSWMP. The objectives that drove this research are:

1. Obtain and report reliable seasonal and annual urban catchment FSP loads that can be compared across outfalls;
2. Obtain long-term consistent data sets that will allow a detection of decreasing trends in urban pollutant loading as a result of effective management actions, should they exist;
3. Document and test the influence road practices and associated road conditions have on urban catchment FSP loading; and
4. Generate comparable PLRM estimates for the site and time period monitored to improve PLRM model development guidance, inform potential future PLRM improvements, and refine the expectations and limitations of comparing measured and modeled stormwater pollutant loading datasets.

A series of data and information were used to document the runoff volumes and FSP pollutant loading from 3 urban catchments, evaluate the influence of changing road conditions on these pollutant loads, and build representative PLRM models to compare to the measured water quality datasets. Three urban catchment outfalls were selected, instrumented and monitored for one complete year (March 1, 2012 to February 28, 2013). The selected water quality monitoring methods targeted cost effective data collection techniques that could obtain precise and repeatable stormwater discharge and FSP concentration datasets. Chronologies and details of road maintenance practices conducted in each catchment were collaboratively defined and reported by the local jurisdictions and the research team. Road condition was periodically documented using Road RAM within each monitored catchment. Catchment land use distributions and land use conditions were determined using best available information, and readily available nearby meteorological data for the year was obtained and used to simulate PLRM pollutant loading for the monitoring interval.

1.1 CATCHMENT POLLUTANT LOADS

This research developed a standardized and consistent annual summary format and template to synthesize the results of a year of catchment outfall water quality monitoring at a single site (see Figure 6.2). The template provides a number of volume and pollutant load metrics normalized by catchment characteristics (catchment area, impervious area, etc.) to allow direct comparisons of measured data across sites. This status summary format can be used for RSWMP reporting, and over time these site-specific status metrics will allow informative temporal and spatial analyses and comparisons.

The short duration of the monitoring component of this research (1 year) limits the interpretation of the dataset obtained. Given these data collection, analysis and reporting methods are intended to inform management questions that require years of consistent data collection, the primary value of this research are the recommendations and guidance on how catchment outfall monitoring datasets can be analyzed and reported to address key management questions, including comparisons to PLRM estimates. The research identifies a number of lessons learned and recommendations concerning the catchment outfall monitoring approach:

- **Discharge and concentration sampling resolution**: Continuous (e.g., minute intervals) discharge monitoring provides the necessary temporal resolution to adequately capture the extreme variability of urban stormwater runoff and is recommended for urban catchment outfall status and trend monitoring. Continuous pollutant concentrations are also desired when possible. This research leveraged previous sampling and data analysis results (2NDNATURE 2013; Heyvaert et al. 2011), and monitored continuous automated turbidity as a proxy for FSP concentrations. Available turbidity to FSP rating curves developed using thousands of paired samples obtained in the Tahoe Basin (2NDNATURE et al. 2014) were used to consistently convert 10 min turbidity data to FSP concentrations.

- **Perform site QA/QC consistently, rigorously and frequently.** The value of consistent, rigorous and frequent field QA/QC procedures to minimize data gaps and verify, calibrate and adjust instrument values (e.g., stage, turbidity) and calculated parameters (e.g., flow, FSP concentration) with manual measurements cannot be overstated. In order to ensure accurate instrument operation and proper conversions of raw datasets, frequent site visits to collect spot stage, discharge, turbidity, etc. measurements during periods when runoff is occurring are essential. The more consistent and comparable the measured datasets obtained by RSWMP (i.e., high sampling precision) the greater our confidence to attribute differences in seasonal or annual loads to management actions.

- **Fill data gaps.** Data gaps due to instrument failure are inevitable given the challenges of monitoring intermittent flow conditions in sub-zero temperatures. This research recommends a simple method to recreate reasonable data to fill these data gaps. A practical and consistent method adopted by RSWMP to fill data gaps will increase our confidence to attribute differences in seasonal or annual loads to management actions.

- **Track treatment BMP condition.** A variety of treatment BMP types are constructed within Tahoe urban catchments to provide significant pollutant load reductions to Lake Tahoe. BMP RAM (2NDNATURE et al. 2009) can be used to rapidly evaluate and track the relative condition of the larger scale treatment BMPs within the urban catchment over time. Should RSWMP long term datasets display unexpected deviations or trends in catchment seasonal and annual pollutant loads, BMP RAM information regularly maintained within the subject catchment could provide documentation if a treatment BMP is not performing as well as expected. This research did not include the appropriate coordination with personnel directly in charge of maintenance to ensure the BMP benchmark and threshold steps are appropriately implemented. Future urban catchment outfall monitoring would benefit greatly from such collaboration and BMP RAM implementation.

1.2 ROAD CONDITION

The Lake Tahoe TMDL and subsequent research have identified paved roads as the most cost-effective, controllable source of FSP in urban stormwater runoff per unit area (LRWQCB and NDEP 2010). The Road Rapid Assessment Methodology (Road RAM; 2NDNATURE et al. 2010) provides a method to evaluate and track the potential FSP load generated from paved roads. The Crediting Program recommends Road RAM be used to verify that observed road conditions are consistent with road conditions and associated RAM scores modeled in PLRM. Using Road RAM, road condition observations were made throughout the monitoring period in all three catchments for two purposes:

1. To continue to make progress on how to test the effectiveness of road maintenance practices to improve and maintain desired road conditions; and
2. To continue to inform our understanding of how road condition influences urban stormwater FSP loading.

A series of data analysis and reporting formats were evaluated to compare the observed Road RAM results with the measured event and seasonal catchment FSP loads. However based on the limitation of obtaining only 1 yr of data, definitive conclusions of the cause and effect linkages between road condition and catchment FSP loading requires continued consistent data collection and subsequent analyses Consistent with past road condition datasets (2NDNATURE et al. 2010, Kuhns et al. 2010) road conditions are generally worse in winter than summer. Given that only 1 year (3 seasons) of data in 3 catchments is available; it is recommended that the Road RAM sampling is continued by RSWMP in urban catchments where FSP pollutant load monitoring is occurring. Once more data available, the data integration and analyses presented herein can be used to better evaluate the influence of road condition variations on measured catchment FSP loads.

An accurate and useable chronology of road maintenance actions performed on the roads is required to test the cause and effect relationship between road maintenance practices and road condition (as measured by Road RAM). This research contributed to the ongoing development of the most appropriate data collection and information management formats necessary to chronicle jurisdictional road maintenance practices to better test the effectiveness of road maintenance practices. The research team continues to collaborate with the Tahoe jurisdictions to spatially and temporally align the documentation of actions and road condition observations through the Basin-wide Road Operations Effectiveness Study using the lessons learned from this effort.

1.3 COMPARING MONITORING DATA TO PLRM

PLRM is a water quality planning tool designed to predict average annual runoff volumes and pollutant loads for use by Tahoe stormwater engineers and managers. The hydrologic approach used in PLRM provides a model structure that can predict runoff volumes at the time scales important to the Lake Tahoe TMDL (i.e., average annual). PLRM developers made a number of design decisions that simplified or automated algorithms from the more complex SWMM model to streamline use of PLRM for the intended user group and to reduce data input needs. Consequently, PLRM users have minimal ability to refine modeled estimates of peak flows or the shape and timing of the stormwater hydrograph on event timescales. For this research, the project team had to make a series of refinements to the PLRM models within the SWMM platform to generate and access volume and FSP estimates on the short-duration time scales needed for comparison to measured data.

The results of the model calibration exercise and comparison to measured pollutant loads suggest that PLRM models can perform reasonably well on the seasonal and annual time scales, as intended based on the objectives of the model design. However, the model's predicted runoff volumes and pollutant loads can have notable discrepancies with the measured data at the event time scale. The discrepancies are particularly evident during periods of snow hydrology when the model is dependent on accurate inputs of temperature data to predict snow accumulation and melt, or when complex drainage conditions are present in the monitored catchment such as a baseflow component.

Based on the lessons learned from this research, below are a number of data requirements to adequately compare PLRM estimates with observed stormwater volumes and pollutant loading data. As the compilation of the requirements below suggest, the generation of reliable data to conduct reasonable comparisons between measured and modeled data is not a trivial exercise.

- **Accurate measured high resolution discharge data.** Equally as important to proper catchment representation in PLRM, the measured discharge dataset must be as accurate as possible. This requires reliable equipment and frequent and detailed field visits to calibrate instruments, conduct accurate manual depth, flow or other relevant measurements, and ensure site instrumentation used to measure discharge on minute time scales is operating and the data as precise as possible. It is impossible to validate a continuous hydrologic model if the observed discharge data is not as accurate as possible.

- **Accurate and representative weather data of the monitored site**. To generate high resolution site-specific PLRM estimates, accurate precipitation and temperature data during the monitoring period is needed. These research results show that weather stations in the vicinity of the study area, but not located within it, produced data that did not adequately predict events with a mixture of rain and snow. Establishment, operation and maintenance of highly representative weather stations are essential, particularly during the winter, if modeled and measured datasets are compared.

- **High-resolution predicted stormwater runoff volumes and pollutant loads generated using SWMM**. These predictions must be completed in SWMM with post-processing of SWMM output completed using supporting spreadsheets. Guidance by the PLRM developers to complete event-based SWMM estimates is included within this report. However, users not familiar with SWMM may have difficulty critically evaluating model outputs to ensure they are reasonable.

- **Reasonable representation of road CRCs at time of stormwater monitoring.** Road characteristic runoff concentrations (CRCs), particularly FSP, have been documented to vary significantly across roads, jurisdictions, months and seasons (2NDNATURE et al. 2010). This variability can be better represented in future PLRM predictions if periodic catchment scale measurements of the condition of contributing roads are used to inform road FSP CRCs. Guidance to adjust SWMM inputs based on the observed road condition measurements is provided in Appendix B. The next version of the PLRM, being developed as part of the Stormwater Tools Improvement Project, will allow users to directly enter a road condition score corresponding to a specific FSP CRC.

- **Reasonable representation of Treatment BMP performance**. A reasonable representation of the actual condition of catchment BMPs, especially treatment BMPs expected to provide significant load reductions, should be tracked to improve confidence that the condition of the BMPs during the monitoring duration is being reasonably represented in PLRM. During this research, flow was found to be bypassing a critical media filter BMP, resulting in a significant underestimate of the actual pollutant loading from the catchment. BMP RAM is designed and available to potentially inform the BMP conditions when trying to represent their performance in PLRM.
  In addition, the default PLRM CECs may not be representative of the actual treatment BMP performance if: the physical configuration of the BMP in PLRM is not accurate; the BMP has not received adequate or regular maintenance; or inflow pollutant concentrations are misrepresented in the model. Treatment BMP CEC representation can be improved or calibrated using effluent sample collection representing the range of event types and flow conditions that occurred at the site during the duration of monitoring.

2 RESEARCH BACKGROUND

In 2011 the US Environmental Protection Agency approved the Lake Tahoe TMDL, providing a "roadmap to improve Lake Tahoe's clarity" (Feinstein, 8/16/2011). The Lake Clarity Crediting Program (Crediting Program; LRWQCB and NDEP 2009) provides the framework to track pollutant load reduction actions in urban runoff associated with the Lake Tahoe TMDL via Lake Clarity Credits, and employs a suite of Tahoe Basin urban stormwater management tools to support TMDL implementation. The Lake Tahoe TMDL analysis has identified that fine sediment particles (<16μm; FSP) are the primary pollutant of concern impacting lake clarity. It is estimated that the urban lands, which comprise 10% of the total drainage, contribute 72% of the average annual FSP load to Lake Tahoe (LRWQCB and NDEP 2010). The Crediting Program recommends the use of the Pollutant Load Reduction Model (PLRM; NHC et al. 2009), an urban hydrology and water quality model, to estimate the average annual pollutant load from an urban catchment for two different representations of land use conditions: pre- and post-implementation of water quality improvements. The difference in pollutant loading between the two land use conditions (or the expected load reduction) is used to define potential credits and guide annual award of credits to the local jurisdictions. The TMDL and subsequent research have identified that paved roads are the greatest potential source of FSP in urban stormwater runoff per unit area (LRWQCB and NDEP 2010). The Road Rapid Assessment Methodology (Road RAM; 2NDNATURE et al. 2010) is recommended by the Crediting Program to evaluate and track the potential FSP load generated from paved roads, and the results can be used to verify that observed road conditions are consistent with road conditions modeled in PLRM.

The long-term verification that collective water quality improvement actions result in a measurable pollutant loading benefit to Lake Tahoe requires consistent and long-term water quality monitoring. Measurement and tracking of pollutant loading trends will be conducted under the Regional Stormwater Monitoring Program (RSWMP). There is a strong need to obtain and utilize measured catchment water quality data to both quantify the effectiveness of our actions and evaluate the outputs from the estimation tool (PLRM) guiding the Crediting Program implementation. This research focused on implementing and documenting urban catchment scale monitoring that could provide valuable guidance for both long-term catchment data collection and analysis techniques to evaluate PLRM results.

2.1 RESEARCH FUNDING & RELATED EFFORTS

This document summarizes the data collection, model development and result comparisons of measured and modeled stormwater runoff and water quality data from three urban catchments in the Tahoe Basin (Figure 2.1). This research continues to build upon a series of urban stormwater research projects conducted by 2NDNATURE and NHC since 2009. The initial efforts entailed focused data collection from 2009 through 2011 to inform the water quality algorithms used in PLRMv1 and informed the development of Road RAM. The final results and recommendations are detailed in *Focused Stormwater Quality Monitoring to Inform Assumptions & Evaluate Predictive Capabilities of Existing Tools* (2NDNATURE and NHC 2012b), and included:

- Road condition (i.e., the relative amount of FSP available on the road surface and a risk to downslope water quality during a subsequent runoff event) has a significant seasonal variability with the poorest conditions consistently observed during winter and spring. Data suggests road condition is most sensitive to, and controllable by, winter road maintenance practices, specifically winter abrasive

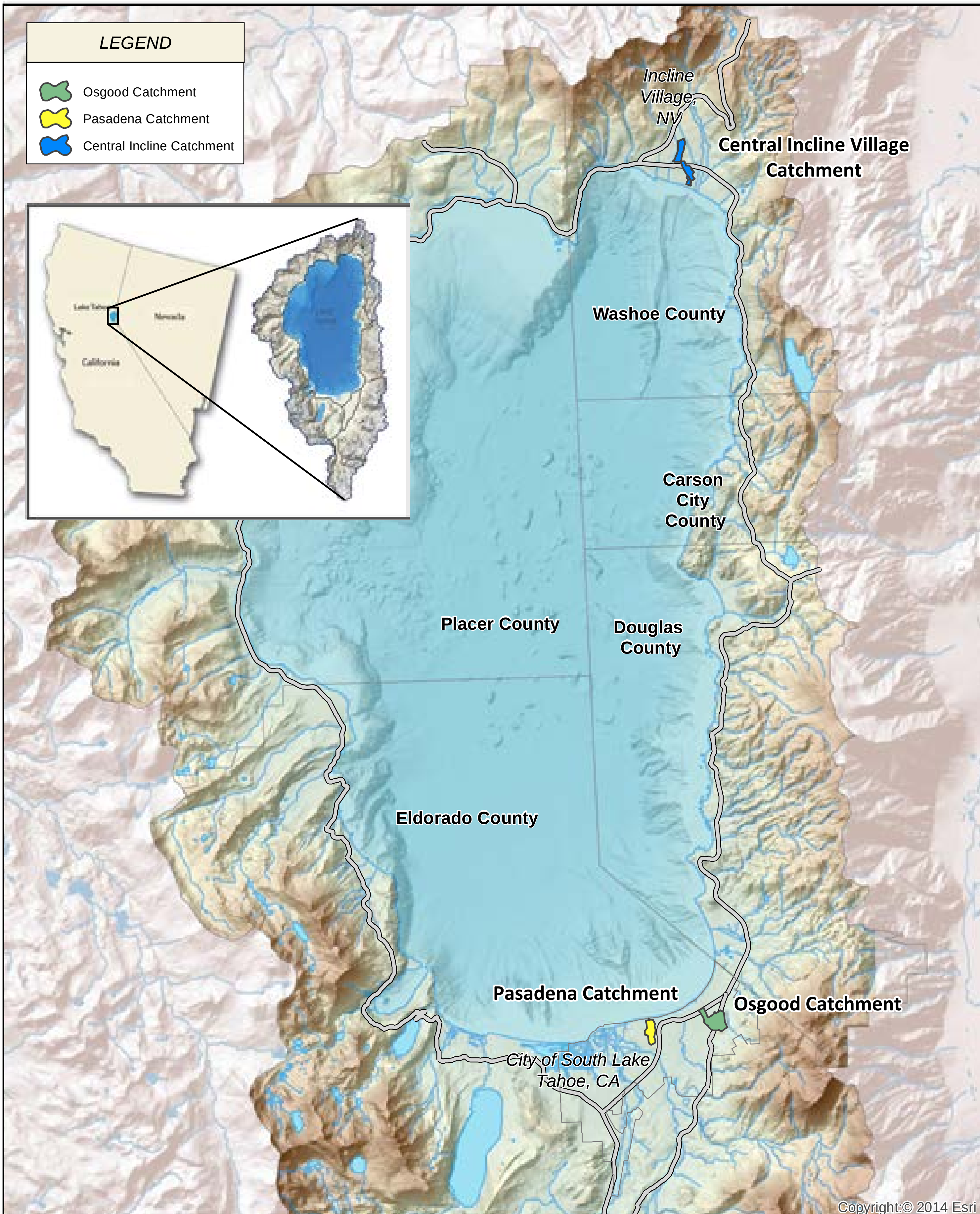

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Figure 2.1 Tahoe Overview of Catchment Locations

Miles
0 0.75 1.5 3
1 in = 3 miles
N

application and frequent street sweeping. Improvements to the PLRM Road Methodology were recommended based on this research.

- Infiltration rates on pervious road shoulders were measured at a range of sites (protected to highly disturbed), and a framework was developed to refine user inputs and adapt PLRM algorithms to better represent pervious road condition and its effects on infiltration and runoff calculations.

- A very strong correlation (significant above 99% confidence) was found between measured and modeled seasonal treated outflow volumes in wet and dry basins across a range of hydrologic conditions, suggesting the model performs well when simulating this important hydrology metric.

- FSP concentrations measured in the treated effluent suggest the PLRMv1 TSS and FSP characteristic effluent concentrations (CECs) are currently lower than achievable for typical Tahoe Basin wet and dry basins. Monitoring results also suggest that the treatment capability of these basins to achieve FSP concentrations <100mg/L is limited when inflow concentrations are greater than 300 mg/L.

In 2010 the USACE funded research, titled *Pilot Catchment Validation Study* (2NDNATURE and NHC 2012b), to test the integration of the urban stormwater management tools on a single urban catchment for WY2011. This *Pilot Catchment Validation Study* resulted in initial data collection protocols, PLRM modeling techniques, and data analysis approaches to facilitate a catchment-scale comparison of pollutant load observations with PLRM predictions for the same time period.

In November 2011, 2NDNATURE and NHC were awarded a SNPLMA Round 11 research grant to complete this effort initiated by the pilot study and expanded monitoring to 2 additional catchments for one year of monitoring. Given contracting timing, data collection occurred from March 1, 2012 to February 28, 2013, rather than on the desired water year calendar (October 1, 2011 to September 30, 2012). This technical report is the final deliverable for the most recent funding and the instrumentation, data management, modeling approach and data analysis lessons learned from this effort will guide future FSP loading data collection and model evaluation efforts, particularly those envisioned for RSWMP.

2.2 RESEARCH GOAL & OBJECTIVES

The controlled urban catchment study strategically characterizes road maintenance practices, assesses land use and catchment conditions, measures discharge and pollutant concentrations, calculates loads, and assesses modeled and tool derived estimates during a complete monitoring year. The research objectives that drove the data collection, data management, and data analysis methods are documented below. The locations within the report where the specific methods and results can be found are also provided for easy reference.

1. **Obtain and report reliable seasonal and annual urban catchment FSP loads that can compared across outfalls and allow detection of decreasing trends in urban pollutant loading as a result of effective management actions, should they exist.** There is a need for long-term water quality data to address key Lake Tahoe management objectives. Of particular interest is obtaining consistent datasets to document pollutant loading trends to Lake Tahoe over time and, if decreasing trends are detected, to verify that they are attributable to effective cumulative management actions and not natural variability or sampling error (see Chapter 6.1). Long-term stormwater monitoring will be conducted under RSWMP, and this research

aimed to inform the key criteria considered when selecting, instrumenting and monitoring a location to meet these RSWMP objectives (see Chapter 3.1).

2. **Identify the role and potential format of meteorological datasets when interpreting measured data.**
   a. Identify methods to constrain the variability associated with seasonal and annual climatic differences when comparing stormwater runoff volumes and pollutant loads across sites and over time (see Chapter 6.1).
   b. Evaluate the effect of antecedent weather conditions on observed road condition (see Chapter 5.2).

3. **Standardize catchment outfall water quality monitoring and reporting.** The research team strategically instrumented catchments to collect high resolution FSP water quality data to characterize catchment loading (see Chapter 3.2). Simple reports are provided as a recommended means for RSWMP to evaluate the long-term water quality benefit based on management actions irrespective of meteorological variability and in spite of instrument failures (see Chapter 6.1).

4. **Document and test the influence that road practices and associated road conditions have on urban catchment FSP loading.** Daily road maintenance logs were provided to the research team by jurisdiction personnel and periodic Road RAM observations were conducted at road segments throughout the contributing catchments to:
   a. Identify the data requirements and factors influencing road condition and the role road maintenance practices have on changes in road condition (see Chapter 5.2).
   b. Evaluate the relationship between road conditions and water quality draining to the lake. Roads are the priority land use affecting pollutant loading to the lake, and there is a need to understand how temporal and spatial differences in road condition influence pollutant loading from an urban catchment (see Chapter 6.2).

5. **Generate comparable PLRM estimates for the site and time period monitored to improve PLRM model development guidance, inform potential future PLRM improvements, and refine the expectations and limitations of comparing measured and modeled stormwater pollutant loading datasets**. The hydrologic approach used in PLRM provides a model structure that can predict runoff volumes at the time scales important to the Lake Tahoe TMDL (i.e., average annual). PLRM developers made a number of design decisions that simplified or automated algorithms to streamline use of the tool for the intended user group and to reduce data input needs. For this research, the project team developed an approach and supporting guidance to refine PLRM within the SWMM platform to generate and access volume and FSP estimates on the short-duration time scales needed for comparison to measured data. This research focused on identifying proper data collection, modeling, and analysis techniques to perform this evaluation appropriately (see Chapters 3.3, 7.1 and 7.2).

2.3 RESEARCH APPROACH

A series of data and information were used to document the runoff volumes and FSP pollutant loading from 3 urban catchments, evaluate the influence of changing road conditions on these pollutant loads, and build representative PLRM models to compare to the measured water quality datasets. Three urban catchment outfalls (see Figure 2.1) were selected, instrumented and monitored for one complete year (March 1, 2012 to

February 28, 2013). The selected water quality monitoring methods targeted cost effective data collection techniques that could obtain precise and repeatable stormwater discharge and FSP concentration datasets. A standardized annual urban outfall monitoring format to summarize the results is developed and recommended. Chronologies and details of road maintenance practices conducted in each catchment were collaboratively defined and reported by the local jurisdictions and the research team. Road condition was periodically documented using Road RAM within each monitored catchment. Catchment land use distributions and land use conditions were determined using best available information. Readily available nearby meteorological data for the year was obtained and used to simulate PLRM pollutant loading for the monitoring interval and provide climatic context of the monitoring period.

2.4 DOCUMENT STRUCTURE

This chapter (**Chapter 2**) provides the research purpose, funding mechanisms, and an overview of the how the collected and modeled data are analyzed to meet the research objectives. **Chapter 3** documents the site selection, data collection, data management, and data analysis techniques, as well as the methodology followed to build and refine the PLRM catchments for each selected site. **Chapter 4** summarizes the specific water year conditions critical to interpreting the context of these monitoring and modeling results, including the site-specific precipitation and air temperature data required as SWMM inputs. **Chapter 5** reviews the data and associated findings from the road condition observations, including road segment, road class and catchment Road RAM scores on seasonal and annual time scales. The specific temporal results are also examined with respect to antecedent weather events and road maintenance actions. **Chapter 6** summarizes the catchment outfall water quality data (discharge and FSP concentrations) for all 3 catchments, including an annual catchment status summary that includes key metrics to compare results over time and across sites. The outfall data is also compared with respect to the road conditions observed throughout the catchment to evaluate the influence of this land use on the overall catchment pollutant signal. **Chapter 7** compares the measured data to the modeled PLRM outputs using the seasonal and annual metrics identified in Chapter 6.

3 MONITORING METHODS

Due to funding delays, the monitoring duration could not be completed over a water year (Oct 1- Sept 30) as desired and recommended in the future. Instead the start of the monitoring period was selected to coincide with the start of the Spring Snowmelt season (March 1), as defined in Lake Tahoe Municipal NPDES permit (Table 3.1; LRWQCB 2011). Given that this monitoring is continuing as part of a long-term monitoring program in support of the Lake Tahoe TMDL, aligning the research with these established definitions ensured a more appropriate translation to the future use of and need for the datasets. All future annual monitoring should be initiated at the start of the water year to standardize comparisons across sites and between years.

Table 3.1. Seasons as defined in Lake Tahoe Municipal NPDES permit (LRWQCB 2011). Season definitions are based on the historic Tahoe Basin hydrologic patterns of fall/winter rain and snow storms, spring snowmelt, and summer thunderstorms.

Season	Start	End
Fall/Winter	October 1	February 28
Spring Snowmelt	March 1	May 31
Summer	June 1	September 30

Measured and modeled data from March 1, 2012 - February 28, 2013 (termed the monitoring period) included:

- Nearby available weather stations managed by others that were assumed to be relevant to the precipitation and temperature conditions driving the hydrology monitored at each catchment outfall.
- Catchment drainage area and drainage routing for each monitored catchment outfall.
- Catchment GIS analysis of urban land use distribution and applicable conditions during the year of monitoring.
- Road maintenance logs managed by the respective jurisdiction to document the chronology of abrasive applications and pollutant recovery.
- Periodic observations of road conditions within each catchment via Road RAM assessments.
- Measured 10-minute discharge and turbidity at each catchment outfall.
- PLRM models using the SWMM platform for each catchment
- SWMM modeled 10-minute discharge and turbidity at each catchment outfall

An overview of the key data collection, model generation, data management and analysis methods is provided below. A data collection plan (2NDNATURE and NHC 2012a) was finalized in February 2012 and provides additional detail on the research objectives, site selection process, data collection strategy, and data analysis and management protocols. Further details not included in the data collection plan, but considered important for future monitoring efforts is included in Appendix A.

3.1 CATCHMENT SELECTION & GIS ANALYSIS

Resources allowed the instrumentation and monitoring of 3 catchment outfalls (see Figure 2.1) for one complete year. Key criteria for selection included jurisdictional cooperation to provide maintenance records to the research team, direct connection of outfall discharge to Lake Tahoe, and catchments where water quality improvement strategies were priorities for the respective jurisdictions to achieve their long-term Lake Tahoe TMDL goals. Below is a brief description of each catchment, including the rationale for its selection.

Osgood (City of South Lake Tahoe; Figure 3.1A)

- Osgood catchment is dominated by residential (multi-family and single-family) land uses. The upper portion of the catchment is steep and includes the main thoroughfares to Heavenly Ski Resort. A larger catchment (Keller Canyon, not shown) is intermittently connected to the catchment outfall during times of high baseflow. Stormwater generated within the catchment is routed into the Osgood Basin through a pre-treatment settling basin prior to discharge to the wet basin. The wet basin outlet is less than ½ mile from the Lake.
- Selection rationale: Osgood was instrumented and monitored during the previous year (2NDNATURE and NHC 2012b) and continued monitoring was extremely cost effective based on the research team's familiarity with the site and established monitoring infrastructure.

Pasadena (City of South Lake Tahoe; Figure 3.1B)

- A low gradient, residential catchment with a recently completed water quality improvement project that included installation of pervious surfaces, perforated drainpipes, treatment vault and cartridge filters. Stormwater is routed through a treatment vault and two Contech Stormfilter cartridge filters located approximately 100 ft upstream of Lake Tahoe before discharging directly into the lake.
- Selection rationale: Pasadena had been previously monitored during Lake Tahoe TMDL development and directly discharges to the Lake.

CIV (Washoe County; Figure 3.1C)

- The relatively steep catchment includes multi-family residential and commercial land uses, in addition to highly-trafficked roads (Village Blvd). Stormwater from the upper catchment is routed to a Vortechnics treatment vault at the intersection of Village and Lakeshore Boulevards. A flow splitting system routes a portion of stormwater entering the vault under Lakeshore Blvd and into a ditch that flows directly to the Lake. Outflow from the treatment vault is split within the vault, with a portion of the flows routed under Lakeshore to the ditch and a portion discharging to a low flow channel along Lakeshore that ultimately discharges to Incline Creek. Additional stormwater from the lower catchment is routed via storm drain under Lakeshore Blvd to the ditch.
- Note, the catchment delineated for this effort varies from the previous delineation by Wood Rogers for Washoe County. The differences are predominantly in the flat-lying athletic ballfields behind the high school and within the lower catchment between Juanita and Lakeshore Boulevard. The differences between the two efforts will not significantly affect predictions of pollutant loading, and the research team does not recommend changing the existing Washoe County delineation based on these differences.
- Selection rationale: CIV is a high priority catchment for the jurisdiction and directly discharges to the Lake.

For each catchment, the catchment spatial characteristics are summarized in Table 3.2 and the road attributes are summarized in Table 3.3. These static inputs were used in the development of the PLRM models described in Chapter 3.3, as well as to evaluate the measured catchment water quality described in Chapter 3.2.3. Appendix A provides details on the spatial analysis methods used to calculate these characteristics.

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Figure 3.1A Osgood Catchment Location Map

Feet
0 250 500 1,000
N

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Figure 3.1B Pasadena Catchment Location Map. Note, the Rufus Allen weather station is not used in analysis due to instrument failures.

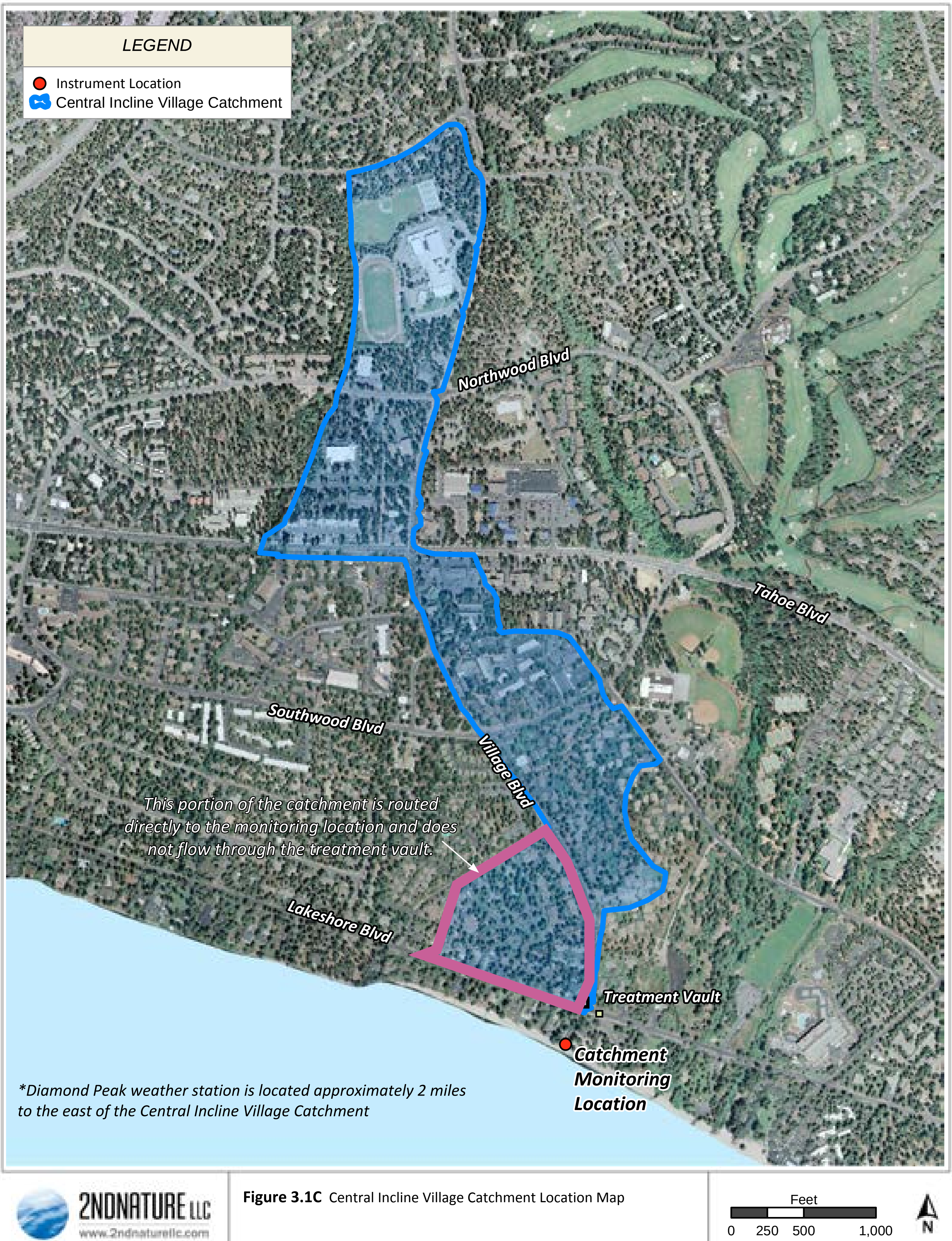

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Figure 3.1C Central Incline Village Catchment Location Map

Table 3.2. Summary of key catchment characteristics developed using available GIS layers and reconnaissance level field surveys. There are a multitude of attributes that are required for PLRM input and this table only provides a selection of those inputs for discussion in this report.

Characteristic	Osgood	Pasadena	Central Incline Village
Location	South Lake Tahoe, CA	South Lake Tahoe, CA	Incline Village, NV
Total Area (ac)	138.5	71.4	116.6
Impervious Area (%, ac)	26%, 35.4	31%, 22.4	42%, 48.4
Directly Connected Impervious Area, DCIA (%, ac)	73%, 25.7	35%, 7.9	45%, 21.8
Road DCIA (%,ac)	36%, 12.6	15%, 3.3	8%,3.8
Average Slope (%)	5%	1%	6%
# Sub-Catchments	3	4	3
Land Use Distribution (acres)			
Primary Roads (PR)	7.5	0	1.5
Secondary Roads (SR)	14.5	12.2	13.8
Commercial Industrial Communications Utilities (CICU)	9.3	2.3	28.7
Multi-Family Residential (MFR)	26.3	9.8	53.8
Single Family Residential (SFR)	35.6	37.1	7.4
Unimpacted Vegetation (EP 1-5)	45.2	10	11.5
Road Directly Connected Impervious Area			
PR (%, ac)	100%, 5.3	*n/a*	50%, 0.7
SR (%, ac)	72%, 7.3	38%, 3.3	50%, 5.5
Private Parcel Infiltration BMP Installation, % TRPA Certification			
CICU (%, ac)	28%, 2.6	11%, 0.2	90%, 25.8
MFR (%, ac)	25%, 6.5	21%, 2.1	35%, 19.0
SFR (%, ac)	26.%, 9.3	18%, 6.6	63%, 4.7

Table 3.3. Catchment road attribute summary by road miles, developed using available GIS layers. Dashes (-) denote the attribute is absent in the catchment. Note, mileage of road shoulder attributes differs from road attributes due to hydrology within catchment (i.e., only one side of road may be routed to the catchment outfall).

Catchment		Osgood	Pasadena	CIV
Total Road Miles		***4.1***	***3.2***	***2.5***
Road Attribute		**Catchment Miles (% of Catchment)**		
Road Risk	Primary High Risk (PHR)	0.1 (3%)	-	0.2 (10%)
	Primary Moderate Risk (PMR)	0.2 (5%)	-	0.9 (35%)
	Primary Low Risk (PLR)	0.7 (17%)	-	0.1 (4%)
	Secondary High Risk (SHR)	0.2 (5%)	0.2 (6%)	0.5 (21%)
	Secondary Moderate Risk (SMR)	2.9 (70%)	0.8 (25%)	-
	Secondary Low Risk (SLR)	-	2.2 (69%)	0.8 (30%)
Road Surface Integrity	Poor	0.6 (15%)	1.2 (40%)	0.0 (0.1%)
	Moderate	2.8 (68%)	1.2 (37%)	0.7 (29%)
	Good	0.7 (16%)	0.7 (22%)	1.8 (71%)
Road Shoulder Condition	Erodible	1.5(22%)	4.0 (69%)	0.3 (10%)
	Protected	0 (0%)	0 (0%)	0.7 (20%)
	Stable	3.5 (49%)	0 (0%)	0.3 (7%)
	Stable & Protected	2.1 (29%)	1.8 (31%)	2.1 (62%)

Catchment		Osgood	Pasadena	CIV
Total Road Miles		**4.1**	**3.2**	**2.5**
Road Attribute		**Catchment Miles (% of Catchment)**		
Road Shoulder Connectivity	DCIA	5.9 (82%)	0.04 (1%)	3.1 (90%)
	ICIA	1.3 (18%)	5.7 (99%)	0.3 (10%)
Road Shoulder Compaction	High	6.4 (89%)	5.7 (99%)	0.43 (9%)
	Moderate	0.03 (<1%)	0 (0%)	0.57 (5%)
	Protected	0.8 (11%)	0.5 (1%)	2.47 (72%)
	n/a	0 (0%)	0 (0%)	0.37 (11%)

3.2 CATCHMENT DATA COLLECTION

This research integrates a number of reliable and cost-effective stormwater monitoring techniques to constrain, sample and model urban pollutant generation in the Osgood, Pasadena and Central Incline Village catchments. Over one complete year from March 1, 2012 to February 28, 2013, field personnel used a variety of methods to collect the following data:

- Meteorology – Air temperature and precipitation data are important for understanding the climatic context of the other monitoring data. In addition, the continuous air temperature and precipitation data are critical SWMM inputs to generate model simulations to compare to the monitored data collected from the catchment outlet. The researchers did not install, collect or manage any meteorological data, and instead utilized the closest available weather station managed by others.

- Chronology of road maintenance practices - The primary controllable driver of road condition (amount of FSP on the road surface available for transport at any point in time) is the respective road maintenance practices both locally and regionally as FSP is generated, accumulated and effectively transported. The research team attempted to coordinate and obtain detailed road maintenance practice chronology data from the respective jurisdictions.

- Road condition tracking – A central assumption of the Lake Tahoe TMDL is that the road network within an urban catchment can have a significant influence on the FSP loading generated within the catchment. Therefore, periodic assessment of road condition using Road RAM to compare to event and seasonal measured catchment FSP loads provides critical data to test this hypothesis.

- Catchment outfall water quality monitoring – In order to quantify and track the pollutant loading to Lake Tahoe over time, long-term continuous monitoring at the catchment outfall is necessary. The catchment water quality signal was monitored using high-resolution discharge and FSP concentration and monitoring to reasonably quantify the seasonal and annual FSP loading from these catchments.

- Treatment BMP condition – Large-scale, flow-through Treatment BMPs are often constructed at the terminal end of a catchment to reduce pollutant loads in urban stormwater. The general understanding of the timing and level of maintenance for each catchment's treatment BMPs was recorded to provide context for the water quality measurements taken below the treatment BMPs at the catchment outfalls. However, resources for this research were not allocated to track the treatment performance of each BMP throughout the monitoring period.

The following sections describe the data collection, QA/QC, and simple data translations for each of the above data types. General data management practices used throughout this research are then described. More specific details on all data collection, quality assurance, and management protocols are included in Appendices A and B.

3.2.1 METEOROLOGY

Relevant meteorological data was needed for both the south shore and north shore sites to represent the weather experienced at each monitoring site. Research resources were limited, so meteorology data was obtained by identifying active weather stations with publically provided data. In the South Shore, CSLT operates and maintains a network of Davis Instrument weather stations throughout the city, including the Fire Station weather station at the intersection of Pioneer Trail and Ski Run Boulevard (see Figure 3.1A) and the Rufus Allen weather station at the City maintenance yard at 1160 Rufus Allen Boulevard (see Figure 3.1B). In Washoe County, DRI operates the Incline Creek weather station in Incline Village, NV at the base of the Diamond Peak ski resort (see Figure 3.1C), and data can be downloaded to a CSV file from http://www.wrcc.dri.edu/weather/incc.html. Air temperature and precipitation are recorded on 10 (South Shore) or 30-minute (North Shore) intervals and downloaded monthly by field personnel.

During the monitoring period, there were inconsistencies with the data collection at all three sites. Data gaps at the CSLT weather stations were QAQC'd using other stations in the South Shore (City Lab site located on Tata Lane and a 2NDNATURE station located on Eloise Avenue). During this analysis, the Rufus Allen weather data was deemed too inconsistent and not used in subsequent analyses. The Fire Station data was therefore used for both Osgood and Pasadena catchments. Data gaps at the DRI Diamond Peak site were supplemented with other weather stations on the north shore, including Tahoe City (048758; www.wrcc.dri.edu) and Mountain Camp (KVINCLI5; www.wunderground.com). Additionally, during the winter months there were issues with the instruments' ability to fully capture the larger snow events. According to the user manual (http://www.davisnet.com/product_documents/weather/manuals/07395-096_IM_07720.pdf), the Davis Instruments heated rain collectors can melt snow at a rate of 0.25 inches (6 mm) of liquid precipitation per hour. However, the instruments may not be able to keep up with larger rates of snowfall. The research team adjusted the precipitation record for any larger snow storms that likely exceeded the capability of the CSLT and DRI weather stations by using the snow water equivalent (SWE) time series for the SnoTel gauge at Fallen Leaf Lake (South Shore) and Marlette Lake (North Shore) and the ratio of average annual precipitation values established in PLRM for the relevant meteorological grids.

3.2.2 ROAD MAINTENANCE PRACTICES

Road condition is defined as the relative amount of FSP available on the road surface at the time of observation, and Tahoe Basin researchers have suggested that road maintenance actions have a significant influence on the relative amount of FSP on a road surface at any given time (Kuhns et al. 2010; NTCD and DRI 2011; 2NDNATURE et al. 2010). Road condition varies in the Tahoe Basin as the balance between changes in road pollutant sources (e.g., abrasive application, material pulverization by vehicles, road surface degradation, road shoulder erosion, etc.) and road pollutant sinks (e.g., sweeping, snow haul, traffic or wind transport, rain washoff events, etc.) over time. In addition to the meteorology data described above, understanding the spatial and temporal sequence of road maintenance practices performed by the jurisdiction is critical to evaluating the patterns and trends in road condition over time. Each jurisdiction manages their roadways differently, though typically every jurisdiction conducts their operations using defined maintenance zones or road networks. During snow events or freezing conditions, abrasives are applied in routes. Similarly, snow plowing activities and street sweeping follow zones or pre-determined routes. The research team worked with the CSLT and Washoe County staff to document the abrasive and pollutant recovery practices conducted by each jurisdiction. Table 3.4 summarizes the general road maintenance practices for abrasive application and pollutant recovery actions by jurisdiction, as provided to the research team by the stormwater managers or maintenance personnel.

Table 3.4. Summary of road maintenance practices for City of South Lake Tahoe and Washoe County, including key components of their abrasive application and pollutant recovery practices are provided. Information provided by the respective jurisdiction's stormwater managers and maintenance personnel.

Jurisdiction	Abrasive Application & Tracking			Pollutant Recovery			
	Spreader Equipment	Abrasive Type	Lane Miles where applied (% of Jurisdiction)	Action Types	Sweeper Equipment	Frequency	Location
CSLT	Monroe Spreader + Plow	Eagle Valley Basin Volcanic Cinders; Huck Salt	52 miles (20%)	Sweeping	Tymco (regen air); Athey Mechanical Broom	Winter – Event-Based; Summer – 2x	All Roads
Washoe County	Epoke	Western Material Spec B Sand; Huck Salt	75 miles (50%)	Sweeping	Tymco DST6; Tennant Sentinel	Winter – Daily as weather allows; Summer – every 6 weeks	Primary roads first, then all roads

Road class is the term used by Road RAM (2NDNATURE et al. 2010) to describe the combination of road maintenance activities that influence the sources and sinks of pollutants on the road surface, or said another way, the abrasive application, plowing or sweeping practices that influence road condition. The information in Table 3.4 is used to define the jurisdiction's road class, per the guidance described in the Road RAM User Manual for Step 3 – Classify Roads (2NDNATURE et al. 2010), shown in Table 3.5. Road class is defined specifically for each jurisdiction, dependent on their maintenance actions, and cannot be used to interpret another jurisdiction's Road RAM data. For example, 'high' abrasive application actions likely happen at a different frequency or at a different rate using different equipment (see Table 3.4) in CSLT than in Washoe.

Table 3.5. Road class definitions for City of South Lake Tahoe and Washoe County, including abrasive application and pollutant recovery. These definitions are based on the practices defined in Table 3.4 and were vetted by the respective jurisdiction's stormwater managers and maintenance personnel.

Jurisdiction	CSLT	Washoe County
	Abrasive Application & Tracking	
High (A)	Highly trafficked, steep roads where abrasives are applied during every storm and may be applied multiple times during 1 storm event.	Highly trafficked, steep main roads and critical intersections where abrasives are applied during every storm and may be applied multiple times per event.
Moderate (B)	Minimally trafficked steeper roads and highly trafficked flat roads (arterial residential roads) where abrasives are applied during most storms, but typically only 1 time per storm event.	Moderately trafficked main roads where abrasives are applied during most storms. Most often these roads are plowed first, and then abrasives are applied as necessary.
Low (C)	Flat roads where abrasives are only applied during extreme events, but are low priority and typically targeted after other roads have been sanded.	Minimally trafficked secondary roads where abrasives are infrequently applied and only during extreme icy conditions.
	Pollutant Recovery	
High (X)	Highly trafficked roads where sweeping is conducted as conditions allow during winter months. Include Pioneer Trail, Ski Run Boulevard, and main thoroughfares to Heavenly Ski Resort.	Roads designated as "Mains" in the Washoe County Maintstar system. These roads are swept as soon as conditions allow during the winter months.
Moderate (Y)	n/a	Moderately trafficked residential roads. These roads are swept as soon as conditions allow, but after the Mains have been swept.
Low (Z)	Less-trafficked residential roads where sweeping occurs in winter months as resources and conditions allow, but are typically targeted during the biannual, jurisdiction-wide sweeping in the summer and fall.	Low traffic residential roads that are not through streets. These roads are swept as conditions allow, but multiple passes are infrequent.

The definitions shown in Table 3.5 were then applied to the roads within the monitored catchments to designate the road class for all roads connected to the catchment outfall monitoring sites. Figures 3.2A-B and Figures 3.3A-B indicate the spatial distribution of abrasive application and tracking (A) and pollutant recovery (B) for CSLT and Washoe County, respectively. These two layers are intersected to create the jurisdiction road class layer, shown in Figures 3.2C and 3.3C and summarized in Table 3.6. These maps were provided to each jurisdiction's stormwater managers and road maintenance personnel for comment, and adjustments were made as necessary to most accurately reflect the actual practices within the jurisdiction.

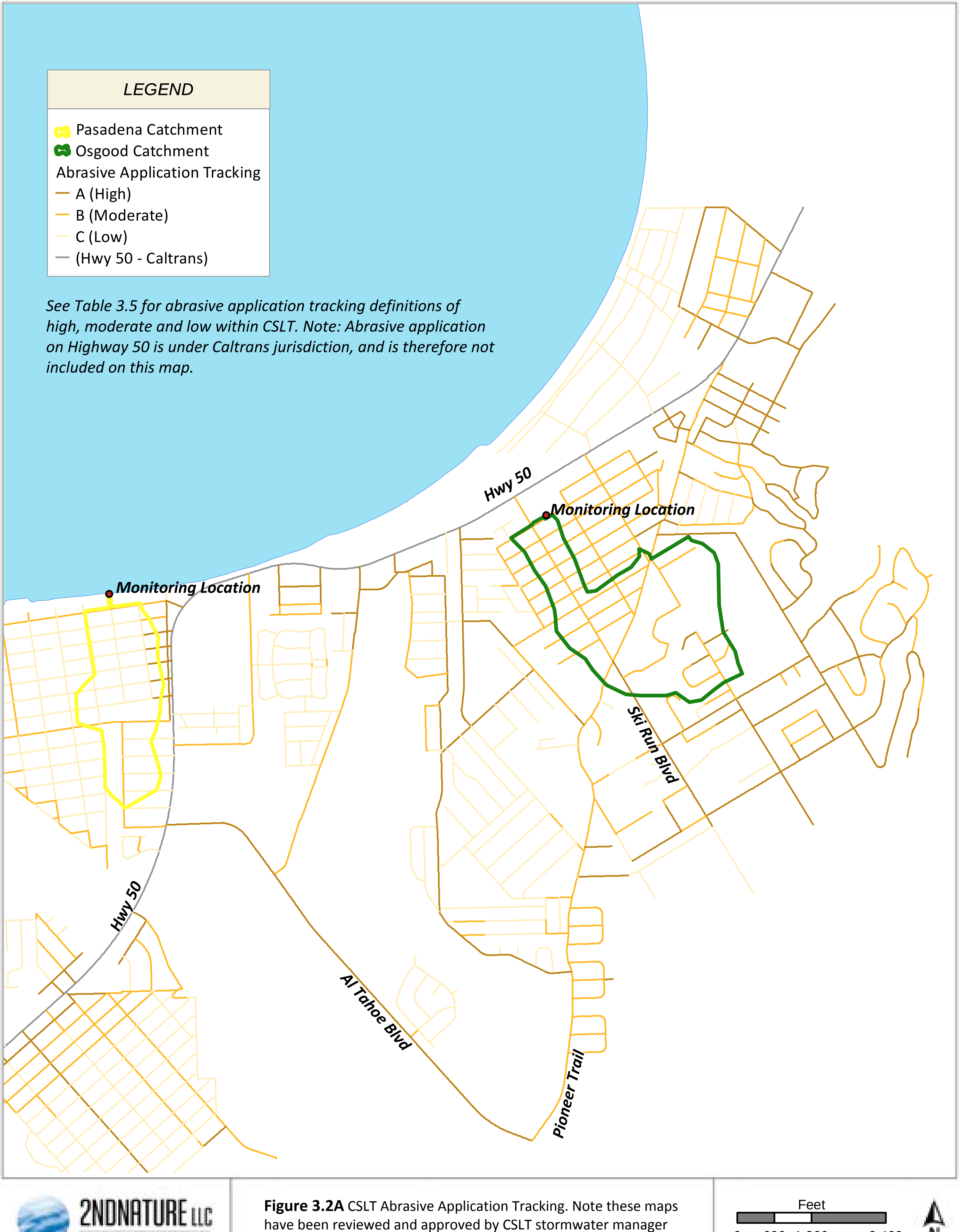

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Figure 3.2A CSLT Abrasive Application Tracking. Note these maps have been reviewed and approved by CSLT stormwater manager and road maintenance personnel for the roads within Osgood and Pasadena catchments.

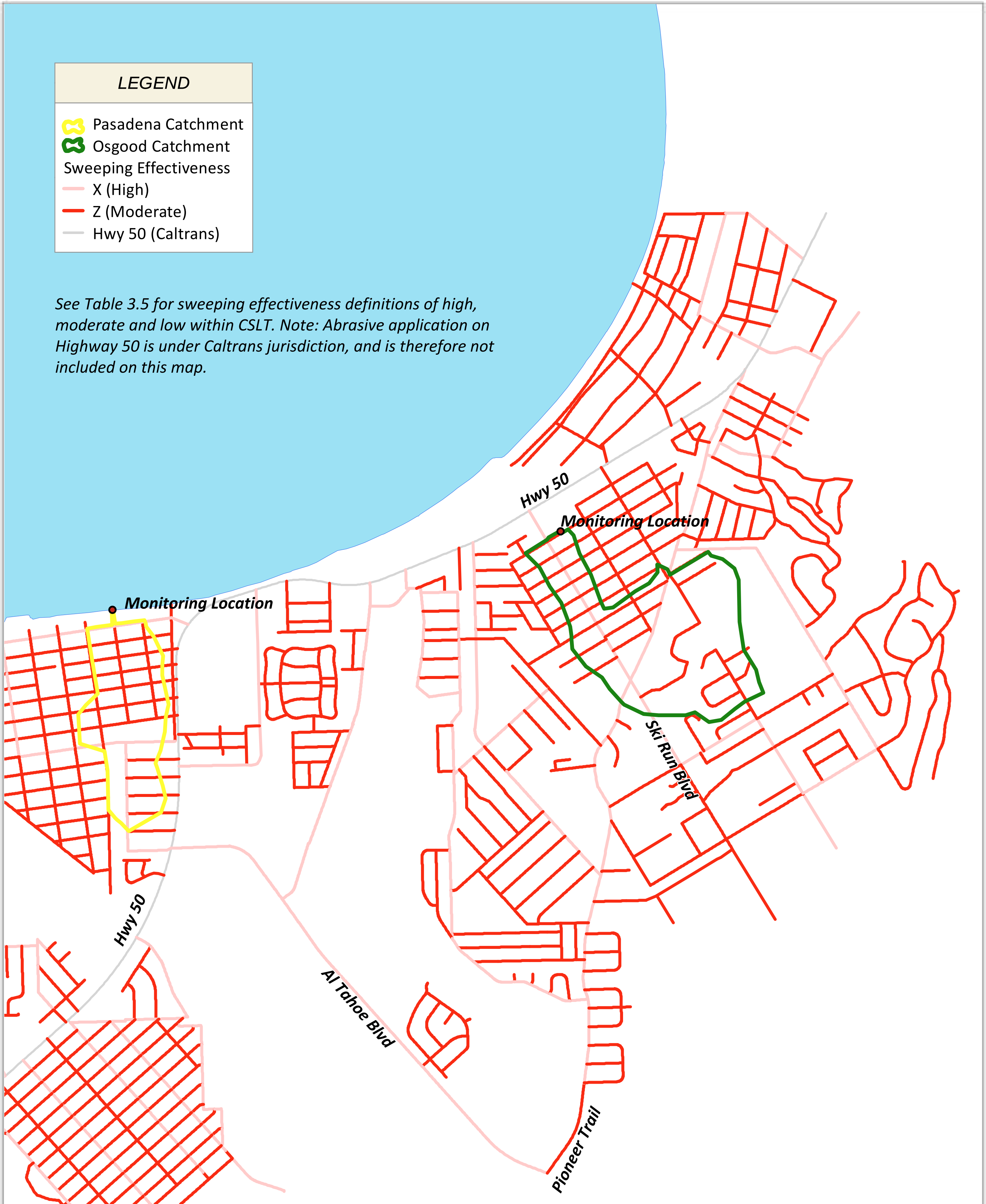

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Figure 3.2B CSLT Pollutant Recovery. Note these maps have been reviewed and approved by CSLT stormwater manager and road maintenance personnel for the roads within Osgood and Pasadena catchments.

Feet
0 600 1,200 2,400
N

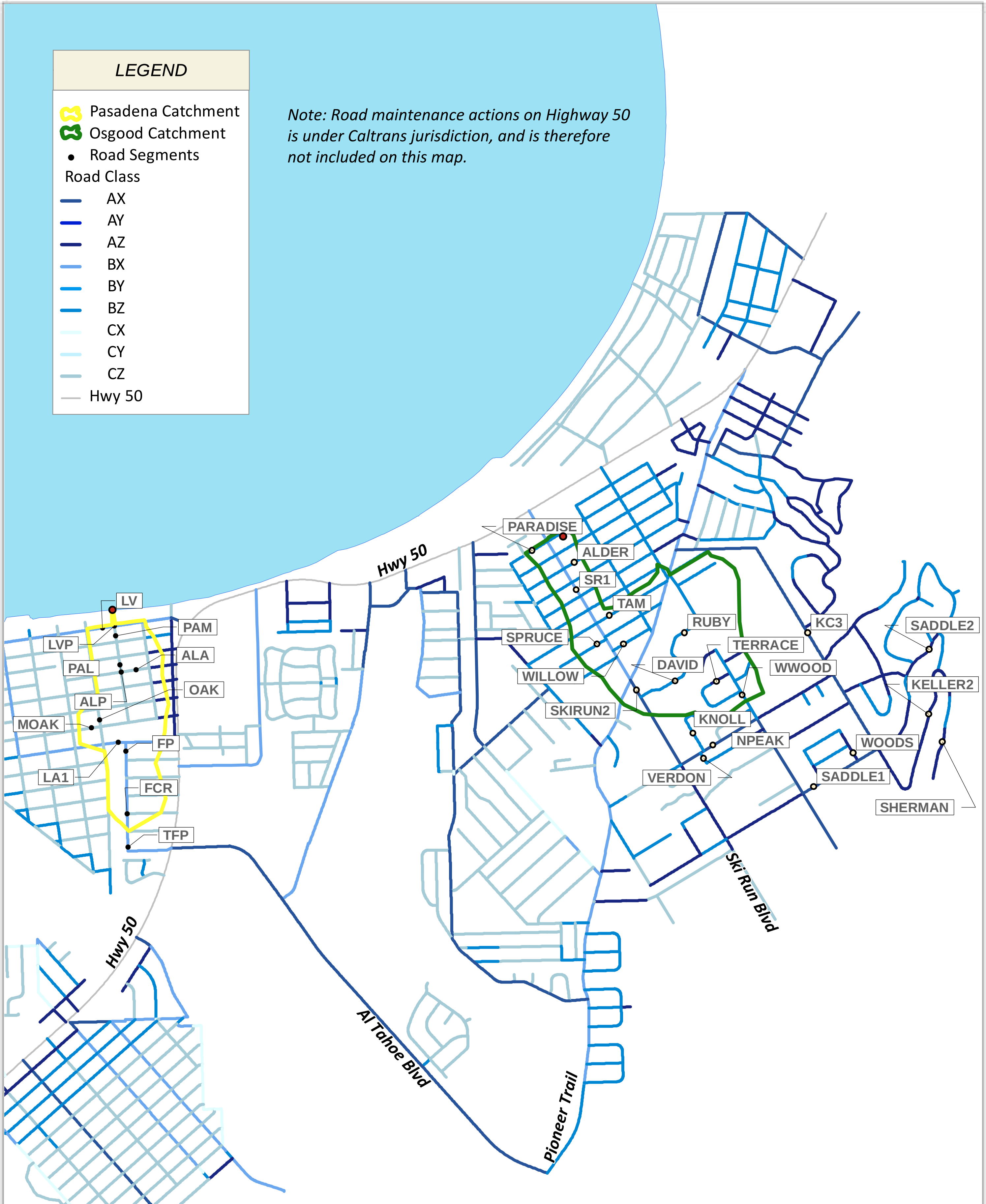

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Figure 3.2C CSLT Road Class and Road Segments. Road class is the intersection of Abrasive Application (see Figure 3.2A) and Pollutant Recovery (see Figure 3.2B).

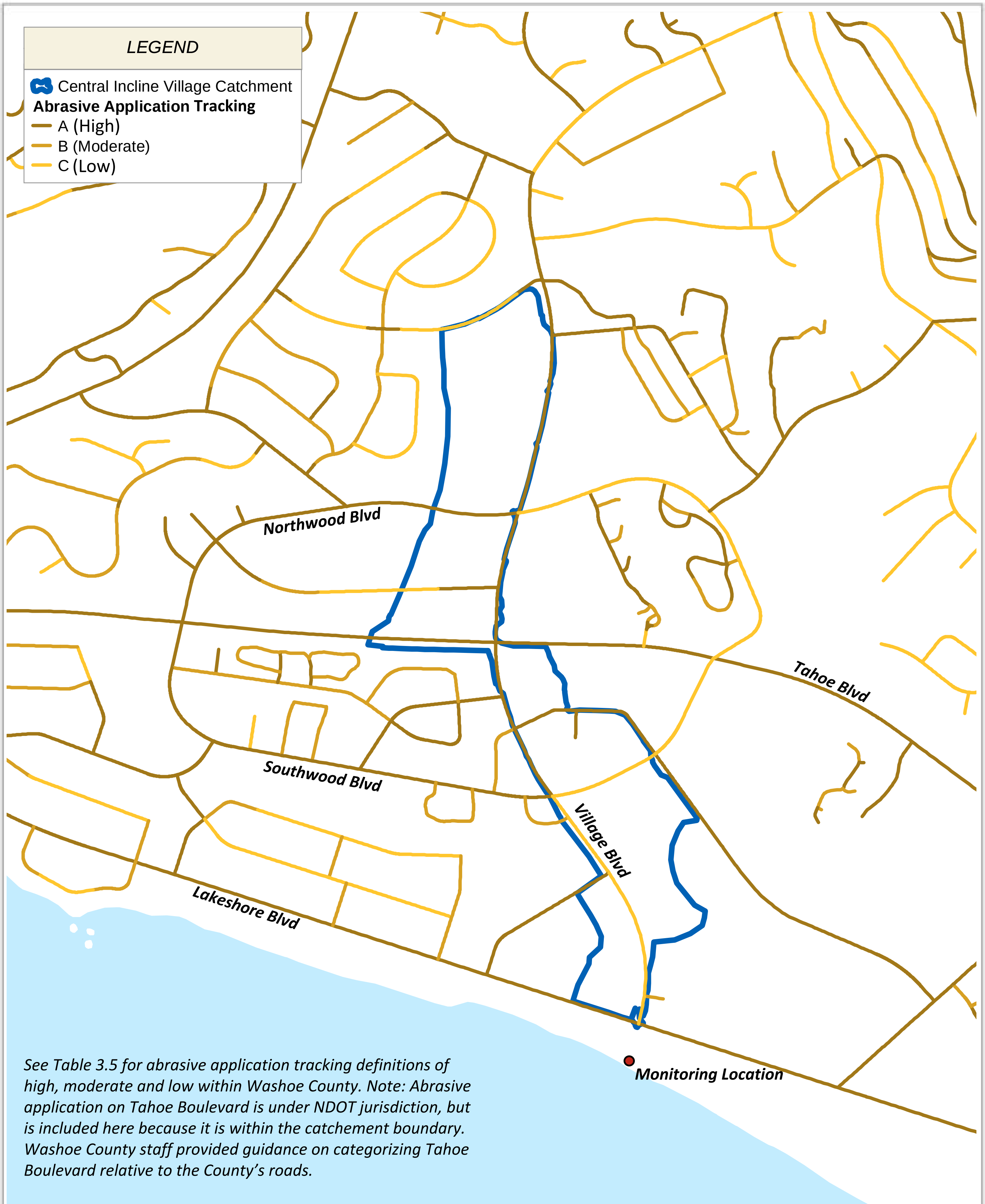

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Figure 3.3A Washoe County Abrasive Application Tracking. Note these maps have been reviewed and approved by Wahoe County stormwater manager and road maintenance personnel for the roads within the CIV catchment.

Feet
0 300 600 1,200
N

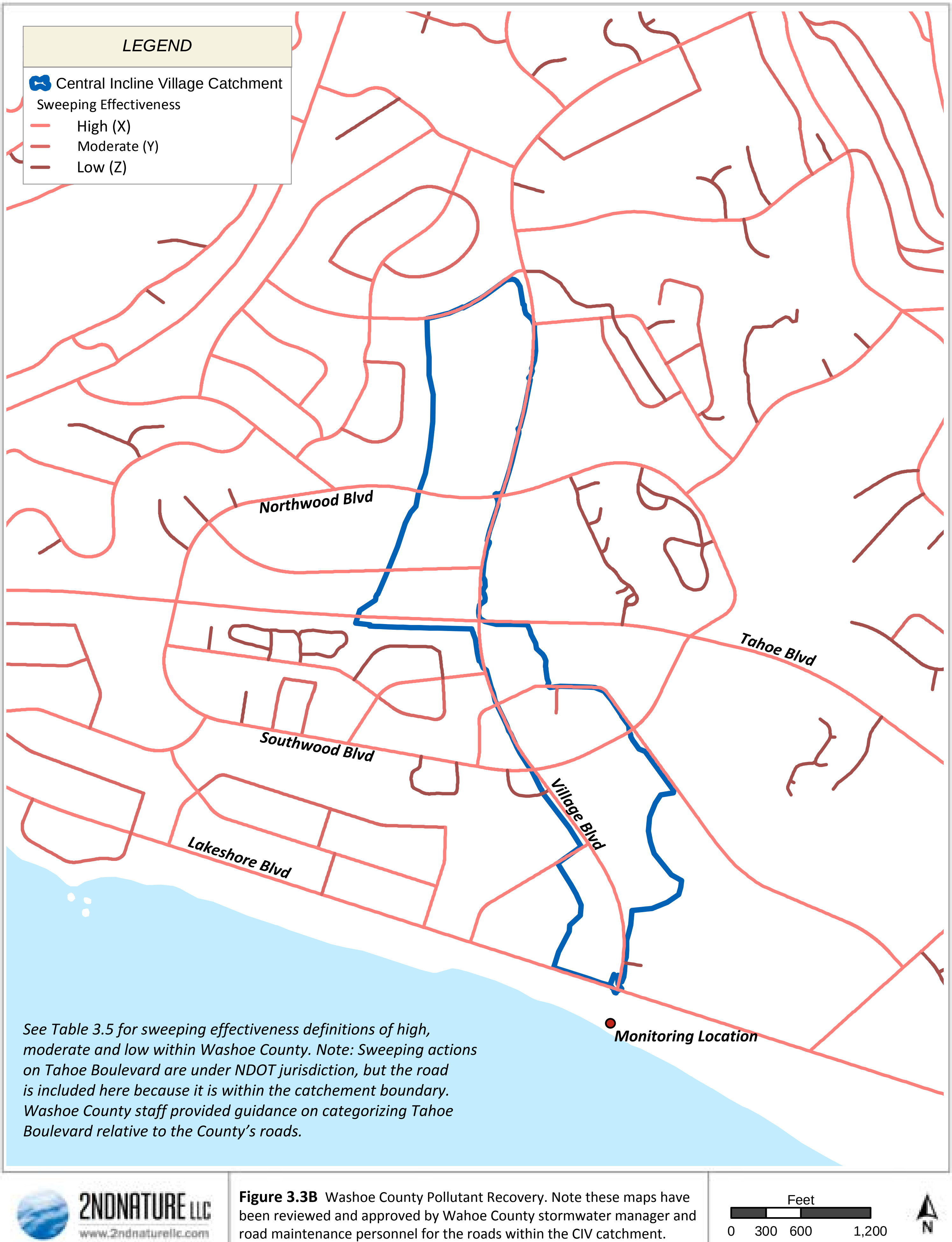

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Figure 3.3B Washoe County Pollutant Recovery. Note these maps have been reviewed and approved by Wahoe County stormwater manager and road maintenance personnel for the roads within the CIV catchment.

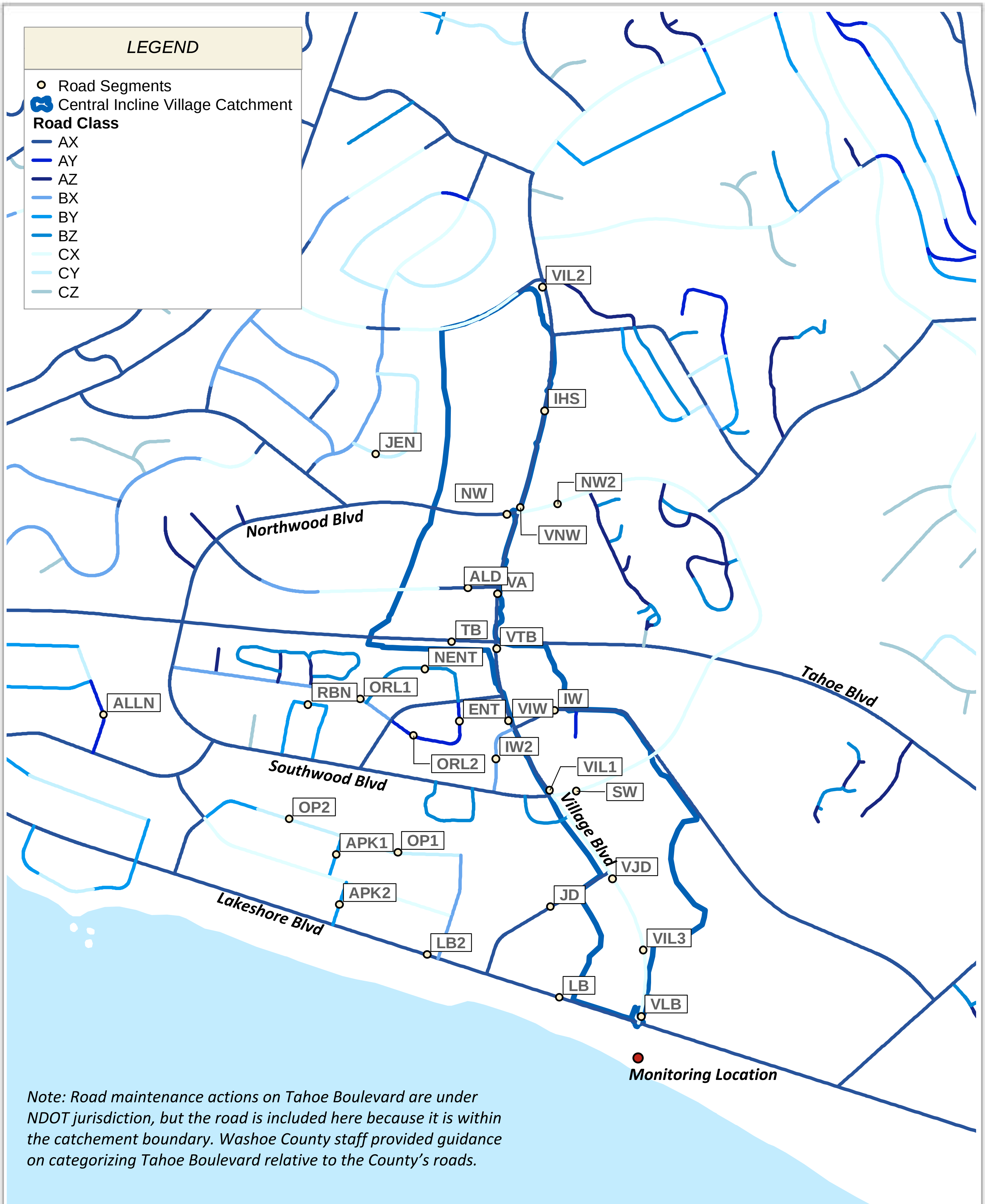

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Figure 3.3C Washoe County Road Class and Road Segments. Road class is the intersection of Abrasive Application Priority (see Figure 3.3A) and Pollutant Recovery (see Figure 3.3B).

Table 3.6. Catchment road class summary by road miles, developed using available GIS layers, and road segments. Dashes (-) denote the road attribute is absent in the catchment. Jurisdiction-specific road class is defined in Table 3.5 and shown in Figures 3.2C and 3.3C, along with the specific locations of each road segment.

Road Class	Osgood		Pasadena		CIV	
	Miles (% of Catchment)	# Road Segments	Miles (% of Catchment)	# Road Segments	Miles (% of Catchment)	# Road Segments
AX	0.1 (3.0%)	4	-	-	1.4 (68.1%)	14
AY	-	-	-	-	0.04 (1.7%)	3
AZ	0.2 (5.0%)	4	0.2 (5.8%)	-	-	-
BX	0.9 (22.0%)	1	0.7 (20.7%)	6	-	3
BY	-	-	-	-	-	3
BZ	2.9 (70.1%)	10	0.03 (0.9%)	-	-	1
CX	-	-	-	-	0.8 (30.2%)	5
CY	-	-	-	-	-	3
CZ	-	-	2.3 (72.6%)	6	-	-
TOTALS	**4.1**	**19**	**3.2**	**12**	**2.5**	**32**

Road class designations are helpful to generally understand the relative distribution of road maintenance strategies being implemented by the jurisdictions; however this classification system does not provide temporal or spatial-specific data to evaluate road condition results at a specific point in time. 2NDNATURE worked closely with the CSLT and Washoe County staff to obtain more detailed information about the spatial and temporal implementation of road maintenance practices. Both jurisdictions provided available daily logs based on their current maintenance and data management protocols.

- CSLT records abrasive application as total yards of sand/salt mixture applied by maintenance zone, assuming an 80:20 sand to salt ratio. Sweeping is recorded by location (street names or zones) and sweeper type. Given resource limitations, the CSLT maintenance crew was not able to complete action logs from October through December 2012, and therefore information is unavailable for much of the winter season. Substantial personnel changes have occurred in the CSLT stormwater and roads maintenance staff within the last two years, and a concerted effort has been made to improve data collection and management of maintenance practices. For example, starting in Winter 2012-2013, CSLT began recording sweeping actions by zone, as opposed to street name, which greatly improved our confidence in the spatial location of the road maintenance action.

- Washoe County records abrasive application as total yards of sand/salt mixture applied by maintenance zone and total miles driven in zone. Ratio of sand to salt is assumed to be 75:25. Pollutant recovery is designated as blowing, plowing, or sweeping, and includes maintenance zone and equipment type. Washoe County uses the Maintstar software package to track maintenance actions and expenditures, allowing for consistent and standardized data tracking and report generation. Maintstar data outputs were relatively easy to translate into the necessary inputs for this research.

Despite coordination and cooperation with the jurisdictions to provide available road maintenance information, the temporal and spatial resolution of the data remains imperfect to accurately document the actions conducted on the catchment road network. The maintenance zones by which the jurisdictions track actions do not perfectly align with the monitoring catchment boundaries, and therefore estimations based on the spatial distribution of the zones within each catchment were necessary to provide appropriate comparisons to the catchment road condition observations (see Chapter 5). The volume of abrasives applied was assumed to be consistent over the total miles and calculated as tons per lane mile in a catchment. While it is not true that abrasives are applied evenly across all miles within a zone (CSLT) or over all miles driven (Washoe), this adjustment was deemed the most appropriate given the information provided. Sweeping data collection lacks sufficient information to compute a standard effectiveness per sweeping effort. A number of operation or site variability factors, such as sweeping speed, road coverage, road access, road surface integrity, etc., can all influence the effect a street sweeper pass can have on subsequent road condition.

3.2.3 ROAD CONDITION OBSERVATIONS

Road RAM is a field observation and data management tool to determine the relative condition (i.e., downslope water quality risk) at the time of observation of urban roads in the Tahoe Basin. Road condition is determined by the integration of a series of standardized rapid visual proxies and simple measurements, and Road RAM results can be expressed as a road condition score (0-5) or a corresponding expected FSP concentration at the time of observations (Table 3.7). The ability of a user to implement Road RAM field protocols consistently, safely and accurately requires a half-day skills workshop and a half-day field practical.

Table 3.7. Road RAM scores relative to road condition and relative risk to downslope water quality. Scores can be translated to FSP concentrations (and vice versa).

Road RAM Score	Condition	FSP Concentration (mg/L) Range
0 - 1.0	Poor	1,592-680
>1.0 - ≤ 2.0	Degraded	679-291
> 2.0 - ≤ 3.0	Fair	290-124
> 3.0 - ≤ 4.0	Acceptable	123-53
> 4.0 – 5.0	Desired	52-23

Within each catchment, a collection of road segments were selected where Road RAM field observations were periodically performed over the course of the monitoring period. Individual road segment results were evaluated in context of the antecedent weather and road management actions prior to specific observations. These road segment results, representing a 10,000 sq-ft area, were also spatially extrapolated to a larger area (miles of roads) based on road class to examine the road condition network as a whole for specific time periods and compare to measured catchment outfall water quality. Seasonal results collected throughout the year were temporally integrated into one number that represents the volume-weighted annual catchment score, which were then compared to the modeled PLRM road condition.

USER PRECISION

Since 2011 2NDNATURE field personnel have conducted over 50 paired field observations. A single paired field observation involves two trained personnel who independently perform Road RAM observations on the same road segment at the same time to measure the field precision of the tool. This research effort contributed 15 paired observations to the ongoing Road RAM user precision assessment. On average, the difference between the scores generated has been 0.3 and 93% of the paired observations are within the accepted tolerance of 0.5 of a Road RAM score. Table 3.8 provides a summary of the field observation precision results.

Table 3.8. Road segment observation precision results. Two trained personnel performed independent observations at the same time at the same road segment, and the difference between the scores was calculated. The accepted tolerance for Road RAM precision is 0.5, and 93% of the paired observations fell within that range.

Metric	Value
Total # of precision observations	54
Average difference in scores	0.3
# observation where difference = 0 (% of total)	9 (17%)
# observations where difference >0.5 (% of total)	4 (7%)

SPATIAL EXTRAPOLATION

Thirty-one road segments were selected between Osgood and Pasadena catchments to represent the range of road classes for the CSLT (see Figure 3.2C), and thirty-two segments in Incline Village to represent Washoe County road classes (see Figure 3.3C). Because the definitions are consistent across the entire jurisdiction, road segments located outside of the catchment boundaries can be representative of road class conditions within the catchment. Table 3.6 includes the number of road segments per road attribute category.

TEMPORAL INTEGRATION

To be consistent with the long-term tracking needs required by the Crediting Program, Tahoe road conditions are best expressed on an average annual basis. Discrete Road RAM observations can be conducted at any given time to provide a snapshot of the road condition; however, in terms of pollutant loading to the lake, it is clear that the most significant loading occurs during the spring due to the combination of spring snowmelt and rain events mobilizing material available on roadways into the stormwater system (Table 3.9). The Road RAM development team defined the temporal distribution (as % weighting) of RAM observations to estimate average annual road condition as they relate to pollutant transport and the potential risk to downslope water quality. The weighting distribution favors the late winter/early spring so that priority is given to maintaining the roads to the best extent possible prior to the big spring rain events that flush the roads of fine sediment.

Table 3.9. Road RAM season definitions and research Road RAM observations by season. Season definitions include both the seasonal % contribution to the total annual FSP loading to the Lake and the seasonal % weighting used to calculate the average annual scores (see Table 8.6 in the Road RAM Technical Document for specific timing and rationale). For research observations, when multiple observations occur during the same season, a seasonal average is calculated first, and then used in the overall weighting. Note these seasonal definitions are different than those defined in the NPDES permits (see Table 3.1).

Season	% of Annual Loading to Lake[1]	% Weighting	Research Observation Dates	# of Observations
Fall (Oct 1 – Dec 31)	8%	20%	Oct 2012	1
Winter (Jan 1 – Feb 28)	13%	20%	Jan 2012 & Feb 2013	2
Late Winter / Early Spring (Mar 1 – Apr 30)	33%	40%	Apr 2012	1
Spring (May 1 – June 30)	42%	20%	May 2012	1
Summer (July 1 – Sept 30)	4%	0%	Aug 2012	1

[1] Based on basin-wide FSP load duration curve from TMDL baseline analysis (LRWQCB and NDEP 2008).

2N personnel conducted Road RAM field observations a total of 6 times from January 2012 through February 2013 (Table 3.9). The observations were conducted to represent the range of time frames defined by the Road

RAM v1 User Manual (2NDNATURE et al. 2010), and allowed for calculation of volume-weighted catchment average Road RAM scores compared to PLRM values. Seasonal Road RAM scores measured on roads throughout the catchments are spatially extrapolated (based on the road class distribution; see Table 3.6) and temporally integrated (using Table 3.9) to generate an observed annual catchment Road RAM score. Observed Road RAM scores can be compared to the predicted PLRM road concentrations to confirm the actual and expected conditions generally align.

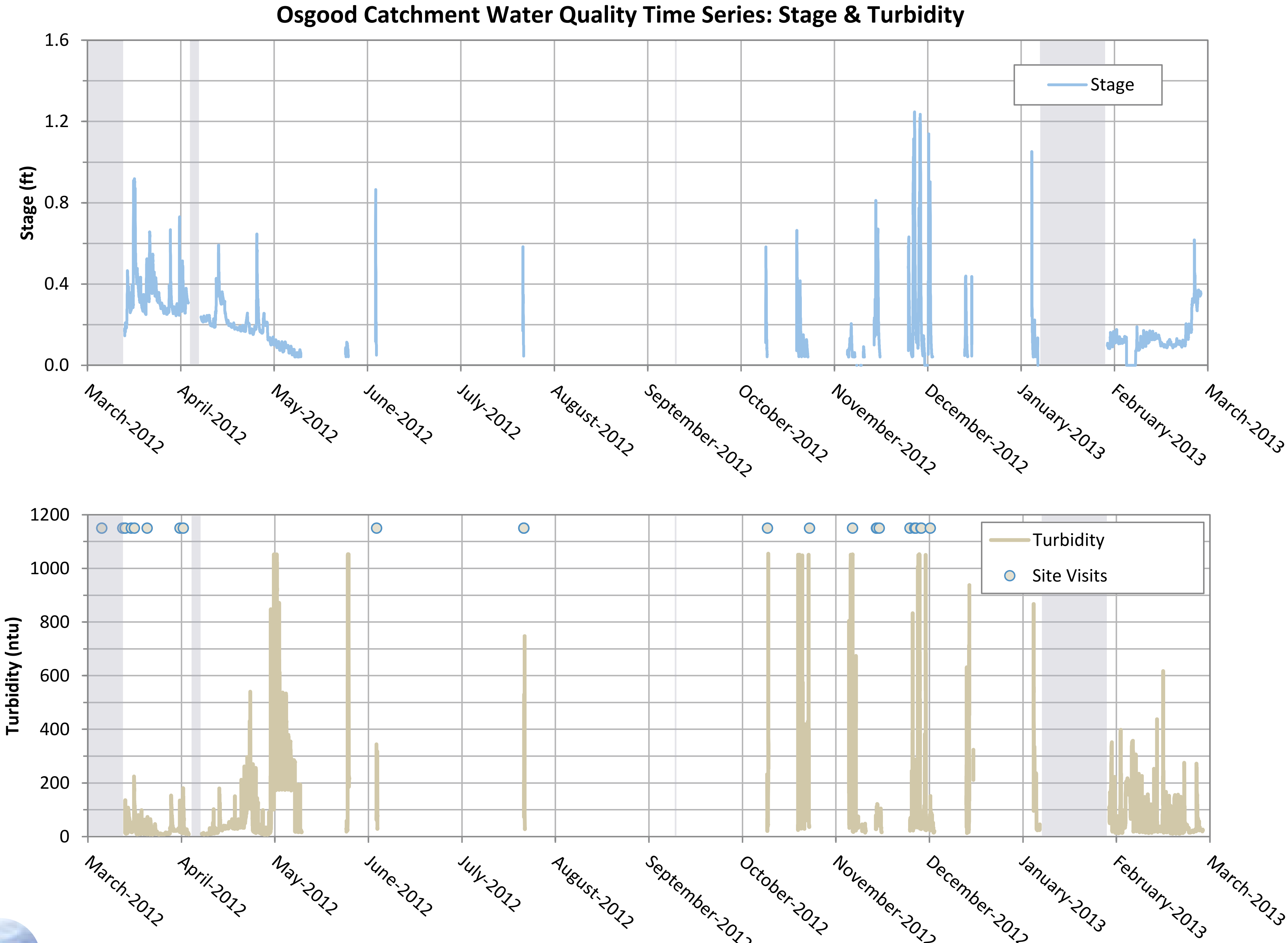
3.2.4 CATCHMENT WATER QUALITY MONITORING

Each catchment outlet was instrumented to obtain 10 minute stormwater discharge (cfs) and FSP concentration (mg/L) data. The time series of these water quality data were used to quantify the FSP loads at the outfall over time intervals of interest including seasons and the full monitoring period.

This research aimed to identify and refine stormwater quality monitoring techniques to obtain high-resolution turbidity and discharge data in intermittent flow environments, where freeze thaw conditions make instrument performance challenging. 2NDNATURE field personnel built upon previous knowledge of instrument calibration and functional issues (see 2NDNATURE and NHC 2012b) to identify instruments that would function properly in this intermittent, freeze/thaw conditions. Campbell Scientific CS450 pressure transducers were installed at all 3 locations (see photos at right) with either FTS DTS-12 (Pasadena, Central Incline Village) or Campbell Scientific OBS-3 (Osgood) turbidity sensors. The instruments were programmed to collect depth and turbidity data on 10-minute intervals (Figures 3.4A-C), which provided high temporal resolution while maximizing the battery life and data storage capacity of the instruments.

From top to bottom, photos of the outfalls of Osgood, Pasadena and Central Incline Village catchments

The depth and turbidity data were then translated to discharge and FSP concentrations to calculate loads. The depth data was converted to discharge (Q, cfs) based on the specific-site hydraulics. The turbidity time series was converted to FSP concentrations using the results of a multi-parameter linear regression model that predicts FSP concentration (mg/L) using turbidity, month of sample and region where the site is located (Figure 3.5) based on 969 data points (2NDNATURE et al. 2014). Frequent depth (using rulers mounted adjacent to the instrumentation – see Osgood photo above) and turbidity spot measurements when water was flowing through the outfall (using a Hach 2100P turbidimeter) were collected by field personnel to QA/QC the instrument data (Figure 3.6). Periodic manual flow measurements were used to verify the hydraulic discharge equations, and occasional submission of water quality grab samples to the analytical laboratory for TSS and percent grain size distribution analysis were included to develop the relationships shown in Figure 3.5. Site-specific details on these translation and QA/QC steps are provided below.



Note, the instrumentation at Osgood is programmed to record data only when there is flow. Therefore, most gaps shown in time series are a result of no flow at the monitoring station. Data gaps where instrument was not functioning are highlighted in grey.

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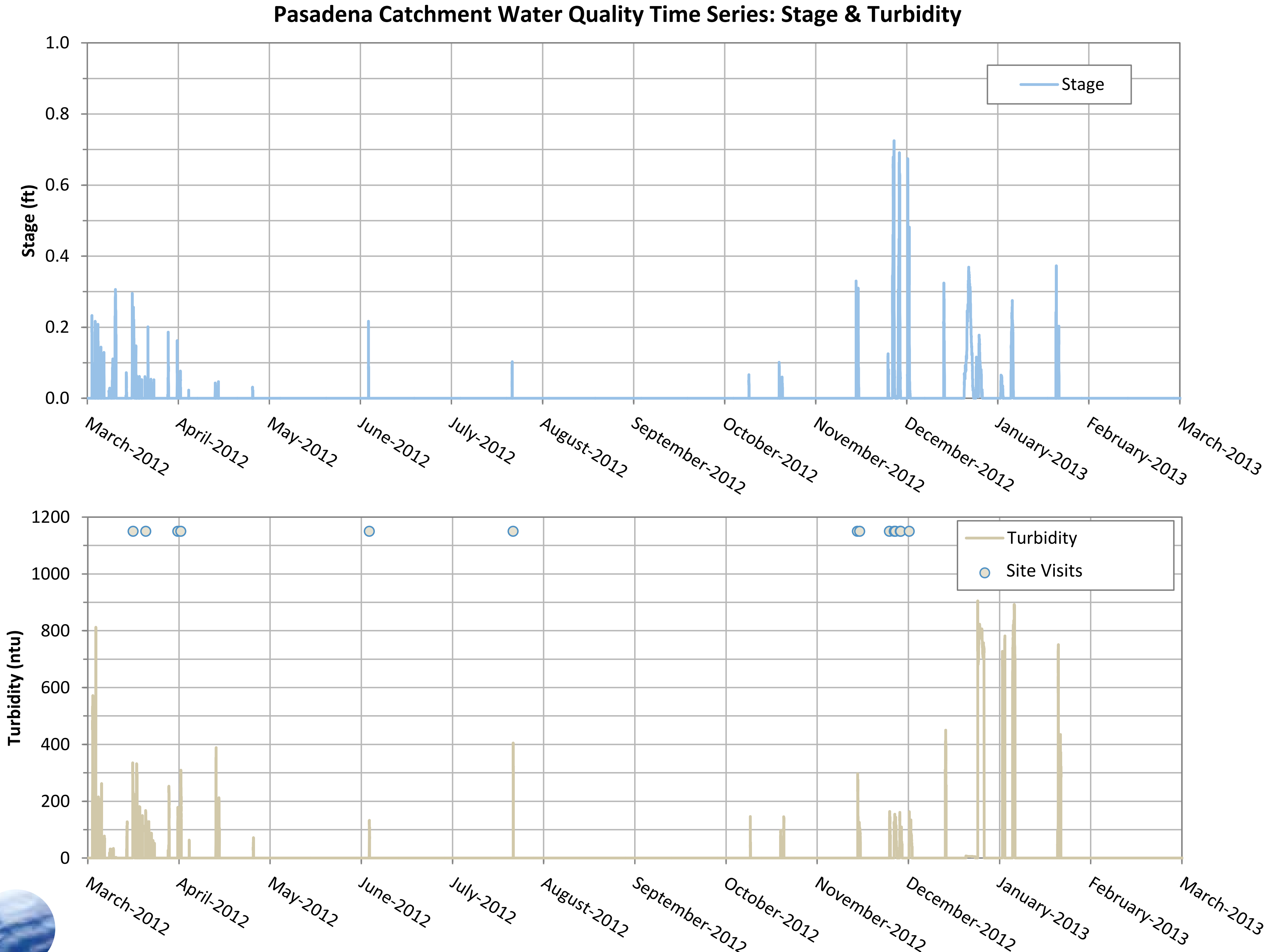
OSGOOD CATCHMENT WATER QUALITY: STAGE & TURBIDITY

FIGURE 3.4A



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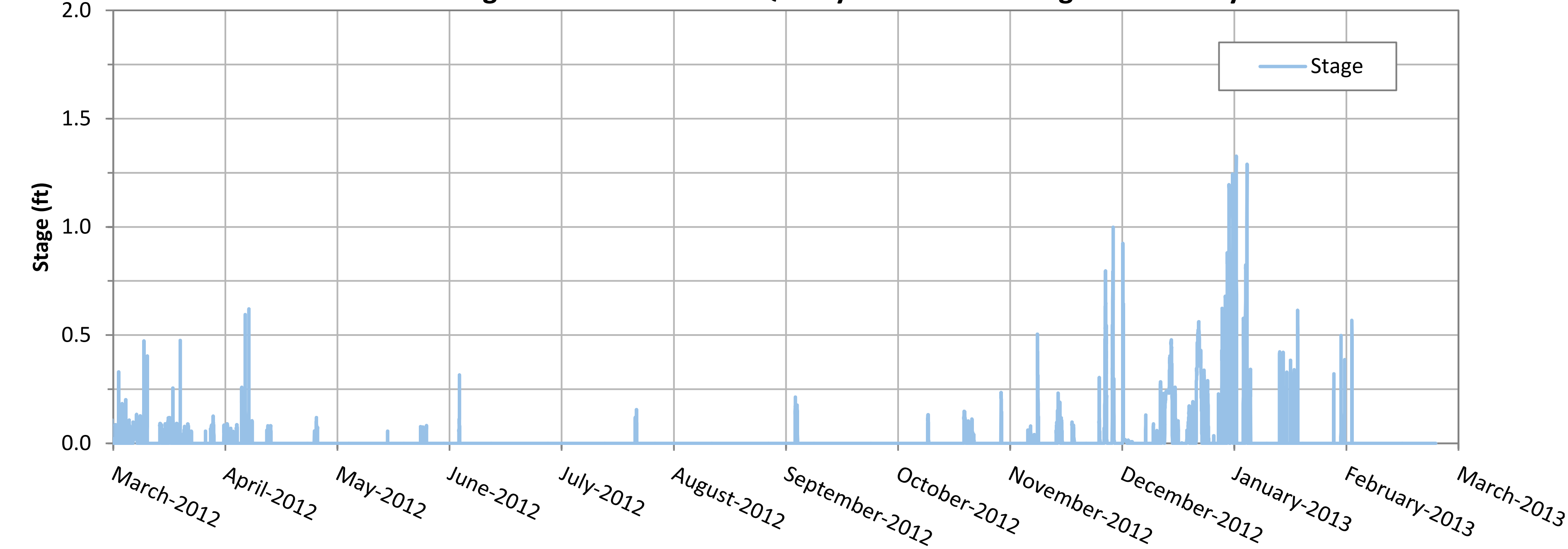
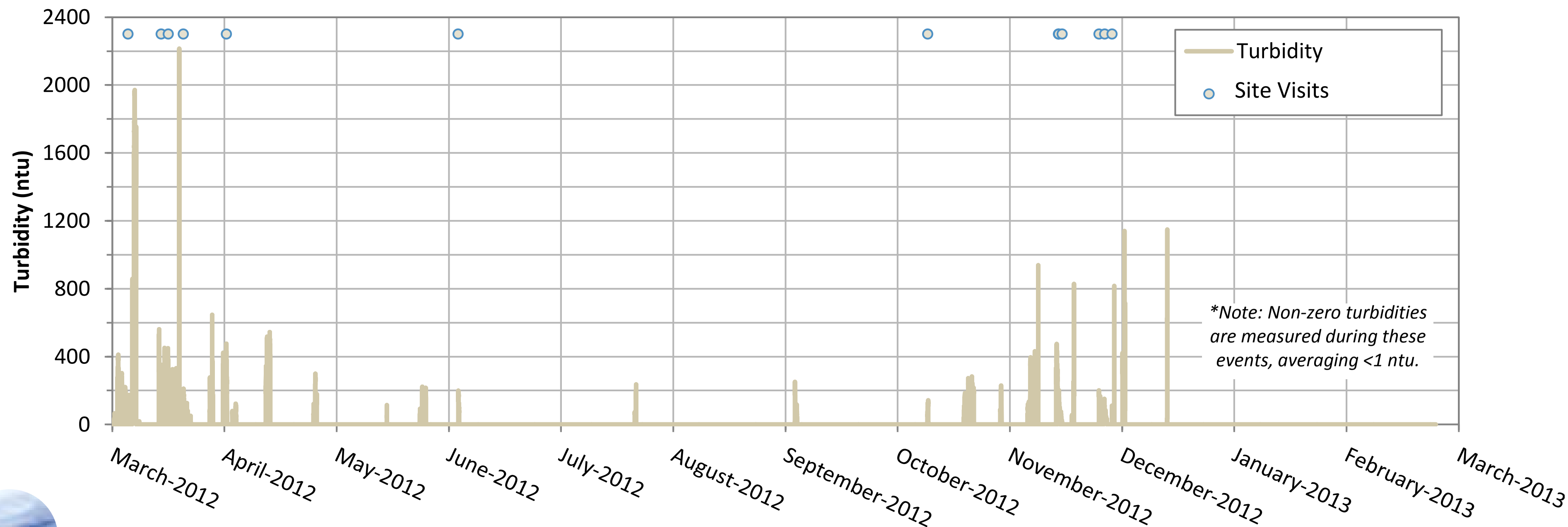
PASADENA CATCHMENT WATER QUALITY: STAGE & TURBIDITY

FIGURE 3.4B

Central Incline Village Catchment Water Quality Time Series: Stage & Turbidity





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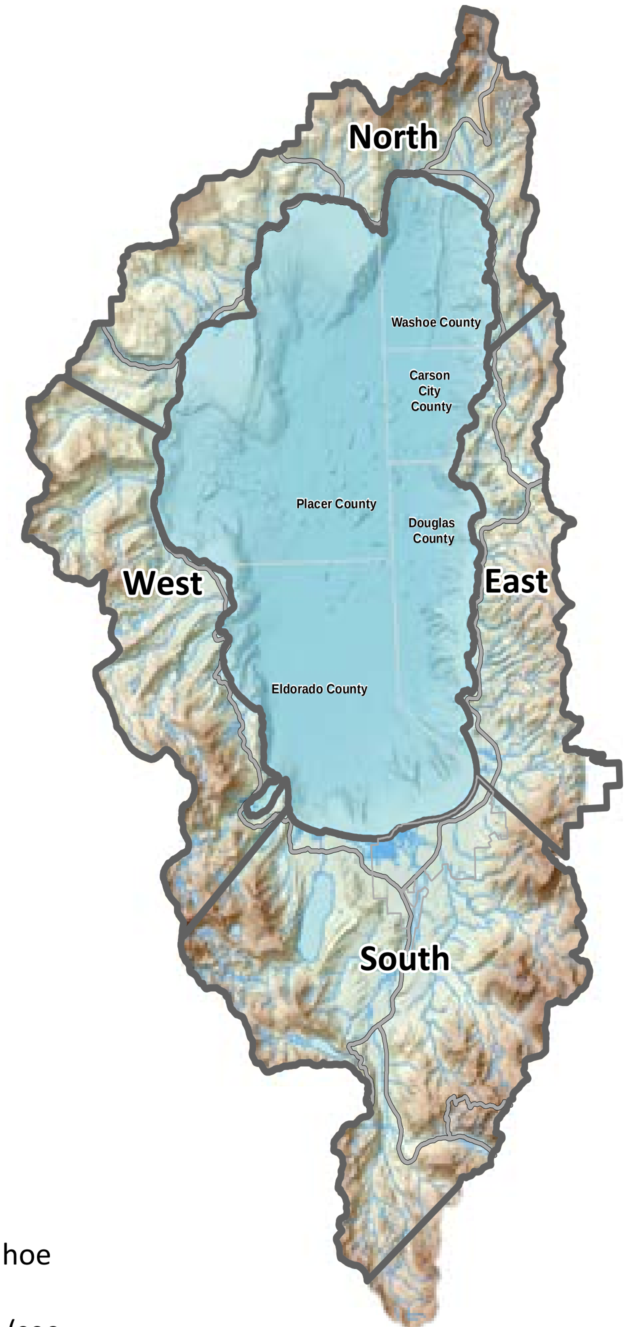
CENTRAL INCLINE VILLAGE CATCHMENT WATER QUALITY: STAGE & TURBIDITY

FIGURE 3.4C

[FSP] = 10^(constant + 1.08* log [Turb])					
Month	Region	Constant	Month	Region	Constant
Jan	East	-0.558	Jul	East	-0.622
Jan	North	-0.453	Jul	North	-0.517
Jan	South	-0.502	Jul	South	-0.566
Jan	West	-0.433	Jul	West	-0.497
Feb	East	-0.624	Aug	East	-0.644
Feb	North	-0.519	Aug	North	-0.539
Feb	South	-0.568	Aug	South	-0.588
Feb	West	-0.499	Aug	West	-0.519
Mar	East	-0.495	Sep	East	-0.630
Mar	North	-0.390	Sep	North	-0.524
Mar	South	-0.439	Sep	South	-0.573
Mar	West	-0.370	Sep	West	-0.504
Apr	East	-0.506	Oct	East	-0.525
Apr	North	-0.400	Oct	North	-0.420
Apr	South	-0.449	Oct	South	-0.469
Apr	West	-0.380	Oct	West	-0.400
May	East	-0.554	Nov	East	-0.700
May	North	-0.448	Nov	North	-0.595
May	South	-0.498	Nov	South	-0.644
May	West	-0.428	Nov	West	-0.575
Jun	East	-0.758	Dec	East	-0.623
Jun	North	-0.653	Dec	North	-0.517
Jun	South	-0.702	Dec	South	-0.566
Jun	West	-0.633	Dec	West	-0.497



Turbidity to FSP relationship using month of data collection and region within the Tahoe Basin. The results are based on a multi-parameter linear regression using 969 data points collected in the Tahoe Basin from 2003 to 2011 by a multitude of researchers (see 2NDNATURE, DRI and UC Davis 2014 for a full discussion).

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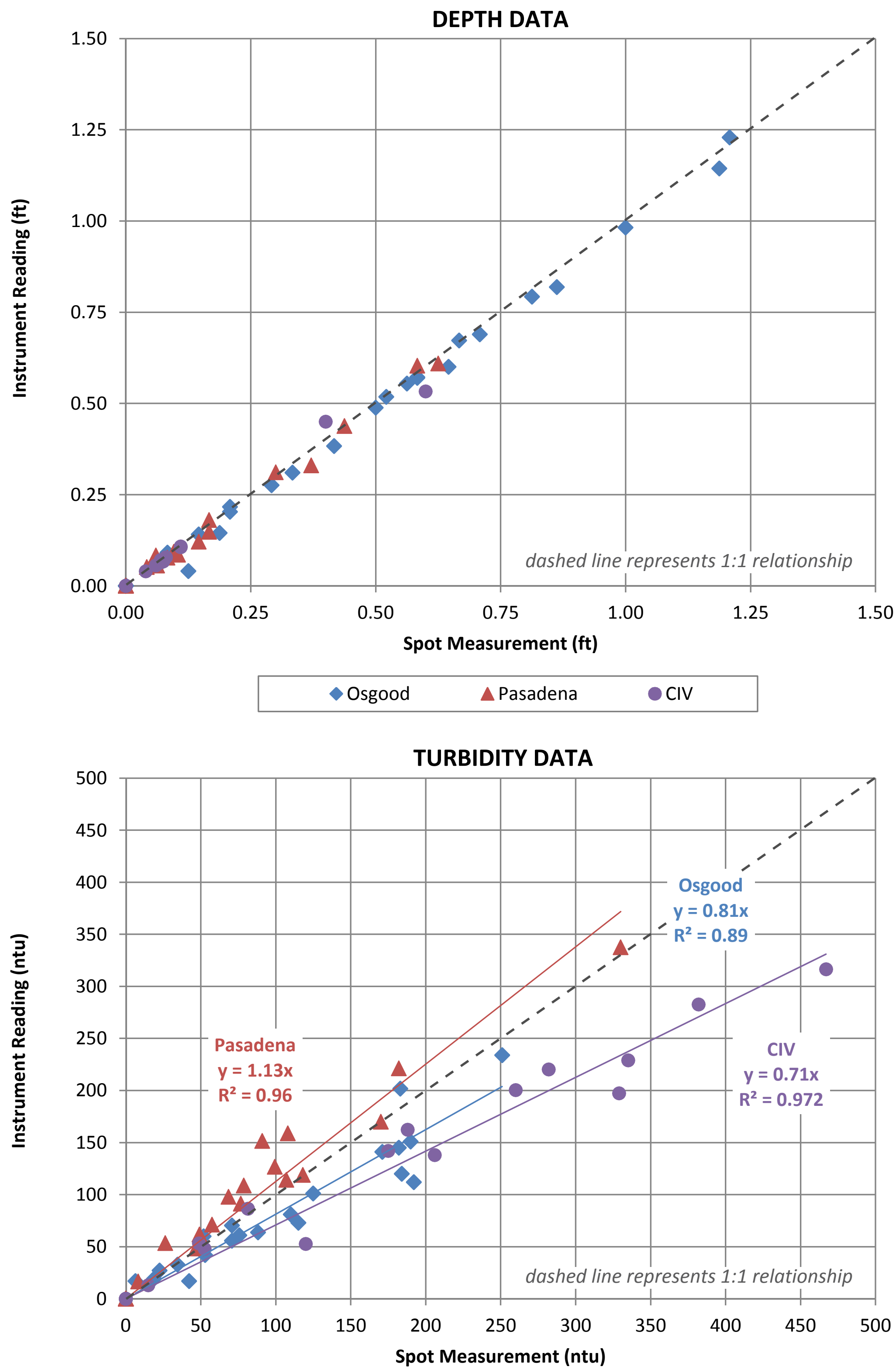
TURBIDITY TO FSP CONVERSION

FIGURE 3.5

Instrument QAQC
Comparison of Spot Measurements to Instrument Readings



Depth spot measurements read from staff plates mounted on flume and/or weir next to instrument location (see photo in Chapter 3.2.4 of Osgood weir). Turbidity spot measurement taken of water flowing through monitoring location using Hach 2100P turbidimeter.

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INSTRUMENT DEPTH AND TURBIDITY QAQC

FIGURE 3.6

OSGOOD CATCHMENT

In Osgood, water quality monitoring was conducted at the outlet of the settling basin prior to discharge to the wet basin (see Figure 3.1A). In February 2011 during the *Pilot Catchment Validation Study*, in coordination with the CSLT, a v-notch weir (see photo on page3.20) was constructed at the outlet. The instruments were also installed at this time to continuously monitor the stormwater inflowing to the wet basin from the settling basin, but only to record data when inflow was occurring. Due to issues with the instrumentation there were 3 different periods when data was not collected, totaling nearly 40 days (or 11%) of missing data (Figure 3.4A).

Thirty-five site visits (see Figure 3.4A; note spot measurements when no flow (14) are not shown) were made during monitoring to verify the instrument stage and turbidity measurements, the discharge equations (see Appendix A), and the turbidity to FSP relationships in Figure 3.5. These visits were timed to include the range of flow conditions experienced at the site, such as storm runoff events, continuous flow during spring snowmelt, and no flow. As shown in Figure 3.6, there was very close alignment between the depth measurements (average percent difference <5%). The instrument turbidity values were adjusted based on spot measurements using the Osgood relationship shown in Figure 3.6 for all instrument readings below 203 NTU (equivalent to the peak spot measurement of 251 NTU); values above 203 NTU were not adjusted.

The depth time series data (see Figure 3.4A) was converted to 10 min discharge (Q, cfs) using a hydraulic discharge equation for flow over a 90° v-notch weir and 5 ft rectangular weir (see Appendix A for details). As documented during Spring 2011 monitoring at Osgood (2NDNATURE and NHC 2012b), there can be a significant baseflow contribution to the monitoring location during the spring snowmelt season from the largely forested Keller Canyon subcatchment (see Figure 3.1 in 2NDNATURE and NHC 2012b). To improve comparability to the other sites and to PLRM simulations, a correction of -0.1 cfs was applied to the measured data during Spring 2012 to remove the estimated baseflow contribution. This average value was determined based on the continuous flow measured during periods when runoff was unlikely (no precipitation or nighttime when cold air temperatures prevented snowmelt). The turbidity time series data (see Figure 3.4A) was converted to FSP concentration using the monthly relationships shown in Figure 3.5 for the South region.

PASADENA CATCHMENT

In Pasadena, monitoring was conducted in the 36" culvert, approximately 75ft downstream of the treatment vault and Contech Stormfilter filters, prior to discharging into the lake (see Figure 3.1B and photo on page3.20). The pressure transducer and turbidity sensor were installed within a Palmer Bowlus flume (generously loaned from DRI) to constrain flow, and depth (Figure 3.4B) was converted to discharge using standard engineering equations for the flume (see Appendix A). The turbidity time series data (see Figure 3.4B) was converted to FSP concentration using the monthly relationships shown in Figure 3.5 for the South region.

Thirty-four site visits (see Figure 3.4B; note spot measurements when no flow (18) are not shown) were made to the Pasadena monitoring location during the monitoring to verify the instrument stage and turbidity measurements, the discharge equations, and the turbidity to FSP relationships in Figure 3.5. These visits were timed to include the range of flow conditions experienced at the site, such as storm runoff events, flow during spring snowmelt, and no flow. As shown in Figure 3.6, there was very close alignment between the depth measurements (average percent difference ~5%). The instrument turbidity values were adjusted based on spot measurements using the Pasadena relationship shown in Figure 3.6 for all instrument readings below 373 NTU (equivalent to the peak spot measurement of 330 NTU); values above 373 NTU were not adjusted. There were no instrument failures at Pasadena catchment, resulting in 100% data completeness.

CENTRAL INCLINE VILLAGE CATCHMENT

In Central Incline Village, the research monitoring equipment was installed within a ditch (see on page3.20), approximately 20 yards from the lake shore. As described in Chapter 3.1, stormwater is routed to the ditch via 3 ways: (1) bypass from the upper catchment around the Vortechnics treatment vault, (2) split outflow from the treatment vault, and (3) directly from the lower catchment. The monitoring sensors were installed within an H flume within the small channel to constrain flow, and depth data (Figure 3.4C) was converted to discharge using standard equations (see Appendix A). The turbidity time series data (see Figure 3.4C) was converted to FSP concentration using the monthly relationships shown in Figure 3.5 for the North region.

Twenty-two site visits (see Figure 3.4C; note spot measurements when no flow (9) are not shown) were made to the CIV monitoring location during the monitoring to verify the instrument stage and turbidity measurements, the discharge equations, and the turbidity to FSP relationships in Figure 3.5. These visits were timed to include the range of flow conditions experienced at the site, such as storm runoff events, flow during spring snowmelt, and no flow. As shown in Figure 3.6, there was very close alignment between the depth measurements (average percent difference <5%). The instrument turbidity values were adjusted based on spot measurements using the CIV relationship shown in Figure 3.6 for all values below 332 NTU (equivalent to the peak spot measurement of 467 NTU); values above 332 NTU were not adjusted. During heavy runoff events in late December 2012, the turbidity sensor did not measure values >1 NTU. Unfortunately no spot measurements were conducted during these events, but based on much higher turbidity measurements at Pasadena and Osgood during the same time period, we believe the turbidity sensor malfunctioned, resulting in 80% data completeness for the monitoring period.

DATA GAPS

Data gaps are a reality of stormwater monitoring, particularly in the freeze thaw conditions of Lake Tahoe and the loss of data can limit our ability to make reasonable temporal and spatial comparisons. Despite frequent site visits, complete instrument failure (stage and turbidity) occurred at the Osgood catchment monitoring location (loss of 11% of the yearly data, see grey areas in Figure 3.4A) and partial instrument failure (turbidity only) occurred at CIV (loss of 20% of the yearly data; see Figure 3.4C). No data gaps exist for Pasadena. To inform and direct future data gap reconciliation for RSWMP, we evaluated a number of potential approaches to identify the most feasible and reasonable method to recreate missing data for urban catchment outfall monitoring sites. Note, the discussion below centers on flow and FSP data, following translation of the stage and turbidity data as described above.

1. Seasonal Averages: Determine average flow and average FSP concentration (including no flow intervals) by season. Apply the seasonal average discharge and FSP concentration to each time interval when instrument data is missing, and update annual volumes and loads using these predicted values.

2. Seasonal Ratios of Proximate Site: Using a nearby monitoring site with similar catchment characteristics (area, land use distribution, etc.), calculate the percent of the seasonal totals represented by the missing time period. Assume the missing to seasonal total volume and load ratios are consistent across the 2 catchments, and adjust the totals of the incomplete dataset accordingly.

3. Correlations to Proximate Site: Using a nearby monitoring site with similar catchment characteristics (area, land use distribution, etc.), develop seasonal Q and FSP correlations between sites when overlapping data exists. Apply these relationships to the time periods when data is missing, and calculate the new annual volumes and loads.

These methods were applied to the missing data in Osgood (see grey areas Figure 3.4A) to evaluate the applicability and usability of the methods for future data analysis. Table 3.10 provides the results of the first two methods described above, using Pasadena monitoring data for method 2, and are compared to the totals using the incomplete dataset collected by the instrument. As described in method 3, correlations between Osgood and Pasadena discharge and FSP data were examined, and while the Q relationship was moderate (slope of 0.8, R-squared of 0.6), the FSP relationship was poor (negative slope and R-squared value of 0.03). Therefore the results of this method are not shown in Table 3.10. A fourth method, using PLRM simulation results to fill in the data gaps, was also employed (see Table 3.10), though given the unlikelihood that meteorologic data representative enough to accurately reconcile measured data gaps for urban catchment water quality will be available in the future, this method was not considered for future use.

Table 3.10. Comparison of results for different potential methods to generate reasonable data to fill data gaps as a result of instrument failures. These methods were used and compared to recreate the 2012-2013 data gaps for the Osgood catchment.

Metric	Instrument Totals (89% data completeness)	Adjusted Values		
		Method 1 (Seasonal Average)	Method 2 (Pasadena Seasonal Ratio)	Method 4 (PLRM Simulation)
Total Flow Volume (ac-ft)	24.6	29.4	34.7	27.6
Total FSP Load (MT)	0.89	1.06	2.12	1.35
Flow Weighted FSP (mg/L)	29	29	50	40

Method 1 results in an approximately 20% increase in total volume and total FSP load, while method 2 yields a 40% increase in total volume and 140% in total load. Method 4, using PLRM, estimates a 12% and 50% increase in total volume and FSP load, respectively. The advantages and disadvantages in using each method are described below.

- The advantage of using method 1 is that the data generation is internal and thus data from an adjacent catchment or model simulation is not required. However, by applying an average discharge and FSP concentration, the assumption is that there is some proportion of flow at every time step. Thus, flow and discharge could be documented for intervals when there is actually no flow and underestimated during peak events. But, over the duration of the data gap, flow and FSP are averaged out.

- The advantage of using method 2 is that information associated with the magnitude of flow events during the data gap can be applied to the site with incomplete data. However, with the same short comings as in method 1 regarding application of average values, using a nearby site assumes that catchment hydrology is similar enough and that a nearby, monitored catchment exists.

As mentioned above, method 4 is not recommended given the difficulty in acquiring reliable catchment meteorologic data, and the complexity associated with establishing a well-calibrated PLRM model for the catchment. These technical efforts would be well outside the typical scope for catchment monitoring.

3.2.5 BMP CONDITION

All 3 catchments have stormwater treatment BMPs at the downstream end of the catchment and in close proximity of the monitoring stations. A settling basin is directly above the Osgood monitoring station, a Contech cartridge filter and treatment vault system are above Pasadena monitoring station, and a Vortechnics treatment vault is above the CIV monitoring location (see Figures 3.1A-C). These BMPs were installed to treat inflowing stormwater and reduce catchment pollutant loading. However, BMP effectiveness monitoring, via comparisons of influent and effluent water quality of the specific BMPs, was outside the scope of this research. Instead, simple site observations and conversations with CSLT and Washoe County maintenance personnel were used to summarize general conditions of the larger scale treatment BMPs in close proximity to the monitoring stations, and the likely impact of the catchment water quality measured downstream of the BMPs.

- The Osgood settling basin had not been cleaned since 2NDNATURE began monitoring the basin in 2008. Previous estimates suggest a monthly accumulation rate of 0.57 MT FSP during the winter (2NDNATURE and NHC 2012b). CSLT maintenance staff had been unable to clean the basin in part due to the installation of the weir, which blocks access to the basin. The unmaintained settling basin may result in elevated FSP concentrations at the monitoring location, due to the significant amounts of stored material that could be entrained during larger runoff events. The weir was removed in late October 2013 and the basin was cleaned in late fall 2013.

- The cartridge filters at the Pasadena catchment outfall were visually assessed by field personnel in April 2012. There was some evidence of FSP on top of the low flow cartridges, but the high flow cartridges appeared clean. The filters had been vactored in Fall 2011, and due to little to no sediment accumulation during the previous 6 months, maintenance was deemed unnecessary at that time. During the monitoring period, an issue in the storm drain system allowed stormwater to bypass the cartridge filters more frequently than the design dictated. Consequently, FSP concentrations may be higher than predicted as measured at the monitoring location. The City retrofitted the storm drain system with orifice plates in September 2013 to address the bypass issue (pers. comm. E. Friedlander April 2014), but this retrofit occurred after the monitoring period had concluded for this research.

- The treatment vault in Central Incline Village was vactored in late summer 2011 and again on April 9, 2012. To the extent that treatment vaults are able to remove FSP in urban stormwater, this well-maintained treatment vault may result in decreased FSP concentrations at the monitoring location.

While a helpful chronology, this qualitative information does not help with quantitative comparisons of BMP condition over time to measured outfall water quality or to inform PLRM simulations. BMP RAM (2NDNATURE et al. 2009) provides a methodology to perform simple field measurements annually to track the relative BMP condition and treatment performance; however, the tool is best used by the jurisdiction in charge of maintenance. The inventory, benchmark and threshold data are best input following scheduled maintenance when there is reasonable assurance that the BMP is in its best achievable condition. When benchmark values are available BMP RAM can be used to track declining condition over time but the research team does not have benchmark values for any of the BMPs within the studied catchments. Future research that aims to compare measured and PLRM modeled data for an urban catchment should include a proper BMP RAM assessment and tracking of the larger scale BMPs in the catchment to ensure their condition is within a pre-determined acceptable range and improve confidence that the BMP condition represented in PLRM is reasonable.

Private parcel infiltration BMPs are constructed throughout each of the catchments to retain runoff on private property and reduce stormwater volumes (see Table 3.2). Previous research (2NDNATURE and NHC 2013) has indicated that there are critical design criteria and maintenance interval considerations to ensure infiltration capacity are maintained over the long term. Given the challenges of making observations over a dispersed area, as well as obstacles in gaining access private land, performing private parcel BMP condition assessments were well beyond this research's scope. PLRM modeling assumes all private parcel BMPs are performing at an acceptable level. Future research intending to compare measured and modeled values should implement some representative sampling of a population of private parcel BMPs using BMP RAM to assure that BMP condition represented in PLRM is reasonable.

3.2.6 CATCHMENT DATA MANAGEMENT

Field personnel recorded Road RAM observations directly into the online database in the field (www.tahoeroadram.com), which provides a standardized data management system and automatically generates Road RAM results. All other data collected during this research have been managed in digital Microsoft Excel spreadsheets and a Microsoft Access relational database. Observations at the road segments and catchment outfall monitoring locations, including staff plate measurements and turbidity reading, field notes, and photo logs, were recorded in field notebooks during all sampling activities. Instrument data downloads and maintenance activities were recorded on pre-printed data logs. Upon return to the office, office personnel QA/QC'd all data for accuracy and completeness before integration into the spreadsheets and database. The laboratory submitted electronic results of analyses, which office personnel checked for data quality and completeness, verified against the chain of custody record, and then entered into the database.

3.2.7 DATA COLLECTION CONCLUSIONS AND RECOMMENDATIONS

ROAD MAINTENANCE RECORDS

To test the cause and effect relationship between road maintenance practices and road condition (as measured by Road RAM), an accurate and usable chronology of road maintenance actions performed on the roads is required. This research contributed to the continued development of the most appropriate data collection and information management formats necessary to chronicle jurisdictional road maintenance practices such that the effectiveness of road maintenance practices can be better tested. Ideally, a daily log of the volume of abrasives and salt/brine applied and the volume of material recovered via sweeping efforts from the road network exclusively within the subject catchment would satisfy the desired data needs from the road maintenance teams. A Basin-wide Road Operations Effectiveness Study is currently underway to collaboratively define and document what is feasible and the desired formats to allow adequate testing of the effectiveness of road maintenance practices.

Below are a number of road maintenance data requirements to adequately compare road maintenance actions with observed road condition and measured catchment water quality data:

- **Consistent spatial extents.** Road maintenance operations are typically conducted within zones, whose borders are inconsistent with catchment hydrologic boundaries. While the research team made every attempt to align the data received from the jurisdictions with research data collection, it is likely that the estimated practices are inconsistent with actual practices within the catchment.

- **Spatially explicit abrasive application rates.** For both jurisdictions, the total volume of abrasives applied is divided by the number of miles driven (Washoe) or within the zone (CSLT), assuming a consistent application rate on all roads. In practice, abrasive application is targeted to specific locations where traffic safety is a concern (intersections, near schools, more shaded areas, etc.).

- **Comprehensive pollutant recovery effectiveness.** There are a number of considerations (travel speed, width of road covered, number of passes, accessibility to entire road width, road surface integrity, etc.) that can affect the ability of a street sweeper to recover FSP from the road surface. Current data collection does not include many of these variables, preventing a full understanding of the contribution each attribute has on the overall effectiveness of a street sweeping program.

- **Accurate road class mapping.** The above issues call into question the accuracy of the road class maps (see Figures 3.2C and 3.3C). While the spatial distribution of both the abrasive application priority (see Figures 3.2A and 3.3A) and sweeping effectiveness (see Figures 3.2B and 3.3B) were vetted by the CSLT and Washoe stormwater managers and road maintenance personnel, the request for this data and the concept of road class is a relatively new development. Road class definitions, mapping distributions, and data management will continue to be refined as jurisdictions move forward with the implementation of the TMDL.

CATCHMENT OUTFALL MONITORING

Based on this research, the following conclusions and recommendations are provided for the implementation of any long-term catchment outfall monitoring project:

- **Proper instrumentation.** Continuous (e.g., minute intervals) discharge monitoring provides the necessary temporal resolution to adequately capture the extreme variability of urban stormwater runoff and is recommended for urban catchment outfall status and trend monitoring. Continuous pollutant concentrations are also desired when possible. This research leveraged previous sampling and data analysis results (2NDNATURE 2013; Heyvaert et al. 2011), and monitored continuous automated turbidity as a proxy for FSP concentrations. Available turbidity to FSP rating curves developed using thousands of paired samples obtained in the Tahoe Basin (2NDNATURE et al. 2014) were used to consistently convert 10 min turbidity data to FSP concentrations. The selected monitoring equipment (Campbell Scientific CS450 pressure transducer and FTS DTS-12 turbidity sensors) approach $10,000 per site, but proved to be a reliable and cost-effective means to quantify FSP loads even in the Tahoe freeze/thaw and intermittent stormwater flow conditions. The sensors performed consistently throughout the winter months, with very few issues and limited data loss.

- **Consistent, rigorous and frequent site QAQC.** In order to ensure accurate instrument operation and proper conversions of raw datasets, frequent site visits to collect spot stage, discharge, turbidity, etc. measurements during periods when runoff is occurring are essential. Field measurements should verify and calibrate instrumentation (stage and turbidity) as well as provide measures of the calculated parameters (discharge and FSP concentration). The value of consistent, rigorous and frequent field QA/QC procedures cannot be overstated. Automated instrumentation has a number of advantages but they still require frequent and continued QA/QC to ensure the data is as reliable as possible. DRI (2014) is currently developing recommended field methods, including instrumentation, for collection of QAQC data to ensure volume and load calculations are as representative as possible. If the researchers intend to compare measured and modeled catchment outfall data, then it is even more critical to ensure the measured data is reliable to evaluate modeled estimates. A standard and consistent method to fill missing data is recommended; however, data gaps should be kept to a minimum to ensure the most robust comparisons across water years, amongst monitoring locations, and with modeled data.

- **Turbidity sensor calibration.** The same turbidity probe model (FTS DTS-12) was installed at two different outfalls (Pasadena and CIV) and based on available spot measurements the calibrations to the same portable turbidimeter (Hach 2100P) were different (see Figure 3.6). The calibration drift of turbidity meters installed in intermittent flow and freeze thaw environments can vary. Turbidity probes installed need to be regularly calibrated using frequent spot measurements with a reliable and well-calibrated portable device. Each turbidity probe will experience different field conditions, and it is critical that site specific manual turbidity is frequently conducted at each site and properly documented. Given the challenges of being on-site to obtain a calibration grab when runoff turbidity is relatively elevated, future catchment outfall monitoring should install passive samplers to collect discrete water samples on the rising limb of runoff events. These first flush samples are more likely to have relatively elevated turbidity values and can improve the range of data available for in-situ probe calibration (see Figure 3.6). In addition, if the turbidity of the passive samples exceed 800 NTU, it can be submitted to the analytical laboratory for FSP concentration analysis and contribute to the regional improvement of turbidity to FSP rating curves (see Figure 3.5).

- **Evaluate and track treatment BMP condition.** Treatment BMPs are installed throughout Tahoe urban catchments as significant components of reducing pollutant loading to Lake Tahoe. Long-term monitoring of urban catchment outfalls by RSWMP should include continued evaluation and tracking of treatment BMPs, such as dry basins, wet basins, infiltration basins, media filters or treatment vaults. BMP RAM (2NDNATURE et al. 2009) can be used to rapidly evaluate and track the relative condition of the larger scale treatment BMPs within the urban catchment over time. In order to properly use BMP RAM, researchers must collaborate with personnel directly in charge of maintenance (either jurisdictions or land owners) to ensure the BMP benchmark and threshold steps are appropriately implemented. This coordination, nor the implementation of BMP RAM, occurred during this research and is a lesson learned for future monitoring. The benefit of establishing and consistently implementing BMP RAM on treatment BMPs in urban catchment monitoring sites are two-fold.

1. Should catchment seasonal and annual pollutant loads over time display unexpected deviations or trends in catchment seasonal and annual pollutant loads, the BMP RAM information regularly maintained within the subject catchment could provide documentation if one or more BMPs are not performing as expected.
2. If one of the objectives of catchment outfall monitoring includes comparing measured and modeled data, the condition of catchment BMPs, especially treatment BMPs expected to provide significant load reductions, should be tracked to improve confidence that the BMP treatment performance during the monitoring period is being reasonably represented in PLRM, as discussed in more detail in Chapter 3.3.

3.3 PLRM SIMULATIONS

An objective of this research is to define and document reasonable methods to generate and compare PLRM outputs with observed catchment runoff volumes and FSP loads. These methods can be used to evaluate model outputs, update PLRM user guidance and generally improve our understanding of the opportunities and limitations of measured and modeled FSP loading data, as well as the comparisons. Tahoe Basin stormwater managers can use PLRM during the project design phase to compare stormwater quality improvement alternatives in an urban catchment based on predicted load reductions for pollutants of concern for lake clarity. In the context of the Crediting Program, once the preferred alternative has been selected and constructed, users model both the pre and post water quality improvement scenarios to estimate the pollutant load reductions (and corresponding potential annual Lake Clarity Credits) associated with the cumulative improvements conducted within an urban catchment.

PLRM combines a long-term continuous hydrologic simulation with a customized water quality module to generate estimates of runoff volumes and pollutant loads. PLRM extrapolates historical meteorological data (Water Years 1989 to 2006) from eight SnoTel gauges in the Tahoe Basin to provide pre-processed hourly precipitation and temperature data for a user-specified location. This data is input into PLRM's parent model, the EPA's Stormwater Management Model (SWMM). The SWMM simulation uses the temperature and precipitation data to continuously simulate rain, snowfall, and snowmelt within the modeled catchment. Using the PLRM interface, the PLRM user can adjust certain hydrologic properties within the catchment, such as directly connected impervious area (DCIA) and infiltration rates, to alter the amount of surface runoff generated from specific urban land uses distributed in the urban catchment.

3.3.1 IMPLICATIONS OF PLRM DESIGN ON ASSESSMENT EXERCISES

To minimize modeling complexity, the PLRM developers made a number of design decisions that simplified or automated algorithms to streamline use of the tool and reduce data input. The simplifying assumptions have produced a tool that most PLRM users find relatively easy to use, but the simplifications and development objectives of PLRM complicate efforts to assess results using event-based monitoring data. For example, the hydrologic routing algorithms in PLRM have been greatly simplified from the full capabilities available in SWMM, and in some cases they have been completely disabled. This approach eliminates a number of data entry needs that would otherwise be required to generate a more rigorous hydrologic simulation (e.g., pipe sizes, lengths, and inverts; open channel dimensions, lengths, and inverts; and overland flow path lengths and roughness coefficients). The hydrologic approach used in PLRM provides a model structure that can predict runoff volumes at the time scales important to the Lake Tahoe TMDL (i.e., average annual). However, the simplifications mean that PLRM users have minimal ability to refine modeled estimates of peak flows or the shape and timing of the stormwater hydrograph on event or even seasonal timescales. Consequently, any study that uses monitoring data to assess PLRM results should consider the objectives of the hydrologic design of PLRM within the following context:

- Comparison of a monitored to a modeled hydrograph that contains short duration runoff is useful to quickly and coarsely assess the reasonableness of modeled output, but it would be inappropriate to validate or invalidate model results based only on an evaluation of event hydrographs.

- In order to be consistent with model development objectives, PLRM assessment exercises should compare measured and predicted stormwater event, seasonal or yearly runoff volumes.

The PLRM water quality module uses the simplest of SWMM water quality options to estimate pollutant generation based on Tahoe-specific data. PLRM spatially integrates the distribution of characteristic runoff concentrations (CRCs) for the various land use types (e.g., residential, commercial, roads, etc.) and expected conditions within the catchment. Reduced pollutant generation potential (or improved land use condition) for a specific land use through management actions is modeled as a decrease in the assigned land use specific CRC. The water quality improvement provided by stormwater treatment BMPs (e.g., dry basins, cartridge filters, etc.) is modeled using a characteristic effluent concentration (CEC), which is a static concentration for each pollutant assigned to all runoff routed through the treatment outlet of the respective stormwater treatment BMP. The runoff volumes are integrated with the pollutant concentration estimates, and via the PLRM interface, the user obtains average annual loads for various configurations of catchment land use practices and stormwater treatment BMPs based on the historic 18-year meteorological conditions.

Given the original PLRM development objectives and the known limitations in using measured data to validate the model, the following are key considerations when attempting to use measured data to evaluate PLRM:

1. To reasonably predict pollutant loading, which is dependent on both water quality and runoff hydrology, the user must build the PLRM model to represent the actual catchment configuration, including land use distribution, directly connected impervious area, infiltration rates, etc.

2. PLRM outputs are used to quantify the average annual FSP load differences between pre- and post-improvement scenarios, given the same meteorological inputs. The model output estimates load reduction benefits on average annual differences over 18 years of continuous simulation, not on event, seasonal or annual time scales. A true validation of PLRM estimates of average annual load reductions would require multiple years of pre- and post-improvement monitoring with a well distributed meteorological pattern (water years above, below, and at average conditions).

3. The static CRC values are appropriate for an average annual dataset; however, to develop a comparable dataset to the measured data, CRCs that represent changing land use conditions are needed. The land use with the most variable condition is paved roads in the Tahoe Basin (Kuhns et al. 2010; 2NDNATURE et al. 2010), and methods to vary road condition in PLRM simulations using Road RAM observations throughout the year were tested by this research.

3.3.2 PLRM MODEL DEVELOPMENT AND SWMM CONVERSION

In order to compare to 10-minute measured datasets, the research team generated PLRM modeled data of stormwater runoff and pollutant concentrations using the measured and representative meteorological data for the same time period as the measured catchment data (March 1, 2012 to February 28, 2013). By using the representative temperature and precipitation record during the time of data collection, theoretically a comparable 10-minute modeled dataset can be created to compare measured and modeled hydrology.

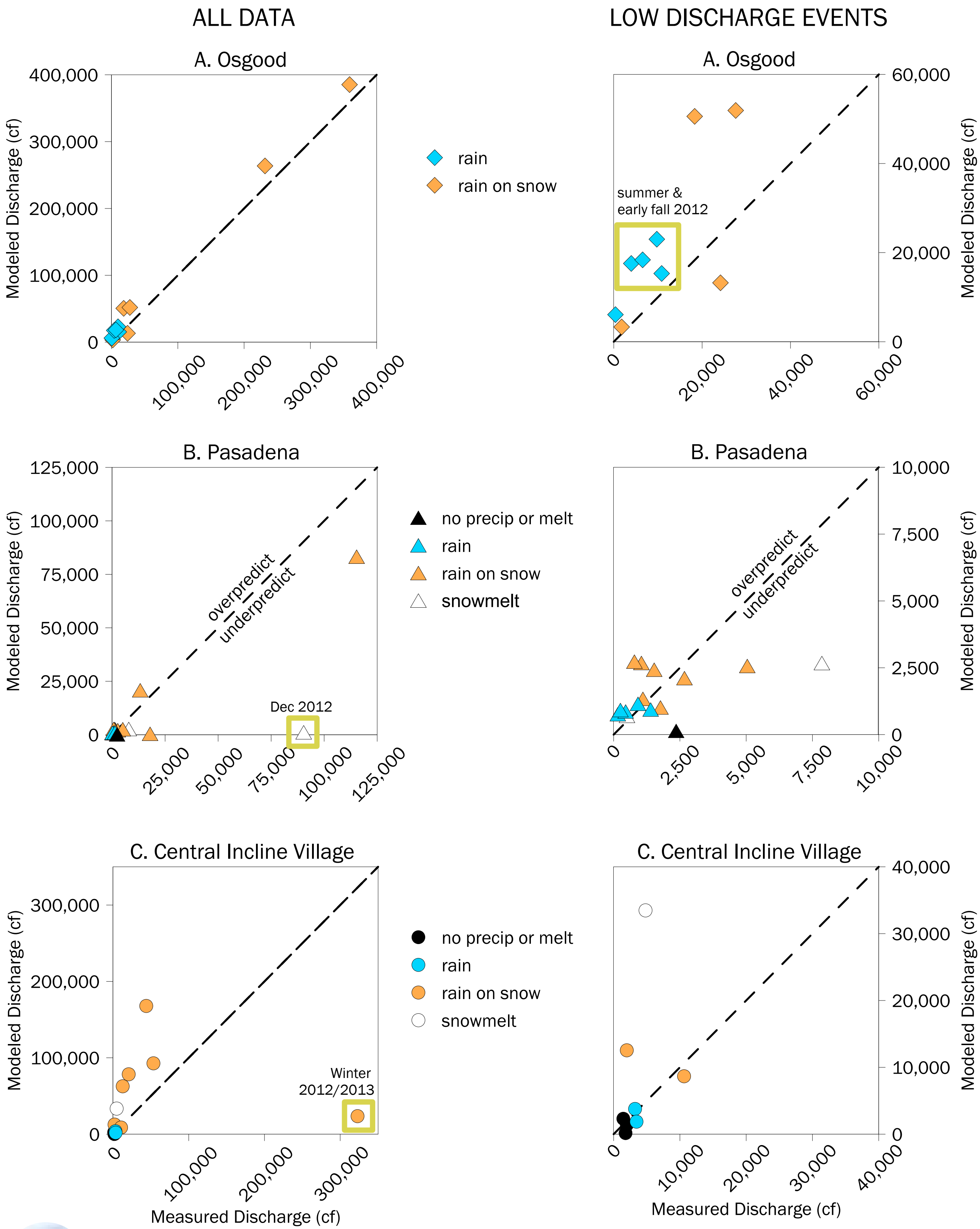
Using the GIS data described in Chapter 3.1, PLRM models were developed to represent each of the three catchments in their condition from March 1, 2012 to February 28, 2013. Models for each catchment were refined from existing models developed by the City of South Lake Tahoe, Washoe County, and their consultants.

The detailed continuous simulation results are not accessible directly from PLRM, since the tool was developed to automatically post-process the time-series output and summarize performance for the user as estimates of average annual pollutant loading. To access the time-series output, the PLRM input file is run directly in SWMM. This approach is necessary when comparing modeled output to monitoring data. However, users not familiar with SWMM or other hydrologic simulation models may not fully understand how to critically evaluate outputs to ensure they are reasonable relative to PLRM objectives. Appendix B contains detailed instructions for importing and running a PLRM input file directly in SWMM using site-specific meteorological data.

3.3.3 HYDROLOGIC MODEL REFINEMENT AND ASSESSMENT

The research team assessed model output by comparing measured and modeled runoff volumes on an event and annual basis. Two hydrologic assessment methods were used and are presented in this section to illustrate various findings by comparing: (1) hydrographs between modeled and measured data and (2) event-based runoff volume estimates. As noted above, comparison of hydrograph data can be useful to coarsely assess the reasonableness of modeled output, but should not be used to validate or invalidate model results. PLRM does not allow a user to access the full suite of SWMM algorithms used to define flow routing and flow attenuation.

Figure 3.7 compares estimated modeled and measured runoff volumes for individual event types over the monitoring period when reliable data was obtained. Runoff event types are defined as either rain, rain on snow, or snowmelt. Event based comparisons for all three sites are shown on Figure 3.7 for all events (left side) and low discharge events only (right side). Exact correlation for a runoff event would fall on the dotted line denoting a 1:1 relationship. Points below the dotted line mean that a runoff event had measured runoff volumes exceeding modeled runoff volumes. Points above the dotted line mean that a runoff event had modeled runoff volumes exceeding measured runoff volumes.



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EVENT SCALE COMPARISONS OF MEASURED V. MODELED DISCHARGE

FIGURE 3.7

OSGOOD CATCHMENT

The initial PLRM scenario developed for the Osgood catchment produced lower total runoff relative to measured total runoff during the monitoring period. The directly connected impervious area (DCIA) inputs for PLRM, particularly for the roads and commercial land uses, were increased based on this observation and further assessments of the catchment conditions. The adjusted DCIA values resulted in what appeared to be a more reasonable comparison of modeled vs. measured total runoff volume over the monitoring period. Figure 3.7A presents estimated modeled and measured runoff volume for individual Osgood event types over the monitoring period when reliable data was obtained. The left graph presents the data for the full range of discharge volumes while the graph on the right shows the comparison for the low discharge events (<60,000 cf). The data gaps as a result of instrument failure at the Osgood monitoring location (see Figure 3.4A) affected comparisons to PLRM outputs at the site.

As shown in Figure 3.7A, the largest runoff events associated with rain-on-snow appear to have a very good correlation. However, the smaller rain events occurring in the summer and early fall (highlighted by yellow box in Figure 3.7A) have a poor correlation, with a noticeable bias of modeled predictions exceeding measured estimates of runoff volume. The observed bias during smaller rain events may indicate that DCIA is actually too high in the PLRM scenario. One hypothesis is that the measured data for the large runoff events may include a baseflow component, as baseflow from the Keller Canyon drainage area is a common and complicating factor at the Osgood monitoring location. An average offset value was applied to the Spring 2012 measured data to adjust for the baseflow component, however during the larger runoff events, the offset value may be too low. The PLRM scenario with the higher DCIA values may appear to correlate well for large runoff events, but may just be masking the baseflow component in the measured data. This inconclusive result highlights the challenges for evaluating a PLRM scenario and modeling results at a monitoring location with baseflow, because the baseflow alters the measured urban stormwater runoff response in a manner that PLRM was not designed to simulate.

PASADENA CATCHMENT

The initial PLRM scenario developed for the Pasadena catchment produced significantly higher runoff relative to measured runoff during the monitoring period. The research team reviewed the as-built drawings for the Al Tahoe Phase 1 Water Quality Improvement Project (WQIP) and determined that the pervious storm drain system installed as part of the project was not well represented in the model. The initial PLRM scenario was adjusted to include larger infiltration facilities to represent the pervious storm drain system. This second attempt resulted in a PLRM scenario that under predicted stormwater runoff relative to measured runoff. Detailed review of measured runoff data in the spring of 2012 revealed a rapid response to snowmelt events at the monitoring location. This observation suggested that a portion of the impervious area in the vicinity of the monitoring location was likely directly connected. The PLRM scenario was adjusted again to represent a portion of the drainage area as directly connected to the monitoring location (i.e., not routed through the pervious storm drain system). This representation of stormwater routing was verified to be reasonable based on discussions between the research team and City of South Lake Tahoe stormwater staff in June 2014. This third adjustment produced a reasonable correlation between modeled and measured data for runoff events occurring in the spring and fall of 2012 (see Figure 3.7B).

As shown in Figure 3.7B (left - all data), there is poor correlation between measured and modeled runoff data for the large December 2012 event (yellow box) and is caused by conflicting measured data. The best available meteorological data used for the study recorded temperatures consistently below freezing during the large precipitation events in the latter half of December 2012. However, monitored flows in both the Pasadena and CIV catchment show significant volumes of stormwater at the monitoring location (Figure 3.8). Both the runoff data and temperature data were quality assured and no obvious measurement or instrument errors were identified. Since the PLRM scenario uses the measured temperature data to predict snow hydrology, the freezing temperature inputs during this time period generate modeled results with snow accumulation and minimal runoff.

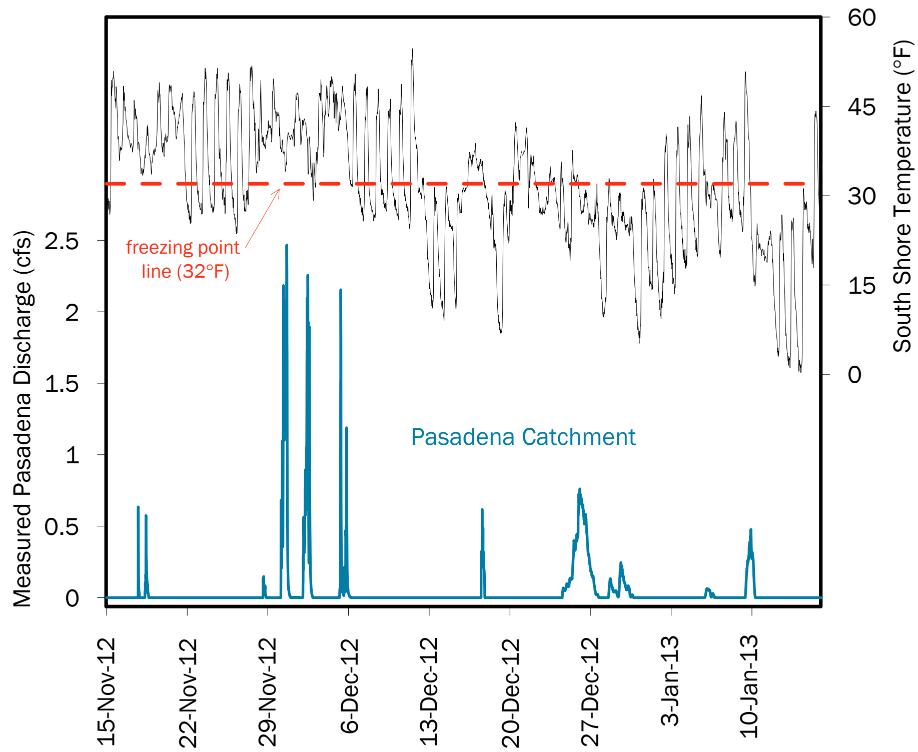
As discussed in Chapter 3.2.1, precipitation and temperature data from the meteorological station at the City of South Lake Tahoe's Fire Station on the corner of Pioneer Trail and Ski Run Boulevard were used to run the Pasadena simulation. Instrument issues at the meteorological station on Rufus Allen Boulevard, which is a much closer meteorological station to the Pasadena catchment, prohibited use of that data. The City's Fire Station is roughly 1.5 miles to the southeast of the Pasadena catchment and 50 feet higher in elevation. It appears that the meteorological data collected at the Fire Station was not representative of temperature conditions in the Pasadena catchment during the 2012-2013 winter storms. This observed issue highlights the need to collect and quality-assure site-specific meteorological data that is representative of the conditions in the monitored catchment when conducting an assessment that includes PLRM snow hydrology.

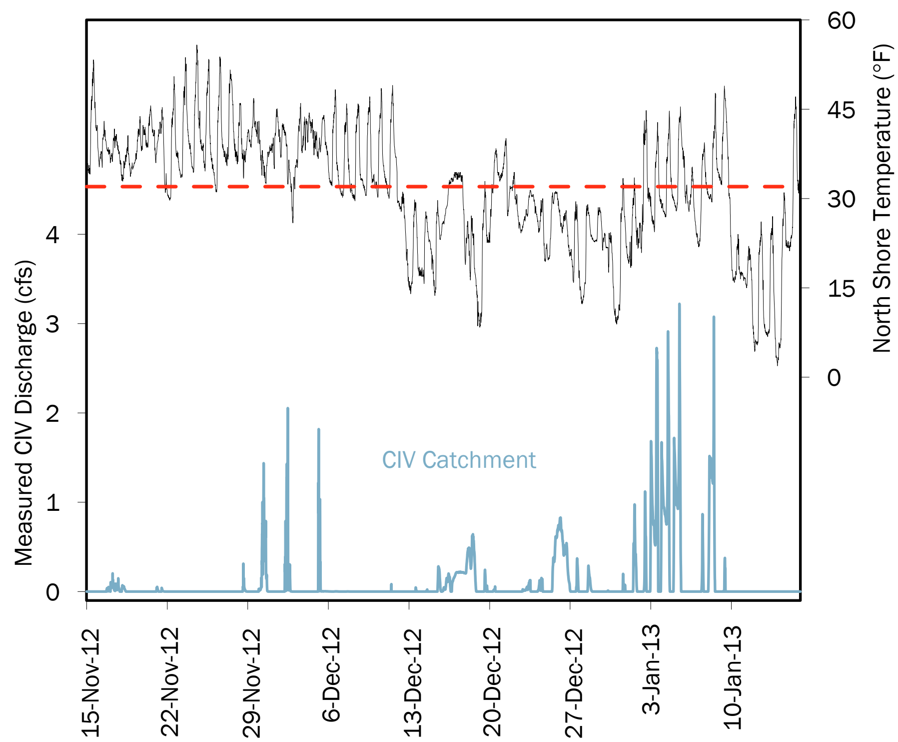
CENTRAL INCLINE VILLAGE (CIV) CATCHMENT

Field personnel did a reconnaissance level survey of the drainage conditions in the CIV catchment and developed modeled subcatchment boundaries based on topography and routing of storm drainage infrastructure. The PLRM scenario representing storm drainage routing from the large upper subcatchment in CIV scenario is complicated by the configuration of stormwater piping at the treatment vault at the corner of Village Drive and Lakeshore Boulevard (see Figure 3.1C). Runoff routed to the treatment vault is split within the vault, with a portion of the flows routed to the monitoring location and a portion discharging to the low flow channel traveling east along Lakeshore Boulevard that ultimately discharges to Incline Creek.

The as-built drawings for the treatment vault were evaluated to determine a representation for the hydraulics of the flow split design in PLRM. The flow split uses two outlet pipes set at the same invert elevation: a 24-inch pipe routes stormwater to the monitoring location, while the 12-inch pipe routes stormwater to the low flow channel along Lakeshore Boulevard. This configuration of storm drainage routing cannot be directly represented in PLRM using the Flow Divider object, which only allows for diversion when the flow rate in the simulation exceeds a set value. When this situation has arisen in the past, PLRM users have divided the subcatchment area in the model that physically drains to the flow diversion in an attempt to mimic the hydraulics of the flow split. This approach was tested by splitting the drainage area of the upper subcatchment into two subcatchments and routing the larger portion of the split subcatchment area to the monitoring location, since it receives runoff from the larger 24-inch storm drain pipe. A second approach, using a detailed SWMM model that represents the detailed storm drainage routing based on the as-built drawings with actual pipe sizes, invert elevations, pipe slopes, and pipe lengths, was also tested. A comparison of the results generated by both approaches suggests the simplified PLRM approach yields similar results to the more

Pasadena and Central Incline Village Catchment Hydrographs for December 2012 Freezing Events





DECEMBER 2012 MEASURED AIR TEMPERATURE V. DISCHARGE

FIGURE 3.8

complicated drainage design representation in SWMM, and therefore is the recommended approach for PLRM users presented with this complication in the future.

For CIV, Figure 3.7C presents estimated modeled and measured runoff volumes by event type over the monitoring period. Similar to the Pasadena catchment, modeled event runoff volumes display a reasonable correlation to measured data for the spring and fall of 2012 and a poor correlation for the winter of 2012/2013 (highlighted by yellow box in Figure 3.7C). The poor correlation is primarily caused by conflicting measured data. The best available meteorological data reports temperatures consistently below freezing during the time period. However, monitored runoff data reports significant volumes of stormwater at the monitoring location (see Figure 3.8). As discussed in Chapter 3.2.1, precipitation and temperature data from the Diamond Peak meteorological station at the base of the Diamond Peak Ski Resort was used to run the CIV simulation. The Diamond Peak station is roughly 1.5 miles to the east of the catchment and 350 feet higher in elevation. It appears that the meteorological data collected at the Diamond Peak station was not representative of temperature conditions in the CIV catchment during the 2012-2013 winter storms. This observed issue highlights the need to collect and quality-assure site-specific meteorological data that is representative of the conditions in the monitored catchment when conducting an assessment that includes PLRM snow hydrology.

3.3.4 WATER QUALITY MODEL REFINEMENT

PLRM estimates runoff concentrations from a catchment at each time step in a simulation as the product of land use specific CRCs and stormwater runoff as shown in the following equation for FSP:

$$Catchment\ FSP\ Concentration\ (\frac{mg}{L})_i = \frac{(CRC_{LU\_1} \times RV_{LU\_1})_i + (CRC_{LU\_2} \times RV_{LU\_2})_i + (CRC_{LU\_X} \times RV_{LU\_X})_i}{(RV_{Total})_i} \qquad \text{EQ (3.1)}$$

where:

i = time step in the simulation

CRC = characteristic runoff concentration for a specific land use (LU) and land use condition

RV = stormwater runoff volume of a specific land use (LU) during time step in the simulation

By definition, CRCs are static average annual values that do not vary during a PLRM simulation for each defined land use and land use condition. However, the volume of stormwater runoff generated by each land use and the relative proportion of stormwater runoff generated among modeled land uses can vary at each time step. Therefore, estimated catchment runoff concentration for a particular pollutant will vary during a PLRM simulation as stormwater runoff generated by land uses varies during the simulation, but this level of technical detail is not presented to the user in the currently available PLRM output reports. To estimate an average annual catchment concentration for a particular pollutant predicted by PLRM, a user can divide the average annual pollutant loading reported by the average annual surface runoff reported.

The static CRC values are appropriate for an average annual dataset; however, to develop a comparable dataset to the measured data, CRCs that represent changing land use conditions are needed. The land use with the most variable condition is paved roads in the Tahoe Basin (Kuhns et al. 2010; 2NDNATURE et al. 2010), and Road RAM observations conducted throughout the year were used to generate a weighted catchment average road condition as described above in Chapter 3.2.3. The research team applied catchment road condition measurements using Road RAM into the model to better represent seasonal observations. The details for adjusting the values in the SWMM input file are provided in Appendix B.

PLRM estimates the water quality improvement provided by stormwater treatment BMPs using a static CEC for each pollutant assigned to all runoff routed through the treatment outlet of the respective stormwater treatment BMP. PLRM contains default CEC values for each treatment BMP type. At the time of development, the CEC values were based on very limited stormwater datasets, and subsequent research (2NDNATURE and NHC 2012a) has suggested that the PLRMv1 FSP and TSS CEC values are currently lower than what is achievable in certain locations. Effluent quality will be dependent on basin siting, design, maintenance and influent water quality. Each of the 3 catchments modeled for this research included a treatment BMP: 1 settling basin in Osgood (modeled as a treatment vault), 1 treatment vault and 2 cartridge filters in Pasadena, and 1 treatment vault in CIV. Variable FSP CEC values were assigned to the Osgood settling basin (150 mg/L), Pasadena treatment vault (200 mg/L) and CIV treatment vault (75 mg/L) based on field observations and discussions with maintenance personnel. All values are higher than the default value of 48mg/L, which was selected assuming the treatment vault was not designed to target FSP removal, but rather to function as a pre-treatment device for the downstream cartridge filters by removing coarse particulates and debris. The cartridge filters were assigned a FSP CEC of 10 mg/L, which is the PLRMv1 default value.

3.3.5 PLRM MODEL DEVELOPMENT TO COMPARE TO MEASURED DATA CONCLUSIONS

For this research, the project team had to make a series of refinements to the PLRM models within the SWMM platform to generate and access volume and FSP estimates on the short-duration time scales needed for comparison to measured data. Below are a number of modeling considerations and data requirements to adequately compare PLRM estimates with observed stormwater volumes and pollutant loading data.

- **PLRM simplification of SWMM.** PLRM developers made a number of design decisions that simplified or automated algorithms to streamline use of the tool and reduce data input for the intended user group. The simplifying assumptions have produced a tool that most PLRM users find relatively easy to use, but the simplifications and development objectives of PLRM can complicate efforts to represent certain drainage conditions in catchments and accurately predict stormwater volumes and loads. Specifically,
    - PLRM is not designed to simulate baseflow from a non-urban land use, but there are some locations where there is a continuous, significant contribution from forested catchments during wet years, particularly in the spring.
    - Flow diversions that split flows continuously cannot be directly represented in the model. For these situations, a reasonable approach in PLRM may be to proportionally scale the drainage area of subcatchments routed to the flow split to mimic the hydraulics of the flow split.

Given these limitations, the selection of sites where the potential comparison of PLRM modeled to measured data should not include baseflow inputs or overly complicated flow routing that are difficult to adequately represent in PLRM.

- **Accurate and representative physical representation of the drainage catchment.** Catchment area, distribution of directly connected impervious area (DCIA), and complex flow routing through the stormwater system, treatment BMPs, bypass, diversions, flow splits, etc. within the contributing catchment all must be understood and accurately represented in the model.

- **Accurate and representative weather data of the monitored site**. The critical weather parameters to generate high resolution site-specific PLRM estimates are accurate precipitation and temperature data that correspond with the timing of stormwater monitoring. In particular, meaningful assessments of modeled vs. monitored runoff data for periods with snow hydrology requires quality-assured and representative temperature data. While seemingly simple, researchers spent significant resources (> 40 hrs of technical senior scientist and principal time per urban catchment) conducting QA/QC procedures on weather data maintained and reported by other sources. Results of the monitoring study show that weather stations located in the vicinity of the study area, but not directly in the study area, produced data that did not adequately predict events that were a mixture of rain and snow. The establishment, operation and maintenance of a highly representative weather station are essential, particularly during the winter. Future correlations and analyses may be improved for events with a mixture of rain and snow by including representative and distributed pavement temperature monitoring along with air temperature monitoring.

- **Reasonable representation of land use CRCs at time of stormwater monitoring.** The water quality module of PLRM spatially integrates characteristics runoff concentrations (CRC) that vary based on land use condition. Road CRCs, particularly for FSP, have been documented to vary significantly across road, jurisdictions, months and seasons (2NDNATURE et al. 2010). This road condition variability can be better represented in PLRM predictions if periodic catchment scale measurements of road condition are used to inform road FSP CRCs. Guidance to adjust SWMM inputs based on these measurements is provided in Appendix B. Even with these modifications to adjust CRCs based on measured road condition, pollutant fate and transport in urban stormwater results in variable time of concentration throughout the catchment. It is likely that the land use surfaces in closer proximity to the monitoring station have a greater influence on the measured pollutant concentration and loads. Pollutants generated in the upper catchment are continuously stored and remobilized, or removed via maintenance practices, during subsequent events. In summary, the complexity of pollutant transport and variations in time of concentration throughout the catchment make the use of the EQ (3.1) a highly simplified and unrepresentative pollutant loading model on short (event) time scales. However, for the intended application of PLRM to represent the average annual load reduction achieved as a result of a series of water quality improvement actions, the use of EQ 3.1 and static CRCs is reasonable.

- **Reasonable representation of Treatment BMP performance**.
  A reasonable representation of the actual condition of catchment BMPs, especially treatment BMPs expected to provide significant load reductions, should be tracked to improve confidence that the condition of the BMPs during the monitoring duration are being reasonably represented in PLRM. During this research, stormwater was found to be bypassing a critical media filter BMP, resulting in a significant underestimate of the actual pollutant loading from the catchment. BMP RAM is designed and available to potentially inform the BMP conditions when trying to represent their performance in PLRM.

In addition, the default PLRM CECs may not be representative of the actual treatment BMP performance if: the physical configuration of the BMP in PLRM is not accurate; the BMP has not received adequate or regular maintenance; or inflow pollutant concentrations are misrepresented in the model. Treatment BMP CEC representation can be improved or calibrated using effluent sample collection representing the range of event types and flow conditions that occurred at the site during the duration of monitoring.

- **Technical expertise.** To create a modeled dataset comparable to measured data, the predictions must be completed in SWMM, not in the PLRM interface that Tahoe stormwater community is accustomed to using. Guidance by the PLRM developers to complete event-based SWMM estimates is provided in Appendix B. However, users not familiar with SWMM or other hydrology simulation models will likely have difficulty critically evaluating model outputs and making appropriate adjustments in the model to ensure they are reasonable.

4 WEATHER DATA

This research focused on data collection and analysis of catchment pollution generation and stormwater quality, which are influenced by the specific runoff patterns and magnitudes (i.e., hydrology) at the site. In order to appropriately place the data and findings obtained into the climatic context it is critical to constrain the natural uncontrollable drivers that inherently influenced the data obtained. Daily, seasonal and water year meteorological variations introduce significant variability into catchment pollutant loading. Ultimately, we are interested in the pollutant load reductions as a result of effective actions, which require techniques to constrain the natural meteorological variability influencing pollutant loading. Below we place the monitored seasons into their context relative to last 100 years.

4.1 WATER YEAR AND SEASONAL CONTEXT

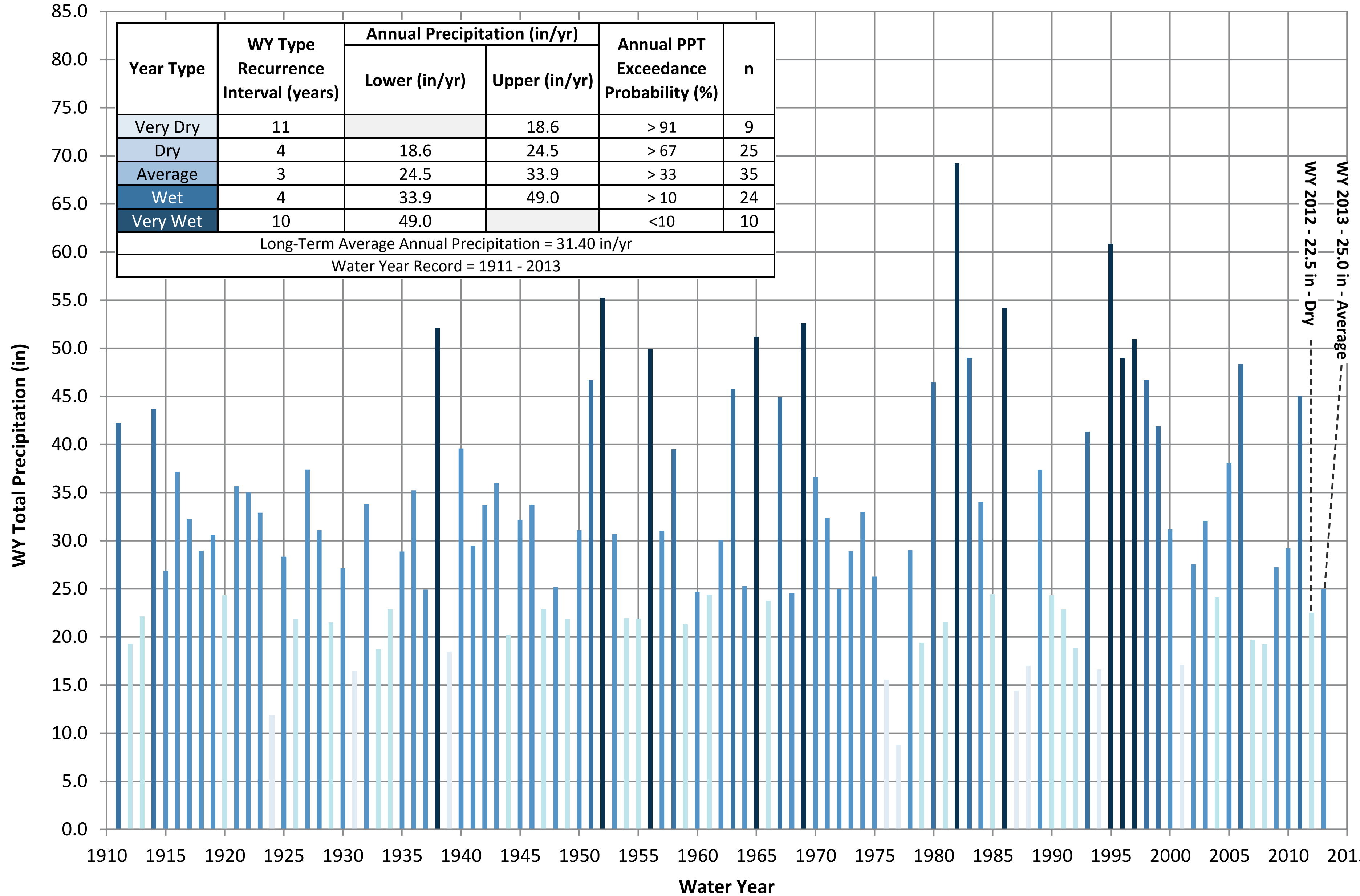
The climatic differences between water years have a direct impact on the resulting urban stormwater runoff observed during the study. Providing climatic context for the monitored years assists the research team with interpretation of these results and will assist researchers with comparisons of these data to future water year observations. The Tahoe City gauge, operated by Western Regional Climate Center (WRCC) (http://www.wrcc.dri.edu/), provides the longest period of record for Tahoe Basin climate data. A precipitation frequency analysis was conducted on the 103 years of Tahoe City precipitation data to determine the recurrence intervals (RI) of annual precipitation totals. The water year type definitions were created using reasonable recurrence intervals to bracket average precipitation totals and ensure the extreme (very wet and very dry) categories have less than a 10% probability of occurring (see table in Figure 4.1). The Tahoe City gauge may not exactly represent the weather conditions experienced at a specific water quality monitoring station included in this research, however, the Tahoe City data is a reliable and easily accessible long-term record that provides a reasonable representation of water year types for the Tahoe Basin urban areas as a whole for the purposes of this research.

Using these water year definitions, Figure 4.1 graphically presents the Tahoe City gauge data for the entire period of record. WY1989-WY2006 are inputs into the PLRM 18-year simulation and represent a range of water year types: 9 years are average or drier and 9 years are above average. WY07 and WY08 were notably two consecutive dry years, while WY09 to WY11 progressively got wetter. WY12 was a dry year, followed by 25.0 inches in WY13, which is on the boundary between an average and a dry year as defined by this research. The considerations of antecedent and actual water year weather conditions are used in our hydrologic and water quality data interpretations herein.

Using standard season breaks (see Table 3.1), we apply the same frequency analysis methodology to designate season types and provide a slightly finer resolution to the weather context. For the 3 seasons, Table 4.1 displays the season types based on 103-year record for the Tahoe City gauge.

Tahoe City Water Year Summary

Year Type	WY Type Recurrence Interval (years)	Annual Precipitation (in/yr) Lower (in/yr)	Annual Precipitation (in/yr) Upper (in/yr)	Annual PPT Exceedance Probability (%)	n
Very Dry	11		18.6	> 91	9
Dry	4	18.6	24.5	> 67	25
Average	3	24.5	33.9	> 33	35
Wet	4	33.9	49.0	> 10	24
Very Wet	10	49.0		<10	10
Long-Term Average Annual Precipitation = 31.40 in/yr					
Water Year Record = 1911 - 2013					



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TAHOE CITY WY PRECIPITATION SUMMARY

FIGURE 4.1

Table 4.1. Seasonal frequency analysis of Tahoe City precipitation gauge using 103 years of data and classification of season types based on recurrence interval (RI) breaks. Seasons are defined consistently with the Lake Tahoe Municipal NPDES permit (LRWQCB 2011).

Type	Recurrence Interval (years)	PPT Exceedance Probability (%)	n	Season Total Precipitation (in)		
				Fall/Winter	Spring Snowmelt	Summer
Very Dry	11	>91	9	<11.4	<2.9	<0.3
Dry	4	>67	25	11.4 – 16.3	2.9 – 5.3	0.3 – 0.9
Average	3	>33	35	>16.3 – 25.5	>5.3 – 8.5	>0.9 – 2.3
Wet	4	>10	24	>25.5 – 36.8	>8.5 – 13.5	>2.3 – 3.9
Very Wet	10	<10	10	>36.8	>13.5	>3.9
			Minimum season precipitation (in)	**4.6**	**1.4**	**0.0**
			Maximum season precipitation (in)	**46.2**	**28.3**	**7.6**
			Mean season precipitation (in)	**22.1**	**7.4**	**1.8**
			Median season precipitation (in)	**20.3**	**6.6**	**1.4**

Using the definitions presented in Figure 4.1 and Table 4.1, Table 4.2 summarizes the water year and seasonal precipitation totals and type over the past 5 years, from WY09-WY13. Of particular note is that while the Fall/Winter of WY2013 was an average year, 18.2 inches, or 96% of the seasonal total, fell in October through December, while only 0.7 inches fell in January and February, making it the driest January/February on record over the last 103 years.

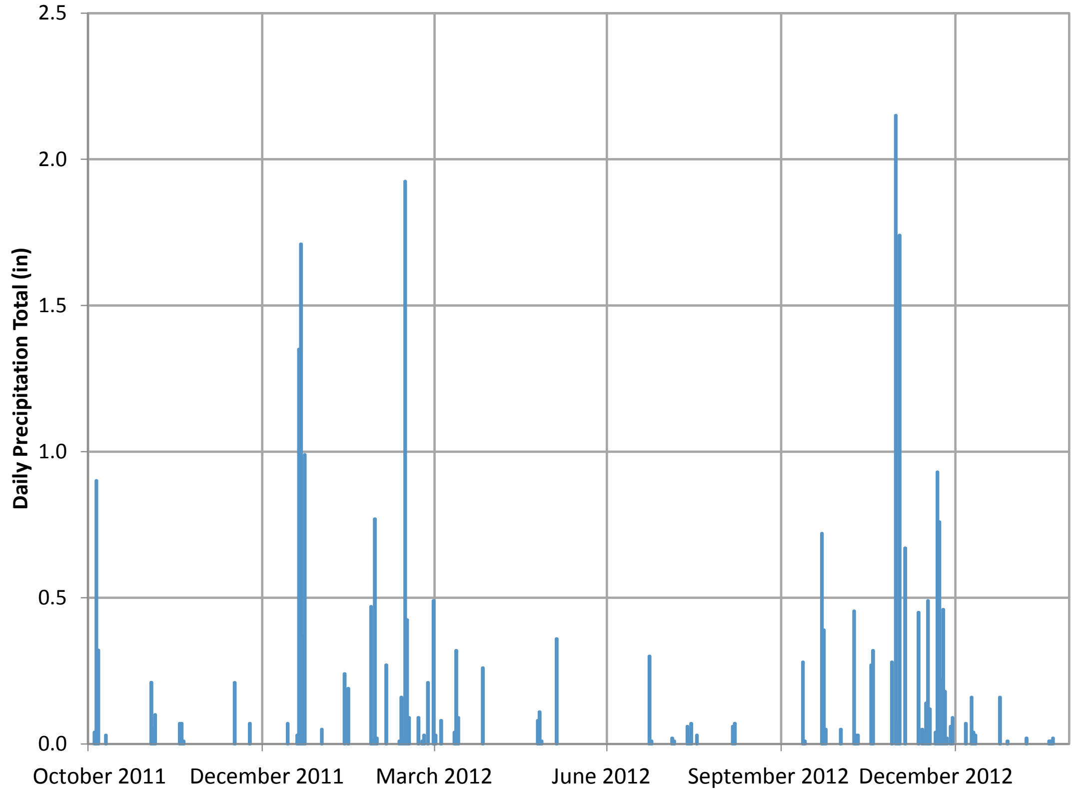
Table 4.2. Total precipitation and water year and seasonal types for WY09-WY13 based on frequency analysis, WY and seasonal definitions (see table in Figure 4.1 and Table 4.1) and the 103-year precipitation record at Tahoe City gauge. The water years and seasons included in this research are highlighted by type for easier reference.

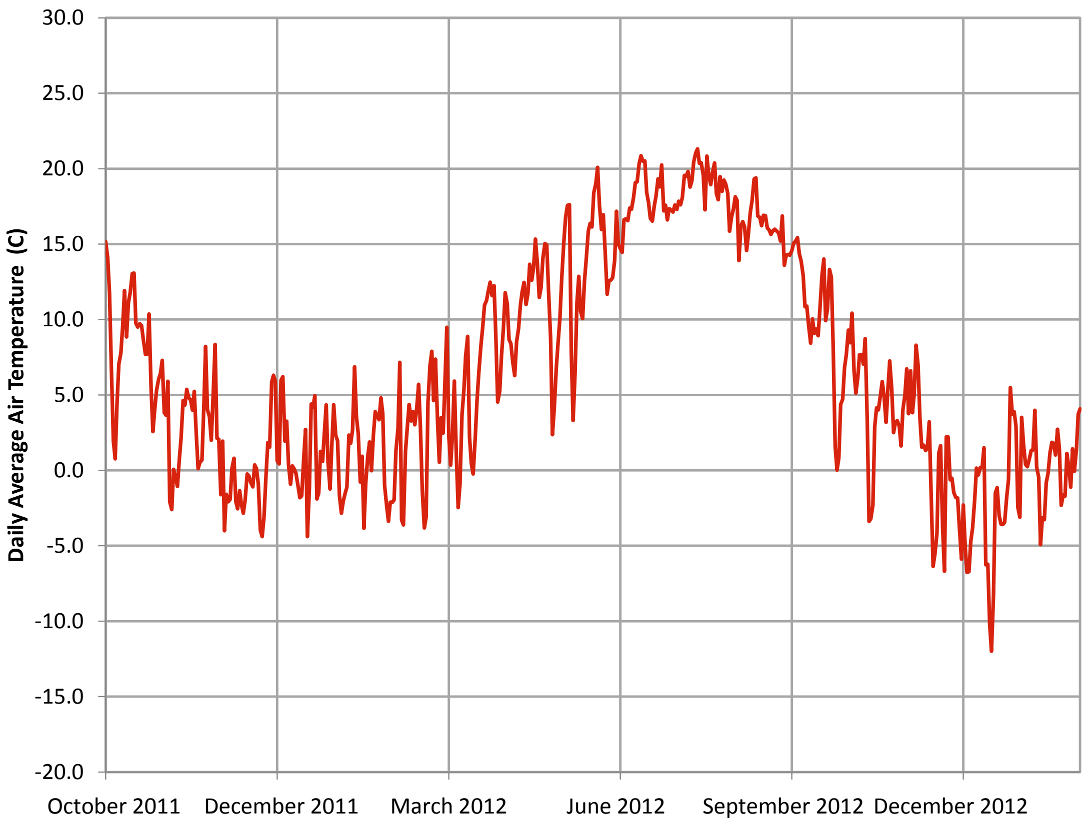
WY	Total Precipitation (in) (WY Type)	Season Total Precipitation (in) and Seasonal Type		
		Fall/Winter	Spring Snowmelt	Summer
WY2009	27.2 (Average)	15.3 (Dry)	11.0 (Wet)	1.0 (Average)
WY2010	29.2 (Average)	18.8 (Average)	9.6 (Wet)	0.7 (Dry)
WY2011	45.0 (Wet)	25.6 (Wet)	16.8 (Very Wet)	2.6 (Wet)
WY2012	22.5 (Dry)	11.0 (Very Dry)	9.7 (Wet)	1.8 (Average)
WY2013	25.0 (Average)	18.9 (Average)	4.3 (Dry)	1.7 (Average)

4.2 WEATHER CONDITIONS

Figure 4.2 provides the daily time series for air temperature and precipitation for the weather stations CSLT Fire Station (A) used for Pasadena and Osgood catchments and DRI Diamond Peak (B) used for the Central Incline Village catchment. These meteorological time series are the direct inputs driving the PLRM hydrology estimates and provide a context for the catchment outfall seasonal and annual volumes and loads. This context will be invaluable as additional data is obtained from the same monitoring locations by others. These records provide context within which to understand the variability observed in road condition as influenced by both winter storm maintenance and rain runoff flushing.

CSLT Fire Station Weather Data
(Osgood & Pasadena Catchments)





**Data provided by CSLT. See Figure 3.1A for station location.*

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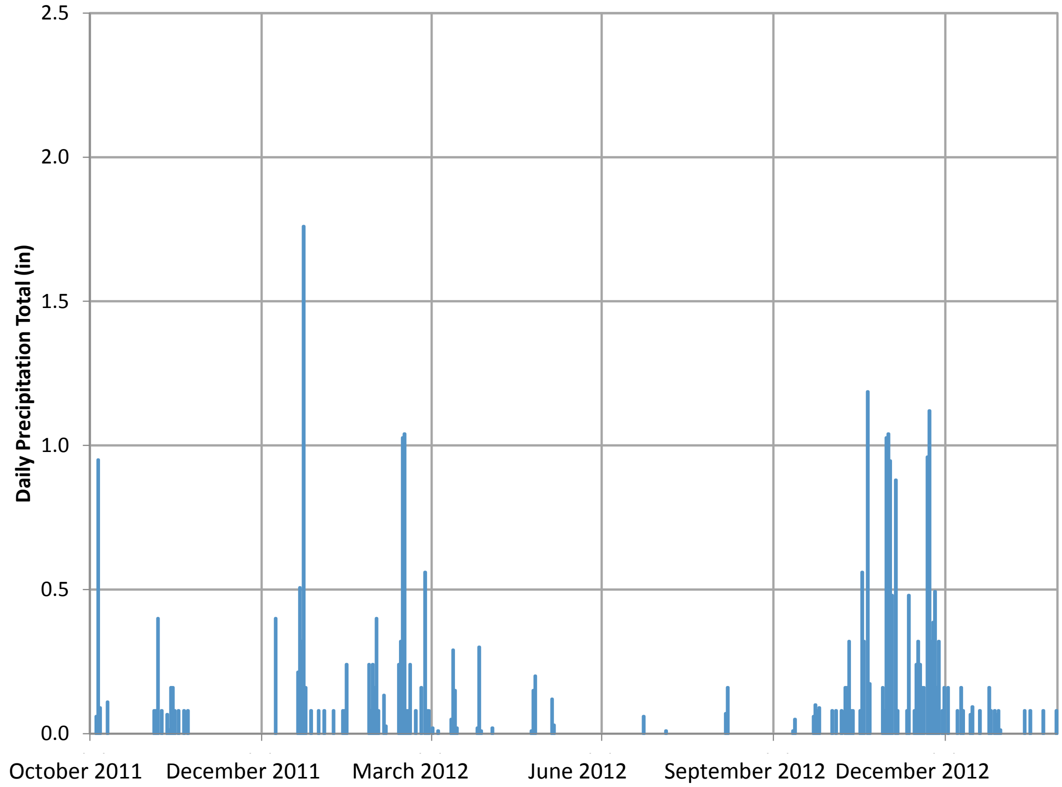
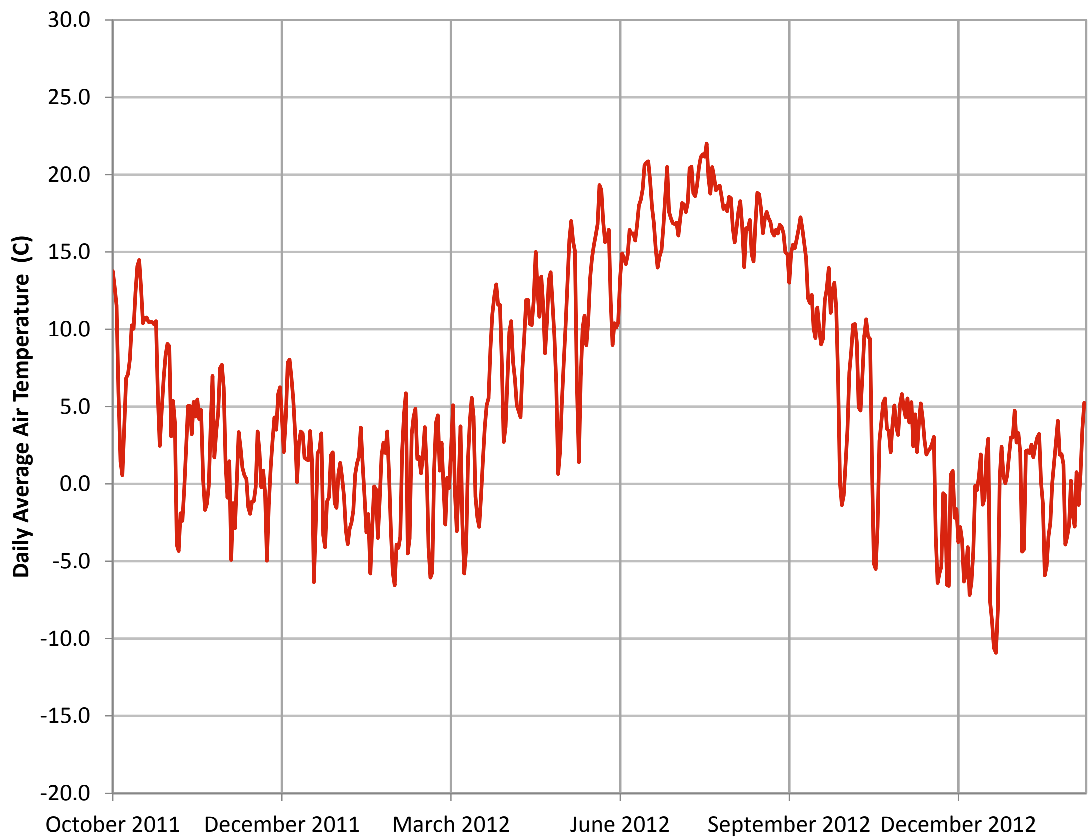
CSLT FIRE STATION WEATHER DATA

FIGURE 4.2A

DRI Diamond Peak Weather Data
(Central Incline Village Catchment)





**Data provided by DRI. See Figure 3.1C for station location*

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5 ROAD CONDITION RESULTS

Urban roads have been identified as the greatest controllable source of FSP per unit area in the Tahoe Basin (LRWQCB and NDEP 2010, Zhu et al. 2009, Kuhns et al. 2010, 2NDNATURE and NHC 2011). Within an urban catchment then, we would expect the condition (i.e., risk to downslope water quality) of the road network to have a measurable influence on the FSP loads measured at the catchment outfall. In an effort to capture seasonal road conditions, 2NDNATURE field personnel implemented Road RAM on a collection of road segments within each of the 3 catchments. The following presents the results on a number of spatial (road segment, road class, catchment) and temporal (observation period, seasonal, volume-weighted annual) scales. These road condition results are then compared to the monthly road maintenance and weather metrics to evaluate the assumption that road condition is sensitive to road maintenance practices.

5.1 ROAD RAM RESULTS

Road condition observations were performed in each catchment 6 times over the course of this research. Table 5.1 provides a summary of all road segment condition scores measured at each road segment from January 2012 through February 2013, and Figures 5.1A-C map the condition scores by color (see Table 3.7 for the range of scores represented by each color) for observations made in each catchment. As expected and observed by past efforts, there is a general trend of poor road conditions during the winter and early spring, when the weather is colder and more abrasives are applied for traffic safety. Road conditions consistently improve in the summer and early fall, following spring runoff events and sustained pollutant recovery actions.

Table 5.2 provides a brief summary of the road segment scores in the three catchments, including statistics on the number of observations of roads in poor (score ≤2) and good condition (score ≥3.5). In general, the road conditions over the year of monitoring were better in the CIV catchment and the poorest road conditions were observed in Pasadena.

Table 5.2. Summary statistics of road segment condition scores by catchment. All observations were conducted over 6 observation periods from January 2012 through February 2013. In general observations in all 3 catchments were conducted over the same 1-2 day period and are therefore directly comparable.

Metric	Total # of Observations (% of total)		
	Osgood	Pasadena	CIV
	94	70	103
# (%) of Road RAM obs ≤ 2.0 (poor condition)	24 (26%)	24 (34%)	12 (12%)
# (%) of Road RAM obs ≥ 3.5 (good condition)	28 (30%)	9 (13%)	54 (52%)

Road RAM utilizes road class mapping to spatially extrapolate discrete observations at road segments to a broader road network (2NDNATURE et al. 2010) for each observation period. The road class designations for each catchment based on the information provided by the respective jurisdiction are presented in Figures 3.2C and 3.2C. Figures 5.2A-C map the road class results for each observation period and Tables 5.3 & 5.4 present the road class scores for CSLT and Washoe County respectively.

Osgood Catchment Road Ram Scores (CSLT)

Name	Road Segment Risk	Road Segment Class	Road Surface Integrity	1/9/2012	4/3/2012	5/22/2012	8/30/2012	10/26/2012	2/12/2013
2NDNATURE_ALDER	SMR	BZ	3	3.3	2.0		3.8		3.2
2NDNATURE_DAVID	SMR	BZ	1	2.8				3.3	2.3
2ndNature_KC3_2011	SHR	AX	5	3.9	1.1	2.0	5	3.1	1.1
2NDNATURE_KELLER2	SHR	AZ	1			2.7	3.5	3.8	2.8
2NDNATURE_KNOLL	SMR	BZ	1	3.1	2.4		3.5	2.7	2.6
2NDNATURE_NPEAK	PHR	AX	5	2.9	1.2	4.4	5.0	4.1	2.2
2NDNATURE_PARADISE	SMR	BZ	3	3.0	1.2		3.7		2
2NDNATURE_RUBY	SMR	BZ	3	2.9					1.5
2NDNATURE_SADDLE1	SHR	AX	1	3.1	2.0	4.3	5	3.3	2
2NDNATURE_SADDLE2	SHR	AZ	3		2.3	5	3.5	2.3	3
2NDNATURE_SKIRUN2	PHR	AX	1	4.0	1.5	2.6	1.8	2.6	3.2
2NDNATURE_SPRUCE	SMR	BZ	1	1.9	1.5		3.6	3.3	
2ndNature_SR1_2011	PLR	BX	5	3.0	1.5	4.2	5	5	3.3
2NDNATURE_TAM	SMR	BZ	3	2.4	1.7		5	5	2.4
2NDNATURE_TERRACE	SHR	AZ	3	3.1	0.6	3.0	3.2	2.8	1.4
2NDNATURE_VERDON	SMR	BZ	3	5.0	1.7	2.9	2.1	2.7	1
2NDNATURE_WILLOW	SMR	BZ	3	3.2	2.0		3.2	3	2
2NDNATURE_WOODS	SHR	AZ	3	5.0	2.5		5	5	1.4
2NDNATURE_WWOOD	SMR	BZ	1	3.8	1.1	4.7	2.8	5	2.9

Pasadena Catchment Road Ram Scores (CSLT)

Name	Road Segment Risk	Road Segment Class	Road Surface Integrity	1/9/2012	4/3/2012	5/22/2012	8/30/2012	10/26/2012	2/12/2013
2NDNATURE_ALA	SLR	CZ	3	1.8	1.9	2.2	4.3	3.2	1.8
2NDNATURE_ALP	SLR	CZ	5	2.5	1.5	3.9	2.5	5	1.8
2NDNATURE_FCR	SLR	BX	3	2.5	1.5	2.5	2.8	5	3.1
2NDNATURE_FP	SLR	BX	3	2.5	2.3	2.8	2.9	2.3	1.5
2NDNATURE_LA1	SMR	BX	5	2.6	1.7	2.5	5	2.7	2.8
2NDNATURE_LV	SMR	BX	5	2.9	0.9	2.7	2.1		1.8
2NDNATURE_LVP	SMR	BX	5	2.6	2.1		1.7	3.3	1.9
2NDNATURE_MOAK	SLR	CZ	3	2.6	1.3	2.3	3.3	4.4	3.3
2NDNATURE_OAK	SMR	CZ	1	2.8	1.7	2.2	2.7	3.3	1.5
2NDNATURE_PAL	SMR	CZ	5	4.8	2.0	3.1	2.7	5	2
2NDNATURE_PAM	SLR	CZ	5	3.3	2.0	4.1	2.2	2	1.8
2NDNATURE_TFP	SLR	BX	3	1.9	0.5	2.3	2.5	2	0.5

Central Incline Village Road Ram Scores (Washoe County)

Name	Road Segment Risk	Road Segment Class	Road Surface Integrity	1/8/2012	4/10/2012	5/23/2012	8/31/2012	10/27/2012	2/13/2013
2NDNATURE_ALD	SHR	AX	5	3.0					2.4
2NDNATURE_ALLN	SHR	AY	3			3.4	2.6		2.6
2NDNATURE_APK1	SMR	BY	5		2.9	3.3	5	3	1.5
2NDNATURE_APK2	SMR	BY	5		4.8	5.0	3	4.4	2.3
2NDNATURE_ENT	SHR	AY	5			4.7	2.7		3
2NDNATURE_IHS	PMR	AX	5	4.2					
2NDNATURE_IW	SHR	AX	3	3.5					3.3
2NDNATURE_IW2	SMR	BX	5		2.6	5.0	3.7	4.1	1.7
2NDNATURE_JD	SHR	AX	5	4.0	2.2	5.0	5	5	1.8
2NDNATURE_JEN	SLR	CY	5		2.4	4.1	3.7	5	1.2
2NDNATURE_LB	PLR	AX	5	2.6	1.6	4.2	3.2		2.3
2NDNATURE_LB2	PLR	AX	5		1.4				2.3
2NDNATURE_NENT	SMR	BZ	1		1.5	3.6	1.6		1.1
2NDNATURE_NW	PMR	AX	5	4.0	2.7	3.4	2.8	4.3	2.7
2NDNATURE_NW2	SLR	CX	3		3.3	4.3	5	3.1	2.4
2NDNATURE_OP1	SLR	CY	5		2.1	3.8	5	3.3	2.3
2NDNATURE_OP2	SLR	CY	5		3.2	3.0	3	4.6	2.6
2NDNATURE_ORL1	SMR	BX	3		3.1	4.5	2.8		2.6
2NDNATURE_ORL2	SHR	AY	5			5.0	2.6		2.6
2NDNATURE_RBN	SMR	BY	3		3.0	3.0	4.3		2
2NDNATURE_RPL	SMR	BX	5	5.0	2.8	2.8	5		2.7
2NDNATURE_SW	SLR	CX	3	5.0	3.1	3.6	5	4.4	3.9
2NDNATURE_TB	PHR	AX	5	4.4	2.7	2.5	3.3	2.7	3.7
2NDNATURE_VA	PMR	AX	5	3.0					3.9
2NDNATURE_VIL1	PMR	AX	5	3.5	3.0	4.9	3.3	3.1	3.3
2NDNATURE_VIL2	PMR	AX	5	3.6	3.1	4.8		1.7	2
2NDNATURE_VIL3	SLR	CX	5	4.5		5.0	3.1		3.3
2NDNATURE_VIW	PMR	AX	5	3.0					3.3
2NDNATURE_VJD	SLR	CX	5	4.5				5	3
2NDNATURE_VLB	SLR	CX	5	3.0	4.3	4.4	3.9	5	2.1
2NDNATURE_VNW	PMR	AX	5	4.3	2.5			2.1	2.1
2NDNATURE_VTB	PMR	AX	3	2.6	2.2	4.4	5		3

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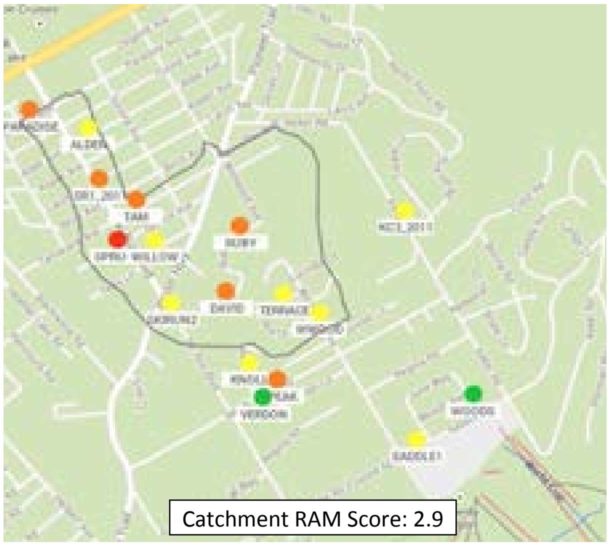
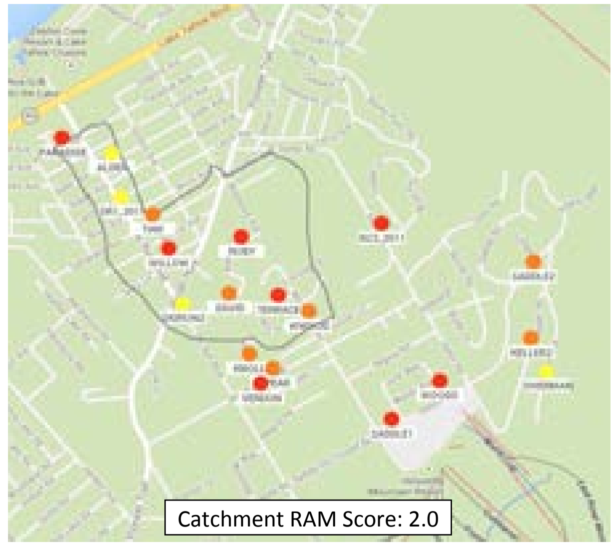
ROAD SEGMENT RAM SCORES

TABLE 5.1

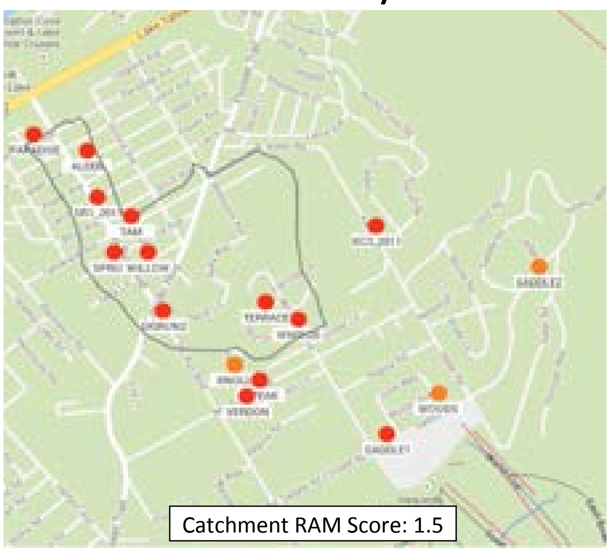
Osgood Catchment Road Segment Condition Scores



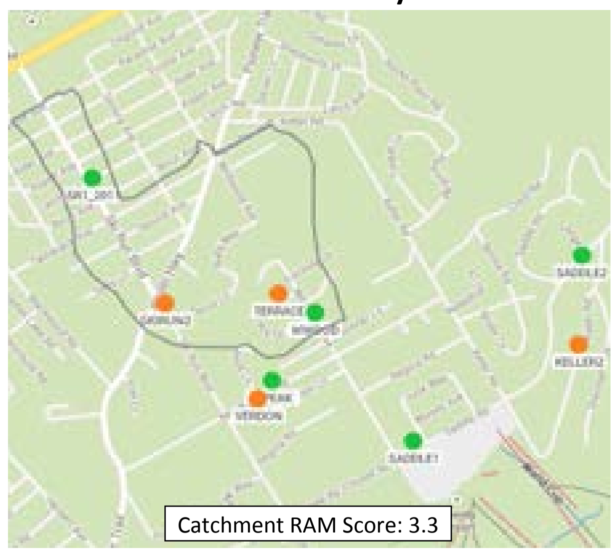
Winter - January 2012



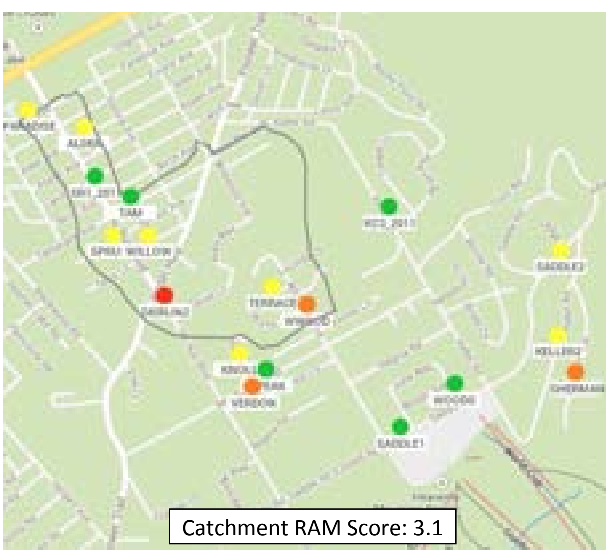
Winter - February 2013



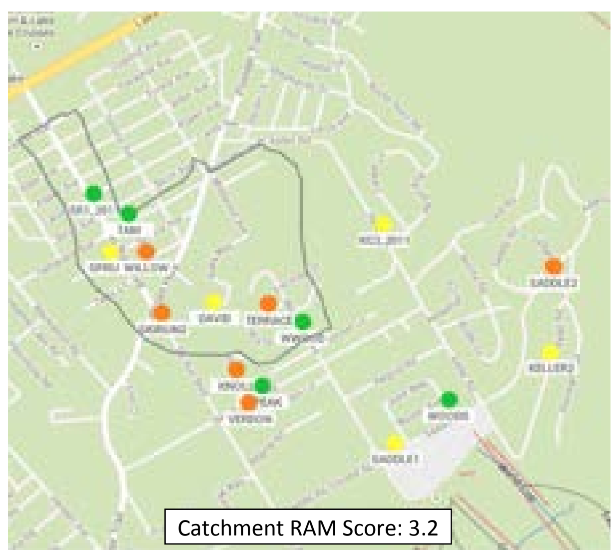
Late Winter/Early Spring - April 2012



Spring - May 2012



Summer - August 2012



Fall - October 2012

Osgood catchment road segment condition maps generated by Road RAM website for observations between January 2012 and February 2013. Spatially weighted catchment Road RAM scores (using road class distribution) also provided.

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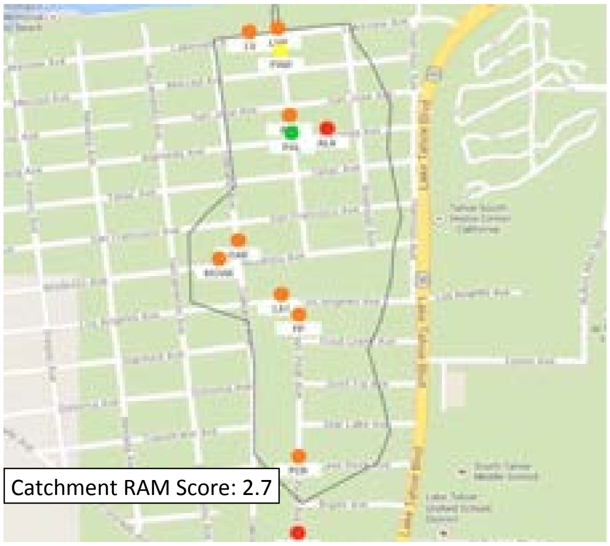
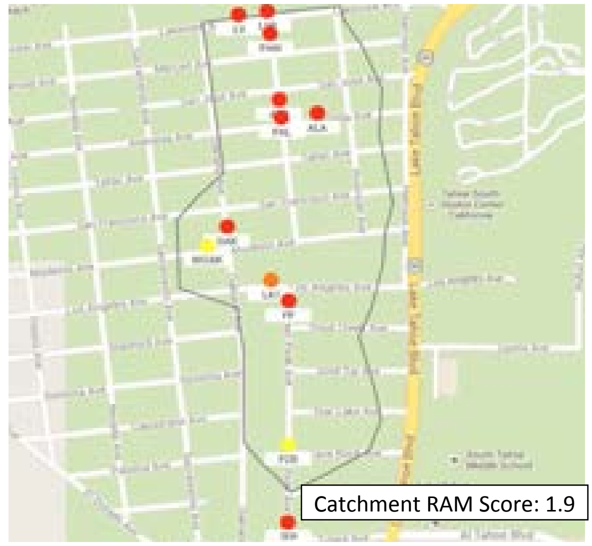
OSGOOD CATCHMENT ROAD SEGMENT CONDITION SCORES

FIGURE 5.1A

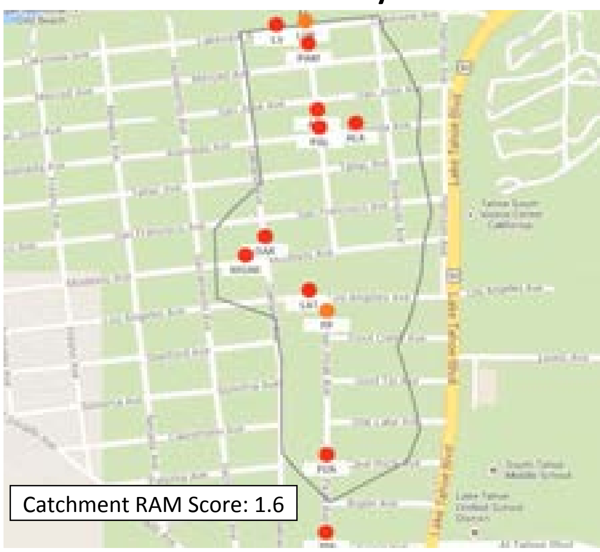
Pasadena Catchment Road Segment Condition Scores



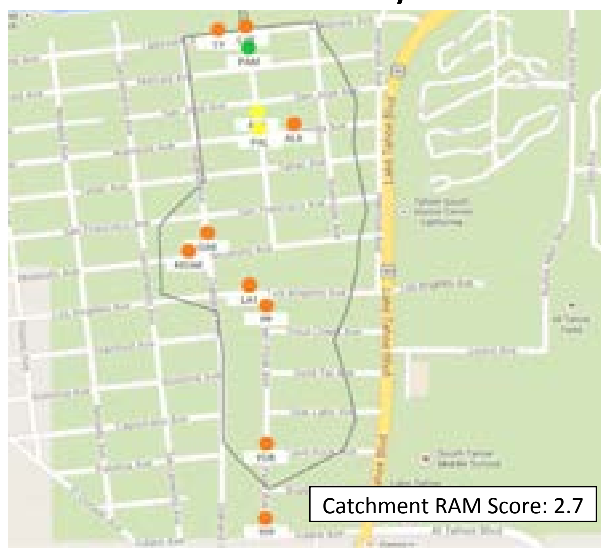
Winter - January 2012



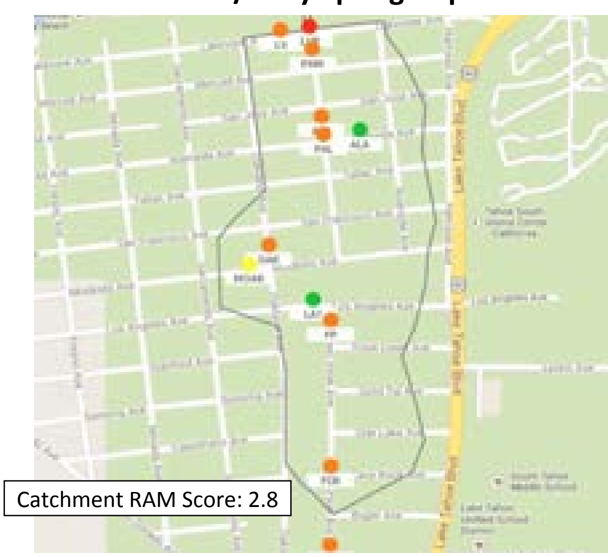
Winter - February 2013



Late Winter/Early Spring - April 2012



Spring - May 2012



Summer - August 2012

Fall - October 2012

Pasadena catchment road segment condition maps generated by Road RAM website for observations between January 2012 and February 2013. Spatially weighted catchment Road RAM scores (using road class distribution) also provided.

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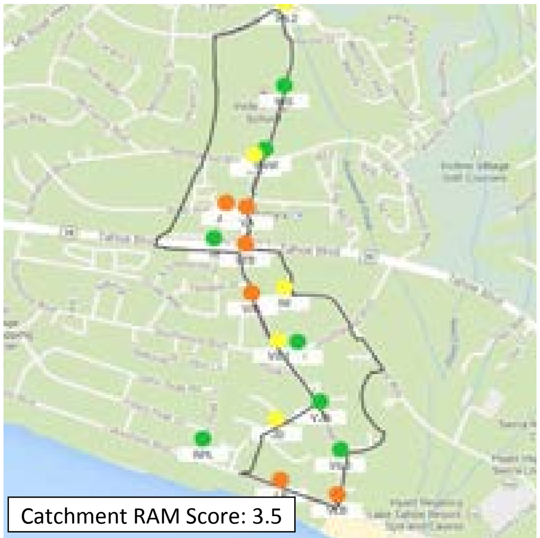
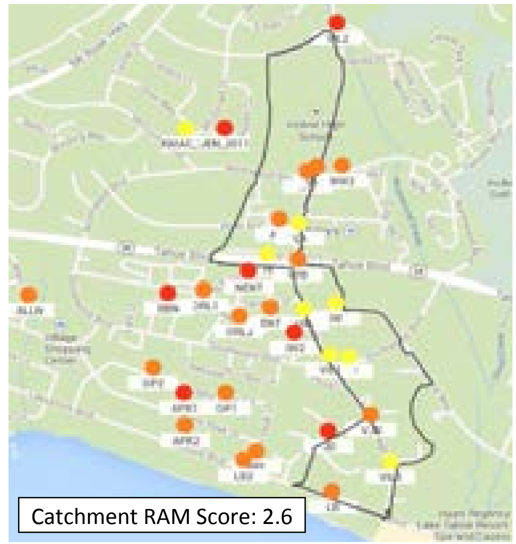
PASADENA CATCHMENT ROAD CONDITION SCORES

FIGURE 5.1B

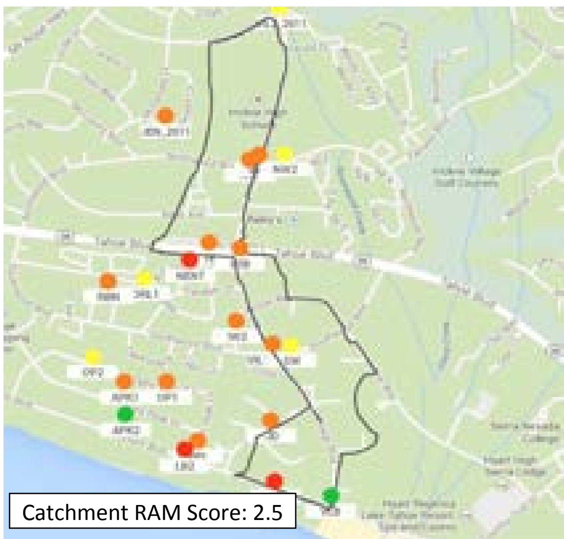
Central Incline Village Catchment Road Segment Condition Scores



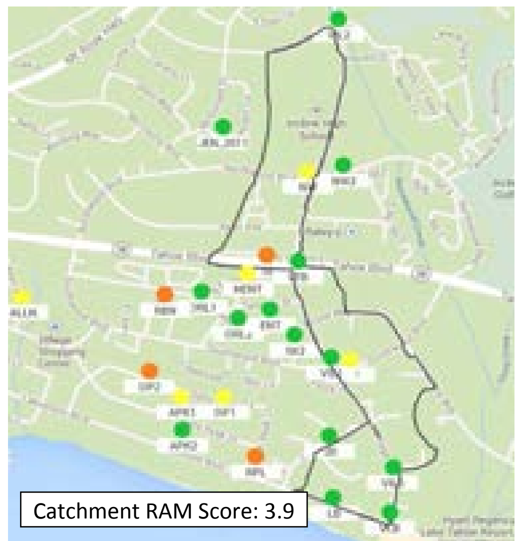
Winter - January 2012



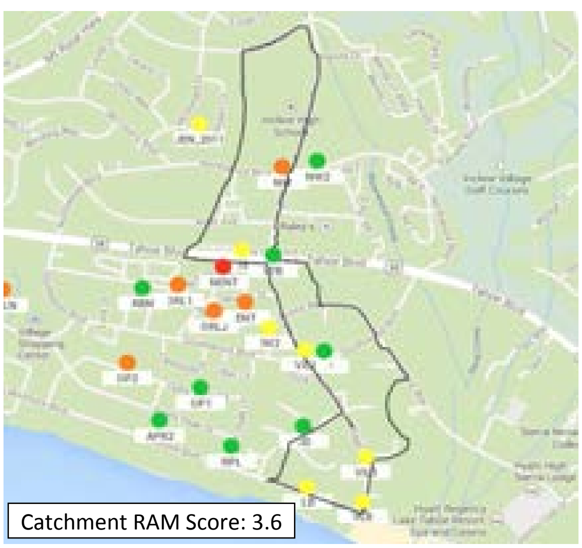
Winter - February 2013



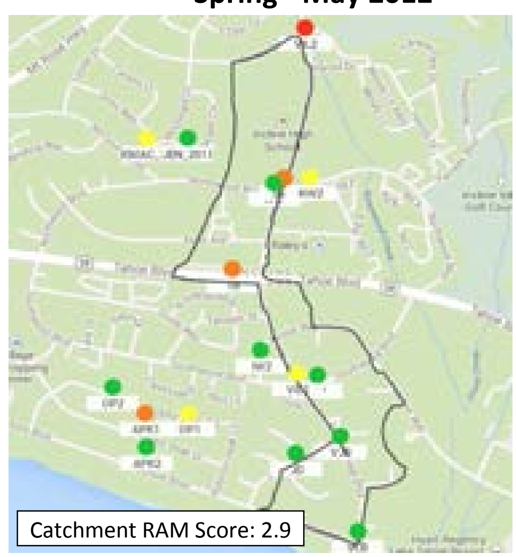
Late Winter/Early Spring - April 2012



Spring - May 2012



Summer - August 2012



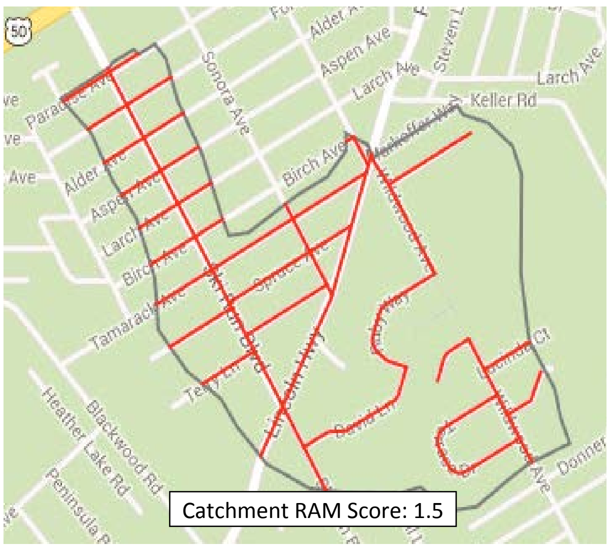
Fall - October 2012

Central Incline Village catchment road segment condition maps generated by Road RAM website for observations between January 2012 and February 2013. Spatially weighted catchment Road RAM scores (using road class distribution) also provided.

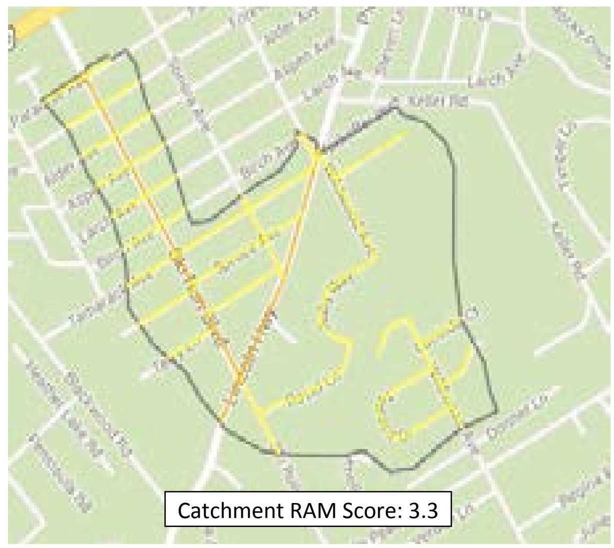
Osgood Catchment Road Class Condition Scores

Winter - January 2012

Winter - February 2013



Late Winter/Early Spring - April 2012



Spring - May 2012

Summer - August 2012

Fall - October 2012

Osgood catchment road class condition maps generated by Road RAM website for observations between January 2012 and February 2013. Spatially weighted catchment Road RAM scores are also provided.

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Pasadena Catchment Road Class Condition Scores

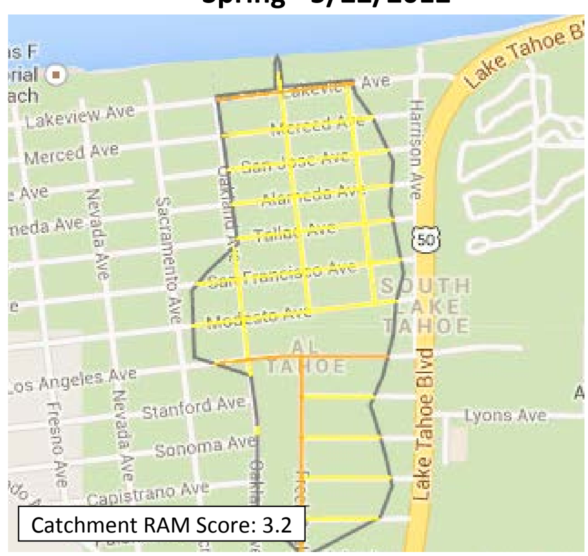
Winter - 1/9/2012

Winter - 2/12/2013

Late Winter/Early Spring - 4/3/2012

Spring - 5/22/2012

Summer - 8/30/2012



Fall - 10/26/2012

Pasadena catchment road class condition maps generated by Road RAM website for observations between January 2012 and February 2013. Spatially weighted catchment Road RAM scores are also provided.

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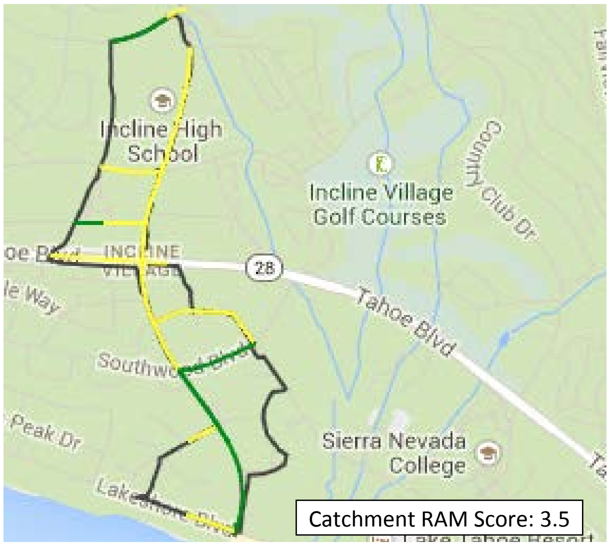
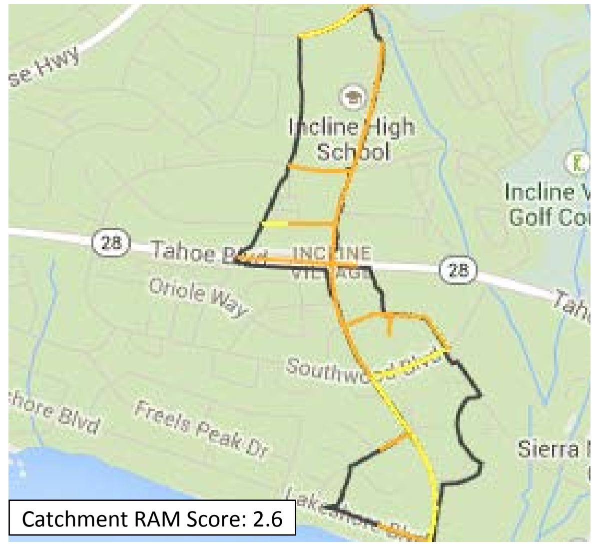
Central Incline Village Catchment Road Class Condition Scores

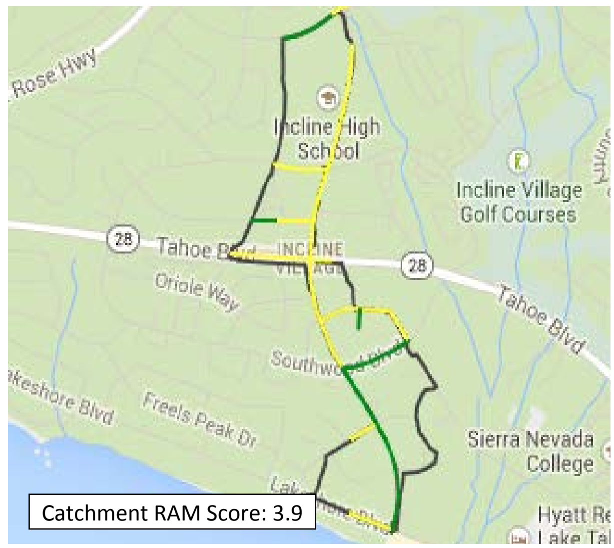


Winter - January 2012

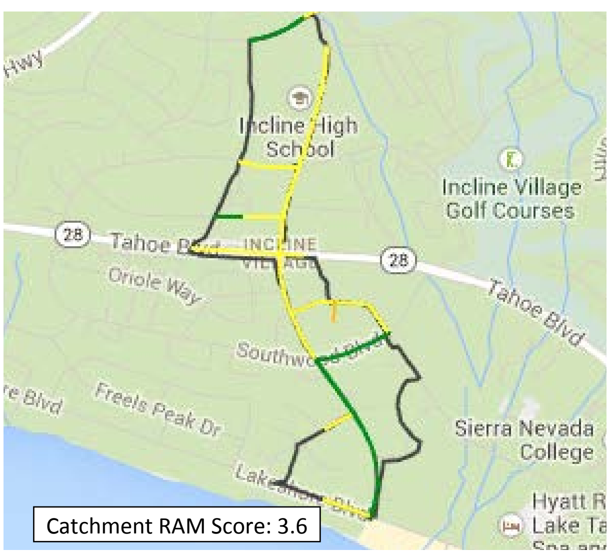


Winter - February 2013

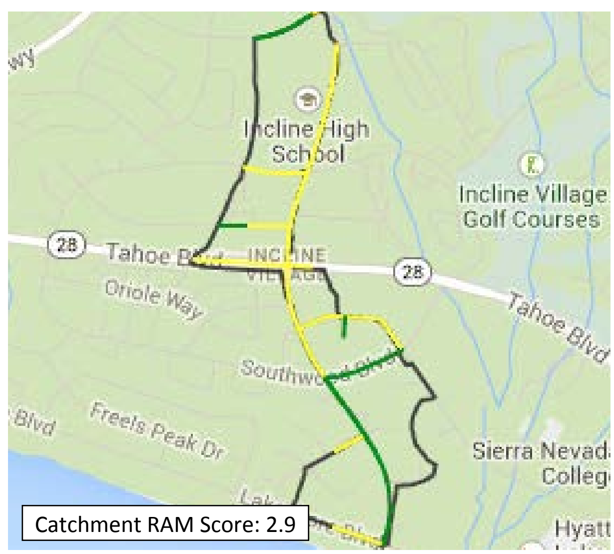
Late Winter/Early Spring - April 2012



Spring - May 2012



Summer - August 2012



Fall - October 2012

Central Incline Village catchment road class condition maps generated by Road RAM website for observations between January 2012 and February 2013. Spatially weighted catchment Road RAM scores are also provided.

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CENTRAL INCLINE VILLAGE ROAD CLASS CONDITION SCORES

FIGURE 5.2C

Table 5.3. Road class is defined consistently throughout the CSLT jurisdiction, and road segment scores from Osgood and Pasadena are combined to calculate the CSLT road class scores. Road class scores are the average of scores for all road segments in that road class observed during the observation period. These results are mapped in Figures 5.2A-B. The volume-weighted average is calculated based on the seasonal weighting in Table 3.9.

Observation Period	Season	Road Class				
		AX	AZ	BX	BZ	CZ
January 2012	Winter	3.4	3.7	2.5	2.9	2.7
April 2012	Late Winter/Early Spring	1.4	1.5	1.3	1.6	1.7
May 2012	Spring	3.5	3.2	2.7	3.5	2.7
August 2012	Summer	3.3	3.7	2.7	3.2	2.8
October 2012	Fall	3.2	3.1	2.9	3.3	3.3
February 2013	Winter	1.9	1.9	1.8	2.0	1.9
Volume-Weighted Average		**2.1**	**2.1**	**1.9**	**2.2**	**2.1**

Table 5.4. Washoe County road class scores by observation period. Road class scores are the average of the scores for all road segments in that road class observed during the observation period. A dash (-) means no observations were made for that road class during that observation period. These results are mapped in Figure 5.2C. The volume-weighted average is calculated based on the seasonal weighting in Table 3.9.

Observation Period	Season	Road Class			
		AX	AY	BZ	CX
January 2012	Winter	3.4	3.5	-	4.0
April 2012	Late Winter/Early Spring	2.2	2.5	1.5	3.5
May 2012	Spring	3.8	4.1	3.6	4.2
August 2012	Summer	3.5	2.6	1.6	4.0
October 2012	Fall	2.7	2.9	-	4.1
February 2013	Winter	2.6	2.6	1.1	2.8
Volume-Weighted Average		**2.7**	**2.9**	**1.6**	**3.6**

Road class is used to spatially extrapolate RAM observation results because road segments of the same road class are assumed to be in similar condition at any given time. The assumption is if abrasive application and sweeping practices are consistently conducted along a specific road network, then the relative amount of FSP on the road surface is similar as measured by Road RAM. The standard deviation of road segment scores for all road segments within the same road class can be used to evaluate the accuracy of the road class designations. For each jurisdiction, Table 5.5 presents the average standard deviation of RAM scores measured for each road class. The results suggest the observed road conditions on a single day were deviating by approximately 0.8 RAM score, when ideally this deviation across segments of the same class on the same day is < 0.5.

Table 5.5. Standard deviation of observed road segment scores by road class for CSLT and Washoe County. These values are compared to the range of target values recommended by Road RAM for calibration and check-up years (see Tables 2.1 and 2.2 in Road RAM User Manual).

CSLT Road Class (# road segments)	Average Standard Deviation	Washoe Road Class (# road segments)	Average Standard Deviation
AX (4)	0.8	**AX (8)**	0.8
AZ (4)	1.1	**AY (3)**	0.4
BX (7)	0.9	**BX (3)**	0.8
BZ (10)	0.8	**BY (3)**	0.9
CZ (6)	0.9	**CX (3)**	0.8
		CY (3)	0.8

Given the average field user precision is within 0.3 of a RAM score (see Table 3.8), it is likely these results are due to improper road class designations. The research team was challenged with properly designating road class to ensure consistency with actual road maintenance practices conducted on the ground. The requests and formats for jurisdictions and road maintenance teams to accurately document and report practices is evolving, but these results suggest the details and consistency of aligning documentation with the road maintenance actions on the ground can still be improved. The road classes presented in this report were ultimately defined by the research team based on available information provided by the respective stormwater managers and therefore the deviations in road segment conditions within the designated classes is not unexpected. In order for Road RAM results to be properly spatially extrapolated via road class the consistency in practices on roads of the same road class is critical. Continued collaboration and coordination with the road maintenance teams to document practices consistently within the manner they are performed is expected.

The Road RAM data is spatially and temporally integrated to generate catchment annual RAM scores. A single Road RAM score for each observation period is generated by spatially weighting the road class results based on the area each road class contributes to the total road area in the catchment (see Table 3.6). The catchment Road RAM scores for each observation period are included on Figures 5.1 and 5.2. The collection of catchment scores are then volume-weighted based on the seasonal percentages shown in Table 3.9 to calculate the volume-weighted annual catchment road condition score. Table 5.6 also provides the predicted average catchment FSP concentration for each observation period and the annual average road condition[1].

Table 5.6. Catchment road condition scores by observation period. Road class scores presented in Tables 5.4 and 5.5 are spatially weighted using the distributions shown in Table 3.6. The volume-weighted average is calculated based on the seasonal weighting in Table 3.9. Both scores and associated road segment FSP concentrations are provided.

Observation Period	Season	Osgood		Pasadena		Central Incline Village	
		Score	FSP (mg/L)	Score	FSP (mg/L)	Score	FSP (mg/L)
January 2012	Winter	2.9	140	2.7	164	3.5	83
April 2012	Late Winter/ Early Spring	1.5	427	1.6	411	2.5	196
May 2012	Spring/Summer	3.3	100	2.7	155	3.9	59
August 2012	Summer/Fall	3.1	114	2.8	149	3.6	78
October 2012	Summer/Fall	3.2	107	3.2	104	2.9	132
February 2013	Winter	2.0	302	1.9	324	2.6	173
Volume-Weighted Average		**2.1**	**257**	**2.1**	**270**	**2.9**	**137**

5.2 COMPARISON TO ROAD MAINTENANCE PRACTICES

Previous research conducted on roads throughout the Tahoe Basin (NTCD and DRI 2011; Zhu et al. 2009; Kuhns et al. 2010; 2NDNATURE and NHC 2012a) suggests that road condition is strongly influenced by the road maintenance actions performed at that location. This research aimed to build upon the previous research by

[1] See Chapter 8 and Table 8.6 in the Road RAM Technical Document (2NDNATURE et al. 2010) for more specific timing and technical rationale.

comparing spatially and temporally-explicit road maintenance practices to road condition observations in two jurisdictions for one complete year.

Figure 5.3 demonstrates the monthly relationships between weather conditions (rain and snow), road O&M actions (abrasive application per lane mile, sweeping, and plowing practices), and catchment Road RAM scores for 1.5 years (October 2011 to March 2013) within the 3 catchments. For each of the 3 urban catchments, peak abrasive application occurs during the winter months accompanying primarily snow events. Figure 5.3 demonstrates that the total volume of abrasives applied to the roads tends to scale to the magnitude of the snow event (i.e., more abrasives are applied during/immediately after larger snow volumes). The total number of monthly sweeping and plowing events is also concentrated in the winter months during precipitation intervals; however, sweeping intervals were also recorded in CSLT and Washoe County in the absence of precipitation and abrasive application (i.e., during the fall and spring months).

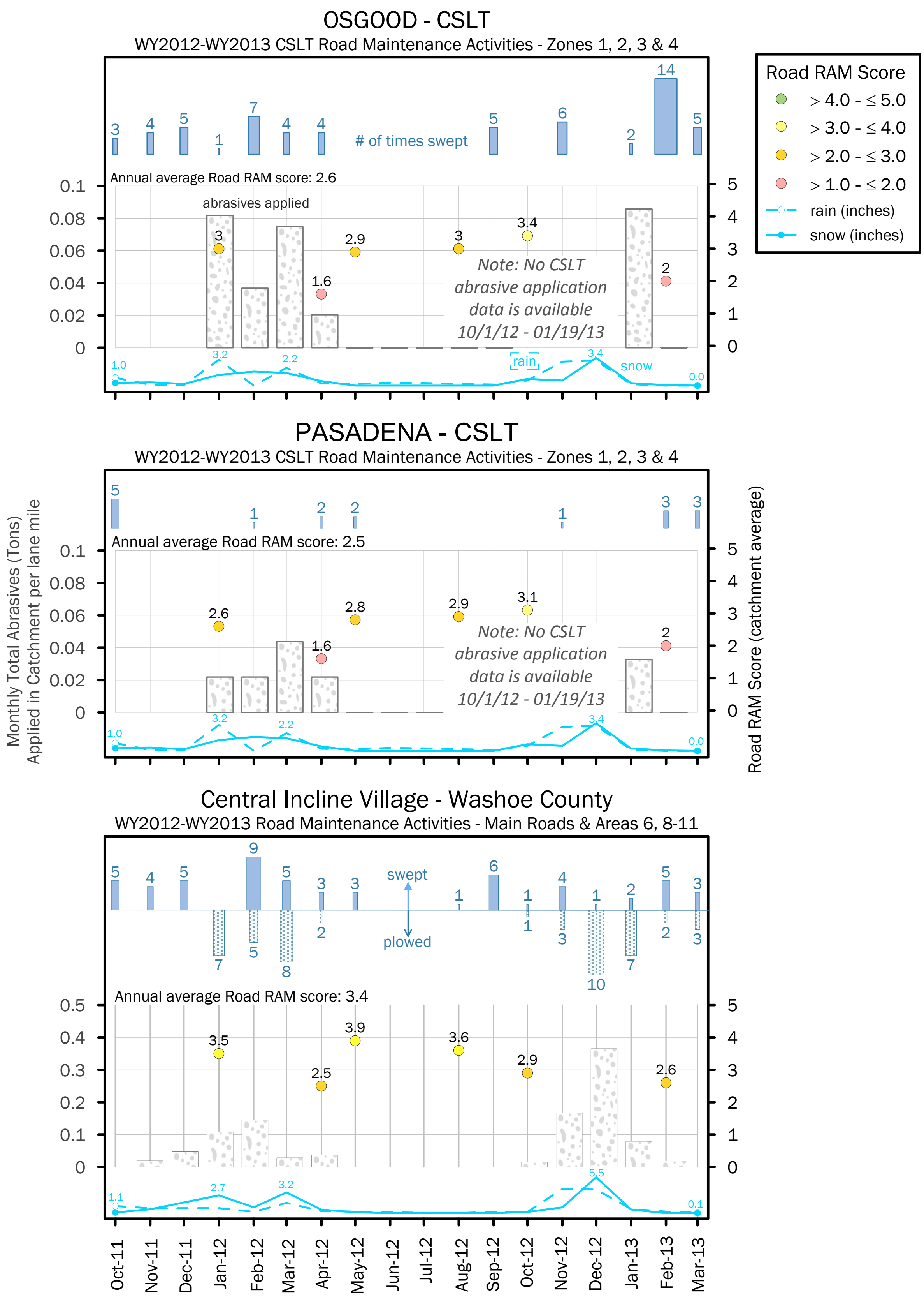
Specific comparisons can be made for catchments within the same city and between jurisdictions. For CSLT, the total amount of abrasives applied per mile is greater in the area that drains through the Osgood catchment compared to the area that drains through the Pasadena catchment. This is expected, as Osgood is a more steeply sloped catchment with highly trafficked roads (Ski Run Boulevard, Keller Road), while the Pasadena catchment is a flatter, more residential neighborhood. With the higher abrasive application, CSLT focuses more pollutant recovery actions within the Osgood catchment to remove those abrasives from the roadways. Comparing CSLT and Washoe County practices, there is an indication that while Washoe County may apply more abrasives per lane mile, there is also a concerted effort to recover those pollutants throughout the year through both sweeping and plowing efforts. Additionally, the increased application rate per lane mile may be due to differences in data collection and management, rather than an actual higher rate in Washoe County.

Figure 5.3 supports the previously observed trends that road conditions are the poorest in the winter and improve during the spring into summer months (2NDNATURE et al. 2010, Kuhns et al. 2010). The lack of significant rain in April and May 2012 suggest that road conditions in all 3 catchments during these months is likely attributable to the effectiveness of pollutant recovery actions. The difference in the frequency and total number of sweeping and plowing actions in the CIV catchment compared to the other 2 catchments is significant and the average annual Road RAM scores correspond to generally better road condition over the year.

Seasonal patterns are similar on the road segment scale. Figure 5.4 depicts the weather and road conditions along with Road RAM scores for two road segments in each catchment. The amount of abrasives applied and the number of sweeping/plowing events is shown for the 30 day window prior to each Road RAM observation. Similar to the catchment averages, the lowest scores at the site-specific scale are recorded during the winter months when there was active abrasive application. In most cases, road condition improves during the spring/summer months but for the sites in CSLT, scores are still below 3.5 at times during the summer and fall months (June– October) in some locations.

Given the lack of spatially explicit data to consistently recreate the chronology of the volume of abrasives put down and recovered from the roads within the monitored catchment and that only 6 road condition observations were made throughout the year, only general comparisons can made across catchment road practices and resulting road conditions.

Weather, Road Maintenance Practices & Catchment Road RAM Score by Catchment



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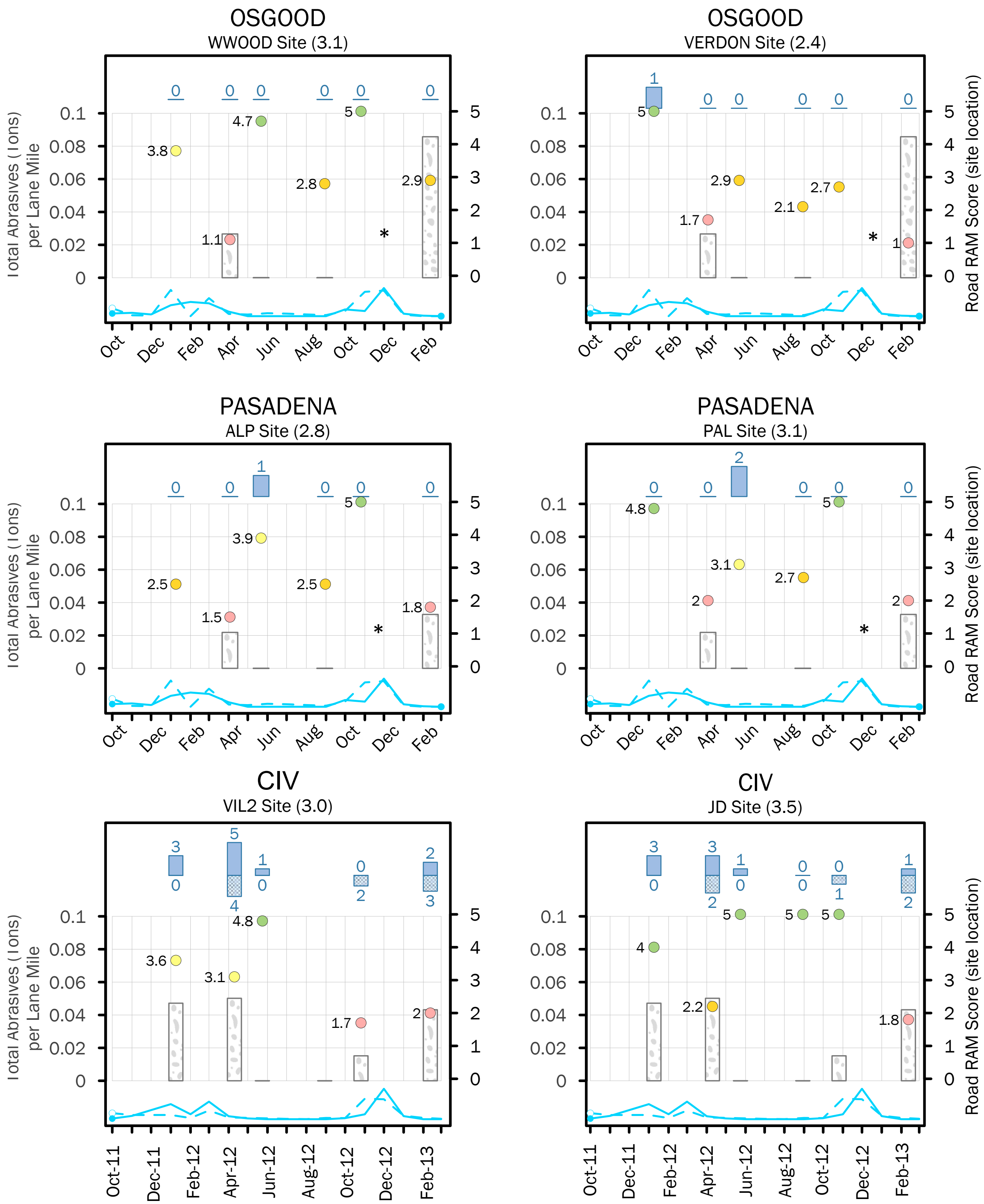
TIMESERIES OF ROAD O&M ACTIONS AND ROAD RAM SCORES BY CATCHMENT

FIGURE 5.3

Site Comparison of Weather, Road Maintenance Practices & Catchment Road RAM Scores



*Note: No CSLT abrasive application data is available 10/1/12 - 01/19/13.

The site specific Road RAM score is given in parentheses and all data (# of sweeps/plows and abrasive application) are evaluated for the 30 days prior to each Road RAM observation.

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2NDNATURE also applied multivariate statistical methods to model Road RAM scores based on the variety of weather and road maintenance variables to predict patterns in Road RAM scores and evaluate the relative influence of each metric on road condition. While the results indicated that all of the variables for CSLT and most of the variables in Washoe have an influence on the Road RAM score, no single variable was substantially more important than any other variable and each of the models explained about half of the variance in the observed Road RAM scores. A full explanation of the methods, metrics, and results is provided in Appendix C. The greatest challenge to the successful prediction of road conditions is developing powerful predictive metrics that are collectively representative of the primary factors influencing changes in road condition over time. While data availability for road maintenance actions on the road network has greatly improved to meet the experimental design needs to explicitly test the effectiveness of road maintenance practices, the information and format provided did not allow an accurate or consistent quantification of the chronology of volume of abrasives applied and recovered from the roads within the monitored catchments.

5.3 ROAD MONITORING CONCLUSIONS

- Over 60 road segments strategically distributed across road classes were assessed for road condition 6 times over the study period within the urban catchments. Seasonal patterns of observed road condition were consistent with those documented by others (2NDNATURE et al. 2010, Kuhns et al. 2010) with greater amounts of road FSP during the winter and spring followed by relatively good condition roads in the summer and fall across all catchments and jurisdictions.

- Based on the data provided during the study period, the road network in the CIV catchment was treated with over 4 times more abrasives per unit area than the other two catchment road networks and the frequency of pollutant recovery actions (i.e., sweeping and plowing) were 2-5 times greater. The average annual road condition of the CIV catchment was 2.9 in comparison to 2.1 and 2.2 observed in Pasadena and Osgood, respectively. While only a deviation of less than one RAM score, the corresponding average FSP concentrations are 137 mg/L versus 270 mg/L and 257 mg/L, respectively, which on an average annual basis, corresponds to a potentially significant difference in the total annual FSP loads generated from the respective road networks.

- This research reiterated the challenges of predicting the Road RAM score at any point in time using a series of weather and road maintenance variables. If possible to create, this type of a predictive model could be used to fill data gaps when Road RAM was not conducted and improve the resolution of road condition data. This type of predictive model is more of a research question than a management need, and in this research the model would have been used to compare road condition to measured catchment outfall FSP loads on event type scales. The current effort was limited by the available weather data, the level of detail of the road maintenance practice information provided, and the resolution of the Road RAM observations conducted during the study. Should future research desire to adequately test if road condition can be predicted as a result of variations in road practices, detailed records that more accurately quantify the amount of abrasives applied, traffic density, sweeping effectiveness, road shoulder condition, road surface integrity, site hydrology and very frequent documentation of road condition is strongly recommended.

- Continued improvements to the ways jurisdictions collect, manage and track their road operations and maintenance data will strengthen the ability to test the sensitivity of road condition to explicit road maintenance practices. Currently underway, the Road Operations Effectiveness Study (funded by NDEP and Army Corps of Engineers) aims to define the average annual Road RAM score using a series of specific road practices. However, the resolution, accuracy and detail of the road practice chronology for roads within the catchment provided for this study are likely not adequate to develop a statistically robust method to predict road conditions (independent of Road RAM observations) on short time scales.

6 CATCHMENT WATER QUALITY

The quantification and tracking of the stormwater pollutant loading to Lake Tahoe over time can be used to evaluate progress towards the goals of the Lake Tahoe TMDL. Stormwater pollutant load reduction tracking requires long-term consistent monitoring of urban catchment outfalls. The long term dataset can be used to quantify the cumulative effectiveness of a multitude of water quality improvement actions to reduce pollutant loading from urban catchments over time. This research established and monitored three urban catchment outfalls for 1 year in an effort to provide data collection, data management, data analysis and data reporting guidance for the long-term stormwater monitoring program in the Tahoe Basin, RSWMP. A primary management objective to be addressed by RSWMP is the ability to detect pollutant load reduction trends as a result of effective management actions, should they exist. This determination of effective management actions requires reliable techniques to remove or constrain the sampling error and inherent natural seasonal and hydrologic variability in stormwater quality data. This research also evaluated the ability to use urban catchment scale monitoring data to evaluate PLRM predictions using available meteorology data concurrent with the monitoring datasets (see Chapter 7). While this research was only conducted for 1 year, initial guidance and lessons learned are documented and will be invaluable for the design and implementation of RSWMP with regard to urban catchment outfall monitoring for volumes and FSP loads.

Catchment water quality was monitored using continuous (minute time scales) stage and turbidity data to quantify stormwater volumes and FSP pollutant loading. The datasets were summarized seasonally and annually and placed in the long-term climatic context to improve the interpretation of these results and provide guidance for future water quality status evaluations. Additionally, comparisons across sites can provide insight into how catchment size and land use differences may impact the pollutant loads measured at the outfalls. Comparisons of the road condition data to subsequent measured catchment pollutant loads were conducted to explore another method to evaluate the impact of road condition on the measured water quality in respective catchment stormwater runoff.

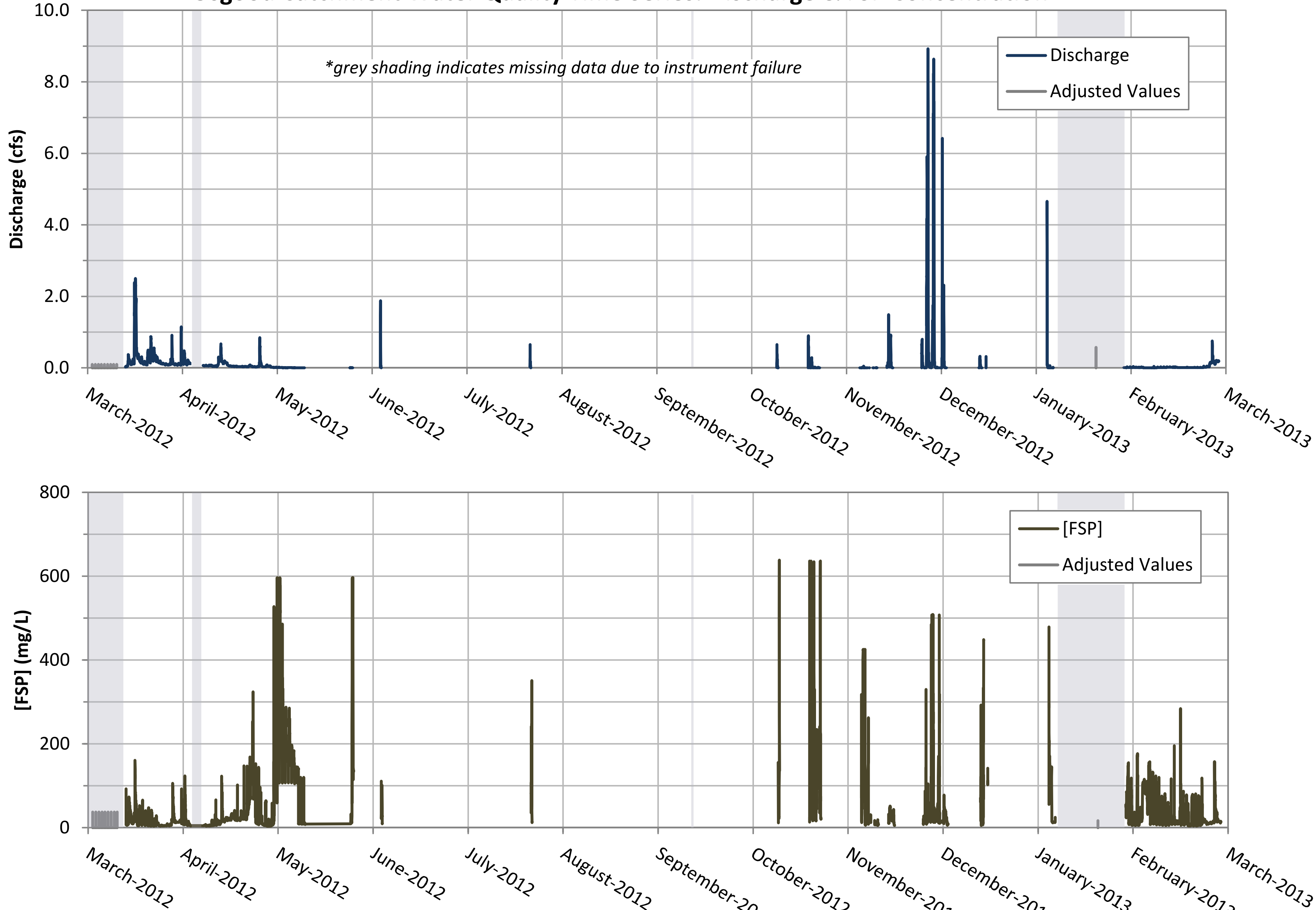
6.1 MEASURED WATER QUALITY

6.1.1 TIME SERIES

Figure 6.1 presents 10-minute time series data for Osgood (A), Pasadena (B), and Central Incline Village (C) discharge (cfs) and [FSP] concentration (mg/L) from March 1, 2012 to February 28, 2013. For all three catchments, peak discharge is concentrated in the late fall and early winter while more frequent but smaller flow events occur throughout the spring. The peak flow events are consistent with the timing of episodic rain and rain on snow events, while the more sustained low flow conditions occur during spring snow melt (see Figures 4.2A-B for concurrent precipitation and air temperature data).

Time series for Pasadena and CIV catchments indicate similar discharges across the two catchments, while Osgood discharge was approximately 3 times higher (see Figures 6.1A-C). Unlike Pasadena and CIV, the Osgood catchment is not an isolated urban catchment. During larger rainfall and rain on snow events, particularly in wet years, the Osgood monitoring location receives runoff from the Keller Canyon subcatchment, a forested upland drainage above the urban area (see Figure 3.1 in 2NDNATURE and NHC 2012b). This periodic runoff

Osgood Catchment Water Quality Time Series: Discharge & FSP Concentration



Notes:
Stage data converted to discharge using standard equations based on geometry at monitoring location. Turbidity converted to FSP concentration using the equations shown in Figure 3.5.
During Spring 2012, discharge data was lowered by 0.1 cfs to account for baseflow signal from Keller Canyon catchment. See Chapter 3.2.4 for details.
To account for data gaps due to instrument failure, seasonal average flow and FSP concentrations were applied to the missing time periods.

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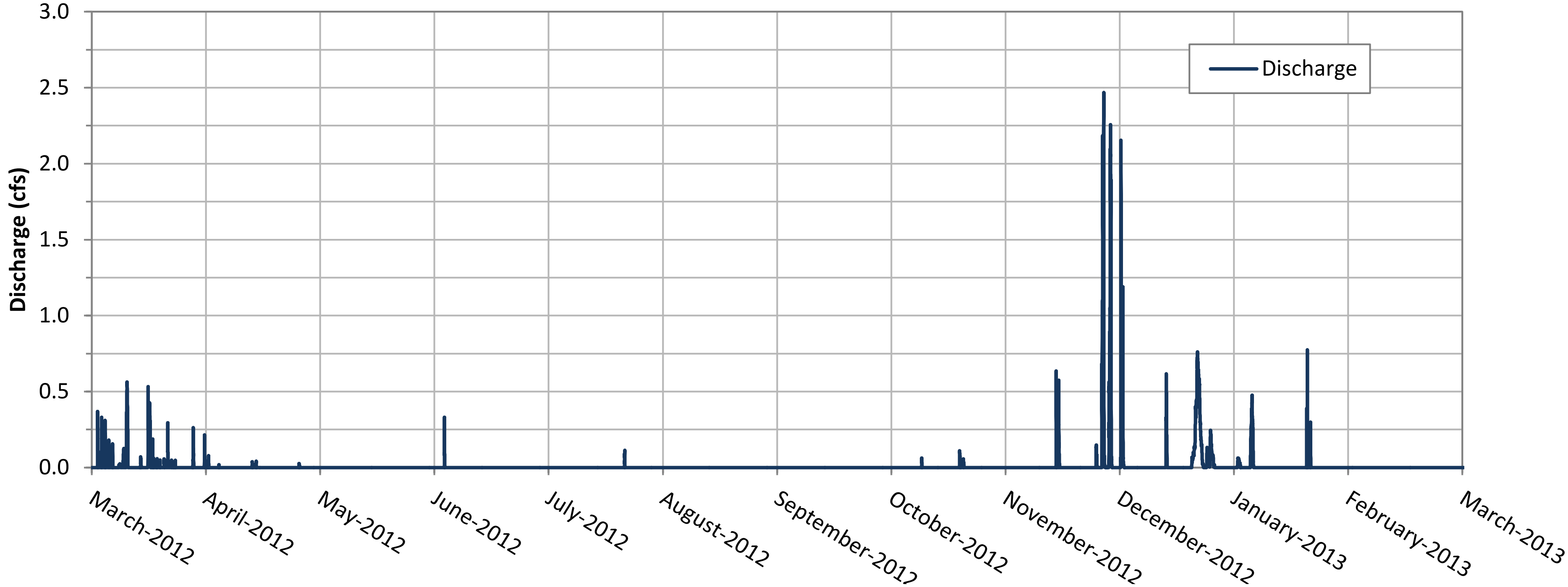
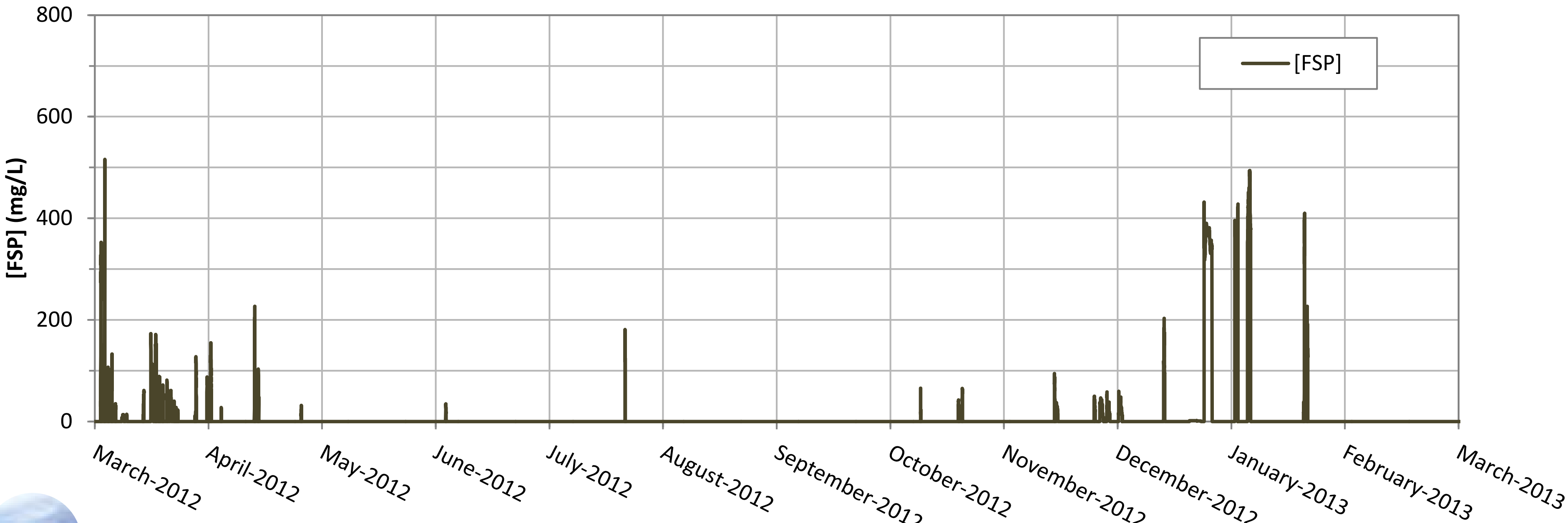
OSGOOD CATCHMENT WATER QUALITY: DISCHARGE & FSP CONCENTRATIONS

FIGURE 6.1A

Pasadena Catchment Water Quality Time Series: Discharge & FSP Concentration





Notes:
Stage data converted to discharge using standard equations based on geometry at monitoring location. Turbidity converted to FSP concentration using the equations shown in Figure 3.5.

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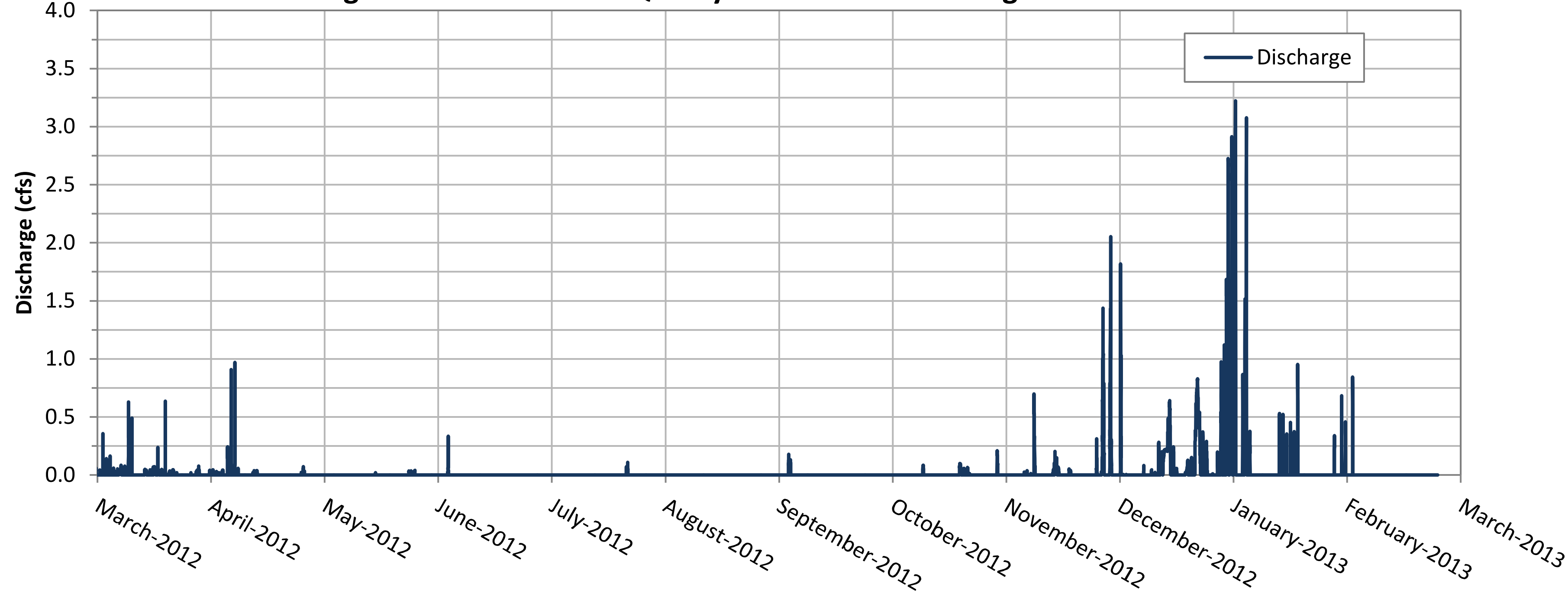
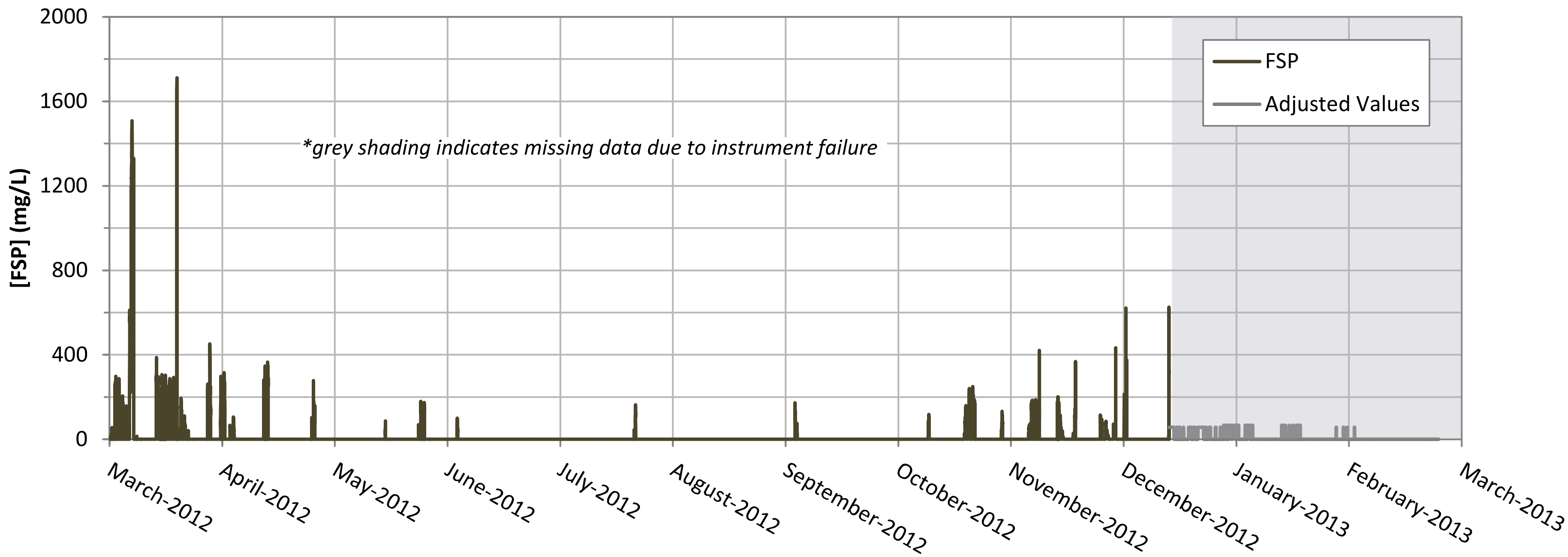
PASADENA CATCHMENT WATER QUALITY: DISCHARGE & FSP CONCENTRATIONS

FIGURE 6.1B

Central Incline Village Catchment Water Quality Time Series: Discharge & FSP Concentration





Notes:

Stage data converted to discharge using standard equations based on geometry at monitoring location. Turbidity converted to FSP concentration using the equations shown in Figure 3.5.

To account for data gaps due to instrument failure, seasonal average FSP concentrations were applied to the missing time periods.

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CENTRAL INCLINE VILLAGE CATCHMENT WATER QUALITY: DISCHARGE & FSP CONCENTRATIONS

FIGURE 6.1C

contribution from the undeveloped area, in addition to the greater total drainage area, likely explains the relatively high peak discharges seen in Figure 6.1A compared to the other outfalls.

The data shown in Figure 6.1 were adjusted to account for data gaps due to instrument error using Method 1 described in Chapter 3.2.4. The seasonal average discharge (see grey shading in Figure 6.1A) was applied to the period of missing data in the Osgood catchment to calculate comparable seasonal and annual volume metrics. The seasonal average FSP concentration (see grey shading in Figures 6.1A&C) was applied to the period of missing data in the Osgood and CIV catchments to calculate comparable seasonal and annual load metrics.

6.1.2 ANNUAL AND SEASONAL METRICS

The purpose of obtaining continuous hydrology and pollutant loading datasets is to evaluate the status and trends of stormwater quality. The discharge and FSP time series (see Figure 6.1) are useful to QA/QC the measured dataset and compare event seasonal patterns within and across sites. However, to evaluate the effectiveness of management actions to reduce stormwater pollutant loads, the continuous time series should be integrated into seasonal and annual water quality metrics. These metrics can document the status of the catchment water quality within the context of the climatic and hydrologic conditions in which the runoff occurred. While this research is limited to a single year, the generation and comparison of these metrics over several years of monitoring will be critical in discerning trends in total discharge, pollutant concentration and pollutant loads independent of water year type and/or specific catchment characteristics.

Figure 6.2 provides a recommended format for reporting Annual Urban Catchment Outfall Monitoring Status with a quick overview of site details and annual monitoring results. The upper half of Figure 6.2 provides a visual snapshot of the monitoring location, data collection, and meteorology and instrument time series for the year. The tabular summary includes key climatic, hydrology and pollutant loading metrics that will allow temporal and spatial comparisons over time. The seasonal durations are consistent with the Lahontan RWQCB NPDES permit reporting requirements for Tahoe jurisdictions. *Note, in future years the urban catchment outfall annual summaries will extend over a single water year from Oct 1 to Sept 31 and the metrics will be calculated by water year to be consistent with TMDL reporting. Future monitoring may also include nutrient data.*

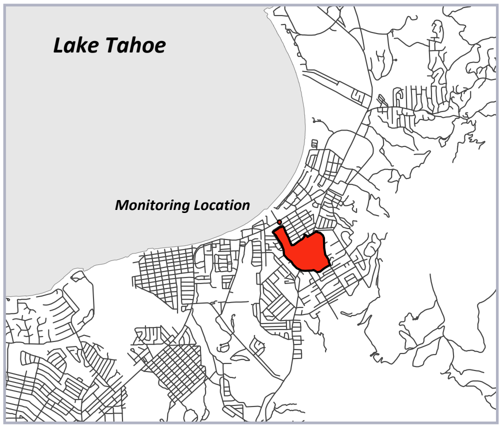
Each metric is defined below:

- Number of days in duration – total # of days in the time period
- Data completeness (%) – percent of the time period when instrument is working properly and measured data is available, calculated as # of data points divided by maximum # of data points possible during time period
- Water Year/Season Type – the water year or seasonal type, based on results presented in Chapter 4.1
- Precipitation – total inches of precipitation during time period measured at local weather station
- % Runoff – percent of total precipitation in catchment that resulted in measured runoff at the outfall, calculated as measured runoff (ac-ft) divided by the product of total precipitation (in) and catchment area (acres) with proper unit conversions
- Duration Dry – frequency of no flow measured at the catchment outfall, calculated as # of data points when discharge = 0 cfs divided by maximum # of data points possible during time period
- Percentile Discharge (cubic feet per second; cfs) – the median (50^{th}) and 90^{th} percentile flow when discharge > 0 cfs

Annual Urban Catchment Outfall Monitoring Status

Mar 2012-2013

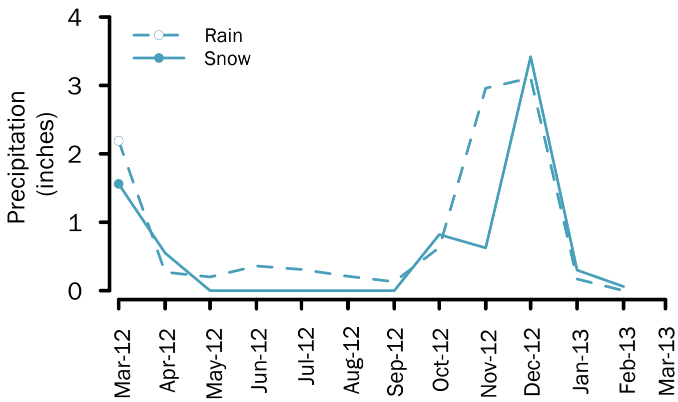
Osgood Catchment, City of South Lake Tahoe



Monitoring and Measurement Data - 16 Site Visits

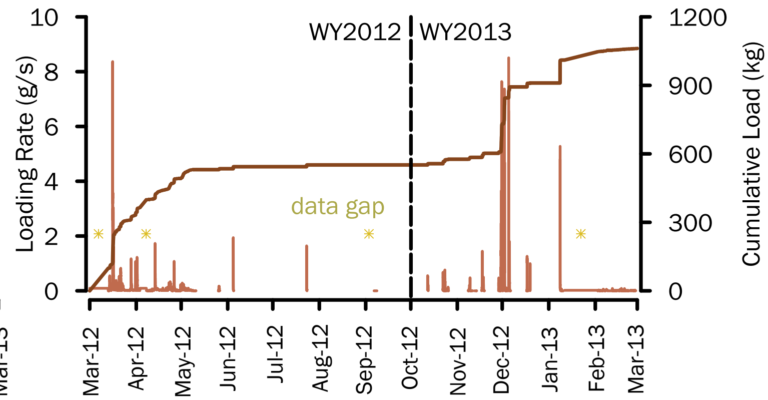
Parameters	Technique	Instrument/Method
Discharge	Stage and V-Notch Rectangular Weir	Campbell Scientific CS 450 *Standard Engineering Eq.*
FSP	Turbidity Sensor Regression Equation	Campbell Scientific OBS-3 Eq. 3.5 (DRI and 2N, 2014)

Tahoe South Shore Rain and Snow Summmary



Weather Data Source: modified from CSLT Fire Station Davis Instrument

Osgood Catchment (CSLT) FSP Loads



Yellow stars indicate location of data gap

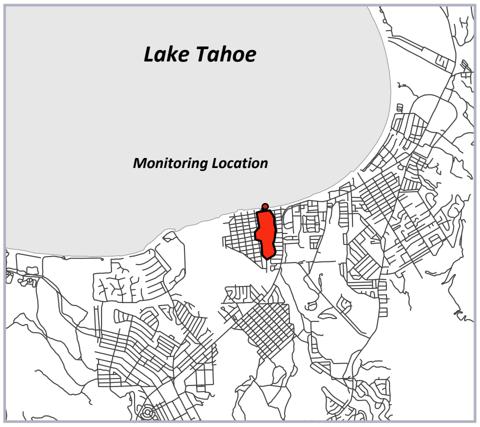
	Metric	Units	Year	Seasonal Metrics		
				Spring Snow Melt	Summer	Fall/Winter
			Mar '12-'13	WY2012	WY2012	WY2013
	# of Days in Duration	days	365	92 (Mar-May)	122 (Jun-Sep)	151 (Oct-Feb)
	Data Completeness	%	89	82	98	85
Precip	Water Year/Season Type[1]			**Wet**	Average	Average
Precip	Precipitation	inches	17.9	4.77	1.01	12.1
Discharge	% Runoff	%	14	28	3	10
Discharge	Duration Dry	%	72	40	>99	70
Discharge	50th Percentile Discharge	cfs	0.05	0.08	0.001	0.02
Discharge	90th Percentile Discharge	cfs	0.17	0.2	0.14	0.05
Discharge	Total Flow Volume	ac-ft	29.4	15.5	0.32	13.5
FSP load	Total FSP Load	MT	1.06	0.53	0.02	0.51
FSP load	FSP Load/Catchment Area	lb/acre	16.9	8.5	0.3	8.1
FSP load	50th Percentile Loading Rate	g/s	0.02	0.04	<0.001	0.02
FSP load	90th Percentile Loading Rate	g/s	0.09	0.12	0.13	0.05
FSP load	Flow weighted FSP	mg/L	29	28	42	31

[1]Defined using the process explained in Chapter 4.1

Annual Urban Catchment Outfall Monitoring Status

Mar 2012-2013

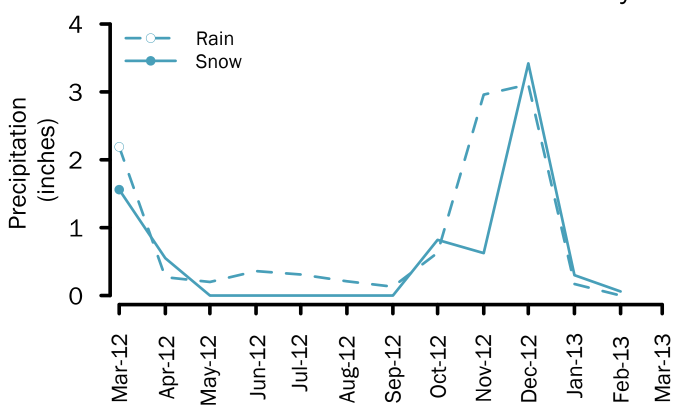
Pasadena Catchment, City of South Lake Tahoe



Monitoring and Measurement Data - 16 Site Visits

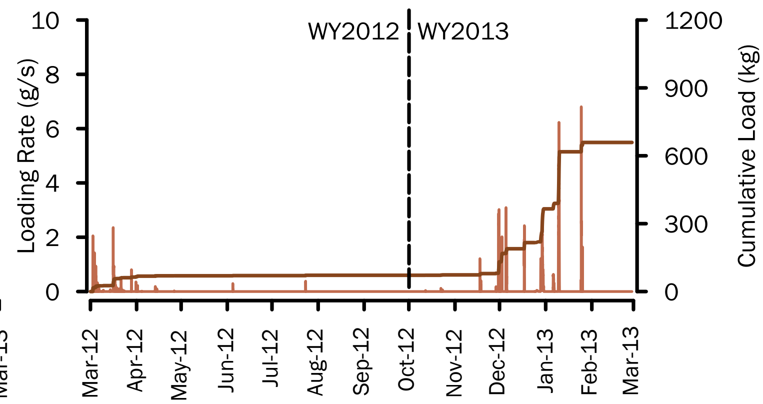
Parameters	Technique	Instrument/Method
Discharge	Stage and Parshall Flume	Campbell Scientific CS 450 *Standard Engineering Eq.*
FSP	Turbidity Sensor Regression Equation	FTS-DTS-12 Eq. 3.5 (DRI and 2N, 2014)

Tahoe South Shore Rain and Snow Summmary



Weather Data Source: modified from CSLT Fire Station Davis Instrument

Pasadena Catchment (CSLT) FSP Loads



	Metric	Units	Year	Seasonal Metrics: Spring Snow Melt	Seasonal Metrics: Summer	Seasonal Metrics: Fall/Winter
			Mar '12-'13	WY2012	WY2012	WY2013
	# of Days in Duration	days	365	92 (Mar-May)	122 (Jun-Sep)	151 (Oct-Feb)
	Data Completeness	%	100	100	100	100
Precip	Water Year/Season Type[1]			Wet	Average	Average
Precip	Precipitation	inches	17.9	4.77	1.01	12.1
Discharge	% Runoff	%	6	2	1	9
Discharge	Duration Dry	%	95	96	>99	92
Discharge	50th Percentile Discharge	cfs	0.07	0.04	0.07	0.09
Discharge	90th Percentile Discharge	cfs	0.54	0.23	0.12	0.64
Discharge	Total Flow Volume	ac-ft	6.8	0.67	0.032	6.1
FSP load	Total FSP Load	MT	0.66	0.07	0.0023	0.59
FSP load	FSP Load/Catchment Area	lb/acre	20.3	2.1	0.1	18.1
FSP load	50th Percentile Loading Rate	g/s	0.07	0.06	0.08	0.08
FSP load	90th Percentile Loading Rate	g/s	1.36	0.57	0.35	0.26
FSP load	Flow weighted FSP	mg/L	78	85	59	70

[1]Defined using the process explained in Chapter 4.1

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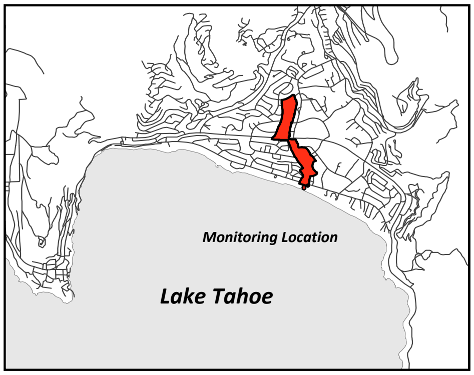
Annual Urban Catchment Outfall Monitoring Status

Mar 2012-2013

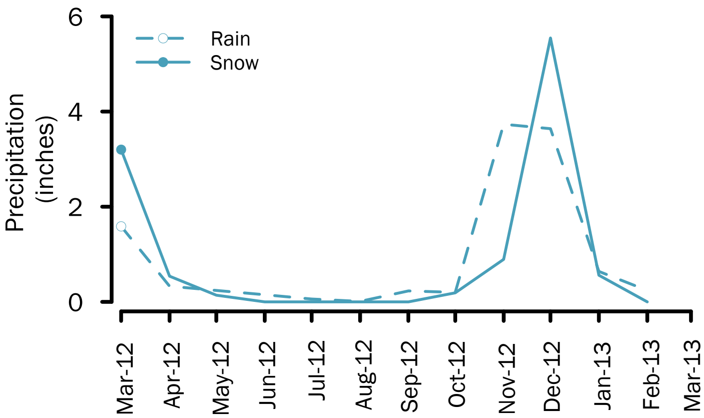
Central Incline Village Catchment, Incline Village, Washoe Co



Monitoring and Measurement Data - 16 Site Visits

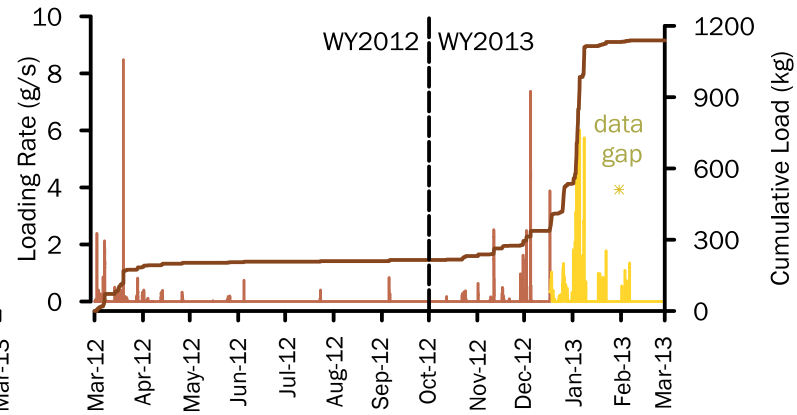
Parameters	Technique	Instrument/Method
Discharge	Stage and H Flume	Campbell Scientific CS 450 *Standard Engineering Eq.*
FSP	Turbidity Sensor Regression Equation	FTS-DTS-12 Eq. 3.5 (DRI and 2N, 2014)

Tahoe North Shore Rain and Snow Summary



Weather Data Source: modified from DRI Incline Creek station data

CIV Catchment (Washoe County) FSP Loads



	Metric	Units	Year	Seasonal Metrics: Spring Snow Melt	Seasonal Metrics: Summer	Seasonal Metrics: Fall/Winter
			Mar '12-'13	WY2012	WY2012	WY2013
	# of Days in Duration	#	365	92 (Mar-May)	122 (Jun-Sep)	151 (Oct-Feb)
	Data Completeness	%	80	100	100	51
Precip	Water Year/Season Type[1]			Wet	Average	Average
Precip	Precipitation	inches	22.2	6.04	0.45	15.7
Discharge	% Runoff	%	6	1	2	8
Discharge	Duration Dry	%	91	90	>99	85
Discharge	50th Percentile Discharge	cfs	0.04	0.03	0.06	0.06
Discharge	90th Percentile Discharge	cfs	0.68	0.06	0.12	0.87
Discharge	Total Flow Volume	ac-ft	13.3	0.74	0.1	12.5
FSP load	Total FSP Load	MT	1.14	0.21	0.01	0.92
FSP load	FSP Load/Catchment Area	lb/acre	21.5	3.9	0.2	17.5
FSP load	50th Percentile Loading Rate	g/s	0.10	0.13	0.09	0.07
FSP load	90th Percentile Loading Rate	g/s	1.17	0.39	0.37	0.6
FSP load	Flow weighted FSP	mg/L	69	224	79	60

[1]Defined using the process explained in Chapter 4.1

- Total Flow Volume (acre-feet) – total volume of flow measured at catchment outfall, calculated by integrating the discharge value over the time period
- Total FSP Load (metric tons; MT) – total FSP load measured at catchment outfall, calculated for every given time interval as discharge times [FSP] and then integrated over the time period with proper unit conversions
- FSP Load/Catchment Area (lb/acre) – FSP load per unit area, calculated as total FSP load (lbs) divided by total catchment area (acres) with proper unit conversions
- Percentile Loading Rate (g/sec) – the median (50^{th}) and 90^{th} percentile FSP loading rate at catchment outfall, calculated as the average value of the product, with unit conversions, of discharge (cfs) and [FSP] (mg/L) when discharge > 0 cfs.
- Flow Weighted FSP (mg/L) – flow-adjusted FSP concentration at the catchment outfall, calculated as the ratio of the total FSP load (MT) to the total flow volume (acre-feet), with unit conversions.

These types of urban catchment outfall status summaries are simple reporting formats to consistently document site monitoring details and results. Once sites are monitored consistently for several consecutive years, runoff volumes and pollutant loading trends can be analyzed to evaluate trends.

POLLUTANT TRENDS

As more years of data are collected, multi-year comparisons will need to account for the climatic differences across seasons and water years in order to properly evaluate if pollutant load reduction trends exist beyond natural variability in the data. Figures 6.2A-C provides the water type context for the current year as an acknowledgement of the need for this data.

Currently funded 2NDNATURE research is evaluating various statistical methods that will allow for meaningful comparisons across years that removes the variability due to seasonal climatic changes. These trend analyses will isolate the cumulative effects of water quality improvement actions on pollutant loading from an urban catchment, from which we can begin to infer long-term trends in pollutant loading to the lake. High quality long term datasets from the Lake Tahoe Interagency Monitoring Program (LTIMP) combined with synthetic datasets generated from PLRM simulations will be used to evaluate a suite of statistical measures. Statistical techniques will be applied in order to remove the fluctuation in FSP concentrations as a result of hydrologic variability prior to trend analysis. The trend analysis will incorporate known changes in management practices to evaluate the influence of load reduction actions on observed urban pollutant loading over time. The findings and recommendations from this research are expected in Fall 2014.

6.1.3 SITE COMPARISONS

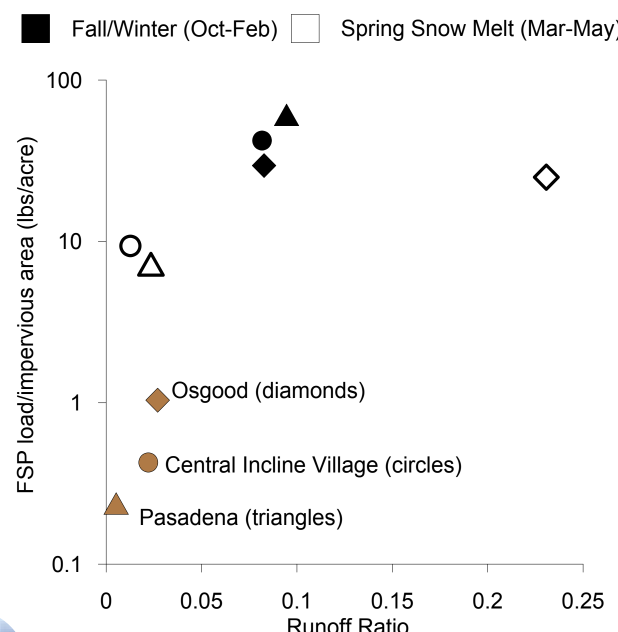
The annual metrics for each outfall are collated in Figure 6.3 to simplify comparisons. In addition to the metrics recommended in the annual site summaries (see Figure 6.2) we include total annual FSP load per unit catchment impervious area, directly connected impervious area (DCIA), and road DCIA. These metrics provide additional comparisons across catchments, where the annual loads are normalized by 3 surface types hypothesized to generate and transport the majority of FSP in urban catchments. Based on data in Figure 6.3A, the following comparisons across the catchments can be made:

A. Discharge and FSP Metrics for March 2012 - Feb 2013 Monitoring Period by Catchment

Metric	Units	Osgood[1]	Pasadena	CIV[1]
Precipitation	inches	17.9	17.9	22.2
% Runoff	%	14	6	6
Duration Dry	%	72	95	91
50th Percentile Discharge[2]	cfs	0.05	0.07	0.04
90th Percentile Discharge[2]	cfs	0.17	0.54	0.68
Total Flow Volume	ac-ft	29.4	6.8	13.3
Total FSP Load	MT	1.06	0.66	1.14
FSP Load / Catchment Area	lb/acre	16.9	20.3	21.5
50th Percentile FSP Loading Rate[2]	g/s	0.02	0.07	0.10
90th Percentile FSP Loading Rate[2]	g/s	0.09	1.36	1.17
Flow weighted FSP	mg/L	29	78	69
Additional Unit Area Load Metrics				
FSP Load / Catchment Impervious Area	lb/acre	66.1	64.9	51.9
FSP Load / Catchment DCIA	lb/acre	91.1	184	115
FSP Load / Catchment Road DCIA	lb/acre	186	440	661
Catchment Characteristics				
Catchment Area	acres	138.5	71.4	116.6
Catchment Slope	%	5	1	6
Catchment Impervious Area	acres	35.4	22.4	48.4
Catchment DCIA	acres	25.7	7.9	21.8
Catchment Road DCIA	acres	12.6	3.3	3.8
Catchment Average BMP Implementation	%	26	18	55

[1]Osgood and CIV catchment metrics are calculated using the data adjusted for monitoring data gaps.
[2]Percentile discharge and FSP loading rate were calculated for time intervals when discharge > 0cfs.

B. Runoff Ratio Compared to FSP Load for Impervious Area in Each Catchment



- Seasonal Runoff Ratios: Highest during fall/winter rain and rain on snow events. Osgood spring snowmelt outlier is likely due to the baseflow contribution from Keller Canyon.
- Seasonal FSP loads: Fall/Winter loads are the highest; followed by spring snowmelt and summer. These seasonal trends are consistent with the seasonal road condition observations (see Figures 5.1 and 5.2).

- The percent runoff in Osgood catchment is twice as high compared to Pasadena and CIV, which can likely be attributed to the intermittent volume contributions from the forested Keller Canyon catchment (see discussion on in Chapter 3.2.4). The increased baseflow contributions likely also explains the less frequent dry conditions, lower average discharge rate, and greater total flow volume observed from Osgood. While the Spring 2012 has in part been adjusted for this contribution, the hydrologic configuration of the Osgood catchment limits comparisons to the two other catchments.

- The CIV annual volume is nearly double Pasadena, which is expected given the higher rainfall, greater catchment area (117 vs 71 acres), greater impervious area (48.4 vs 22.4 acres), larger area of DCIA (22 vs 8 acres), and steeper slope (6% to 1%) in CIV (see table in Figure 6.3). However, the measured % runoff is identical between the two catchments. This may be due to the relatively higher distribution of private parcel infiltration BMPs within the CIV catchment (55% implementation versus 18%) or other functional implementation to disconnect impervious surfaces in CIV. Continued data collection at these sites will provide additional data to better evaluate the measured % runoff in each catchment.

- The total measured FSP load is nearly twice as much in CIV than Pasadena (1.14 MT vs. 0.66 MT), but when compared on a per unit area (total catchment, impervious area, DCIA, and road DCIA) basis the loads are very similar.

Figure 6.3B provides a simple seasonal comparison of the FSP load per unit impervious area as a function of measured % runoff for each catchment by season. The graphical comparison of these two ratios provides a way to evaluate relative runoff volumes and pollutant loads independent of catchment size. Figure 6.3 shows seasonal differences (fill color of marker) and by catchment (marker shape). As expected, relatively higher % runoff corresponds to higher FSP loads per impervious area.

- Seasonal % runoff – The ratios are highest during fall/winter events, when the precipitation events are usually the greatest magnitude and highest intensity. At some point, pervious surfaces become saturated and the reduced infiltration capacity translates into more runoff.

- Seasonal FSP Load to Impervious Area – The results follow typical seasonal patterns with lower FSP loads in the summer and higher loads in the fall/winter and spring (see Table 5.6).

These comparisons can improve the understanding of the relationship between land use, impervious area connectivity, and water quality at catchment outfalls. As more years of data are collected from these catchments, our ability to compare the data across sites and over time and evaluate trends will improve.

6.2 ROAD CONDITION TO CATCHMENT WATER QUALITY

A continuing research challenge in Tahoe stormwater has been how to use available data to test and validate the hypothesis that paved roads are the greatest FSP source per unit area to urban stormwater. Numerous researchers have employed various monitoring and analytical techniques to address this critical stormwater question (Zhu et al. 2009; NHC et al. 2009; 2NDNATURE et al. 2010; Kuhns et al. 2010; NTCD and DRI 2011). With this research, the 5 Road RAM observations conducted between March 1, 2012 and February 28, 2013 in the 3 catchments are compared to the measured FSP loads on both event (14-day post RAM observation) and seasonal scales. *(Note: The sixth observation was conducted in January 2012, prior to the initiation of catchment* *water quality monitoring.)* Figure 6.4 presents the data, where FSP load per unit area is calculated using catchment impervious area (top row), catchment DCIA (middle row), and catchment road DCIA (bottom row).

The comparisons of date-specific Road RAM conditions with the measured FSP loads 2 weeks directly following each Road RAM assessment of the catchment road network are shown in Figure 6.4A (left side). Because the timing of Road RAM observations is not coordinated to precede the timing of discharge, there is at least one instance for each catchment when there is no discharge within the 2 weeks following Road RAM assessments. For all catchments, there is a general trend that poorer Road RAM scores correspond to higher FSP loads per unit area across all area calculations (impervious, DCIA, road DCIA). Two key assumptions are made in these comparisons:

1. The road condition assessed is relatively consistent for the subsequent two week period for which the FSP load measured at the catchment outfall is quantified. Given that road conditions can vjsmhr significantly as a result of both management actions and runoff events, this assumption is likely not valid in all instances.

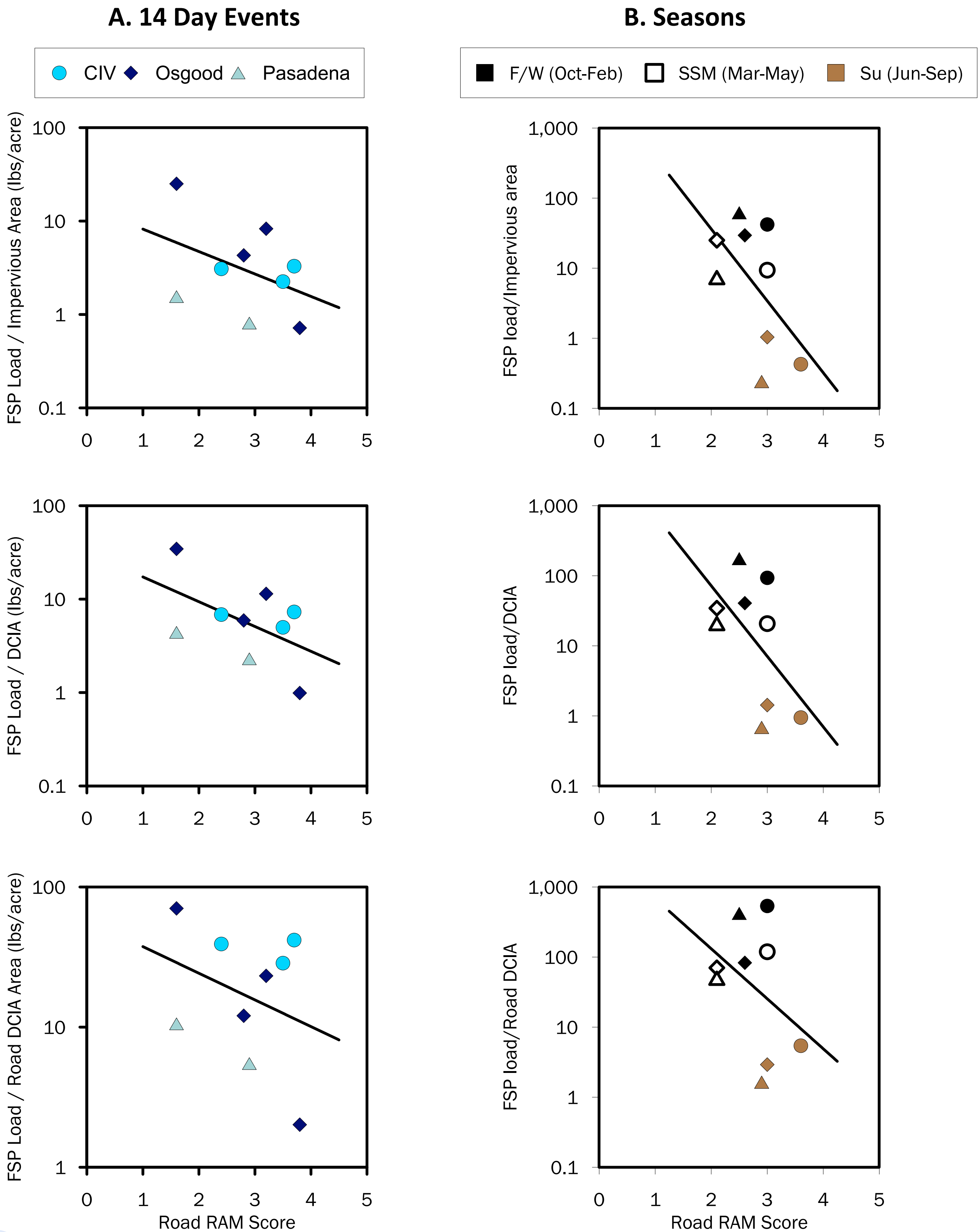
2. There is a relatively consistent relationship between the amount of FSP available on the road surfaces (as determined by Road RAM results) and the load of FSP transported to the outfall within the 2 week window following the road assessments. In reality, the fate and transport of FSP observed on the road surfaces results in gradual and intermittent mobilization and storage within the stormwater system until it eventually reaches the catchment outfall. To partially account for the expected variability in FSP fate and transport, the average road condition scores in Figure 6.4 represent the road segments that are most directly connected to the catchment outfall.

The seasonal comparisons of the average catchment road condition scores to FSP load per unit area are shown in Figure 6.4B (right side). The seasonal approach addresses a number of the short-term fate and transport issues noted above, by providing a comparison of road conditions to catchment FSP over a longer time period. The same negative relationship is demonstrated in the seasonal graphics, with higher Road RAM scores (i.e., better observed road condition) corresponding to lower measured FSP loads per unit area.

6.3 CATCHMENT OUTFALL WATER QUALITY CONCLUSIONS

- Continuous (e.g., minute intervals) discharge monitoring provides the necessary temporal resolution to adequately capture the extreme variability of urban stormwater runoff and is recommended for urban catchment outfall status and trend monitoring. Continuous pollutant concentrations are also desired. This research leveraged previous sampling and data analysis results (2NDNATURE 2013; Heyvaert et al. 2011), and monitored continuous automated turbidity as a proxy for FSP concentrations. Available turbidity to FSP rating curves developed using thousands of paired samples obtained in the Tahoe Basin (2NDNATURE et al. 2014) were used to consistently convert 10 min turbidity data to FSP concentrations.

Catchment Road RAM Score Compared to FSP Load per Unit Area



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CATCHMENT ROAD RAM SCORE TO FSP LOAD PER UNIT AREA

FIGURE 6.4

- Interpretations of the datasets are limited due to only 1 year of data collection. However, a number of data analysis and reporting formats have been recommended to guide future catchment outfall monitoring efforts.
  - Recommended annual summaries (Figure 6.2) provide a standardized format for synthesizing the data and communicating the key spatial and temporal metrics for a year of monitoring at a single site. The application of this status summary format can be used for RSWMP reporting and over time these site-specific status metrics will allow informative temporal and spatial comparisons.
  - A number of volume and pollutant load metrics normalized by catchment characteristics have been provided to allow direct comparisons of measured data across sites.
  - While the frequency of Road RAM assessments should be greater in the future, we provide a preliminary method to pair road conditions with catchment water quality data. Future data analysis and comparisons could likely continue to be improved to evaluate the sensitivity of catchment outfall water quality on observed road conditions.

- A key management objective of the catchment outfall monitoring is to evaluate the progress towards the goals of the Lake Tahoe TMDL, specifically long-term reductions in FSP pollutant loading to the lake. The one year of data collection during this research cannot be used to evaluate trends, but the annual and seasonal metrics provided in Figure 6.2 provide a framework for beginning this analysis. Currently funded research is investigating various statistical methods to assess potential FSP load reductions beyond natural seasonal variability and potential anthropogenic influences on long-term climate changes and expected to be released in Fall 2014.

- In order to achieve sustained pollutant load reductions, both concentration and volume reductions of stormwater runoff are desired. With increased implementation of hydrologic source controls, we would expect the rainfall to runoff ratio to decrease as volume retention is increased within an urban catchment. While these data are limited to only 1 year, the CIV catchment had a comparable measured % runoff to the other two catchments, regardless of higher % imperviousness. Coincidently, the CIV catchment also had much higher distribution of private parcel BMPs and a lower % of directly connected impervious area.

- While the data is limited, results of this research demonstrate that better Road RAM scores on both an event (14-day) and seasonal time scale correspond to lower measured FSP loads per unit area (impervious area, DCIA, and road DCIA) at the catchment outfall.

- Long-term catchment outfall monitoring in the Tahoe Basin will be used to compare and evaluate stormwater quality status and trends and provide a quantitative measure of TMDL effectiveness. The value of consistent, rigorous and frequent field QA/QC procedures to minimize data gaps and verify, calibrate and adjust instrument values (e.g., stage, turbidity) and calculated parameters (e.g., flow, FSP concentration) with manual measurements cannot be overstated. A standard and consistent method to fill missing data is recommended. The more consistent and comparable (i.e, low sampling variability) the measured dataset is, the greater our power to detect changes in water quality due to management action (should they exist) will be.

7 CATCHMENT WATER QUALITY MEASURED TO MODELED COMPARISONS

The Pollutant Load Reduction Model (PLRM) is the recommended tool in the Crediting Program to estimate the average annual pollutant load reduction associated with the implementation of water quality improvements on a catchment scale. As such, there is a desire by the stormwater community to define and document reasonable methods to generate and compare PLRM outputs with observed catchment runoff volumes and pollutant loads. To best utilize the model results, it is important that PLRM is evaluated using accurate measured discharge and pollutant concentrations to the extent possible. PLRM is a water quality planning tool designed to be relatively simple to use for the prediction of average annual runoff volumes and pollutant loads. The hydrologic approach used in PLRM provides a model structure that can predict runoff volumes at the time scales important to the Lake Tahoe TMDL (i.e., average annual). However, PLRM is a simplified and constrained tool relative to the modeling algorithms available in SWMM and these model simplifications mean that PLRM users have minimal ability to refine modeled estimates of peak flows or the shape and timing of the stormwater hydrograph on event or even seasonal timescales. In addition, simulating PLRM catchments for the same time period as the available measured data requires modeling in SWMM itself.

For this research, a series of refinements were made in SWMM to generate the modeled estimates, but this type of model parameterization is likely difficult for others not intimately familiar with SWMM and urban hydraulic modeling. PLRM outputs from 10-minute simulations of discharge and FSP concentration are compared to measured data for the Osgood, Pasadena, and Central Incline Village catchments for the March 1, 2012 to February28, 2013 monitoring period. The details of the inputs and parameterization methods to generate the catchment outfall time series are provided in Chapter 3.3.

7.1 MODEL SIMULATION RESULTS

Below we present the model simulation results. Prior to discharging into Lake Tahoe, the catchment runoff in each of the 3 catchments is routed through a treatment BMP that uses particle capture as a primary treatment process: a settling basin in Osgood catchment and a treatment vault in Pasadena and CIV catchments. In Pasadena, the flow is then routed from the treatment vault to a series of cartridge filters. Research on the effectiveness of particle capture to reduce FSP loads in Tahoe urban stormwater has been minimal and varied in its results. Particle settling removes particulates via flow attenuation, which is likely not effective for FSP due to the low settling velocities of these particles in suspension. Any FSP that did settle out is assumed to be entrained during a subsequent flow event and carried through the BMP outlet. However, as evidenced by the photo at right, observations indicated a significant amount of FSP can be retained by the settling basin, and therefore including the settling basin to some extent within PLRM is appropriate. The Pasadena and CIV treatment vaults were vactored during the monitoring period, which removed material accumulated in the vaults, and therefore including the performance of the treatment vaults within the model is appropriate.

Osgood Settling Basin, looking towards outlet, December 2011

OSGOOD CATCHMENT

Stormwater runoff from the Osgood catchment is routed into the Osgood Basin through a pre-treatment settling basin prior to discharge to the wet basin (Figure 7.1A), and the water quality monitoring was conducted at the settling basin outlet. Based on the Road RAM assessments conducted over the year the catchment volume-weighted average (see Table 5.6) was used as the FSP value (257 mg/L) for all roads in the 2 Osgood subcatchments. The settling basin was modeled to treat the influent to an FSP CEC of 150mg/L. The modeled cumulative loading time series is compared to the measured cumulative loads in the bottom half of Figure 7.1A.

Comparisons of the measured and modeled cumulative loads in the Osgood catchment (see Figure 7.1A) are complicated by the flow volume discrepancies driven by the baseflow contribution from Keller Canyon (described in Chapter 3.2.4). Figures 7.2A provides the timeseries of discharge (cfs), FSP concentration (mg/L), and FSP loading rate (g/s) generated from the SWMM simulations below the settling basin, along with the modeled and measured cumulative loads. The annual and seasonal summary metrics using the modeled data, which are identical to those provided in Chapter 6 for the measured data, are presented in Table 7.1.

PASADENA CATCHMENT

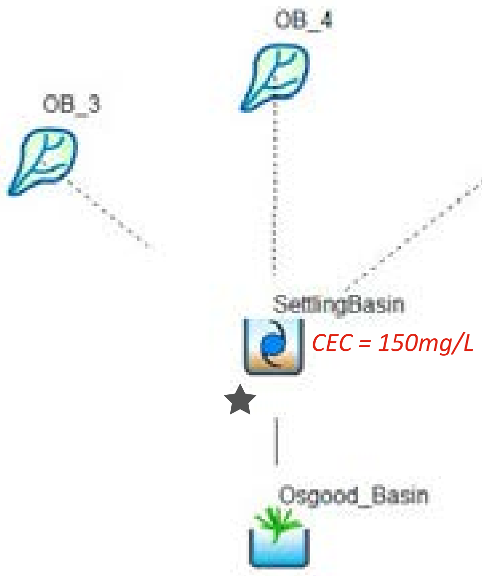
The Pasadena catchment runoff is routed through a treatment vault and two cartridge filters and then discharges into Lake Tahoe through a 36" culvert (Figure 7.1B), where the monitoring occurred. An average annual FSP value of 270 mg/L was assigned to all roads in the 4 subcatchments, equivalent to the catchment volume-weighted average shown in Table 5.6. The treatment vault was modeled to treat the influent to an FSP CEC of 200 mg/L, and the cartridge filters with a CEC of 10 mg/L. During the monitoring period, CSLT staff identified an issue in the storm drain system that allowed stormwater to bypass the cartridge filters more frequently than the targeted design flow rates. The City retrofitted the storm drain system with orifice plates in September 2013 to address the bypass issue (pers. comm. E. Friedlander April 2014). Given this issue, the model results below the treatment vault, but above the cartridge filters, are compared to the measured data and the cumulative loads are shown in the bottom half of Figure 7.1B.

Due to the lack of available water quality data that quantifies the treatment effectiveness of treatment vaults in the Tahoe Basin, a treatment vault CEC value which optimized comparisons to the measured data was selected. In the Pasadena catchment, the optimized value is 200 mg/L. (*Note, 150mg/L is the input value currently used by CSLT. Given that this comparison includes only 1 year of data, we do not recommend changing the PLRM models at this time.*) Figure 7.2B provides the timeseries of discharge (cfs), FSP concentration (mg/L), and FSP loading rate (g/s) generated from the SWMM simulations below the treatment vault, along with the modeled and measured cumulative loads. The annual and seasonal summary metrics using the modeled data, which are identical to those provided in Chapter 6 for the measured data, are presented in Table 7.1.

CENTRAL INCLINE VILLAGE (CIV) CATCHMENT

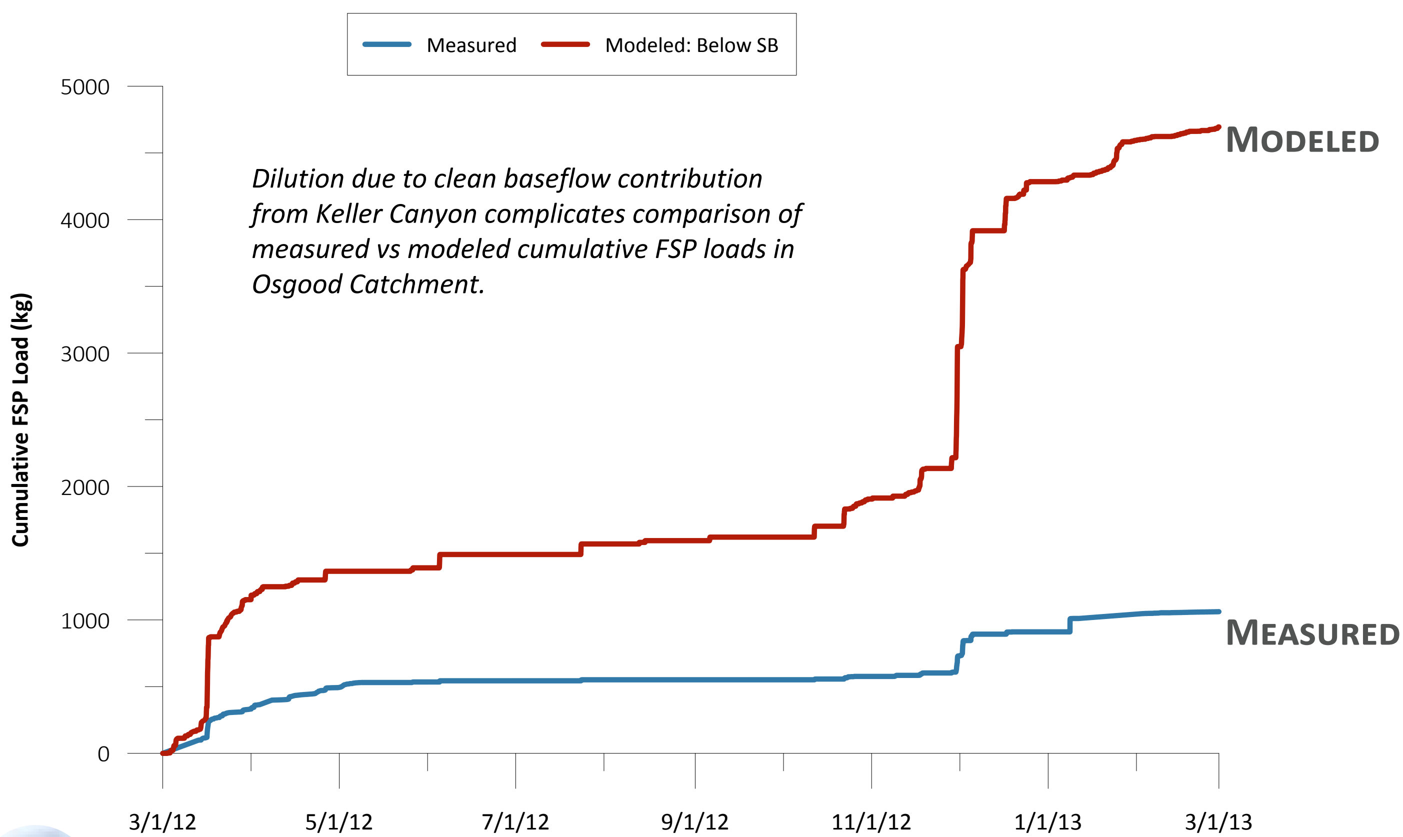
In Central Incline Village, stormwater from the upper catchment is routed to a treatment vault, where a flow splitting system routes a portion of stormwater entering the vault into a ditch that flows directly to the Lake. Additional stormwater is routed in a storm drain from the lower catchment (Figure 7.1C) directly to the ditch,

A. Osgood Catchment Representation in PLRM

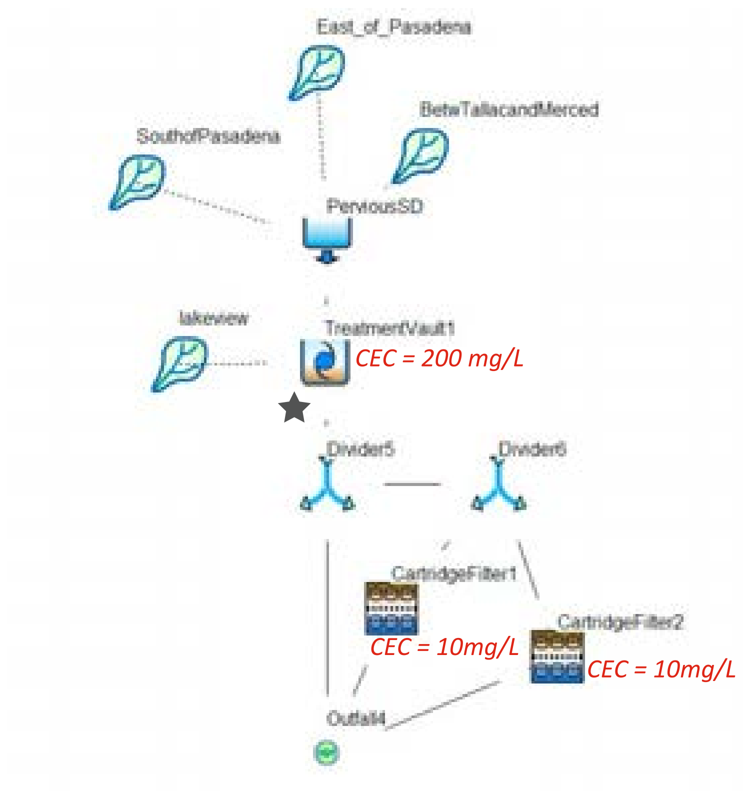


Simulation results are summarized below settling basin prior to wet basin (★). Representative of catchment monitoring location. Settling basin modeled with CEC of 150 mg/L.

B. Cumulative Load Comparison: Measured v Modeled

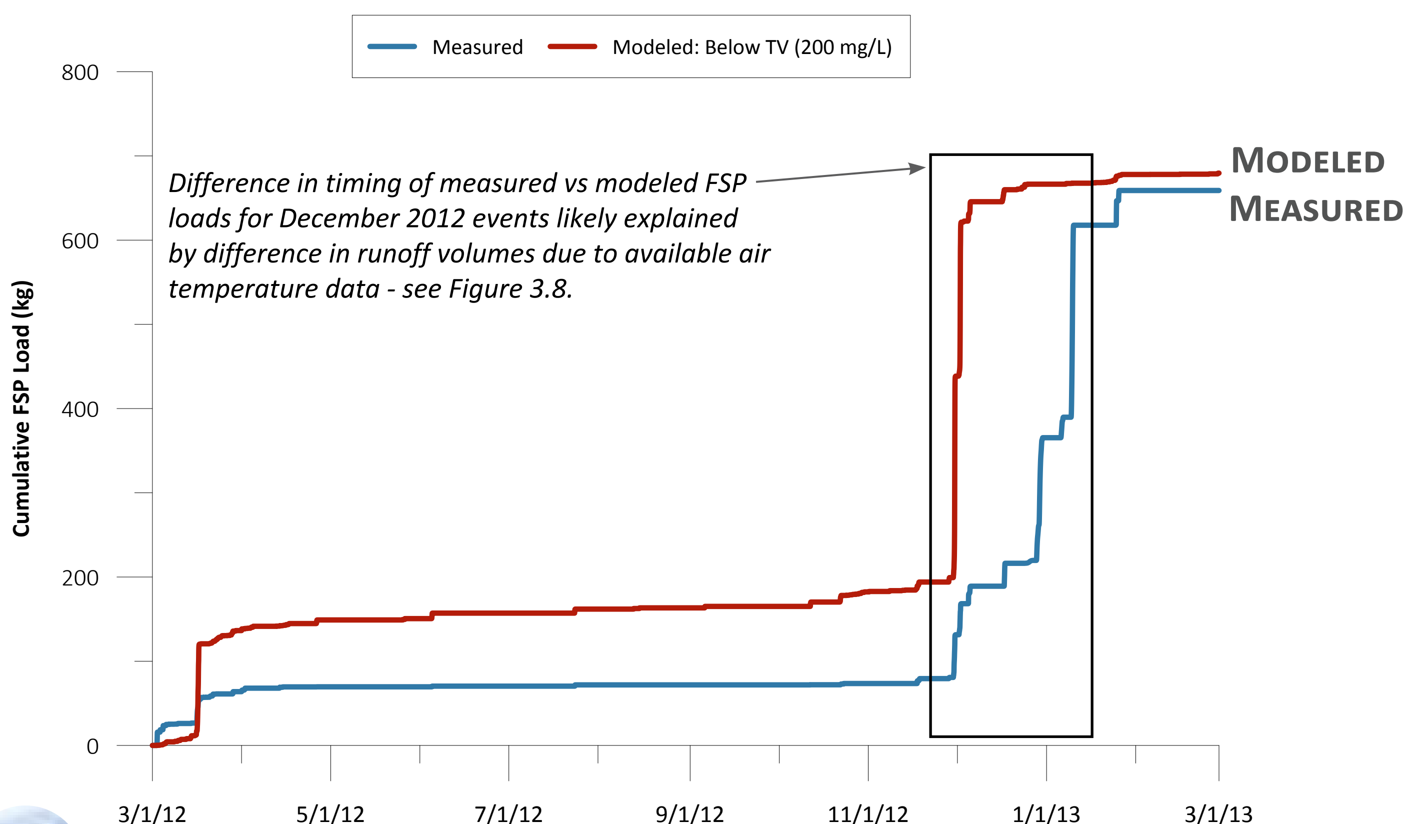


A. Pasadena Catchment Representation in PLRM



Simulation results are summarized below treatment vault (TV), but above cartridge filters (CF). Designated with ★ in schematic at left. Treatment vault modeled with CEC = 200 mg/L. This model assumes a significant portion of stormwater was bypassing the cartridge filters.

B. Cumulative Load Comparison: Measured v Modeled



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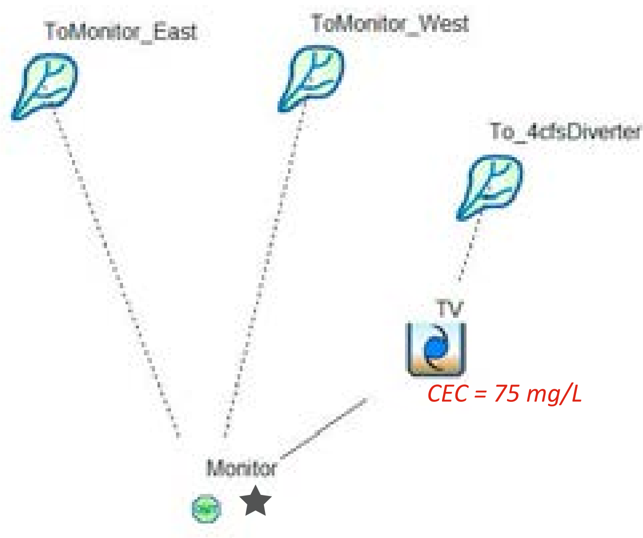
PASADENA: PLRM REPRESENTATION & CUMULATIVE LOAD COMPARISON

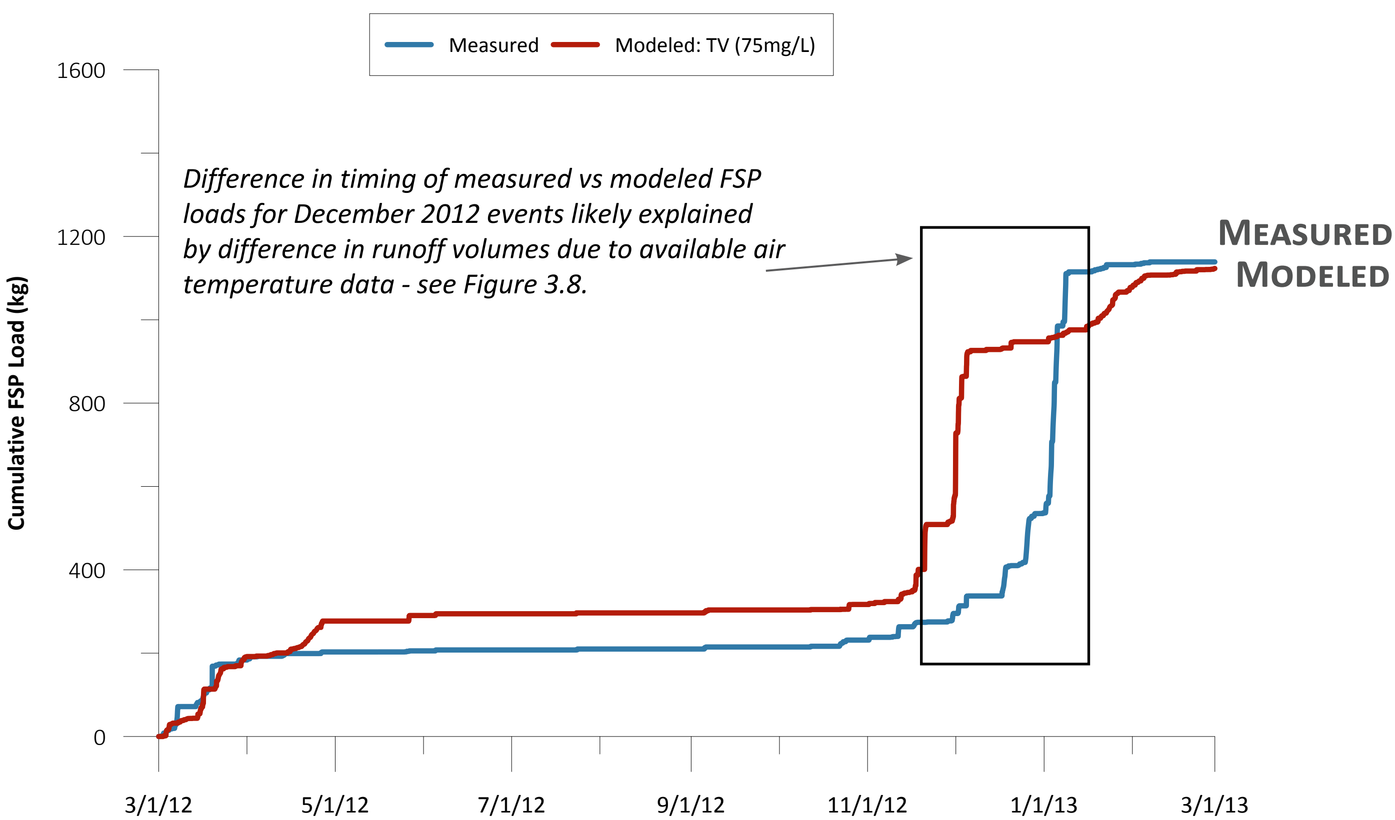
FIGURE 7.1B

A. CIV Catchment Representation in PLRM



Simulation results are summarized at catchment outfall, which is representaive of the monitoring location(★). Treatment vault modeled with CEC = 75 mg/L .

B. Cumulative Load Comparison: Measured v Modeled



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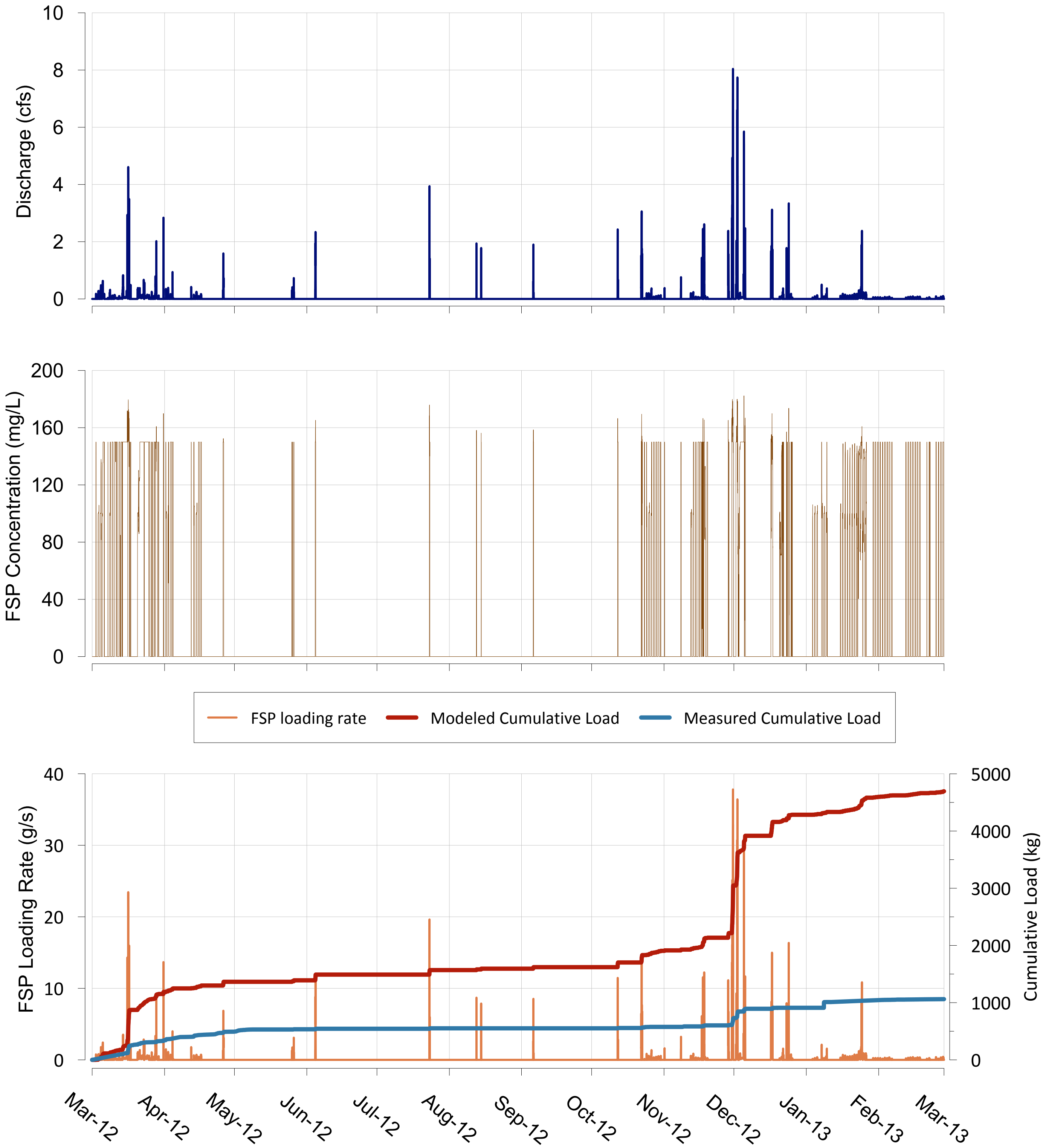
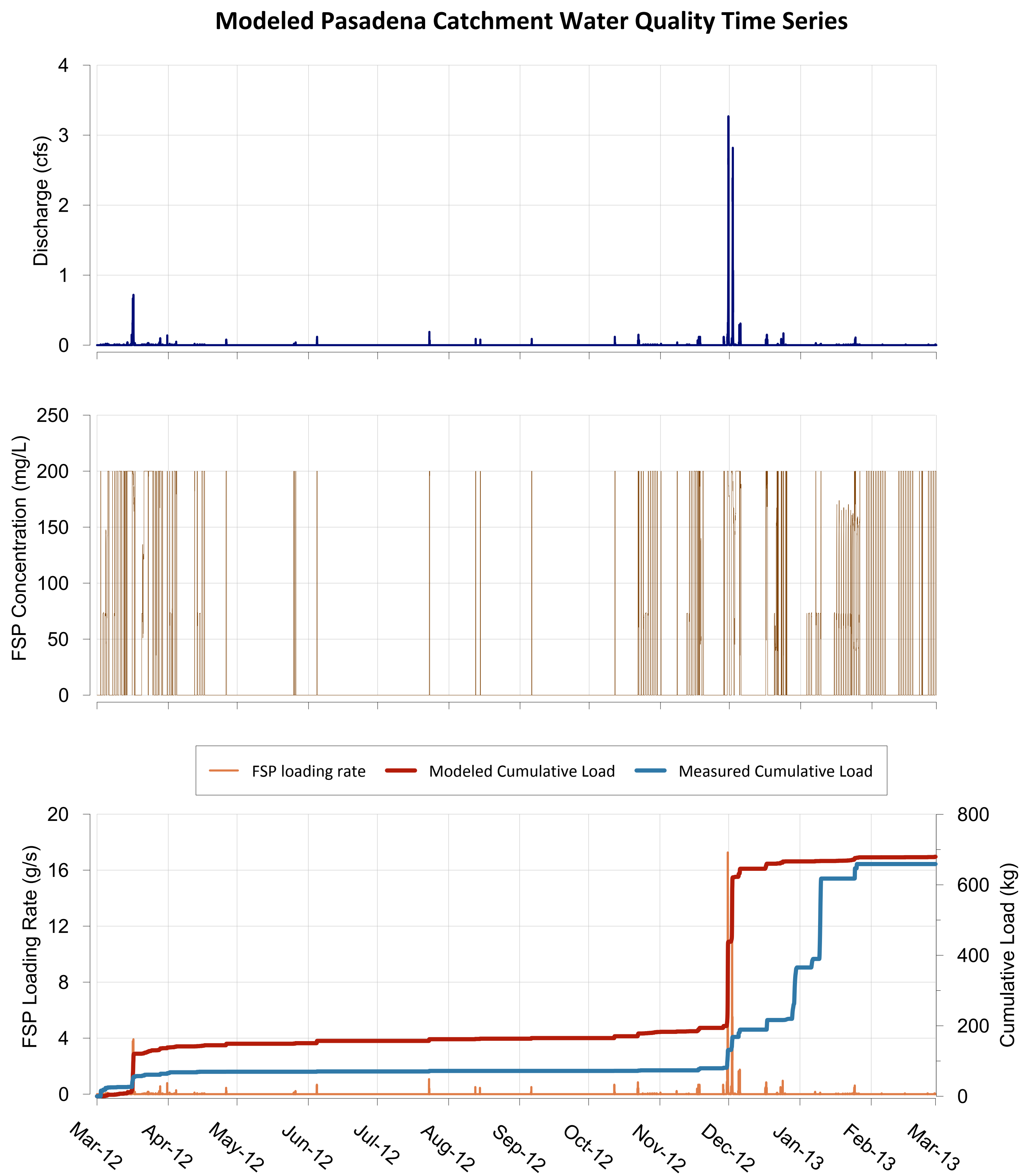
CIV: PLRM REPRESENTATION & CUMULATIVE LOAD COMPARISON

FIGURE 7.1C

Modeled Water Quality Time Series
Osgood Catchment





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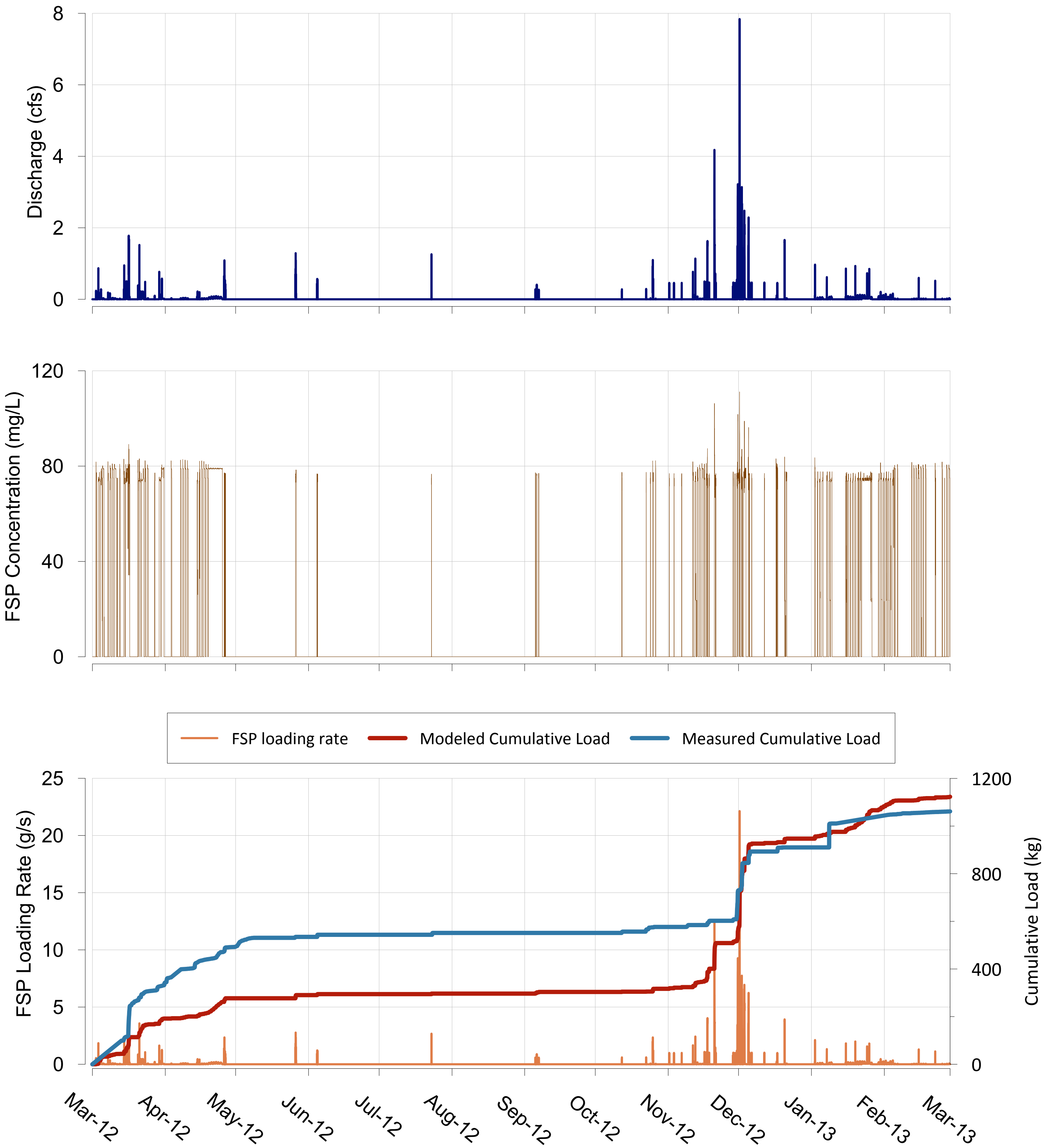
2012-2013 PASADENA CATCHMENT PLRM PREDICTIONS

FIGURE 7.2B

Modeled Central Incline Village Catchment Water Quality Time Series



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2012-2013 CENTRAL INCLINE VILLAGE CATCHMENT PLRM PREDICTIONS

FIGURE 7.2C

Modeled Discharge and FSP Metrics for March 2012 - Feb 2013 Monitoring Period by Catchment

Metric	Units	Osgood				Pasadena				CIV			
		Year	SSM	Su	F/W	Year	SSM	Su	F/W	Year	SSM	Su	F/W
% Runoff	%	12	14	10	12	2	2	1	3	4	4	3	4
Duration Dry	%	86	78	99	79	95	91	99	94	86	75	99	82
50th Percentile Discharge	cfs	0.06	0.07	0.43	0.06	0.01	0.01	0.03	0.01	0.03	0.03	0.08	0.03
90th Percentile Discharge	cfs	0.38	0.35	1.9	0.37	0.11	0.06	0.10	0.14	0.18	0.14	0.30	0.35
Total Flow Volume	ac-ft	25.1	7.6	1.2	16.2	2.9	0.64	0.06	2.2	11.2	3.1	0.14	8.0
Total FSP Load	MT	4.7	1.4	0.23	3.1	0.68	0.15	0.02	0.51	1.1	0.29	0.01	0.82
FSP Load / Catchment Area	lb/acre	74.7	22.1	3.7	48.9	21.0	4.6	0.4	15.9	17.9	4.6	0.21	13.0
50th Percentile FSP Loading Rate	g/s	0.27	0.30	1.8	0.25	0.06	0.06	0.17	0.06	0.07	0.07	0.17	0.06
90th Percentile FSP Loading Rate	g/s	1.7	1.3	8.5	1.8	0.62	0.29	0.57	0.77	0.38	0.30	0.65	0.76
Flow weighted FSP	mg/L	152	148	154	154	189	189	198	189	81	77	76	83
Additional Unit Area Load Metrics													
FSP Load / Catchment Impervious Area	lb/acre	292	86.6	14.3	192	66.9	14.7	1.4	50.6	69.9	18.1	0.8	51.0
FSP Load / Catchment DCIA	lb/acre	403	119	14.7	264	189	42.0	4.0	144	96.3	24.9	1.1	70.3
FSP Load / Catchment Road DCIA	lb/acre	821	243	40.3	538	454	101	9.7	344	197	50.8	2.3	143

and the research monitoring equipment was installed within this ditch. An average FSP value of 137 mg/L was assigned to all roads in the 3 subcatchments, equivalent to the catchment volume-weighted average shown in Table 5.6. The treatment vault was assigned a CEC value of 75 mg/L. The modeled results are compared to the measured cumulative loads in the bottom half of Figure 7.1C.

The treatment vault is regularly (semiannually) vactored by Washoe County maintenance personnel and visual observations suggested that stormwater containing some FSP was retained within the vault between storms. Given these conditions, a treatment vault CEC value of 75mg/L was deemed appropriate. Figure 7.2C provides the timeseries of discharge (cfs), FSP concentration (mg/L), and FSP loading rate (g/s) generated from the SWMM simulations below the treatment vault, along with the modeled and measured cumulative loads. The annual and seasonal summary metrics using the modeled data, which are identical to those provided in Chapter 6 for the measured data, are presented in Table 7.1.

7.2 MEASURED VS MODELED COMPARISON

Figure 7.3 provides a scatter plot comparison of measured versus modeled values for four metrics: total flow volume (ac-ft), total FSP load (MT), % runoff, and FSP load per catchment area (lb/acre). Similar to Figure 6.3, the seasonal and annual values (fill color) are presented for each catchment (marker shape). The dashed 1:1 line corresponds to alignment between the measured and modeled data; values above the line correspond to an overprediction by the model (modeled > measured), whereas an underprediction is represented by values below the line (measured > modeled). Tables 7.2-7.4 present the data in tabular format.

Table 7.2. Comparison of Osgood discharge and FSP annual and seasonal metrics for measured and modeled data.

Metric	Measured Data				Modeled Data			
	Year	SSM	Su	F/W	Year	SSM	Su	F/W
Total Flow Volume (ac-ft)	29.4	15.5	0.32	13.5	25.1	7.6	1.2	16.2
Flow-weighted FSP (mg/L)	29	28	42	31	152	148	154	154
Total FSP Load (MT)	1.1	0.53	0.02	0.51	4.7	1.4	0.23	3.1

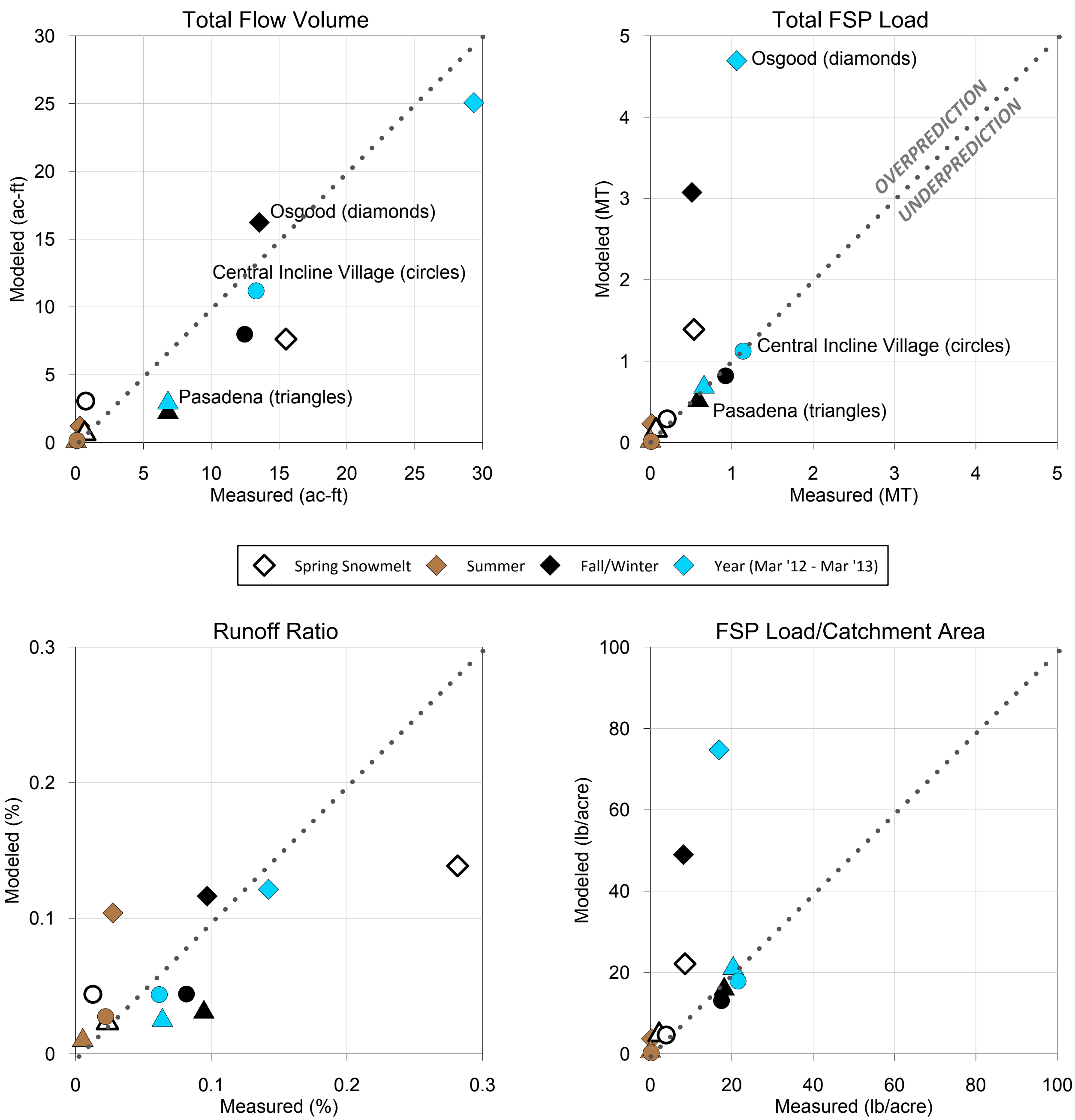
Table 7.3. Comparison of Pasadena discharge and FSP annual and seasonal metrics for measured and modeled data.

Metric	Measured Data				Modeled Data			
	Year	SSM	Su	F/W	Year	SSM	Su	F/W
Total Flow Volume (ac-ft)	6.8	0.67	0.03	6.1	2.9	0.64	0.06	2.2
Flow-weighted FSP (mg/L)	78	85	59	70	189	189	198	189
Total FSP Load (MT)	0.66	0.07	0.00	0.59	0.68	0.15	0.02	0.51

Table 7.4. Comparison of CIV discharge and FSP annual and seasonal metrics for measured and modeled data.

Metric	Measured Data				Modeled Data			
	Year	SSM	Su	F/W	Year	SSM	Su	F/W
Total Flow Volume (ac-ft)	13.3	0.74	0.10	12.5	11.2	3.1	0.14	8.0
Flow-weighted FSP (mg/L)	69	224	79	60	81	77	76	83
Total FSP Load (MT)	1.1	0.21	0.01	0.92	1.1	0.29	0.01	0.82

Measured versus Modeled Discharge and FSP Metric Comparison



OSGOOD (diamonds)

- Poor alignment between measured vs modeled FSP data is due to the baseflow contribution from Keller Canyon. This cannot be modeled in PLRM and likely leads to lower measured FSP loads due to signal dilution.

PASADENA (triangles) & CIV (circles)

- Strong alignment between measured and modeled data across all time periods.
- Poor event-scale alignment in Dec 2012 shown in Figure 3.8 is not seen when data is summarized by season or annually.

7.2.1 CATCHMENT VOLUMES

With the exception of the Osgood site, the discharge metrics show good alignment between the measured and modeled results. At the Pasadena and CIV sites, the measured vs. modeled plots in Figure 7.3 for total flow volume and % runoff show slight scatter around the 1:1 line (which corresponds to agreement). The hydrology data was used as the primary means to optimize and calibrate each of the catchment SWMM models, and thus we would expect relatively decent agreement between measured and modeled discharge metrics. It is important to note, the event-scale discrepancies in December 2012 in Pasadena and CIV catchments noted in Figure 3.8 do not result in poor alignment when viewed on the seasonal and annual scale. This suggests that PLRM models performed well on the seasonal and annual time scales, as intended based on the objectives of the model design, but can have notable discrepancies in predicted runoff volumes at the event timescale.

Specific site and seasonal discharge differences are summarized as:

- In Osgood, the baseflow contribution from the Keller Canyon drainage area cannot be modeled in PLRM, and therefore limits the validity of the seasonal and annual comparisons.

- The Osgood summer modeled metrics are significantly higher than the measured values (see Table 7.2). Initial model calibration included high DCIA values to match annual measured runoff volumes that included baseflow (see Chapter 3.3.2). The high DCIA values result in large stormwater volume responses in the model during flashy summer rainstorms, while the measured response is muted due to a combination of flow attenuation, lower DCIA, and perhaps higher than modeled depression storage.

- The model-predicted spring snowmelt volume in CIV is nearly 3 times higher than the measured volume (see Table 7.4). This is largely driven by the April 26, 2012 event. However, as can be seen in Figure 7.3, the overall magnitudes of the CIV spring snowmelt volumes are relatively minor when compared to other seasons and sites.

7.2.2 CATCHMENT FSP LOADS

In Pasadena and CIV catchments, the FSP load metrics show strong alignment between the measured and modeled values (see Figure 7.3). On an annual basis, the modeled FSP loads are within 3% (overestimate) and 1% (underestimate) of the measured loads in Pasadena and CIV, respectively. Seasonally, the modeled values overestimate the spring snowmelt and summer, while underestimating the fall/winter measured loads. Given that the final modeling scenarios were selected based on the treatment BMP CEC values that most aligned with the measured data, these comparisons represent model calibrations to the measured data. At least one additional year of data collection would have been necessary to evaluate the models. The Pasadena treatment vault CEC is modeled at 200 mg/L, while 75mg/L is applied to the CIV treatment vault. (*Note, the Pasadena cartridge filters are not included in the final PLRM model, as there were known routing issues during the monitoring period causing stormwater to bypass the cartridge filters.*) There are two contributing factors that may justify the difference in CECs:

1. Based on Road RAM observations of the contributing catchment, the stormwater runoff flowing into the CIV treatment vault is likely cleaner than the influent to the Pasadena treatment vault. The catchment volume weighted road FSP concentrations were 270 and 137 mg/L from Pasadena and CIV, respectively. Previous research (2NDNATURE and NHC 2012a) has indicated that treatment capability of stormwater treatment BMPs is influenced by the incoming FSP concentrations.

2. The CIV treatment vault is regularly (at least twice a year) vactored by Washoe County maintenance staff. This consistent maintenance ensures trapped sediments are not entrained during subsequent events, reducing the FSP loads measured at the catchment outfall.

Both the lower influent loads and the greater frequency of maintenance suggest that a lower CEC value for the CIV treatment vault is justified, though this research is limited to 1 year of monitoring. One objective of RSWMP monitoring is to evaluate the efficacy of properly maintained priority BMP types. Pairing water quality monitoring with regular BMP RAM assessments will allow correlations between the relative performance of respective treatment processes and measured differences between inflow and outflow pollutant loads. For each BMP type, monitoring at multiple locations should occur simultaneously across a range of hydrologic conditions and water year types to assess treatment performance of properly maintained BMPs and inform any updates to PLRM CECs.

The alignment between the modeled and measured values in the Osgood catchment is not as good as the other two catchments (see Figure 7.3). The model over predicts on an annual basis by over 300%, with poorer performance during the fall/winter than spring snowmelt. Poor performance in the spring is likely due to the dilution of FSP concentrations by the relatively clean (i.e., FSP concentrations <15mg/L) Keller Canyon baseflow contribution. The misalignment in the fall/winter is largely driven by the early December 2012 rainfall event (see Figure 7.2A). As discussed in Chapter 3.3.2, adjustments in the PLRM model were made to match the measured runoff volume, but the measured runoff volume may include a notable baseflow signal. Thus, the adjustments produce a poor calibration and may result in poor model performance during fall/winter rainfall events relative to measured data. As mentioned previously, the baseflow contribution cannot be modeled in PLRM and therefore makes comparisons of measured and modeled data difficult.

7.3 SUMMARY OF MEASURED TO MODELED CONCLUSIONS AND RECOMMENDATIONS

The same caveats associated with the limitation of a single year of data also apply to the measured to modeled comparisons. The one year of seasonal and annual comparisons between modeled and measured data in Pasadena and CIV catchment are well aligned (see Figure 7.3). These seasonal alignments occur despite the event-scale discrepancies in December 2012 when temperature data indicated sustained sub-freezing conditions, but runoff was consistently observed at all sites. This suggests that PLRM models can perform reasonably well on the seasonal and annual time scales, as intended based on the objectives of the model design, but the model can have notable discrepancies in predicted runoff volumes at the event time scale.

The final PLRM catchment models were the result of an extensive and iterative process. The measured hydrologic datasets provided an excellent opportunity to parameterize each catchment model to best align with the measured data. At the onset of the modeling a number of catchment flow routing, delineation and DCIA characteristics were defined using typical field evaluations and the available spatial data. The deviations between measured and modeled data resulted in a systematic investigation of both the representativeness of the PLRM model as well as the accuracy of both the input meteorology data and the measured catchment hydrology. The research resulted in a detailed understanding of the hydrology of the subject urban catchments and the development of the best possible SWMM models to represent the hydrology for each respective catchment. In addition, with representative modeled hydrology, the research provided an opportunity to inform our understanding of the water quality benefits and model representation of two treatment BMPs types. One key lesson is that well maintained treatment vaults and settling basins likely can provide a meaningful level of FSP load reduction, although probably not to the level of treatment assumed by the default CECs in the current version of PLRM (1.1).

For the purposes of this research, the treatment BMP CEC values input into each model were calibrated using the available measured data. More than likely, PLRM users will not have monitoring data available to select the appropriate CEC for their model. Additional research should continue to inform the appropriate CECs for typical treatment BMPs in the Tahoe Basin, particularly dry basins, wet basins, treatment vaults and media filters, based on inflowing catchment pollutant concentrations, the specific BMP design parameters, and the actual maintenance performed. Currently in development, the RSWMP monitoring strategy will include detailed data collection, management and analysis protocols to correlate the relative performance of respective processes relied upon for pollutant load reductions (i.e., infiltration, particle settling, media filtration or nutrient cycling) with measured differences between inflow and outflow pollutant loads. This analysis will inform future updates to PLRM CEC values, as well as quantify the effectiveness of maintenance actions beyond natural variability of the datasets.

Comparisons between measured and modeled data require: (1) QAQC of monitoring data that includes numerous site visits to ensure the instruments are recording properly throughout the year and (2) properly calibrated PLRM models that accurately represent the conditions within the catchment. Numerous recommendations are provided in Chapter 3 for the collection and management of measured data (see Chapter 3.2.) and development of PLRM models (see Chapter 3.3.5). For measured data, these recommendations include:

- Rugged instrumentation that can function effectively in the harsh Tahoe Basin environment to collect the key parameters required to quantify FSP loads at the catchment outfall.
- Consistent, rigorous and frequent site QAQC, including spot measurements to calibrate instrumentation (stage and turbidity) as well as calculated parameters (discharge and FSP concentrations).
- Site-specific turbidity sensor calibration.
- Condition of treatment BMPs intended to provide a significant pollutant load reduction.

The final PLRM simulations were run by experts using the SWMM platform, a significant deviation from the PLRM version typically used by Tahoe stormwater managers and engineers. The generation of data to conduct reasonable comparisons between measured and modeled data is not a trivial exercise. Recommendation for those who do develop PLRM models for comparison to measured data include:

- Selection of sites that can be accurately represented in PLRM, as certain characteristics (i.e., baseflow from non-urban land uses, flow diversions that split flow continuously) complicate efforts to reasonably represent stormwater runoff and pollutant loading in PLRM.

- Accurate and representative physical representation of the drainage catchment, including catchment area, DCIA values, treatment BMPs, flow diversions, etc.
- Accurate and representative high-resolution precipitation and temperature data that corresponds with the timing of stormwater monitoring. Specifically, maintenance of a weather station within the catchment during periods with snow hydrology is essential.
- Reasonable representation of land use CRCs at time of stormwater monitoring using road condition observations conducted multiple times (suggested monthly, with more frequent observations during the critical spring snowmelt season) throughout the catchment.
- Reasonable representation of treatment BMP performance, including representative CECs, during the monitoring period.
- Users must be familiar with SWMM to critically evaluate model outputs and create a modeled dataset comparable to measured data.

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APPENDIX A. DATA COLLECTION DETAILS

The following provides more details on the data collection methodology described in Chapter 3.

CATCHMENT GIS ANALYSIS

Spatial catchment characteristics, including total acreage, impervious area, and land use distribution, provide important context for interpreting the road condition, catchment outfall hydrology, and water quality data. All of these factors are also required to build representative PLRM models for the respective catchments . Spatial analyses using GIS and reconnaissance level field assessments of drainage were performed within each catchment to generate the necessary PLRM inputs and summarize key attributes. The following described the key steps in the spatial analysis to represent each catchment as they exist during the monitoring period.

1. GIS data was queried to develop input data for each PLRM catchment within a model (e.g., land use distribution, soil distribution, and average slope). The processes and algorithms used to develop the input data are described in the PLRM Applications Guide (NHC et al. 2010). The following GIS datasets were used:
   a. *TMDL Land Use GIS Layer*: The layer can be downloaded from the LRWQCB website at http://www.waterboards.ca.gov/lahontan/water_issues/programs/tmdl/lake_tahoe/index.shtml
   b. *2006 Tahoe Basin Soil Survey*: The layer can be downloaded from the Natural Resources Conservation Service (NRCS) website for Soil Survey Symbol = CA693 at http://soildatamart.nrcs.usda.gov/Survey.aspx?State=CA
   c. *PLRM Road Risk Layer*: Road risk is a proxy for the relative likelihood of pollutant generation and transport downslope from a road (PLRM; NHC et al. 2009). Both CSLT and Washoe County updated the default PLRM road risk layer for roads within their jurisdiction in March 2011, and the shapefile is available on the TIIMS website (http://www.tiims.org/TIIMS-Sub-Sites/PLRM/docs-downloads.aspx).
   d. *PLRM Road Shoulder Conditions Layer*: This layer includes road shoulder condition, road shoulder connectivity, and road shoulder compaction. Road shoulder condition characterizes the source control efforts to reduce road shoulder and primary flow path erosion along the side of the roadway (PLRM; NHC et al. 2009). Connectivity is degree of hydraulic connection between the road surface and the surface water resource, and compaction describes the degree to which the road shoulder has been disturbed by vehicular and pedestrian traffic. With funding from SNPLMA Grant PO23, NHC field personnel mapped road shoulder condition, road shoulder connectivity, and road shoulder compaction throughout the Tahoe Basin. The March 2011 shapefile is available on the TIIMS website (http://www.tiims.org/TIIMS-Sub-Sites/PLRM/docs-downloads.aspx).
   c. *Road Surface Integrity Layer:* Road surface integrity is the quality of road pavement with respect to cracks, fissures, etc. (Road RAM; 2NDNATURE et al. 2010). 2N field personnel mapped the road surface integrity within each catchment in May 2013 according to Road RAM STEP 2 protocols described in the *Road RAM User Manual* (2NDNATURE et al. 2010).
2. Reconnaissance level field inspections were used to validate the data derived from the GIS analysis listed above and to inform PLRM input parameters that cannot be developed from a GIS analysis, including the impervious area connectivity of CICU, SFR, and MFR land uses. The amount of impervious area associated with SFR, MFR, and CICU land uses that is directly connected impervious area (DCIA) was estimated through field inspection.

Information on the degree of private property BMP implementation, as of 2011, was received from CSLT and Washoe County and counts all certified parcels, as defined by TRPA code. This information was post-processed in GIS to estimate the percentage of private property BMP compliance by land use within each modeled drainage catchment.

CATCHMENT WATER QUALITY MONITORING

OSGOOD

The depth time series data (see Final Technical Report, Figure 3.5A) was converted to 10 min discharge (Q, cfs) using a hydraulic discharge equation for flow over a 90° v-notch weir (EQ1) and 5 ft rectangular weir (EQ2).

90° V-notch weir: $Q\ (cfs) = 2.48 * H_v^{2.5}$ EQ (1)

5ft Rectangular weir: $Q\ (cfs) = 3.33 * 5 * H_r^{1.5}$ EQ (2)

where H_v is the water depth in the v-notch as recorded by the level transducer up to a maximum depth of 0.83 ft and H_r is the water depth in the rectangular weir, which is equivalent to the water depth as recorded by the level transducer less the height of the v-notch weir (0.83 ft).

PASADENA

The pressure transducer and turbidity sensor were installed within a Palmer Bowlus flume (generously loaned from DRI) to constrain flow, and depth (see Final Technical Report, Figure 3.5B) was converted to discharge using standard engineering equations for the flume:

$$Q\ (cfs) = -0.028 + (0.69 * H) + (4.14 * H^2) - (1.76 * H^3) + (1.67 * H^4) - (0.34 * H^5) + (1.65 * H^6) - (2.11 * H^7) + (0.66 * H^8) \quad \text{EQ (3)}$$

where H is the water depth in the flume as recorded by the level transducer.

CIV

The monitoring sensors were installed within an H flume within the small channel to constrain flow and depth data (see Final Technical Report, Figure 3.5C) was converted to discharge using standard equations for the flume:

$$Q\ (cfs) = 2.06 * H^{1.58} \quad \text{EQ (4)}$$

where H is the water depth in the flume as recorded by the level transducer.

APPENDIX B. SWMM PROTOCOLS TO GENERATE MODEL OUTPUTS FOR COMPARISON TO CONTINUOUS MEASURED DATA

RUNNING A PLRM 1.1 SIMULATION IN SWMM 5

How-to Document V1

June 2014

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STEP 1 – LOCATE THE CORRECT PLRM FILE

1. Use the PLRM Project and Scenario Manager to locate the directory for the input file for SWMM.
   a. It's the blue pathname appearing at the bottom of the form when the desired PLRM Scenario is selected (Figure 1).

Figure 1. Locate Directory

2. Browse to the directory and copy the file name "tempSWMM.inp" to a new directory (Figure 2).
   a. The file "tempSWMM.inp" is the SWMM input file created by PLRM. Each time a user runs a new PLRM simulation this file is deleted and updated.
   b. It's a good idea to rename the file to provide better context.

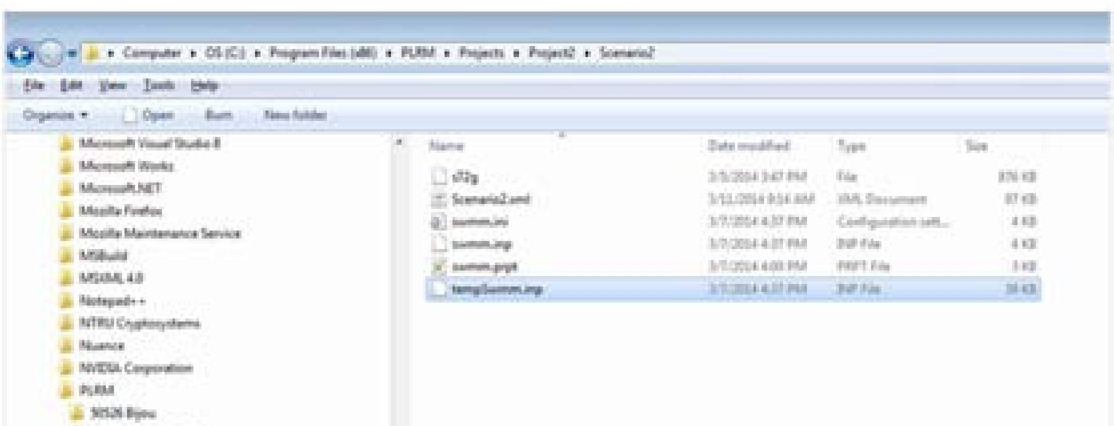

Figure 2. Copy "TEMPSWMM.INP" File

STEP 2 – OPEN THE FILE IN SWMM AND SETUP VISUAL OBJECTS

1. Open the SWMM program.
   a. From the SWMM File menu, select FILE then OPEN.
   b. Using the form that appears, locate the ".inp" file you renamed in Step 1 and open.

2. When the SWMM file opens, visual objects will not appear in the SWMM Map because the PLRM code doesn't automatically provide coordinates for each object.
   a. You can manually add visual objects to the SWMM Map by first expanding the list of available objects in the DATA tab (Figure 3).
   b. For each object you would like to place on the SWMM Map, you can add it my selecting the name of the object in the DATA tab.
      i. Hold the left mouse button down when selecting the name of the object and drag it into the SWMM schematic window and release the mouse button.
      ii. The object should appear but will not be named.
      iii. Repeat this process for all objects you want to add.

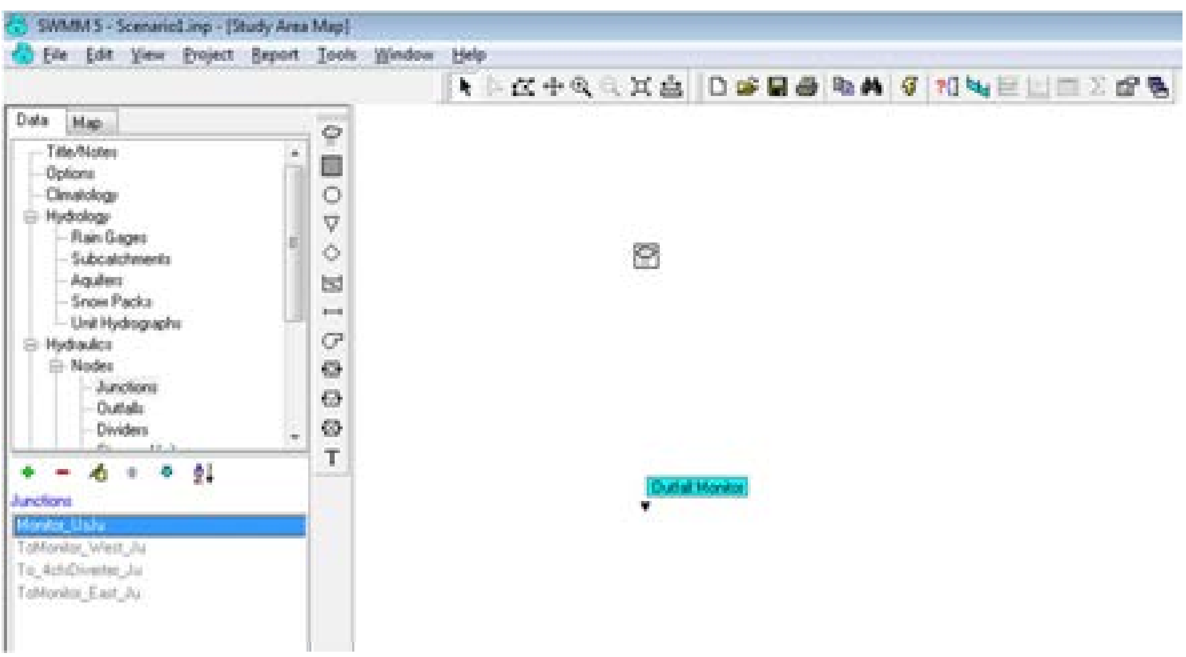

Figure 3. Adding Visual objects to the SWMM MAP

3. To display the names of the objects:
   a. From the SWMM menu, select TOOLS and then MAP DISPLAY OPTIONS
   b. The form shown in Figure 4 will appear. From that form select ANNOTATION and then check the boxes for objects where you want the names displayed.
   c. Checking the boxes for Link, Subcatchment, and Node IDs will display the names of all objects of interest.

4. Rearrange objects in the SWMM Map after naming to make the structure more intuitive.

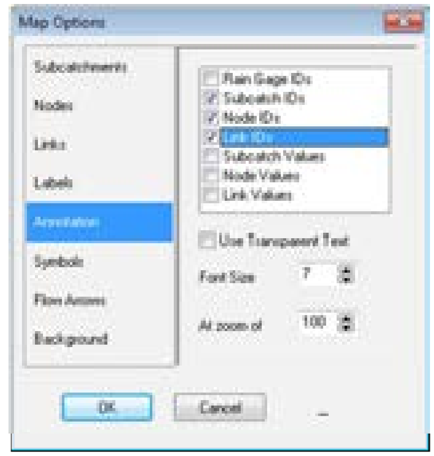

Figure 4. Displaying Names of Map Objects

STEP 3 – CUSTOM METEOROLOGICAL DATA SETUP

1. If you want to run site specific meteorological data collected from a monitoring study you will need to develop customized precipitation and temperature time series data formatted for SWMM input.
   a. Note that you need temperature data if you are attempting to simulate snowfall, snow accumulation, and snowmelt.

2. Select a precipitation and temperature time series file that PLRM automatically generates.
   a. These files will be in the directory: …\PLRM\Data
      i. The precipitation text file is named "xxx_Precip.dat"
      ii. The temperature text file is named "xxx_Temp.dat".

3. Open the files using a text editor. Pay careful attention to the formatting of both files.
   a. You'll need to format your site specific meteorological data in the exact same format, which are slightly different for the precipitation and temperature files.

4. Precipitation file (Figure 5):
   a. Format is: Met Grid; Year; Month; Day; Hour; Minutes; Precipitation Depth (not precipitation intensity)
   b. You can use any number as the Met Grid value.
   c. SWMM only needs time steps with precipitation that is greater than zero; but times steps need to be sequential or the program will not run.

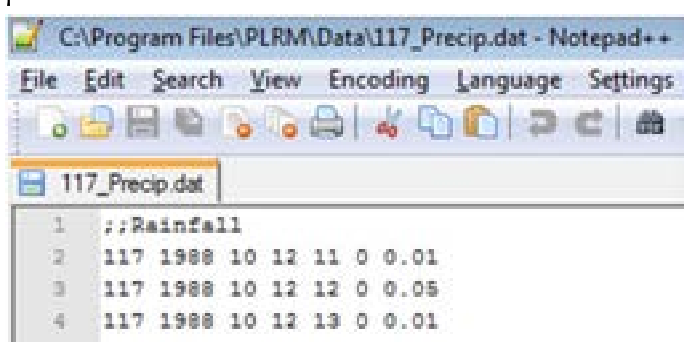

Figure 5. Precipitation Input Format

d. PLRM uses 1-hour met grid increments, so the Minutes value is set to zero in the PLRM files. Make sure this input is formatted correctly if you are using shorter duration precipitation data.

5. Temperature file Figure 6):
   a. Format is: mm/dd/year; hh:mm; temp in degrees Fahrenheit

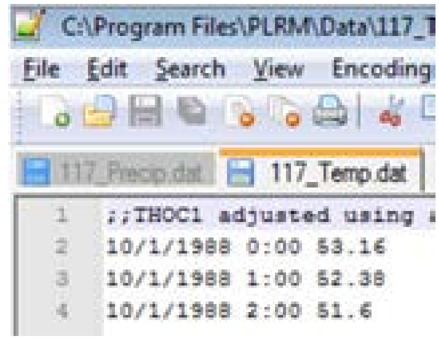

Figure 6. Temperature Input Format

6. Numerous methods may be used to create the precipitation and temperature text files in the necessary format. One suggested method that has worked for others is:
   a. Format your data columns in an Excel spreadsheet exactly as shown in Figures 5 and 6 for precipitation and temperature.
   b. Save each spreadsheet as a Text (tab delimited) file.
   c. Open the tab delimited text file in Microsoft Word and replace tabs with 1 space. Tab character is denoted as ^t.
   d. Save changes, while keeping the file as a ".txt" file.
   e. Locate the file in Windows explorer and change file type to ".dat" from ".txt".

STEP 4 – SWMM SETUP

1. The following section describes a number of steps you will need to make with the setup of the SWMM model to properly run and generate time-series output.

2. Select OPTIONS under the DATA Tab in SWMM. Then Select DATES by double-clicking in the text in the lower tab. Figure 7 will appear, which is the SWMM Simulation Options form.
   a. Adjust the START ANALYSIS and END ANALYSIS dates in the form to match your precipitation and temperature data.
   b. Adjust START REPORTING, typically you would also adjust this date to start at the beginning of your simulation.
   c. As an Option – you can click on the tab in this form titled TIME STEPS and adjust the reporting time step to match the time step of your monitoring data.
      i. For example, if you have runoff data recorded at 30 minute increments you can set SWMM to report modeled runoff at 30 minute increments.

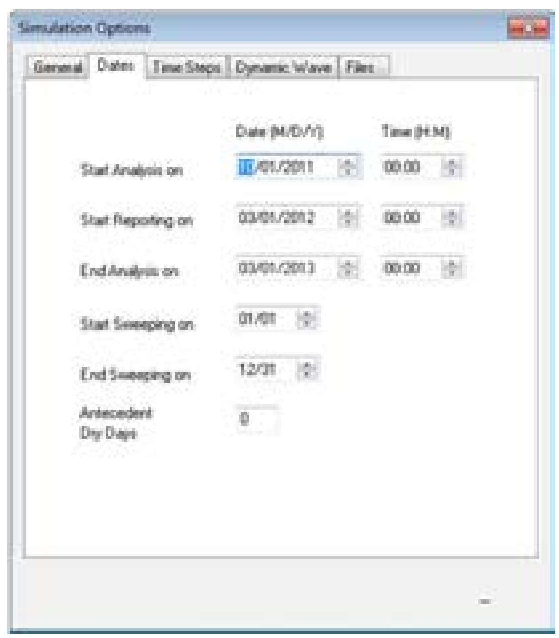

Figure 7. Simulation Options Form

3. Select OPTIONS under the DATA Tab in SWMM. Then Select REPORTING by double-clicking in the lower tab on the text. Figure 8 will appear, which is the SWMM Reporting Options form.
   a. Check the box for the respective tabs to include reporting at ALL NODES and ALL SUBCATCHMENTS.
   b. The ALL LINKS option is already checked because this is what PLRM version 1.1 uses for reporting.

Figure 8. Reporting Options Form

4. Select RAIN GAGES under the HYDROLOGY menu in the DATA Tab. Then double-click on the Rain Gage that appears in the lower tab. For a PLRM created simulation this will be a number like "815". Figure 9 will appear, which is the Rain Gage Editor.
   a. If you are using precipitation depths, then **Rain Format** = VOLUME.
   b. **Time Interval** must match the time interval of your precipitation data, or else the simulation will give an incorrect water balance. When starting with an input file created by PLRM, this will be set to one hour.
   c. **File Name:** double click on the pathname to open up a SWMM browser. Browse and select your customized precipitation data – ".dat" file you created in Step 3.
   d. **Station ID** should match the number in your precipitation file (first column) – this is the PLRM Met Grid number in a PLRM simulation.

Figure 9. Rain Gage Editor

5. Select CLIMATOLOGY in the DATA Tab in SWMM. Then double-click on the TEMPERATURE option that appears in the lower tab. Figure 10 will appear, which is the Climatology Editor.
   a. Double click on the icon next to the TIME SERIES option to open up a SWMM browser.
   b. Browse and select your customized temperature data you created in Step 3.

Figure 10. Climatology Editor

STEP 5 – VIEWING RESULTS

Figure11. Selecting Time Series output

1. Run the SWMM program.
   a. To start the simulation select PROJECT and then RUN SIMULATION from the File menu; or hit the Lightning Bolt icon.
2. After the simulation has completed:
   a. Click on the object in the SWMM Map that you would like to review for time series results.
   b. Select REPORT and then GRAPH to review time series result plotted in SWMM. A number of outputs may be reviewed from this form (Figure 11).
      i. Certain graphs are useful to check for quality assurance and de-bugging.
      ii. For example, you can check System variables for Temperature, Precipitation, and Snow Depth.
         1. Do the time series reports look reasonable for the data you entered for precipitation, temperature, and snow depth?
         2. Note that SWMM report snow water equivalent depths, not actual snow depth.
   c. You can also do a quick quality assurance check by review the SWMM Scenario Report.
      i. Select REPORT and the STATUS from the File menu.
      ii. In particular, review the Runoff Quantity Continuity portion of this report.
         1. Does total precipitation reported match your total precipitation for the data you input?
   d. Select REPORT and then TABLE and then BY OBJECT to see tabular results.
      i. Select the output you would like to view.
      ii. You will probably want to adjust the time format to DATE/TIME
   e. When viewing the time series of tabular results, if you want export the results:
      i. Select EDIT and then SELECT ALL from the SWMM menu
      ii. Then EDIT and COPY TO also from the SWMM menu
      iii. You will have the option to copy to the clipboard or a text file.
   f. After exporting the results you can export to a program like Excel to compare with monitoring data.

STEP 6 – MODIFYING A PLRM FILE AND RE-IMPORTING TO SWMM

1. If you modify a PLRM input file you will need to re-import the SWMM input file after re-running PLRM.
2. Note that as soon as PLRM begins to run, the “tempSWMM.inp” file you need to re-import will be ready (you don’t need to wait for PLRM to complete its run to grab this file).
3. An experienced SWMM user could expedite some of the Steps outlined above by modifying the “.inp” file directly using a text editor.
   a. For example you could skip Step 2 above by cutting-and-pasting the coordinates for visual objects you previously added directly into the [MAP] block of the SWMM input code from the old file.

STEP 7 – MODIFYING ROAD FSP CRC VALUES

1. Modifying the ".inp" file can also be useful for changing specific runoff parameters. The following example will provide guidance on how to change the road FSP characteristic runoff concentrations (CRC) directly in the ".inp" file.
   a. Make a copy of the "tempSwmm.inp" in a separate location. This is a precaution in case the code is altered incorrectly causing the file to be corrupted.
   b. Modify the "tempSwmm.inp" file extension to ".txt" instead of ".inp". This will allow the file to be opened using a text editor.
   c. Once opened, the code for the SWMM model will appear (Figure 12).
   d. Scroll down to near the bottom of the .txt file to the heading titled "[WASHOFF]" (Figure 13). The far left column below "[WASHOFF]" is titled "Land Use".
   e. To modify the road FSP CRCs, scroll down until this column lists each catchment name followed by the road risk categories (e.g., PrrHi, PrrMo, PrrLo, SerHi, SerMo, SerLo).
      i. Under the column title "BMP Pollutant Effic.", locate the rows associated with FSP.
      ii. The actual values of these pollutants can be changed by altering the numbers of the second to last column on the right titled "Coeff1" (Figure 14). The values must be changed for each road risk category for each catchment.
   f. Once all the desired values have been changed, save the file. Change the extension back to a ".inp" and replace the file in the same project location. The modified scenario can now be utilized in SWMM.

Figure 12. View of SWMM file when opened in text editor.

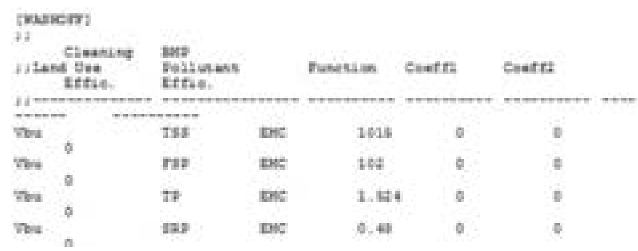

Figure 13. [WASHOFF] section column headings.

Figure 14. Road FSP CRC fields. Specific fields that can be changed are highlighted in blue. Note that changing values is specific to the watershed and condition.

APPENDIX C. ROAD CONDITION PREDICTION

METHODOLOGY

Building upon the research and subsequent data analyses conducted by DRI and NTCD (2011) and 2NDNATURE (2012), we were interested in testing the ability to use a collection of the weather and road maintenance metrics to predict road conditions. 2NDNATURE (2012) had found road condition sensitive to the number of sweeps within a 2 week period, but were unsuccessful at predicting road condition. Given that road condition varies on short times scales during the winter and spring in particular, such predictive power would allow a statistically valid method to make reasonable predictions of Road RAM scores during time periods between Road RAM observations. The development of higher resolution (i.e., daily or weekly) Road RAM scores would allow direct alignment of the road condition data with measured catchment outfall water quality datasets. Such alignment would improve our ability to test the influence of road condition on measured catchment FSP loads.

Weather metrics were developed from real-time data collection, and road maintenance practices were developed from jurisdiction-specific information. Dozens of metrics were used to try to predict Road RAM scores for CSLT (33 metrics) and Washoe County (71 metrics). We hypothesized that Road RAM scores are the result of multiple interacting conditions (i.e., predictor variables) whose overall influence is not adequately captured by examining individual variable relationships with Road RAM scores (like those shown in Figures 5.3 and 5.4). Appendix C includes the complete listing of the weather and road practice metrics for CSLT and Washoe County.

2NDNATURE applied multivariate statistical methods to model Road RAM scores (response variable) based on the variety of predictor weather and road maintenance variables to determine if it is possible to predict patterns in Road RAM scores and evaluate the relative influence of each metric on road condition. A PLS (Partial Least Squares or Projection to Latent Structures) model allows for quantification of the variation in Road RAM scores when individual variables have strong linear correlations to one another. In order to improve our understanding of how the predictor variables interact to influence Road RAM scores, Variable Importance in Projection (VIP) scores were used to estimate the importance of each predictor in the PLS model. The VIP metric simplifies interpretation of the PLS model output, as well as the comparison of the PLS results between the two different jurisdictions.

RESULTS

The results indicated that all of the variables for CSLT and most of the variables in Washoe have an influence on the Road RAM score. However, no single variable was substantially more important than any other variable and each of the models explained about half (50%) of the variance in the observed Road RAM scores. Furthermore, there were no overlapping variables of primary significance between the two jurisdictions. Consequently, a PLS model and a linear regression model with fewer (<10) predictive variables were also tested to try to improve the ability to predict Road RAM scores based on weather conditions and road practices. However, the resultant simplified models explained significantly less of the variance in the Road RAM scores than the original PLS model.

The greatest challenge to the successful prediction of road conditions is developing powerful predictive metrics that are collectively representative of the primary factors influencing changes in road condition over time. While data availability for road maintenance actions on the road network has greatly improved, there is still a large amount of error in estimates of brine and abrasive application timing and rates on specific road segments and likely not all sweeping passes are equal, with some having better road coverage and better efficiency than others. In addition, the precipitation and temperature datasets from which the metrics are developed fail to provide statistical insight on snow pack accumulation and subsequent melt dynamics, which will have a significant influence on the road specific hydrology/runoff experienced over time. In addition, there were only 6 Road RAM observation periods per segment, which limits the available data for this analysis. Should future research desire to adequately test if road condition can be predicted as a result of variations in road practices, detailed records that more accurately quantify the amount of abrasives applied, traffic density, sweeping effectiveness, site hydrology and very frequent documentation of road condition is strongly recommended.

Table C.1 Metrics for road condition prediction.

Type	ID	Variable	Units	Watershed
Predictor Variables	SinceR	# of days since last rain event	# of days	CSLT, Washoe
	SinceS	# of days since last snow event	# of days	CSLT, Washoe
	R15	Amount of rain over the last 15 days	inches	CSLT, Washoe
	S15	Amount of snow over the last 15 days	inches	CSLT, Washoe
	SinceP	# of days since last precipitation (rain + snow) event	# of days	CSLT, Washoe
	P5, P15, P30	Amount of precipitation (rain + snow) over the last 15 days	inches	CSLT, Washoe
	I5, I15, I30	Maximum rain intensity for the last 5, 15, and 30 days	in/hr	CSLT, Washoe
	AvgT5, AvgT15, AvgT30	Average daily temperature over the last 5, 15, and 30 days	°C (daily)	CSLT, Washoe
	MaxT5, MaxT15, MaxT30	Maximum daily temperature for the last 5, 15, and 30 days	°C	CSLT, Washoe
	Sweeps5, Sweeps15, Sweeps30	# of sweeping events over the last 5, 15, and 30 days	# of events	CSLT, Washoe
	SweptUP5, SweptUP15, SweptUP30	Swept debris total over the last 5, 15, and 30 days	volume/ft^3	CSLT, Washoe
	PLastObs	Precipitation amount for last precipitation event	mm	CSLT, Washoe
	RLastObs	Rain amount for last observation	mm	CSLT, Washoe
	SLastObs	Snow amount for last observation	mm	CSLT, Washoe

Type	ID	Variable	Units	Watershed
	ILastObs	Maximum rain intensity for the last observation	in/hr	Washoe
	AvgTLastObs	Average daily temperature for last observation	°C (daily)	CSLT, Washoe
	MaxTLastObs	Maximum daily temperature for last observation	°C (daily)	CSLT, Washoe
	SweepsLastObs	# of sweeping events for the last observation	# of events	CSLT, Washoe
	SweptUpLastObs	Swept debris total for the last observation	volume/ft^3	CSLT, Washoe
	AbrAp15, AbrAP 30	Amount of abrasives applied for the last 15 and 30 days	cubic yards	CSLT, Washoe
	AbrApLastObs	Amount of abrasives applied for the last observation	cubic yards	CSLT, Washoe
	SweepZone		10,11,m 10,m 11,m 6 6,10,m 6,8,m 6,m 8,m	Washoe
	SweepDist5, SweepDist15, SweepDist30	Sweeper miles driven for the last 5, 15, and 30 days	miles driven	Washoe
	SweepDistLastObs	Sweeper miles driven for the last observation	miles driven	Washoe
	SweepType15	Sweeper type for the last 15 days	Tymco, none	Washoe
	SweepType30	Sweeper type for the last 30 days	Tymco, Mixed, none	Washoe
	SweepTypeLastObs	Sweeper type for the last observation	Tymco, Mixed, none	Washoe
	Plows15, Plows30	Plowed # of times for the last 15 and 30 days	# of times	Washoe
	PlowsLastObs	Plowed # of times for the last observation	# of times	Washoe
	PlowDist15, PlowDist30	Miles plowed over the last 15 and 30 days	miles	Washoe

Type	ID	Variable	Units	Watershed
	PlowDistLastObs	Miles plowed for last observation	miles	Washoe
	BlowersLastObs	Blower # of times for last observations	# of times	Washoe
	BlowerDistLastObs	Blower miles for last observation	miles	Washoe
	AbrAps5, AbrAps15, AbrAps30	# of times abrasives were applied for the last 5, 15, and 30 days	# of times	Washoe
	AbrApsLastObs	# of times abrasives were applied for the last observation	# of times	Washoe
	AbrDist5, AbrDist15, AbrDist30	# of miles for abrasive application for the last 5, 15, and 30 days	# of miles	Washoe
	AbrDistLastObs	# of miles for abrasive application for the last observation	# of miles	Washoe
	AbrBrine30	Amount of brine applied for the last 30 days	amount of brine	Washoe
	AbrBrineLastObs	Amount of brine applied for the last observation	amount of brine	Washoe
	AbrMass5, AbrMass15, AbrMass30	Amount of sand and salt applied for the last 5, 15, and 30 days	amount of sand and salt	Washoe
	AbrMassLastObs	Amount of sand and salt applied for the last observation	amount of sand and salt	Washoe
Response variable	RAM Score		1-5	CSLT, Washoe
	[FSP]	Concentration of fine sediment particles <16um	mg/L	CSLT, Washoe