ROAD RAM TECHNICAL DOCUMENT | FINAL NOVEMBER 2010

Tool prepared for use by: Lake Tahoe Stormwater Community and Environmental Improvement Program (EIP)

LAKE TAHOE ★ ROAD TO CLARITY

ROAD RAPID ASSESSMENT METHODOLOGY (ROAD RAM)

Environmental Incentives

2NDNATURE
ecosystem science + design

nhc

Road Rapid Assessment Methodology (Road RAM)

Road RAM Technical Document
Final November 2010

The Road RAM development is part of a multi-stakeholder collaborative effort to minimize the deleterious effects of urban stormwater on the ecosystem and economy of the Lake Tahoe Basin. This product would not be possible without the generous participation of several Basin regulatory and project implementing entities.

Prepared for:

Prepared by:

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Any questions regarding the Road RAM tool or associated protocols should be directed to the Database Administrator. Contact information is available on the website (www.tahoeroadram.com). Additionally, there is a technical support forum at http://environmentalincentives.centraldesktop.com/supportservicesforum/.

With great appreciation to our technical advisory committee

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The **Road Rapid Assessment Methodology (Road RAM)**[1] is a simple and repeatable field observation and data management tool that can assist Tahoe Basin natural resource managers in determining the relative **condition** of impervious road surfaces. The primary purpose of the Road RAM is to rapidly determine and track the relative potential impact to the immediate downslope water quality from roads should a runoff event occur at the time of observation. Road RAM observations are based on scientifically defensible research and pollutant geochemical concepts, but facilitate rapid evaluations of **road condition** over many miles of roads. Road RAM can be implemented by anyone with a small amount of training and the results are simply communicated to a wide array of audiences. Road RAM results will inform the user of the relative maintenance needs to control pollutants from roadways and protect downslope water quality. Results can be used to inform a large number of water quality management questions, including potential WQ project design alternatives and justify the award of Lake Clarity Credits.

ES.1 KEY CONCEPTS

The condition of a road on any particular day results from a balance between sources and sinks for the pollutant of concern. **Fine sediment particles** (**FSP**; particles < 16µm in diameter) have been identified as the priority **pollutant of concern** under the Tahoe Basin Total Maximum Daily Load (TMDL) (LRWQCB and NDEP 2010), though a variety of sediment and nutrient species are known to impair Lake Tahoe water clarity. Multiple urban stormwater research efforts within Tahoe Basin have identified that impervious roadways are one of the most significant sources of FSP to Tahoe Basin (LRWQCB and NDEP 2008a). Winter road safety requires thousands of cubic yards of anthropogenic road abrasives to be applied each year, and the pulverization by vehicles of these abrasives and other native material on the impervious road surface generates elevated amounts of FSP on Tahoe Basin roads. A variety of strategies are employed to protect receiving waters from pollutants, including capital improvement projects, ordinances and enhanced road maintenance practices. Source reductions such as reducing the annual amount of abrasives applied, employing abrasives with fewer fines and using brands more resistant to breakdown are all critical advancements in abrasive application strategies. Similarly, road maintenance practices should continue to maximize effective road sweeping efforts and other techniques to recover pollutants.

The Road RAM is a tool that balances the need to quickly assess large areas of roads while maintaining reasonable statistical defensibility. To accomplish this objective, simple and repeatable **field observations** are used to determine the condition of a specific **road segment** on a specific day. The condition is expressed as a **road segment score** ranging from 0 (worst) to 5 (best). The road segment score is correlated to a runoff FSP concentration expected from that road segment should a runoff event occur at the time of observation. The user classifies roads within the area of interest based on similar road maintenance practices and frequencies. It is assumed that roads of the same **road class** within a single jurisdiction have a similar condition on any particular day. Classification of roads based on similar and consistent road maintenance practices allows the spatial extrapolation of road segment scores to a **Road RAM score** for all roads within a designated area of interest. The Road RAM scores can be used to track the condition of roads throughout Tahoe Basin over time and compare actual observed road conditions to the expected road conditions based on road maintenance practices. The consistency of results within a particular road class provides valuable quality control information to inform maintenance practice effectiveness and potential needs for improvement. By analyzing data over time, maintenance practices can be optimized to increase

[1] Terms defined in *Chapter 12: Acronyms and Glossary* are **bolded** at first use.

the cost effectiveness of controlling pollutants, as well as address other emerging water quality protection concerns.

The RAM score generation and tracking of road condition over time are automated functions of the ***Road RAM Database*** (**database**). The Road RAM results can be overlain with other **road attributes** to inform future improvements in design and maintenance strategies on Tahoe Basin roads to minimize the potential water quality impacts. The future data analysis possibilities of Road RAM results are infinite and future syntheses of Road RAM data throughout Tahoe Basin could specifically address and inform a number of water quality protection questions.

ES.2 ROAD RAM IMPLEMENTATION

The Road RAM consists of a series of six STEPs that have been designed for ease of use and practicality from the user's perspective (Table ES.1). The STEPs lead a user through collection of data about the roads within the area of interest, population of the database and interpretation of 0-5 condition scores generated by the database. The Road RAM tool integrates GIS analysis with an online database, rapid field observations, Google Maps® display, and tabular exports.

Road RAM STEPs 1, 2 and 3 are completed one time and result in a comprehensive mapped **inventory** of all roads and their road attributes within the area of interest. Road attributes are other characteristics of roads that, when integrated with Road RAM scores, can inform management strategies to improve water quality protection. Road RAM STEPs 4-6 define the sequence of field observation and analysis STEPs required to obtain Road RAM scores and assess the condition of a road network with respect to the potential water quality impacts downslope should a runoff event occur. Road RAM STEPs 4-6 are repeated as often as condition scores are desired.

Table ES.1 Summary of Road RAM STEPs implemented by the user.

Road RAM STEP #	Road RAM STEP Name
1	Define AREA of interest
2	Create INVENTORY of road attributes
3	CLASSIFY roads
4A **4B**	Select ROAD SEGMENTS Conduct FIELD OBSERVATIONS
5	Obtain Road RAM SCORE
6	ANALYZE results

Road RAM STEP 1 – Define AREA of interest

The spatial area of interest to complete the Road RAM can include an urban catchment, an entire jurisdiction, or the road network within any other user defined urban area where consistent pollutant control practices are employed with the expectation of achieving consistent results. The product of Road RAM STEP 1 is the delineation and identification of the area of interest.

Road RAM STEP 2 – Create INVENTORY of road attributes

The user creates a spatial inventory of the roads within the STEP 1 area of interest using an existing road GIS layer. Depending on the user's analysis goals, the roads can be categorized based on a variety of road attributes that are expected to vary across the area of interest. Typical attributes in Tahoe Basin include **PLRM road risk**, **road shoulder condition**, **road surface integrity**, **road shoulder connectivity**, etc. The product of Road RAM STEP 2 is one or more GIS layers of the road attributes within the area of interest defined in STEP 1.

Road RAM STEP 3 – CLASSIFY roads

Road RAM STEP 3 is the grouping of roads within the area of interest by similar road maintenance practices as conducted by the local jurisdiction. Road maintenance practices must be consistently defined by the **abrasive application priority, sweeping effectiveness**, and any other pollutant control practices that are expected to have a significant effect on the resulting road condition. Abrasive application priority and sweeping effectiveness are the most likely priority pollutant sources and sinks that influence on-going road maintenance practices, but jurisdictions have flexibility to define the combined road maintenance practices for each class. Road RAM STEP 3 product is a **road class** map which categorizes all roads into one of 9 potential road classes and used to by Road RAM to spatially extrapolate discrete field observations to the network defined in STEP 1.

Road RAM STEP 4 – Select ROAD SEGMENTS (4A) and Conduct FIELD OBSERVATIONS (4B)

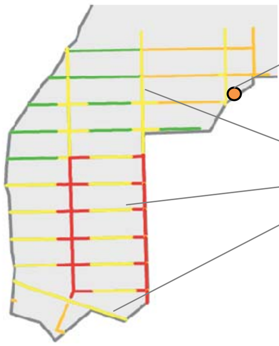
The evaluation and tracking of Road RAM scores is based on a set of standardized, repeatable and rapid field observations that include both visual observations and measurements that are proxies to predict runoff FSP concentration. Field observations are conducted on a series of road segments selected by the user (STEP 4A) and typically take two trained field personnel approximately 10 minutes to evaluate using STEP 4B protocols. STEP 4B can be repeated as frequently as desired and discrete records of actual observed road conditions are tracked over time. Figure ES.1 illustrates how a road segment is a spatially discrete point within a road network of interest.

Road RAM STEP 5 – Obtain Road RAM SCORE

RAM scores are used at a number of spatial scales to express condition using a 0-5 scale. A score of 0 indicates poor road condition and a high risk to downslope water quality and a score of 5 is the best possible road condition with minimal immediate water quality risk downslope (Table ES.2). Field observations are used to calculate road segment scores. Road class is used to spatially extrapolate road segment scores to a greater area of roads and calculate Road RAM scores for the area of interest defined in STEP 1 (see Figure ES.1). STEP 5 products can either be tabular Road RAM results or color coded maps for simple communication of actual conditions.

Table ES.2 Road RAM scores relative to road condition and relative risk to downslope water quality.

Road RAM Score	Condition	FSP Concentration (mg/L) range	Description
0 - 1.0	Poor	1,592-680	• Significant potential risk to downslope water quality should runoff event occur • Road maintenance practices require immediate improvements • Capital improvement projects downslope may need to be considered to capture road generated pollutants
>1.0 - ≤ 2.0	Degraded	679-291	• Likely potential risks to downslope water quality • Road maintenance practices require immediate improvements • Capital improvement projects downslope may need to be considered to capture road generated pollutants
> 2.0 - ≤ 3.0	Fair	290-124	• Road condition is closer to degraded than desired, may pose downstream water quality risk • Road maintenance should be prioritized as needed if time and resources permit
> 3.0 - ≤ 4.0	Acceptable	123-53	• No immediate risk to downslope water quality should runoff event occur • Minimal need to improve road maintenance practices
> 4.0 – 5.0	Desired	52-23	• Maximum achievable road condition • No need to improve road maintenance practices



Road Segment:
An area of road that can be reasonably evaluated by a single set of rapid Road RAM field observations. Each road segment where field observations are conducted is represented by a point in the database and the observed condition is expressed as a Road Segment Score, ranging from 0-5. In this example, the road segment score is 2.5.

Road Class:
A grouping of road segments that share similar fine sediment sources and sinks. All roads of the same road class are expected to be in similar condition on any given day. The Road RAM Score is an average of all segment scores within the road class. In this example all yellow segments in the diagram belong to the same road class and have a RAM score of 3.2.

Figure ES.1. Visual summary of key Road RAM concepts.

Road RAM STEP 6 – ANALYZE results

The Road RAM tool establishes a standardized methodology to display, evaluate, track and inform changes in road condition over time (Figure ES.2). In addition, the overlay of Road RAM results with different road attributes can provide valuable spatial information on pollutant sources, sinks and transport risk.

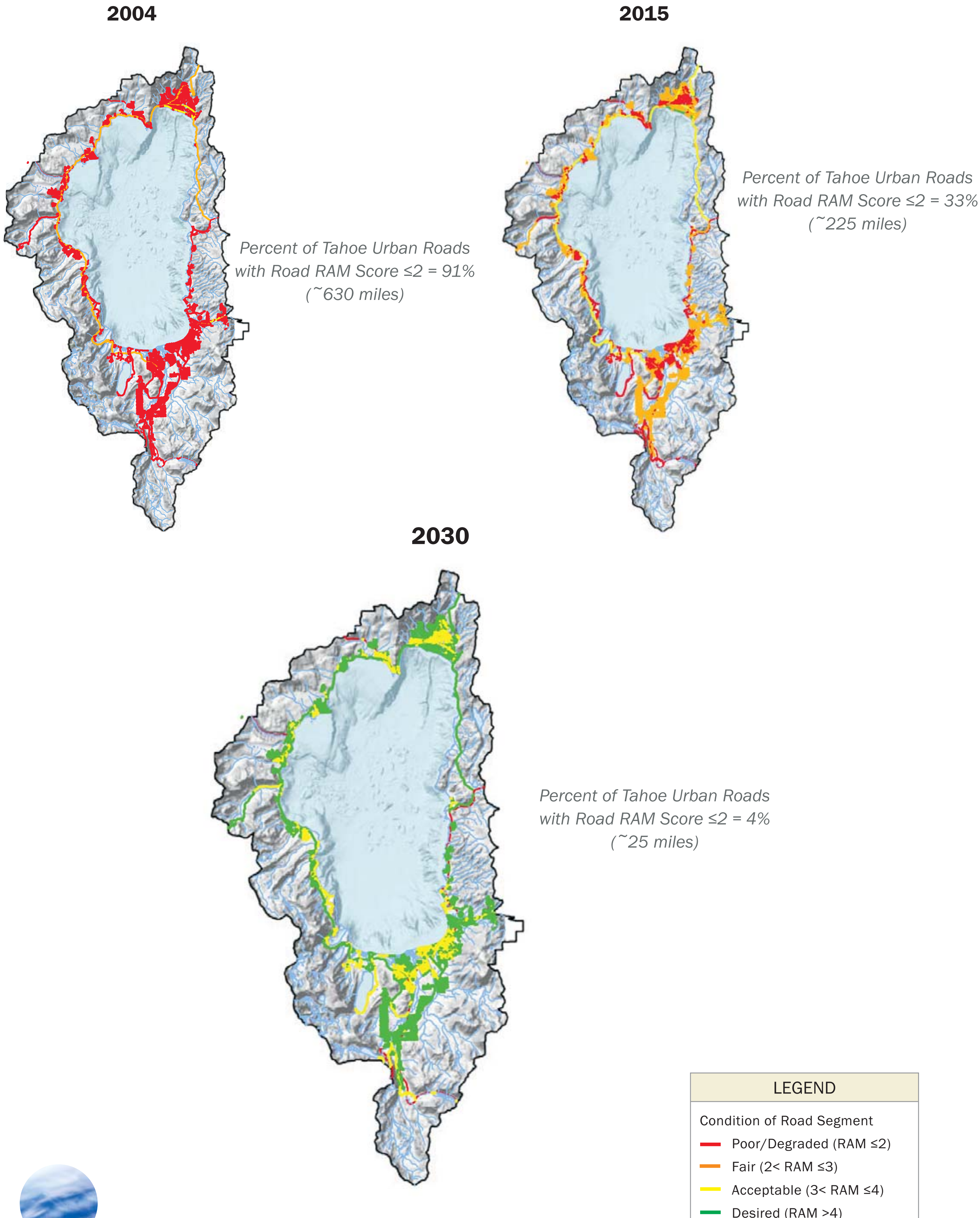
ES.3 ROAD RAM COMPONENTS AND AUDIENCE

The Road RAM is a tool that can be applied in the Tahoe Basin by urban jurisdictions and regulators to strengthen their stormwater programs. Urban jurisdictions can use the Road RAM as a quality assurance tool to ensure maintenance, pollutant control practices and capital improvements are achieving desired results, and to target the use of limited staff and equipment resources. Stormwater managers and operations and maintenance (O&M) personnel can use the Road RAM to define desired road conditions, which clarifies communications and provides a common point of reference to connect managers with field staff. Regulators can explicitly integrate the Road RAM into the Lake Clarity Crediting Program as the best available approach to assess annual conditions of roads and inform the award of credit for effective actions to reduce pollutant loading, consistent with the Lake Tahoe TMDL.

Road RAM documentation consists of three main components: *Road RAM Technical Document.pdf, Road RAM User Manual.pdf*, and *Road RAM Database v1*, available at www.tahoeroadram.com.

The *Road RAM Technical Document* is primarily targeted to the stormwater managers of urban jurisdictions. It provides the background and scientific underpinnings of the Road RAM and provides stormwater managers with the rationale supporting the tool development. It is possible to successfully collect data and work with the database without reviewing the *Road RAM Technical Document*, but the user would be less familiar with the rationale behind certain terms, procedures and components of the tool.

The *Road RAM User Manual* details the specific process and protocols necessary for users to create a road inventory, conduct field observations and interact with the database. The *User Manual* is primarily targeted to the field personnel who are expected to complete the Road RAM field observations and data entry over time. The initial Road RAM STEPs (STEPS 1, 2, 3 and 4A) will require collaboration between field personnel, O&M personnel, stormwater managers and GIS specialists. Field personnel completing Road RAM observations (STEP 4B) should always have a hard copy of the *User Manual* when making field observations. Stormwater managers should be familiar with the *User Manual*, particularly the office-based procedures for mapping road characteristics and managing the database. The *Road RAM Database* is a web-based application and manages all necessary data and information generated by the Road RAM tool and substantially automates Road RAM result calculations and presentations in either map or tabular format.



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HYPOTHETICAL PROGRESSION OF TAHOE BASIN ROAD CONDITION OVER TIME

FIGURE ES.2

CHAPTER 1: OVERVIEW AND GOALS

The Road Rapid Assessment Methodology (Road RAM) has been developed to provide a tool to Tahoe Basin urban land managers to rapidly evaluate the relative condition and determine the urgency of maintenance modifications for impervious roadways within the Tahoe Basin to protect immediate downslope water quality should a runoff event occur. Road RAM facilitates the rapid evaluation of road segments and the spatial extrapolation of discrete observations to many miles of a road network by road class. Road RAM provides a complete and consistent field evaluation and data management tool for jurisdictions to determine and track the condition of roads over time in response to future road water quality improvements.

The need for a road rapid assessment tool is based on the assumption that roads are a significant source of particulate pollutants due to the combination of winter road abrasive applications, road surface and tire degradation, erosion of unprotected road shoulders, and the pulverization of particulate material on the road surface by vehicular traffic. In addition, impervious road networks are the primary transport pathway for stormwater runoff. Even in mixed land use catchments, the road network often comprises the majority of the **directly connected impervious area (DCIA)** and routes the greatest fraction of the urban stormwater that reaches a surface water system and eventually Lake Tahoe. The existing condition of impervious roads in Tahoe Basin provides a significant opportunity for the implementation of water quality improvement projects (including pollutant and hydrologic source control, advanced road maintenance practices and treatment BMPs) by local jurisdictions toward meeting the Tahoe Basin TMDL goals (LRWQCB and NDEP 2008A).

The Road RAM solely addresses the impervious roads and is one component of the complete Tahoe Basin Urban RAM toolbox. Many of the Road RAM concepts, procedures and techniques are consistent with version 1 of the **BMP RAM** (**Best Management Practices Maintenance Rapid Assessment Methodology**) tool released in October 2009 (2NDNATURE et al. 2009).

1.1 TOOL NEED & DEVELOPMENT PROCESS

Rapid Assessment Methodologies (RAMs) are standardized, defensible and low-cost tools to rapidly evaluate the condition of an area, process, or feature. The underlying philosophy behind any RAM is that the relative condition of the feature, area or system can be evaluated using a select number of key observations. In general, environmental RAM approaches focus on the visible, physical and/or biological structure of the attributes being assessed and use simple proxies to infer the physical, chemical or biological state and/or function. RAMs allow a much more cost-effective application of existing scientific knowledge of system function by implementing simple, repeatable, targeted observations or measurements over a much larger spatial area than can be evaluated using more advanced evaluation techniques. The rapid observations do not replace the potential need for more rigorous evaluations and monitoring to validate the assumptive linkages between the proxies and the processes of interest or quantitative values.

The development team conducted a literature review to document the strengths, weaknesses and approaches utilized by a number of existing and well-accepted RAMs. The Road RAM is based on a growing body of scientific literature and practical experience to apply rapid assessment concepts to a variety of aquatic systems. RAMs have been developed for wetland habitats (e.g., Miller and Gunsalus 1997; Mack 2001; Collins et al. 2008) to evaluate the relative condition of various wetland components such as landscape, hydrology, physical structure, and biotic structure. RAMs for stream assessment (e.g., Rosgen 1996; Roth et al. 1996; Starr and McCandless 2001; Montgomery and MacDonald 2002) generally focus on fluvial morphology, water quality, channel stability, erosion risk, biological indicators, physical in-stream habitat, and riparian habitat. Vegetation and habitat RAMs (e.g., Barbour et al 1995; CNPS 2004) are often used to quickly assess and map the extent of all vegetation types and biological condition in relatively large, ecologically defined regions.

The development team also conducted a number of interviews with Tahoe Basin jurisdictions and resource managers to document the existing techniques employed locally to inventory and track priorities and maintenance activities on roads. The information gained from these background research efforts informed development of the Road RAM tool.

1.2 GOAL AND OBJECTIVES

The Road RAM provides a tool to consistently validate the relative condition of a road with respect to the immediate risk to downslope water quality. The condition of a road is variable and will change over the year depending upon the relative sources and sinks of pollutants at any given time. The Road RAM tool allows the evaluation and tracking of the condition of specific roads and road classes over time. The Road RAM has been developed to provide a reliable and cost-effective tool to support the Crediting Program's validation requirements.

GOAL

Develop a precise, cost-effective, and simple tool that can repeatedly assess the relative condition of a large area of roads in relation to potential downslope water quality risks over time.

OBJECTIVES

- Consistent with BMP RAM - As appropriate, maintain consistency of the Road RAM with the initial Tahoe Basin Urban RAM components (BMP RAM; 2NDNATURE et al. 2009), including implementation steps, scoring nomenclature and other key concepts to preserve the general structure of the Tahoe Basin Urban RAM stormwater toolbox.
- Simple field observations **-** Define simple and repeatable field observations of roads that will be consistently indicative of the relative water quality impact of the pollutant of concern (FSP) transported downslope should a runoff event occur. Condition will also be indicative of the relative impact of other key Tahoe Basin pollutants, specifically sediment and nutrient species.
- Score relative condition - Define relative condition such that each numeric RAM score on a 0-5 scale is indicative of relative risk to downslope water quality should a runoff event occur.
- Standardized data management structure - Create a user friendly relational database to manage data generated by user, output Road RAM results in both tabular and spatial format, and facilitate the power of consistent data management and analysis techniques across users and over time.
- Easily adoptable - Create simple procedures and database tools to increase the likelihood for adoption and implementation by local jurisdictions as a means to assess and track road condition and prioritize operations and maintenance expenditures over time.
- Spatial extrapolation of results to similar roads within same catchment or jurisdiction - Identify and integrate techniques to classify roads into expected similar condition on short (weekly) time scales.
- Temporal extrapolation of results- Define a methodology to integrate a series of Road RAM observations over a year and express the average annual road condition for an area of interest to support condition reporting for the Lake Clarity Crediting Program.

CHAPTER 2: KEY TERMS

The following key Road RAM key terms are used throughout the Road RAM documentation and summarized visually in Figure 2.1. A complete glossary and acronym list is included in *Chapter 12: Acronyms and Glossary*.

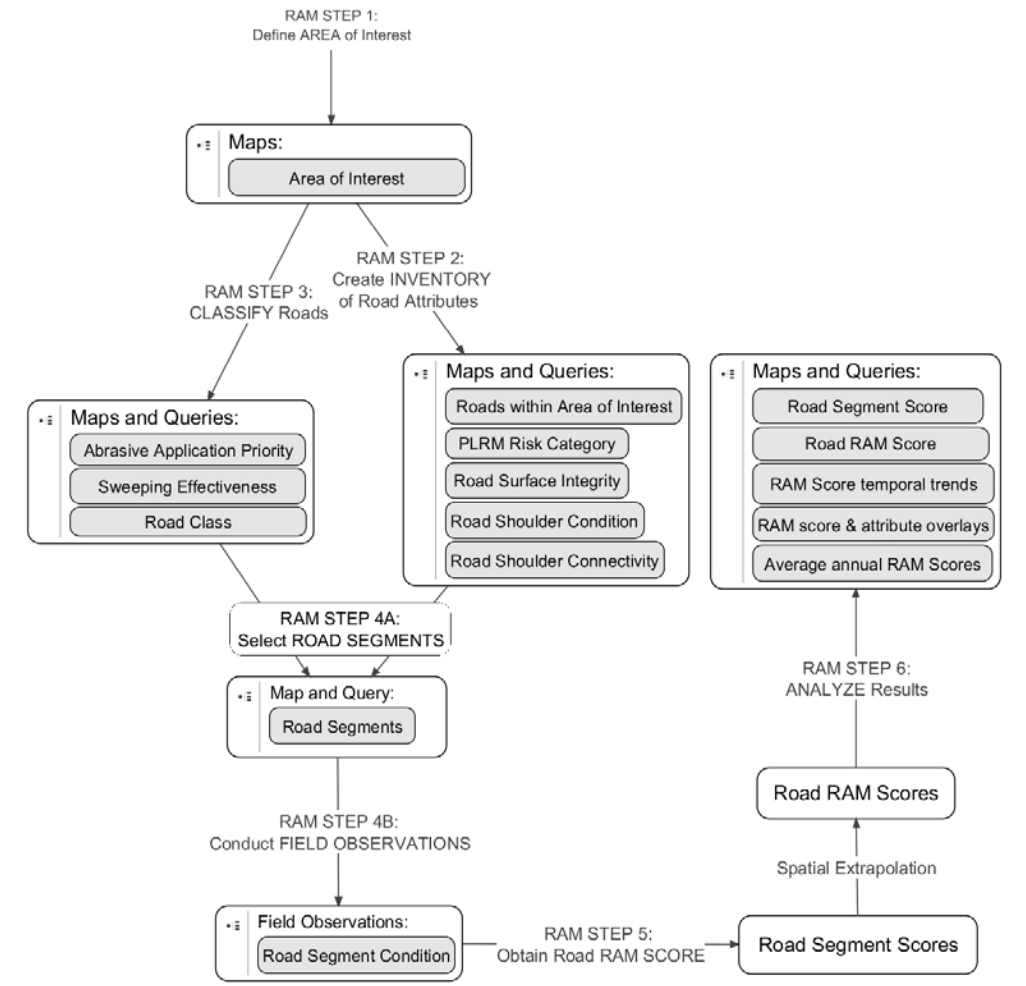


Figure 2.1. Visual summary of Road RAM user STEPs.

<u>Road Condition:</u> The relative risk to the immediate downslope water quality from an impervious roadway at the time of observations, quantitatively expressed as a Road RAM score. The primary pollutant of concern is fine sediment particles (FSP <16µm), but **total suspended sediment (TSS)** and nutrient species are also assumed to vary in relative magnitude with road condition. The condition of a road fluctuates over time due to the continual balance of pollutant sources and sinks based on a variety of factors, primarily climate and associated road maintenance practices. Road condition is expressed using a 0-5 scale, with 5 being the best possible condition and relatively low downslope water quality risk.

<u>Road RAM:</u> A simple and repeatable field observation and data management tool to assist Tahoe Basin natural resource managers in determining the relative condition and relative maintenance urgency with respect to expected downslope quality of the respective roads. The tool consists of six distinct RAM STEPs implemented by the user and the corresponding information stored in a custom online database. Road RAM quantifies road condition for specific road segments using the Road RAM field protocols at a discrete point in time and spatially

extrapolates the results to all of the roads within the subject area of interest. Road RAM results can be temporally extrapolated for comparison to expected annual road conditions.

Road RAM STEPs:

Table 2.1 Summary of Road RAM STEPs implemented by the user.

Road RAM STEP #	Road RAM STEP Name
1	Define AREA of interest
2	Create INVENTORY of road attributes
3	CLASSIFY roads
4A **4B**	Select ROAD SEGMENTS Conduct FIELD OBSERVATIONS
5	Obtain Road RAM SCORE
6	ANALYZE results

Road RAM Score: A value between 0 and 5 that represents the temporally-discrete, spatially-extrapolated road condition as a result of Road RAM field observations conducted at one or more road segments. The Road RAM score is an average of road segment scores for roads of the same road class. A Road RAM score of 5 is the achievable score that results in a minimal downslope impact to water quality during a subsequent runoff event. The Road RAM score declines as the relative amount of available fine sediment particles present on the road segment increases, thus increasing the risk to downslope water quality should a runoff event occur.

Road Segment: A 10,000 ft^2 road unit is the standardized road area evaluated by the user using the STEP 4B Road RAM field protocols. This size is assumed to be large enough to be representative, while small enough that the road condition can be evaluated rapidly (approximately 10 minutes).

Field Observations: A compilation of distinct rapid observations and/or measurements made at road segments over time to evaluate and track condition.

Road Segment Score: A value between 0 and 5 obtained from Road RAM field observations at one point in time for a 10,000 ft^2 road unit. Road segment scores are obtained from a number of road segments belonging to the same road class and averaged to determine a Road RAM score.

Road Class: Nine road classes are defined based on the combination of pollutant control practices employed on a particular road throughout the year, including the relative planned abrasive application priority during winter road conditions and relative planned sweeping priority when the weather is favorable for pollutant recovery. Road class is used to spatially extrapolate road segment scores to a greater area of roads to calculate Road RAM scores. The jurisdictions classify the roads in their jurisdiction based on actual maintenance practices during STEP 3.

Road Attribute: Any trait of a road network that can be spatially mapped and is expected to vary across an area of interest. Examples of road attributes include road shoulder condition, road shoulder connectivity, road surface integrity, PLRM road risk, etc. The specific categorical designations within each attribute are called road attribute categories. Typically there are three to four categories associated with an attribute, defining the relative high and low bookend values and allowing for intermediate values. Road attributes are defined in STEPs 2 and 3 and applied during STEP 6 data analysis to allow visual and quantitative comparisons of attributes and Road RAM scores.

Road RAM Database (database): Version 1 of the Road RAM database is a web based application (www.tahoeroadram.com) with Google® Maps display that stores and manages all information necessary to implement, track and maintain Road RAM data and results over time. The Road RAM user generates data and/or information from GIS or field observations and enters it into the database.

CHAPTER 3: ROAD RAM PROGRAMMATIC INTEGRATION

The Road RAM is a tool to rapidly determine and track the condition of impervious road surfaces over time and can be used by a multitude of different users for different purposes. The tool includes standardized data collection and data management protocols to ensure consistency of results and improve communication across stakeholders. Existing and continued research suggests improved road conditions throughout the Tahoe Basin are expected to result in reductions of pollutant loading to Lake Tahoe. Urban jurisdictions can use Road RAM to clarify expectations for the use of limited maintenance resources to maintain good road conditions, identify potential water quality project design alternatives and meet annual reporting requirements under the Lake Clarity Crediting Program.

3.1 USERS

The primary user of the Road RAM is the urban jurisdiction that has load reduction requirements through National Pollutant Discharge Elimination Systems (NPDES) permits or stormwater Memoranda of Agreement (MOA). Urban jurisdictions can use the Road RAM results to prioritize road maintenance efforts or water quality improvement actions and support declarations of Lake Clarity Credits within the Crediting Program.

Implementation of the Road RAM will primarily be the responsibility of office-based stormwater managers and field personnel, both filling different roles. Stormwater managers need to fully understand the concepts and outcomes of each Road RAM STEP, and thus should carefully review the *Road RAM Technical Document*. Field personnel should have a basic understanding of the Road RAM's underlying principles and a strong, operational knowledge of the procedures for carrying out the field observations. Field personnel should focus their time on understanding the *Road RAM User Manual*, which includes a brief summary of information in the *Road RAM Technical Document*. The *Road RAM User Manual* is designed to be carried in the field by field personnel, while the *Road RAM Technical Document* can remain in the office.

Stormwater managers are expected to complete Road RAM STEPs 1-4A at the onset of the Road RAM in their area of interest. In most instances STEPs 1-4A will only be completed once, though minor adjustments may be made over time. GIS assistance is required during all of these STEPs. Road maintenance personnel should be consulted and/or assist with the completion of STEP 3 by providing field knowledge of how specific roads are and will be maintained in practice.

Field personnel are expected to be responsible for the repeated field observations at representative road segments and completion of field datasheets (STEP 4B). Scoring and analysis (STEPs 5 & 6) can be completed by the jurisdiction staff best suited for the task.

ADDITIONAL USERS AND APPLICATIONS

The Road RAM data and results have a number of additional applications for several user groups. Regulators rely on the Road RAM results to understand if expected conditions defined in Crediting Program catchment credit schedules are being achieved, which provides evidence to justify award of Lake Clarity Credits for permit compliance and to show progress toward meeting TMDL load reduction milestones. Project funders can use the results to inform funding priorities, evaluate proposed WQ improvement locations, set expectations for ongoing operations, and identify when contractual maintenance requirements have been fulfilled. Scientific researchers can use Road RAM to test a number of hypotheses such as road maintenance practice effectiveness or correlate

Road RAM scores with high-intensity water quality monitoring results on a road, catchment or watershed scale. *Chapter 10: Application of Road RAM Data and Results* provides an extensive discussion of the potential applications and uses of the road attribute spatial datasets generated and Road RAM results for a multitude of users.

3.2 INTEGRATION WITH JURISDICTION STORMWATER PROGRAMS

Integrating Road RAM into a stormwater program can improve communications between managers and field staff, which can result in more efficient and effective use of limited resources to reduce pollutant loading, while maintaining public safety.

CONNECTING PERSONNEL TO ENHANCE UNDERSTANDING

The use of Road RAM by a jurisdiction will strengthen the communications among maintenance staff and stormwater managers so both groups understand how to most effectively improve road condition. The assignment of road classes (1) allows stormwater managers to communicate their expectations, informed by their detailed understanding of pollutant fate and transport, and (2) provides a means for maintenance staff to communicate to stormwater managers their field knowledge of public safety needs and practical maintenance considerations.

Road RAM scores provide valuable quality assurance feedback to determine if maintenance plans are being effectively implemented and offer information to identify when plans should be adjusted to address operational and resource constraints. Stormwater managers are encouraged to analyze Road RAM results within a week of data collection and review findings with maintenance personnel. The review of findings from each **observation period** provides important feedback regarding operational performance and initiates a dialog between stormwater managers and maintenance personnel to identify operational efficiencies and align plans with on-the-ground constraints.

Once a trained technician conducts several Road RAM field observations and understands the results they will develop an “eye” for road conditions. It is extremely valuable for maintenance personnel to develop the ability to quickly determine road conditions based on sources and sinks of the **pollutants of concern**. This knowledge will help them target maintenance efforts to achieve conditions that protect downslope water quality. It is also valuable for stormwater managers to gain sufficient experience performing Road RAM field observations that they develop an intuitive understanding of the physical conditions related to the range of Road RAM scores. By performing a certain number of observations together each year, maintenance staff and stormwater managers can increase the understanding of each other’s intents, needs and constraints. *Chapter 10.4: Utilize Road RAM Data to Inform Road Maintenance Practices* provide specific details on how a jurisdiction can use the road attribute spatial datasets and Road RAM results to inform and optimize road maintenance strategies to protect water quality on specific roads over time.

In order to keep Road RAM field observation and data entry user errors to a minimum, it is suggested that a jurisdiction identify specific field personnel responsible for Road RAM STEP 4B implementation. As discussed above, trained field personnel will develop an “eye” for road condition and likely become highly efficient at completing Road RAM protocols, determining road segment condition, reducing the overall level of effort on the part of the jurisdiction.

SELECTING THE ENTIRE JURISDICTION AS THE AREA OF INTEREST

Stormwater managers may consider catchment specific requirements during the development of stormwater management plans and catchment credit schedules, and use these considerations when developing maintenance plans and other pollutant control strategies. However, by selecting the entire jurisdiction as the area of interest, the urban jurisdiction can minimize the level of effort to perform Road RAM assessments while 1) providing sufficient information to ensure maintenance plans are being implemented effectively and 2) gathering the information necessary to support annual stormwater reporting needs. This is also practical as it can be difficult for maintenance staff to differentiate between different catchments during their daily operations.

3.3 APPLICATION TO THE LAKE CLARITY CREDITING PROGRAM

The Lake Clarity Crediting Program Handbook (Crediting Program Handbook) (LRWQCB and NDEP 2009) defines land and treatment BMP conditions as a practical observable proxy for pollutant loading to award credits consistent with the Lake Tahoe TMDL. The Crediting Program has identified specific roles for both the Road RAM and the **Pollutant Load Reduction Model** (PLRM) in the effort to manage and track the benefits from implementation of pollutant controls to restore Lake Tahoe clarity. The PLRM Version 1 Road Methodology predicts average annual **characteristic runoff concentrations (CRC)** for roads based on a combination of road maintenance practices. Ideally, the PLRM Road Methodology v1 is updated to align inputs and outputs more directly with Road RAM (see *Chapter 10.5 Relationship of Road RAMv1 to PLRMv1*) in order to provide a more transparent link between expected road conditions in PLRM load reduction estimates and actual conditions observed over time using Road RAM.

The Crediting Program Handbook provides a form for jurisdictions to summarize O&M plans and expected pollutant load reductions called a catchment credit schedule. Section *C.3: Roads Operation Implementation Summary* of the catchment credit schedule includes an inventory of roads, which identifies expected road conditions consistent with the Road RAM 0-5 scale. Field observations throughout the year can be used to document and track actual on-the-ground road conditions and inform annual credit awards under the Crediting Program. These field observations are intended to represent road conditions in advance of seasonal pollutant load delivery to receiving waters.

The Crediting Program's *Step 2.1: Inspect* identifies the use of the Road RAM to inspect road conditions and report annual road condition scores for each class of roads identified in active catchment credit schedules. A series of discrete Road RAM observations must be completed at critical times throughout the year and temporally integrated to establish an annual road score for each road class. The actual condition scores are compared to expected scores to inform the credit declarations and awards for each catchment. *Chapter 8: Spatial and Temporal Integration of Observations* provides the justification and approach to spatially and temporally integrate Road RAM observations to obtain annual road condition scores for an entire jurisdiction. The *Road RAM Database* automates the calculations and result summaries using the Road RAM data entered by the user.

LEVEL OF EFFORT

By striking the right balance, Road RAM results can provide valuable information to increase the effectiveness of maintenance activities and represent annual road conditions, without diverting significant effort from effective maintenance activities. In an attempt to attain this balance, a two-tiered approach is presented to choosing the number of road segments per observation period and the number of observation periods during a water year. This two tiered system includes significant effort to establish consistency of results every fifth year (**calibration years**), while efficiently using information to perform quality assurance checks with minimal effort in the interim four years (**check up years**).

Calibration years

During the first year an urban jurisdiction is using the Road RAM and every fifth-year thereafter, a large number of field observations performed at many different times throughout the year is necessary to calibrate the abrasive application, sweeping and other pollutant control practices that result in road conditions that meet expectations. Low statistical variation among field observations should be achieved during calibration years. During these years, extra attention should be paid to ensure maintenance plans are realistic and can result in expected conditions.

During calibration years, five (5) Road RAM observation periods should be distributed during the year as described in *Chapter 8: Spatial and Temporal Integration of Observations*. The level of effort required for each observation period should not be more than 5 full time days of field time for 2 staff working together. The total estimated level of effort during calibration years is expected to be 16% of a full time equivalent (FTE) position, including field time, 1 day of staff time per observation period for data entry, analysis and review, and 2 days for annual reporting.

Check up years

Once a jurisdiction's implementation plans and operational activities are calibrated with Road RAM scores, a reduced number of observations focused on the most critical times of the year is sufficient to ensure that maintenance plans are being implemented effectively to achieve expected conditions. Because of the reduced number of observations, moderate statistical variability is acceptable during check-up years. However, high variability is potentially an indication of a performance problem that should be investigated and addressed.

During check-up years, three (3) observation periods should be targeted during critical winter and early spring periods as described in *Chapter 8: Spatial and Temporal Integration of Observations*. The level of effort required for each observation period should not be more than 3 full time days of field time for 2 staff working together. The total estimated level of effort during calibration years is expected to be 8% of a full-time-equivalent (FTE) position, including field time, 1 day of staff time per observation period for data entry and management, and 2 days for annual reporting.

ROAD RAM SCORE AND CREDIT AWARDS

The annual Road RAM results for any given water year provide critical information to determine if road conditions defined in catchment credit schedules as estimated from PLRM are being maintained to justify the award of credits (Figure 3.1). Using the temporal integration method, the *Road RAM Database* provides tabular and spatial summaries of annual road RAM scores by road class for an area of interest (see *Road RAM User Manual* for details).

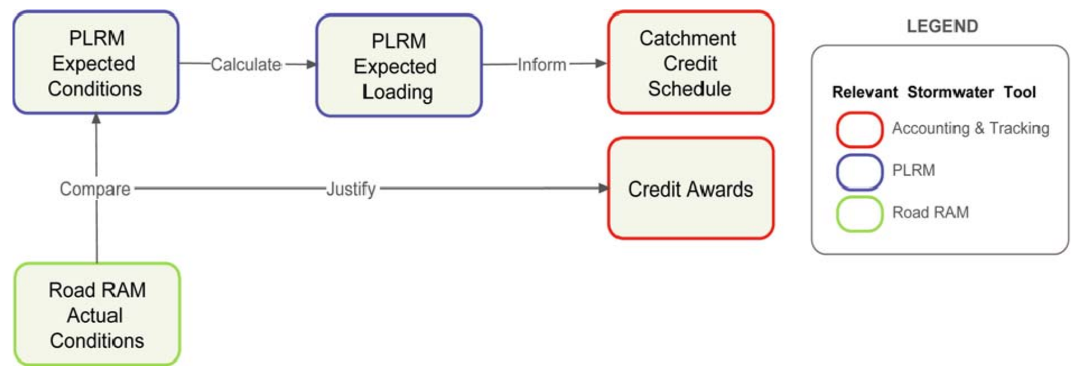


Figure 3.1. Schematic relating the TMDL Accounting and Tracking, PLRM Road Methodology and Road RAM tools

Subject to reasonable consistency of self-reported results with third-party validation results, credits are awarded whenever the annual road class score is within a defined tolerance of the expected condition in the catchment credit schedule. The Crediting Program Handbook version 0.99 defines this tolerance as being within a 0.5 Road RAM score, but this criteria is subject to change and the user should reference the most current version of the Crediting Program Handbook (see Crediting Program Handbook *Appendix C3: Credit Award Determination* for additional information). When observed conditions during a year are lower than the expected conditions less the tolerance, a penalty is applied with respect to each catchment that is underperforming. Depending on whether road condition improvements are a key or essential component to the overall pollutant control strategy in the catchment, this can result in moderate to complete reductions in the credit awarded for a catchment for the year.

CHAPTER 4: POLLUTANTS OF CONCERN

The continued decline in Lake Tahoe water clarity is attributable to both the increased loading in fine sediment particles (<16µm in diameter) (FSP) and algae production. In suspension, FSP have settling rates on the order of years, and numerical modeling suggests that they may be responsible for nearly two-thirds of the current loss in water clarity (Swift et al. 2006). Increased availability of phosphorous (P) and nitrogen (N) delivered to Lake Tahoe have increased the primary production rates in the Lake and are also considered key pollutants that cause clarity impairment of Lake Tahoe (USDA 2000). The Road RAM focuses on the generation and potential fate of FSP on roads, with the assumption that a scientifically sound rapid assessment tool focused on fine sediment particles is a reasonable proxy for the relative total suspended sediment (TSS), total phosphorous (TP) and soluble reactive phosphorous (SRP) based on the physical and geochemical similarities of these pollutants in stormwater. The generation, fate and transport of nitrogen species are not expected to be as well correlated to FSP as phosphorous species, however phosphorous is the limiting nutrient for Lake primary producers, and therefore a greater priority than nitrogen for non-point source control in Tahoe Basin. Justification for this assumption is provided below.

4.1 SEDIMENT

Research for the Tahoe TMDL (LRWQCB and NDEP 2010) has indicated that 72% of the total annual contribution of fine sediment particles to the Lake is generated from urban stormwater runoff. The Tahoe TMDL provides key strategies to reduce the loading of these pollutants of concern to the Lake, with reduction and control in urban areas as the primary source of focus. Tahoe Basin-specific urban hydrology and pollutant loading models (LSPC Watershed Model (LRWQCB and NDEP 2010); Pollutant Load Reduction Model (PLRM; nhc et al. 2009a and 2009b)) indicate that roads are the greatest potential source of FSP per unit area of all land use types and thus a priority land use to achieving FSP load reductions in the Tahoe Basin.

Sediment in Tahoe Basin is typically characterized by two distinct analytic species, total suspended sediment (TSS) and fine sediment particles (FSP; <16µm). TSS is the mass of sediment contained in a known volume of water, and stormwater samples analyzed for TSS can be used to quantify the suspended sediment loads transported in runoff. Most existing studies examining sediment loads in the Tahoe Basin report sediment concentrations as TSS; however, the future water quality studies, modeling estimates and tools will include and prioritize FSP as the primary pollutant of concern. FSP refers to the mass fraction of the TSS concentration that consists of particles 16µm or smaller, expressed as a % TSS by mass and allowing a concentration of FSP to be simply calculated. The Road RAM is based upon a wide array of Tahoe Basin-specific urban catchment water quality monitoring (see Appendix B of the PLRM Model Development Document [nhc et al. 2009b]), as well as road-specific controlled experiments to develop and validate the Road RAM observations as reliable proxies for road FSP concentrations observed in the Tahoe Basin (2NDNATURE and nhc 2010a, 2010b).

The Tahoe TMDL program is tracking FSP by number of particles <16µm. A sediment sample is sieved and the sediment <16µm is analyzed using a particle counter to determine the number of individual particles within the sample. The cost and complexity of the particle analysis make the estimate by FSP particle numbers impractical for all water samples collected within the Tahoe Basin. Thus, empirical relationships have been developed and are continuing to be refined by local academic institutions to convert the mass of FSP to the number of particles. At the time of this report, the current particle converter indicates 1kg of FSP = 1.12×10^{14} particles <16µm (TERC 2009).

4.2 NUTRIENTS

The primary nutrient species contributing to the decline in Lake Tahoe clarity include nitrogen (N) and phosphorus (P). Results from long-term algal growth bioassay experiments (Goldman et al. 1993) and atmospheric nitrogen studies (Jassby et al. 1994; 1995; 2001) show a clear shift from co-limitation by both nitrogen and phosphorous in the middle of the 20th century, to persistent phosphorous limitation in the phytoplankton community in Lake Tahoe. Thus phosphorous is the primary nutrient of concern with respect to the Tahoe Basin TMDL.

Both N and P exist in solid and dissolved forms. Dissolved nutrient species (<0.45µm) are biologically available and consequently are of utmost concern to resource managers tasked with reversing the decline in Lake Tahoe water clarity. The dissolved nutrient species are dissolved inorganic nitrogen (DIN) and soluble reactive phosphorous (SRP), respectively. Total nitrogen (TN) and total phosphorous (TP) are determined by the analysis of non-filtered samples and include all nitrogen or phosphorous adhered to particles and/or incorporated within organic biomass. For a more extensive discussion on the relationship and details of the key nutrient species of concern in Tahoe Basin, see 2NDNATURE (2006a).

Tahoe Basin-specific urban water quality monitoring has demonstrated strong correlations between TSS and TP in urban stormwater due to the high adsorption of phosphorous to clay particles (LRWQCB and NDEP 2010). Additional Tahoe-specific monitoring has shown that the greatest nonpoint sources of SRP in urban stormwater are fertilizer applications to maintain vegetation (e.g., ballfields) (SH+G 2003; 2NDNATURE 2007). Based on the geochemical nature of SRP and FSP, it is reasonable to hypothesize that FSP and SRP concentrations co-vary on roads; however, additional urban stormwater and road monitoring is being conducted to evaluate this hypothesis (2NDNATURE and nhc 2010a).

CHAPTER 5: ROAD CONDITION

The condition and relative downslope water quality risk of any impervious road surface at any one time is the result of a balance of pollutant sources and sinks. This balance continually changes as result of climate, traffic density and road maintenance practices. The magnitude and processes controlling the below sources and sinks that influence road condition are not yet well quantified, but Road RAM evaluates the resulting integration of sources and sinks on a road surface with respect to FSP.

5.1 ROAD POLLUTANT SOURCES

Potential sources of FSP on Tahoe Impervious road surfaces include:

+ Road abrasive application,
+ Erosion from adjacent native soils due to human or car disturbance and/or wind transport,
+ Snow plow on unprotected road shoulders,
+ Road surface and tire degradation, and
+ Pulverization of material by cars.

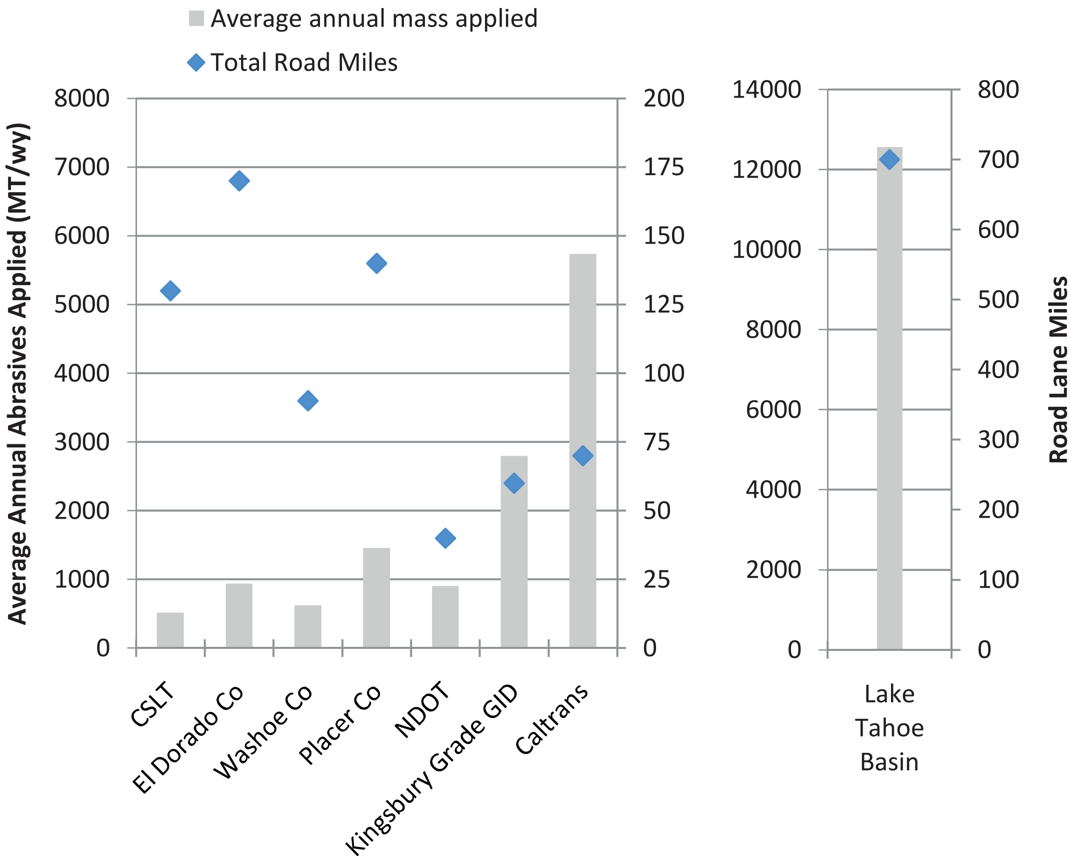
A compilation of the annual road maintenance reports and data obtained from the Tahoe Basin jurisdictions for the past decade suggest the average annual mass of anthropogenic road abrasives applied to Tahoe Basin roads over the last decade is 12,600 MT per water year (wy) or 10,250[2] yd^3/wy (Figure 5.1). This mass of road abrasives is brought into the Tahoe Basin and chronically added to the annual sediment budget each year. Records from the past decade indicate that certain jurisdictions have made a concerted effort to reduce the total amount of abrasives applied on roads while maintaining traffic safety as indicated by Figure 5.2. The 2009 Basin-wide total (7,855 MT) was 38% lower than the decadal average despite total snowfall during the 2009 water year being relatively average (see Figure 5.2). Continued targeted abrasive application efforts to reduce the total abrasive and FSP mass applied on roads by all jurisdictions will improve the future winter road conditions in Tahoe Basin for water quality.

Snow plow disturbance on an unprotected road shoulder

Erosion of road shoulders is known to occur either by stormwater runoff and/or as a result of car or human disturbance and tracking of native soils from an unprotected road shoulder onto the road surface. Snow plow use on an unprotected road shoulder can disturb the upper soil layer (*photo to left*), making native material more mobile during snow melt and subsequent runoff events. Road surface and car tire degradation are also potential sources of pollutants, particularly FSP, to an impervious road surface.

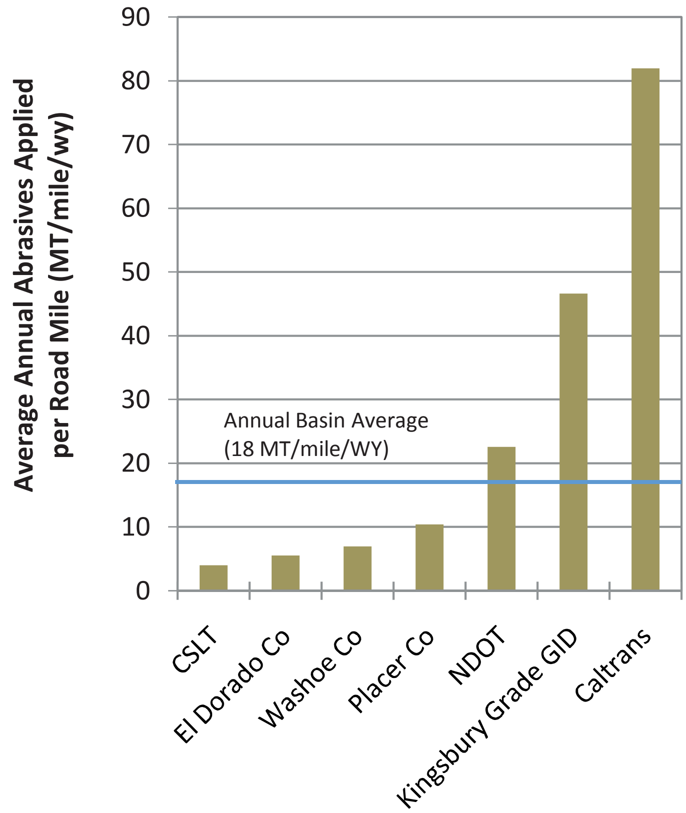
All of these sources of pollutants, when present on the road surface, are subjected to pulverization as result of vehicle passage. The longer the material remains on the road surface, the greater the likelihood the material will be pulverized by vehicles directly increasing the mass of FSP, the primary pollutant of concern, on the road surface. The relative magnitude and processes leading to FSP source generation vary spatially and temporally and are not well quantified at this time.

[2] Density of dry sand assumed to be 1.6 g/ml; 2,700 lbs/yd^3.



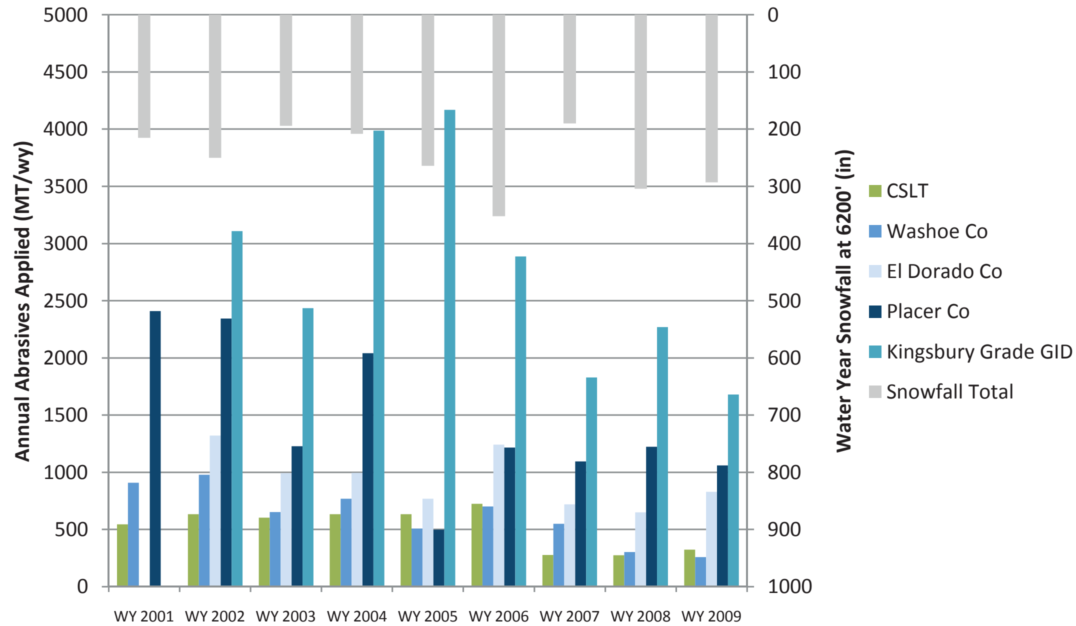
A. Average annual abrasives applied by jurisdiction based on annual reports from 2001-2009, compared to the total urban road (primary and secondary) miles within each jurisdiction (TRPA 2009). Based on this data, the 700 urban road miles are treated with 12,560 MT (10,250 yd^3) of road abrasives on average each water year.

B. Average annual abrasives applied by jurisdiction per road mile. Based on this data, the road mile is treated with 18 MT of road abrasives on average each water year.

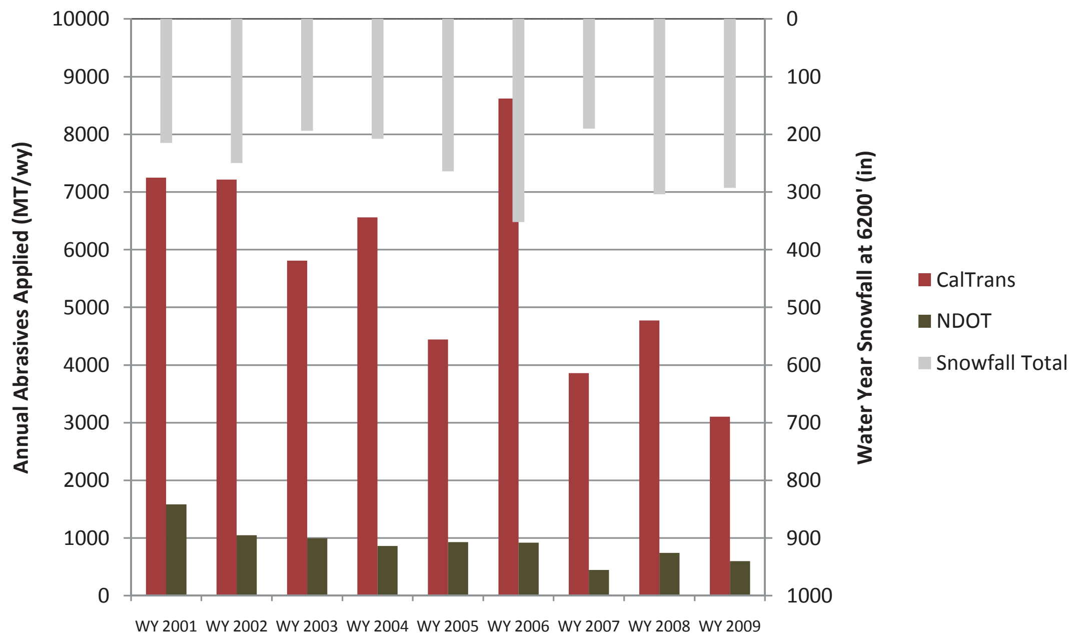


NOTE: In Douglas County, the general improvment districts (GID) are in charge of road maintenace practices within their designated areas. To maintain consistency with the road segments monitored by 2NDNATURE (2010a, 2010b), data from Kingsbury Grade GID is used for comparison to other Lake Tahoe urban jurisdicitions.

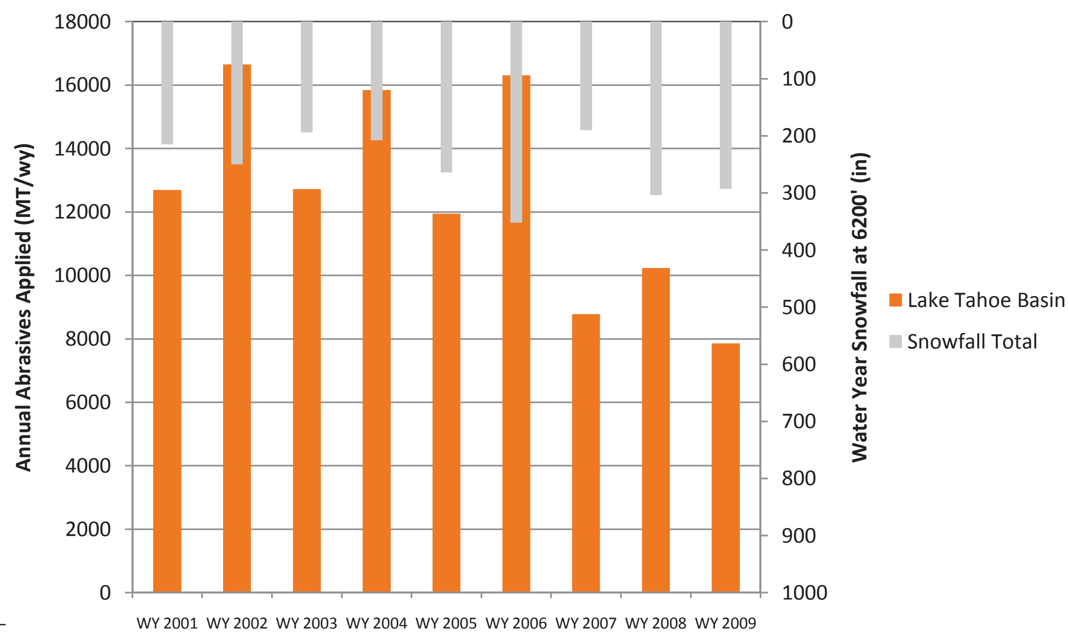
A. Tahoe Basin jurisdictions annual road abrasives applied by WY as documented in road maintenance annual reports. WY snowfall totals are also provided for climate context (Squaw Valley, 2010).



B. Local Transportation agencies annual road abrasives applied by WY as documented in each road maintenance annual report. WY snowfall totals are also provided for climate context (Squaw Valley, 2010).



C. Total annual abrasives applied each WY in Tahoe Basin. WY snowfall totals are also provided for climate context (Squaw Valley, 2010).



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TAHOE BASIN ANNUAL ABRASIVE APPLICATION BY WATER YEAR

FIGURE 5.2

5.2 ROAD POLLUTANT SINKS

Potential sinks that remove pollutants from the impervious road surface include:

- Road sweeping,
- Snow haul and/or snow plow,
- Traffic and wind transport, and
- Rain events.

Note that other strategies or controls that act as sinks for FSP generation on a road surface, such as trapping of material in drainage systems or Treatment BMPs, are outside of the scope of Road RAM.

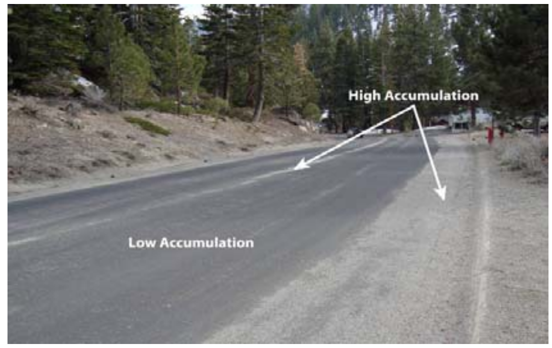
Road sweeping is conducted worldwide by local jurisdictions to protect downslope water quality and reduce the potential transport of road pollutants into stormwater. In alpine climates like Tahoe Basin, road sweeping is a water quality protection action necessary to recover anthropogenic road abrasives applied for traffic safety during winter storms prior to entrainment of those pollutants and their transportation downslope in stormwater. A significant amount of material recovery effectiveness research exists for a range of road **sweeper types**, models and frequency (CWP 2008; Selbig and Bannerman 2007; Shoemaker et al. 2002; Sutherland and Jelen 1997), yet existing sweeper effectiveness research does not directly address the Tahoe Basin primary pollutant of concern (FSP <16µm). PLRM applies the existing research to estimate the average annual characteristic runoff concentration (CRC) reduction expected given different combinations of sweeper types and frequencies (nhc et al. 2009b). While a Tahoe Basin-specific sweeper study has not yet been completed, the results of controlled road observations in Tahoe Basin support the existing research outside the Basin that both the sweeping frequency and sweeper type are important components of maintaining achievable road conditions. All existing sweeper effectiveness studies mentioned above agree mechanical broom sweepers have limited ability to remove fine sediment (silt-sized and smaller) from a road surface. Vacuum-assisted sweepers are necessary to recover particles smaller than clay from the road surface; however, infrequent sweeping with vacuum-assisted sweepers will minimize the pollutant removal effectiveness due to the hardening of clay to the road surface.

Snow haul is a highway snow removal process that is conducted during and/or following a snow accumulation event on a selection of roads in the Tahoe Basin. Roads with minimal shoulder or local storage may include center lane storage of snow during the event to provide driver safety and minimize road accumulation of snow. Snow haul is conducted by a snow blower and loader tandem to physically remove accumulated snow and transport to a snow storage facility. This action likely removes some fraction of road abrasives applied to the road surface during the recent snowfall event. Snow plowing is another snow removal process that physically removes accumulated snow from the road surface to either the immediate shoulder or other locations.

Primary flow path inaccessible to road sweeping or snow haul

Both snow haul and sweeping are limited to the impervious surface of the road. Based on the hundreds of road observations within the Tahoe Basin, there are road segments in the Tahoe Basin that are subjected to intensive road abrasive applications where the drainage flow path adjacent and parallel to the road is not accessible by road maintenance pollutant removal techniques (photo to right). Typically these drainage flow paths are pervious and topographically irregular. In these instances, the road-generated pollutants from road abrasive applications cannot be removed using manual techniques, yet they can be transported downslope by subsequent stormwater flows. The relative mass of abrasives stored on adjacent pervious surfaces, which cannot be received by typical road maintenance practices is not well-quantified at this time, however visual observations suggest significant volumes (>1 gallon) can be easily recovered in some extreme circumstances.

Traffic and wind can transport material both onto and off the road surface. The typical distribution of material on a Tahoe Basin winter road is illustrated in the picture at right. This distribution pattern is the result of air currents created by passing cars that mobilize material from the drive lane and transport it to the road center and shoulders. During windy conditions very fine particles can likely be entrained by cars and transported beyond the road shoulder.



Typical distribution of material on a road

The road conditions in Tahoe Basin have been observed to measurably improve following the first significant rain storm of the spring even on roads where sweeping is never conducted, indicating spring rains essentially wash the impervious surfaces of pollutants (2NDNATURE and nhc 2010a). Tahoe Basin roads are subjected to high source loading of pollutants during winter months when snow fall and associated abrasive applications are common. Stormwater runoff events are less likely during the winter due to cool air temperatures that cause the majority of precipitation delivered to the Tahoe Basin to be in the form of snow. As spring temperatures increase, snowmelt and rain storms increase stormwater runoff frequency and magnitude well beyond localized snowmelt conditions. During spring rain events, sheet flow over the road surface and concentrated flows in the primary flow path along the road shoulders mine stored material from cracks and crevices of the road surface. Controlled road monitoring indicates spring rain events mobilize and entrain pollutants from the impervious surface directly reducing the subsequent FSP concentration measured on a specific road segment, regardless of the jurisdiction's sweeping practices (2NDNATURE and nhc 2010a). A significant amount of Tahoe specific road research was conducted to refine our technical understanding of road condition and the development of Road RAM protocols. The experimental methods, datasets obtained and statistical analyses are detailed in *Chapter 6: Experimental Validation of Road RAM Concepts and Protocols.*

CHAPTER 6: EXPERIMENTAL VALIDATION OF ROAD RAM CONCEPTS AND PROTOCOLS

Road RAM technical development has been supported by a large amount of Tahoe-specific research and water quality monitoring over a number of years. The Road RAM development team has leveraged existing datasets and obtained research grants to provide the scientific justification to link geochemical data with visual observation proxies to rapidly determine road condition on a 0-5 scale. The existing datasets include Lake Tahoe TMDL monitoring that documented event mean concentrations (EMCs) with primary roads as the highest fine sediment particle source per unit area land use in the Tahoe Basin (LRWQCB and NDEP 2010). The Pollutant Load Reduction Model (PLRM) Road Methodology was developed using the available TMDL datasets and comparisons of catchment water quality and associated relative road conditions within respective catchments. Detailed hypotheses regarding the sources, processes, fate and transport of FSP from roads are provided in PLRM documentation (nhc et al. 2009) and research grants were obtained to test and refine these hypotheses. Recent research has focused on identifying scientifically defensible observation proxies for rapid and repeatable techniques to document and track road condition throughout the Tahoe Basin and over time. Protocol development and initial data collection efforts during 2009 were funded by the US Army Corps of Engineers (ACOE) and documented by 2NDNATURE and nhc (2010a). The USDA Forest Service Pacific Southwest Research Station SNPLMA Round 9 research grant continues to build upon the ACOE research and a final report will be released in the Fall of 2011 (2NDNATURE and nhc 2010b). Below we detail the methods of the road condition research, summarize results and present the relevant conclusions that support the technical components of the Road RAM tool contained herein. Future versions of Road RAM and other Urban RAM tools will continue to incorporate knowledge gained from relevant research and monitoring.

6.1 DATA COLLECTION METHODS

The Road RAM field protocols have been developed using a number of experimental field techniques. A custom portable sampler was developed to consistently sample a 1ft^2 road surface and samples were analyzed for a variety of pollutants, most importantly FSP. Simultaneously, in adjacent 1ft^2 areas that appeared similar in condition, a number of visual proxies were conducted with the goal of being able to predict the FSP concentration measured by the portable simulator using a series of rapid and repeatable measurements and observations. A basic conservation of mass concept is used to extrapolate the observations within these 1ft^2 areas over a greater area of road (i.e., a road segment) such that reasonable estimates of road condition for a road segment could be made using rapid techniques. The experimental data collected across jurisdictions, different road types and over a complete year of observations have also provided a reasonable means to extrapolate road segment scores to a complete road network that is supported by the both the data and existing knowledge of jurisdictional road maintenance practices in the Tahoe Basin.

CONTROLLED ROAD SAMPLING

2NDNATURE, in consultation with Liquid Innovations and County of El Dorado County of Transportation, designed and fabricated a portable simulator that applies a standardized volume of water (1L) at a constant intensity over a 1ft by 1ft controlled area of an urban road surface (see photo at right; 2NDNATURE and nhc 2010a). The runoff experiment design facilitates a consistent sampling across many roads while keeping water application rate, intensity, contributing area, and water sample collection

Portable simulator used to collect controlled road surface samples.

methods constant. Water samples collected from the portable simulator were immediately run for turbidity using a calibrated field turbidity unit and then submitted to the analytical laboratory for analysis of TSS, grain size distribution, SRP and TP. FSP concentrations are calculated by the product of TSS concentration and the % by mass < 16μm. The constraint of the primary hydrologic parameters across sampling locations provides confidence that computed differences in water quality constituents are due to differences in roadway condition and not due to natural hydrologic or sampling variability. Precision testing of the portable simulator indicated an average of 11% field sampling error for FSP, which was strongly influenced by relatively dirty sites where FSP concentrations >2000 mg/L were measured. Field precision of samples where FSP concentrations were < 2000 mg/L is +/- 5% error. Detailed protocols are provided in 2NDNATURE and nhc (2010a and 2010b).

The Road RAM field observations have been conducted at 238 road segments simultaneously with the controlled sampling on each road segment. A road segment is defined as 10,000ft^2 area of a continuous impervious surface. Roads tend to possess a common pattern of material accumulation, with relatively clean drive lanes and greater amounts of material accumulated in the center lanes and edges of right of way. Each road segment can be reasonably delineated into 3 **material accumulation categories** (heavy, moderate and light). Material accumulation categories are characterized relative to the specific road segment evaluated and **not** relative to all road segments during the observation period or over time. Material accumulation distribution is based on conservation of mass and used to spatially integrate discrete observations in 3 areas of accumulation to provide estimates of the condition of a 10,000 ft^2 road segment. The heavy and light accumulation categories of the specific road segment at the time of observation set the bookend scales of the existing condition for these factors, and then % distribution of each category is estimated and confirmed by all field personnel. At a location safe for field personnel at the edge of the right away, the visual proxies and controlled experiments were conducted in adjacent and comparable 1ft by 1ft squares. These side by side rapid and measured FSP concentration data were used to define and then validate the predictive power of the Road RAM protocols and the results are presented below.

VISUAL PROXIES

Initially a number of visual proxies were used in an attempt to find observations that could statistically predict the FSP concentrations obtained from 1ft^2 adjacent controlled sampling. The measured FSP concentrations appeared to be dependent upon the amount of sediment and particulates on the road surface, but more importantly the amount of material that was clay-sized or smaller. Thus, the majority of the research focused on dry material collection which entailed measuring the volume of material within a 1ft^2 area, the thickness and texture material adhered of a wet finger rubbed over the road surface within the 1ft^2 area, and a vigorous sweep test to measure the thickness and height of the fine particle plume. In order to characterize a 10,000ft^2 road segment, these observations were made within each material accumulation category (heavy, moderate, and light) and the relative distribution of each material accumulation area was estimated by field personnel.

ROAD SEGMENTS SAMPLED

The detailed road monitoring was repeated on 32 road segments within the Tahoe Basin (2NDNATURE and nhc 2010a, 2010b) over 8 different observation periods between March 2009 and March 2010. These road segments were selected to focus upon a range of PLRM road risk categories within each of the 7 Tahoe Basin urban jurisdictions (Table 6.1). Road risk is an objective proxy developed for PLRM that was intended to predict the relative amount of abrasive application frequency to protect driver safety (nhc et al 2009) thus a range of road risk sites would result in likely range of road conditions within each jurisdiction. The selected road sites also vary across a range of other road attributes, including road shoulder condition, road surface integrity, road shoulder connectivity, and slope. The spatial distribution of sites allows a comparison of road condition across jurisdictions as well as across road risk categories that were hypothesized to have dramatically different FSP source and sink rates as influenced by jurisdictional road maintenance practices, particularly during the winter months. The temporal distribution of observations allowed an evaluation of the seasonal differences of observed road conditions, to inform the hypothesis that the winter road conditions are the greatest potential risk to water quality due to the increased frequency and magnitude of abrasive applications.

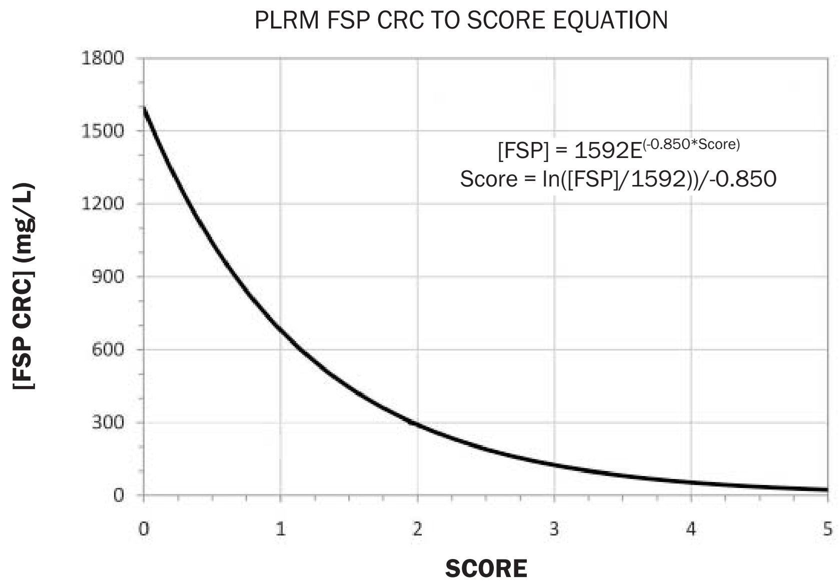
Table 6.1. Summary of road characteristics monitored in WY2009-10.

Jurisdiction	Road Risk Category[1]						Totals by Jurisdiction
	PHR	PMR	PLR	SHR	SMR	SLR	
Cal Trans	4	2	0	0	0	0	**6**
NDOT	3	0	2	0	0	0	**5**
El Dorado Co	0	0	1	1	0	1	**3**
Placer Co	0	0	0	2	4	0	**6**
Washoe Co	0	0	0	2	2	1	**5**
Kingsbury GID	0	0	0	0	2	1	**3**
CSLT	0	0	0	2	1	1	**4**
Totals by Road Risk Category	**7**	**2**	**3**	**7**	**9**	**4**	**32**

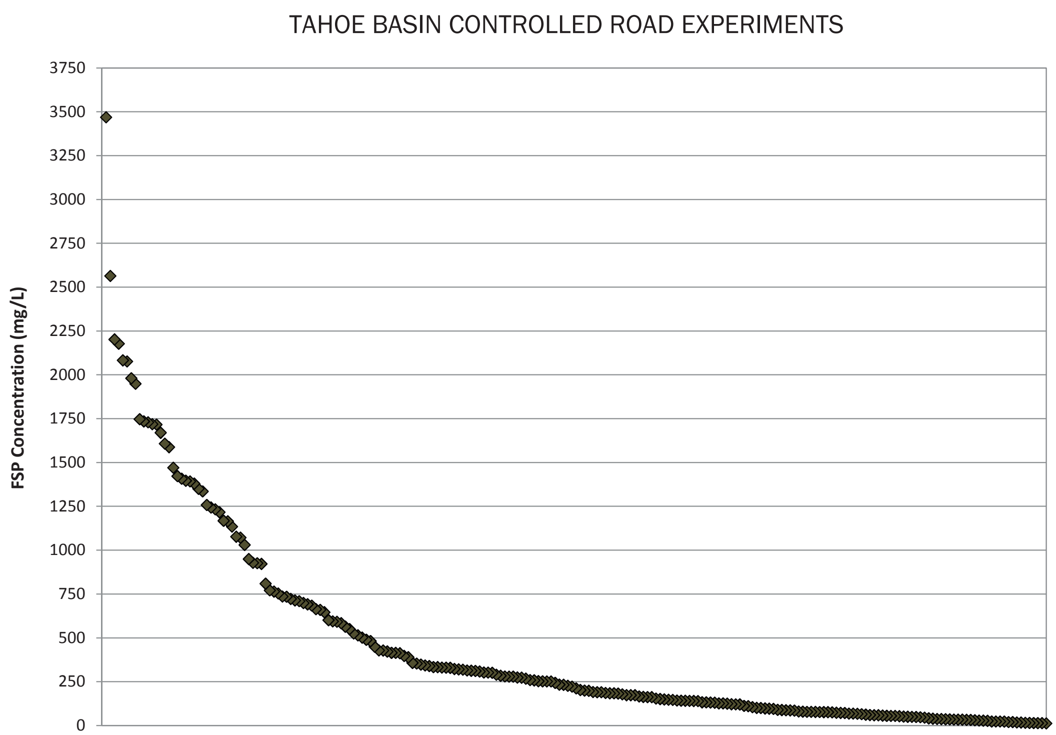
[1] Road risk categories are Primary High Risk (PHR), Primary Moderate Risk (PMR), Primary Low Risk (PLR), Secondary High Risk (SHR), Secondary Moderate Risk (SMR), and Secondary Low Risk (SLR).

6.2 ROAD CONDITION VARIABLITY

The controlled road sampling was originally initiated to verify the PLRM Road Methodology FSP CRC values (Figure 6.1 upper pane; nhc et al 2009) that were determined using limited Tahoe Basin urban catchment water quality data and assumptions regarding the associated road distribution and conditions (2NDNATURE and nhc 2010a). Due to the seasonal and spatial variations of road conditions, the 238 moderate accumulation areas sampled across Tahoe Basin roads over one complete year appear to yield a representative distribution of expected conditions for any road surface within the Tahoe Basin (Figure 6.1 bottom pane). While all of the controlled experiment/visual proxy pairs were obtained from the area of moderate accumulation on any specific road, the condition of the moderate area of accumulation varied greatly over time and across sites (see Figure 6.1 bottom pane). Road surfaces where minimal visual dust or sediment was present yielded low FSP concentrations (< 50mg/L) and sites in this condition were measured during each of the 8 observations periods. Road surfaces where significant amount of fines were present, fingerprints were not visible and dust clouds were prolific yielded high FSP concentrations (> 2,000mg/L). Road sites in very poor condition (FSP > 2,000 mg/L) were only observed during the winter sampling events (January, February or March). The experimental field data in Figure 6.1 verifies that the shape of the FSP to score relationship used in PLRM is reasonable. The data collection verified that the minimum modeled CRC values in PLRM (22mg/L FSP) are achievable with an observed minimum of 12 mg/L FSP in a moderate accumulation area of a road. In addition, the maximum values observed well exceed the FSP CRCs modeled by PLRM (1,014mg/L). Using a simple conservation of mass approach to extrapolate the 1ft^2 FSP concentrations to an entire 10,000 ft^2 road segment, the maximum values > 2,000mg/L for the moderate accumulation area are anticipated to be FSP concentration > 1,000mg/L when spatially weighted for the road segment, thus aligning with the PLRM maximum values (see Figure 6.1 upper pane).



Equation used in PLRM Road Methodology (nhc et al. 2009) is based on limited Tahoe Basin catchment water quality data and associated road distribution and condition.



Range of measured FSP concentrations, ranked high to low, from 238 controlled experiments on 1ft² areas of moderate accumulation on road surfaces conducted during 2009 and 2010 (2NDNATURE 2010a, 2010b). Over one year of data collection, it appears a representative distribution of expected 1ft² conditions have been sampled.

6.3 VISUAL PROXIES FOR FSP CONCENTRATIONS ON 1FT^2 ROAD AREAS

The development of visual proxies to predict the FSP concentrations measured by the controlled road experiments were conducted on the above road segments (see Table 6.1) during 8 observation periods throughout 2009 and 2010 that were assumed to represent the potential range of Tahoe Basin road conditions (2NDNATURE 2010a, 2010b). Rapid observations within 1ft^2 areas were experimentally-tested as proxies to estimate the FSP concentration as measured by the controlled experiments. Two hundred and thirty eight water samples collected from the portable sampler were analyzed for FSP <16µm by an analytical laboratory and compared to the visual observations made by field personnel concurrent with sample collection on adjacent 1ft^2 areas.

A general linear model was implemented to test the effect of the two factors 'Degree of Fines' (categorical) and 'Dry Mass' (continuous) with FSP concentration from the portable simulator as the dependent variable for 217 observations on Tahoe Roads. The F statistic in Table 6.2 is used to test whether the effect of a term in the model is significant and is used to determine the p-value. S is measured in the units of the response variable and represents the standard distance data values fall from the fitted values. For a given study, the better the model predicts the response, the lower S is. The p-values in the table below indicate that both visual proxies are highly significant in the model to predict FSP concentration, and the adjusted R^2 shows that together they explain 76.4% of the variance in the FSP data.

Table 6.2. General linear model results of the predictive capability of Dry Mass and Degree of Fines proxies to predict FSP concentration as measured on an adjacent 1ft^2 by the custom portable road sampler.

Model Results Model Performance[1]: R^2 = 76.7%, Adjusted R^2 = 76.4, S = 0.68, S =0.67		
Predictor Variable	**F**	**p-value**
Degree of Fines	25.79	<0.001
Dry Mass	277.34	<0.001

[1] Model performance measures include R^2 (the proportion of variation in the response data explained by the predictors); Adjusted R^2 (R^2 modified for the number of terms in the model); and S (the standard distance of the observed from the predicted values, measured in the units of the response variable [mg/L]).

As suspected, the measured FSP concentration is more sensitive to the degree of fines than the total mass of material on the road surface. These findings are corroborated by numerous observations where a very small amount of material (<2g) was recovered from a 1ft^2 area, but measured FSP concentrations were high (>2,500mg/L) (2NDNATURE and nhc 2010b). Similarly, a large amount of coarse material (> 50g) can be recovered from a 1ft^2, yet FSP concentrations have been observed < 100mg/L. The coefficients from this model were used in equations to predict FSP concentrations as a result of 'Dry Mass' at the three levels of 'Degree of Fines' (high, moderate and low) and used to create the curves provided in *Chapter 9: Road RAM Scoring*. The moderate-low and moderate-high 'Degree of Fines' categories were interpolated to provide an even distribution model to estimate FSP as a function of fines and mass.

The rapid 'Dry Mass' and 'Degree of Fines' observations were conducted on over 600 1ft^2 areas to provide field precision estimates of these protocols across users. Field triplicates of the bulk dry mass measurements were conducted throughout 2009 and 2010 on a range of road conditions to determine field precision, and error was calculated to be 8% or less. Precision testing was also performed on the visual observations to predict the degree of fines (5 categories ranging from high to low) present within an adjacent 1ft^2. Independent observations were performed by 4 field personnel at 25 sites during the winter of 2010[3] to compare and standardize the qualitative assessments made in the field. Field personnel observed the same degree of fines category 90% of the time using the Road RAM fines and dust tests, and when differences existed, the categorical difference was never more than ± 1 category.

The 238 water samples collected from the portable sampler were analyzed for both turbidity in the field and FSP <16µm by an analytical laboratory. These data led to the development of a regression model that can explain 92.4% of the variance in FSP concentrations using turbidity and the slope of the regression was significant at the 99% confidence level (F-test) for turbidity < 2000ntu (Figure 6.2). Turbidity can be used as a proxy for FSP for more cost-effective testing of the RAM field observations to predict FSP concentrations on a 1ft^2 area of road.

The identification of reasonably reliable rapid observation proxies to predict the relative FSP concentration from a 1ft by 1ft square impervious road surface on a resolution required to meet Road RAM objectives has been achieved. Given the significant range of observed FSP concentrations on Tahoe Basin roads (<10mg/L to > 3000mg/L; see Figure 6.1), the Road RAM visual proxies provide a reliable and rapid method to confidently estimate the FSP concentrations as measured by the portable simulator on a 1ft by 1ft square.

6.4 FSP CONCENTRATIONS ON 1FT^2 AREA TO ROAD SEGMENT FSP CONCENTRATION

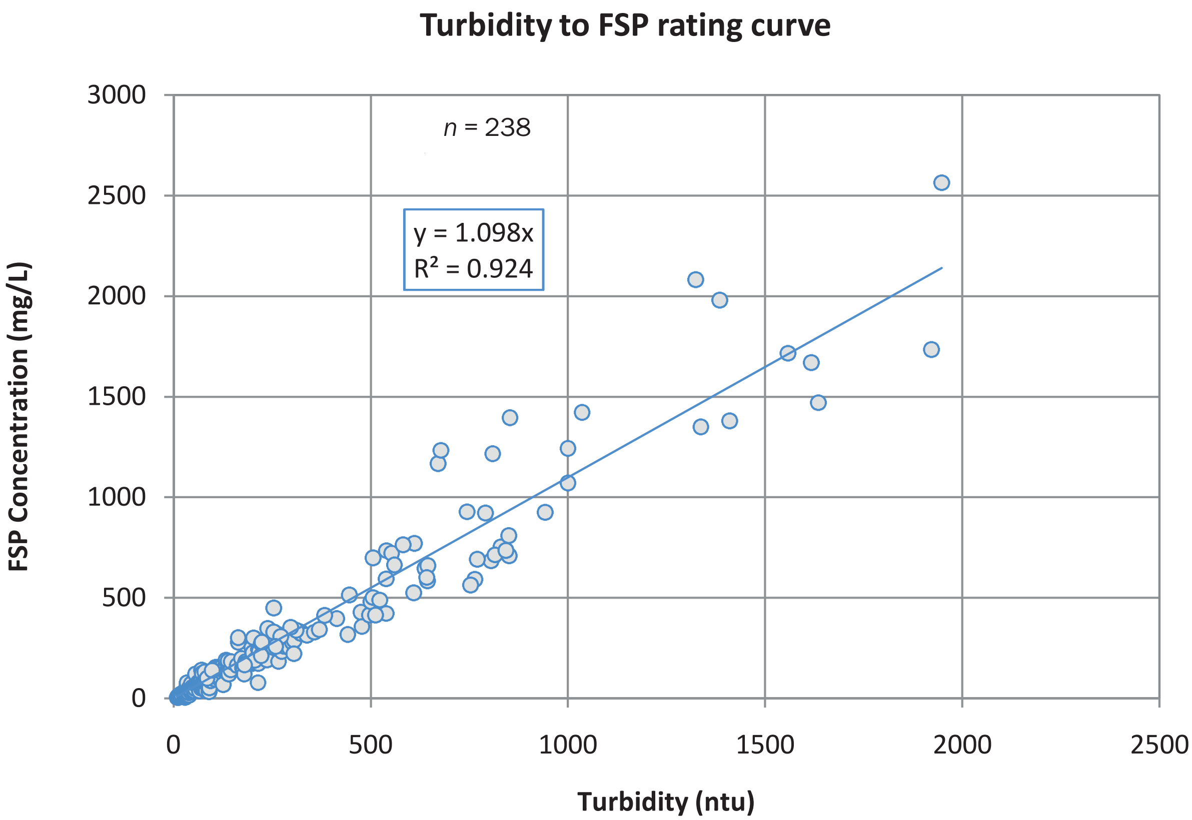
The RAM tool requires a number of spatial extrapolation techniques to expand the experimentally derived data from a 1ft^2 to greater areas of interest. Because material is not distributed evenly across the road segment, three material accumulation areas are chosen to represent the range of sediment accumulation across the full area of the road segment. The extrapolation of the 1ft^2 results to a 10,000 ft^2 road segment applies a simple conservation of mass concept using a weighted-average based on the relative distribution of up to 3 distinct material accumulation categories on the subject road segment. Precision testing of the percent distribution protocols was conducted by 4 field personnel at 25 road segments. Comparisons of the % accumulation delineations of the 25 road segments were consistently (85% of the time) within 5% of one another for all 4 field personnel. Thus, Road RAM recommends users estimate % accumulation using increments of ±5%.

The Road RAM requires the user to define the distribution of material accumulation areas as a percentage of the road segment during a discrete observation period. The scoring process to generate a road segment score is detailed in *Chapter 9: Road RAM Scoring*, but in summary the FSP concentration per area of accumulation are spatially weighted to obtain a road segment FSP concentration and then converted to a 0-5 score using the validated equation presented in Figure 6.1 (upper pane). Ideally, a controlled road experiment where a rain simulator rains on entire 10,000ft^2 area is conducted to verify the FSP concentrations on the segment scale. However, logistically this type of experimental simulation is unrealistic. Regardless, the spatial weighting approach is consistent with the expected conservation and distribution of mass across a road segment and therefore the spatial weighting of FSP concentrations is scientifically reasonable. The measured FSP concentrations are within the range of PLRM FSP CRC values (see Figure 6.1) and appear to be reasonable representations of FSP concentrations expected from roads in the Tahoe Basin (see 2NDNATURE and nhc 2010a for more details on the verification of the PLRM FSP CRC values).

Sensitivity analyses for all field observation proxies were conducted to determine the variation in road segment scores as a result of reasonable differences in user field observation inputs. Reasonable differences from a trained

[3] Precision testing was conducted in winter when Tahoe Basin roads possess the greatest variability in condition (see seasonal variability discussion below in *Chapter 6.5: Measured Road Condition Variations*).

TAHOE BASIN CONTROLLED ROAD EXPERIMENTS



Correlation plot of turbidity versus FSP concentration based on 238 controlled Tahoe Basin road experiments collected and analyzed in 2009 and 2010 (2NDNATURE 2010a, 2010b).

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TURBIDITY V. FSP CORRELATION PLOT

FIGURE 6.2

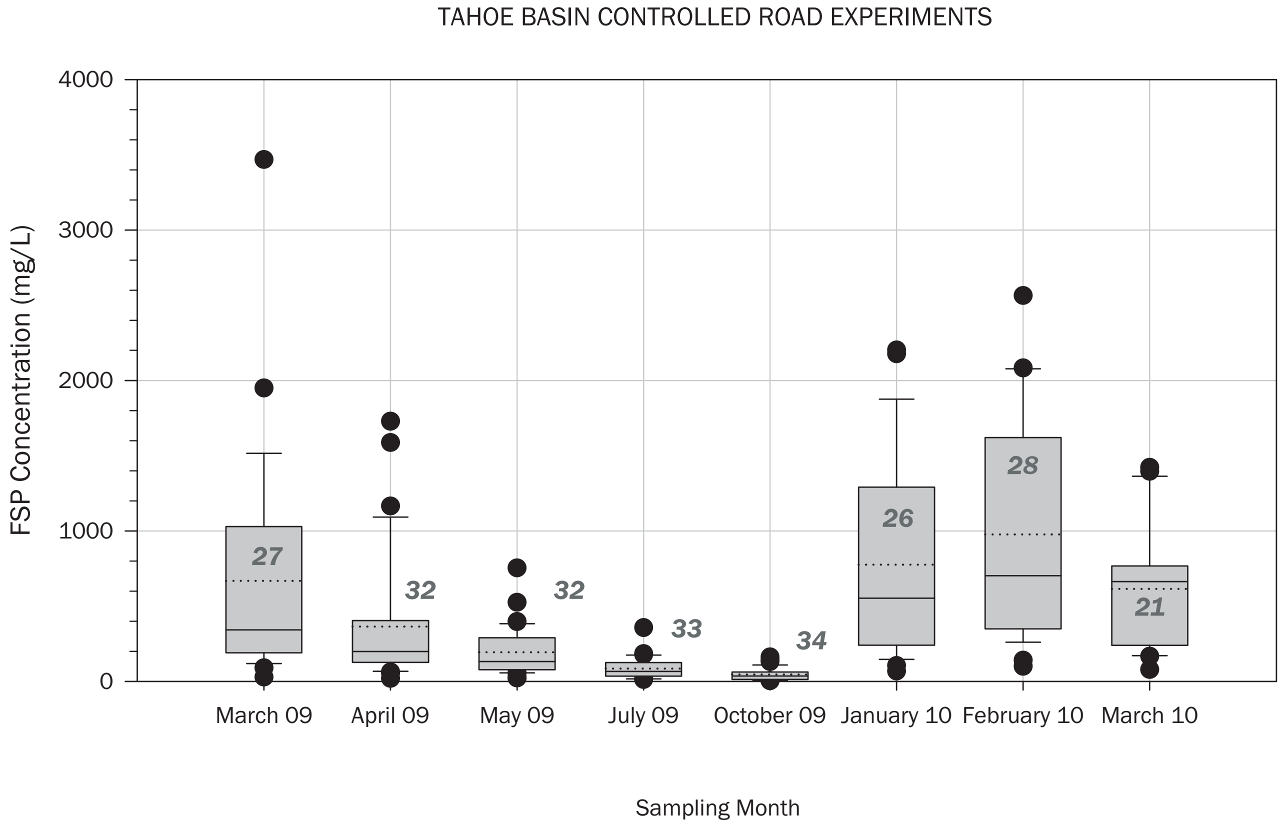
user were defined as ± 15% material accumulation distribution, ± 1 fines category, and/or ± 3 mL of dry mass volume. There is very high confidence that all trained Road RAM users can consistently discern roads from those in good and poor condition (above 3.5 or below 2.0, respectively). Road segments scores are most sensitive to user observations in material accumulation categories that cover the majority of the road segment area (>50%), and therefore Road RAM protocols encourage rigorous analyses of the areas that represent the majority of a road segment. The potential for variability across users is greatest when majority of the road is relatively good condition (score > 3.0), due to the small difference in road segment FSP concentration for road segment scores between 3 and 5 (123 and 23 mg/L, respectively). However, when a road is in relatively poor condition (score <2), the conversion of FSP concentration to RAM score is less sensitive to reasonable user input differences and score differences across users will not vary dramatically. It is desirable that the Road RAM tool has a higher precision across users for conditions that are problematic (i.e. score < 2). It must be stated that a Road RAM score of 3.5 or greater is a minimal potential risk to downslope water quality. In the future, if all roads in the Tahoe Basin are observed to consistently be at a RAM score of 3.5 or higher and roads with a condition of 3.0 or lower become obsolete, the Road RAM tool could be refined to better resolve RAM scores for roads, by today's standards, pose little risk to downslope water quality. However, further testing of the field and scoring protocols is needed by other users and a QA/QC analysis of user precision should be performed.

6.5 MEASURED ROAD CONDITION VARIATIONS

SEASONAL VARIATIONS

The balance of the sources and sinks on roads vary by season. Figure 6.3 demonstrates seasonal variability in road condition as measured by FSP concentrations obtained during controlled experiments (2NDNATURE and nhc 2010a). During each observation period, the same road segments were sampled by field personnel; dates with relatively fewer observations were the result of resource and time limitations. During the winter months, road abrasives are applied to the road surface to provide traction and protect driver safety during snowy and icy weather conditions and the highest FSP concentrations for the year are observed during these times. The large variation across controlled road sampling sites is evident in the height of the winter boxes in Figure 6.3 and can be attributed to differences in jurisdictional road maintenance practices and physiographic characteristics, which will be discussed in more detail below.

As shown in Figure 6.3, the maximum concentrations and variability across sites significantly decreases from the winter months (January – March) through the spring and summer. By early summer, the measured FSP concentrations are reduced to <100mg/L on all roads, regardless of the road condition prior to the runoff event This finding is likely the combined result of (1) warmer temperatures reduce the need for road abrasive applications, (2) jurisdictions have more time to sweep since the most recent winter storm, and (3) late spring/summer rain events mobilize and essentially wash the sediment accumulated on the road surface, thereby reducing the FSP concentrations measured. There are some road segments where it is known that winter road abrasives were applied, but no sweeping actions were conducted at any point during the year. At these sites the measured FSP concentrations were reduced from > 1,000mg/L during the winter to < 200mg/L during summer and fall observations (Figure 6.4). These observations indicate that spring rain events can essentially wash road surfaces and effectively remove material and pollutants from the road surface, transporting them into the stormwater conveyance system.



The strong seasonal pattern of urban road condition is demonstrated by the box and whisker plots of Tahoe Basin road FSP concentrations measured during the controlled experiments for WY09 and WY10 (2NDNATURE 2010a, 2010b). The dotted horizontal line is mean value, and the solid line is median for each sampling effort. n values (number of observations per month) are presented for reference.

Based on the available research, the most manageable risk to downslope water quality is the improvement of road condition after snow and ice have melted from the road before the spring rain events occur. The poorer the road condition and the greater the amount of pollutants accumulated on the road surface or within the primary flow path prior to intense spring rain events, the greater the load of pollutants transported downslope from the road surface and into the stormwater conveyance system.

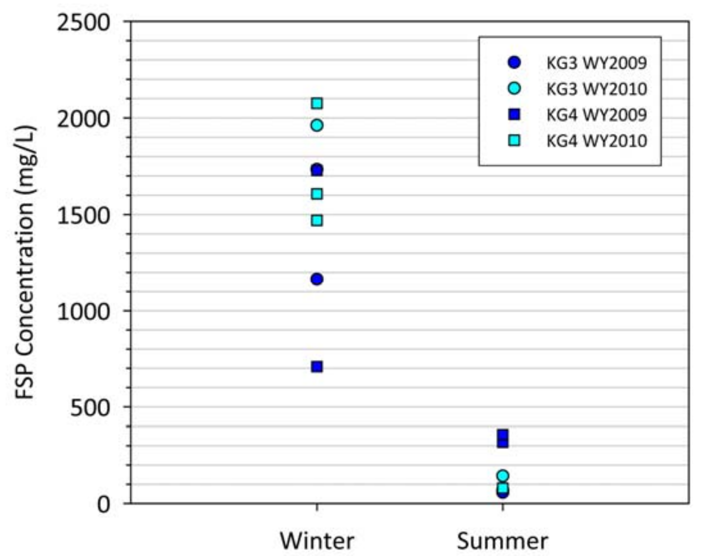


Figure 6.4. Seasonal comparison of FSP concentrations at sites where abrasive application occurs with no pollutant recovery actions.

JURISDICTIONAL VARIATIONS

The jurisdictions managing roads within Tahoe Basin implement a wide range of road maintenance practices that vary due to jurisdictional priorities, available resources, physiographic characteristics of their roads, and other factors. The 2NDNATURE team faced significant challenges to obtain accurate and complete road abrasive application, road sweeping and other road practice information logs from jurisdictions for each road segment included in the controlled experiments (2NDNATURE and nhc 2010a, 2010b), but general road maintenance practices are available. The range of practices implemented across Tahoe Basin roads (and the road sites evaluated by 2NDNATURE and nhc 2010a, 2010b) were used to improve our understanding of the influence road maintenance practices have on the observed condition of roads in Tahoe Basin. Based on existing information and data, road condition correlates to road maintenance practices implemented by the responsible jurisdiction.

Statistical Testing

It is hypothesized that while many factors can influence the condition of a road on any one day, road condition is most sensitive to road maintenance practices: the source inputs of abrasives and the sink outputs from frequent and effective sweeping and snow haul. In order to test this hypothesis a statistical analysis was conducted on the controlled experiment winter dataset to test the relative sensitivity of measured FSP concentrations across road segments. Because each jurisdiction has a different road maintenance strategy the segments must be analyzed within each jurisdiction independently. This allowed an evaluation of the relative influence of abrasive application priority, sweeping effectiveness, PLRM road risk category, road surface integrity, and/or road shoulder condition on road condition as reflected in the measured FSP concentrations. The research team ranked the relative abrasive application priority and sweeping effectiveness for all of the road sites using existing road maintenance annual reports (see *Chapter 5: Road Condition*), jurisdictional conversations, and knowledge of road maintenance practices, sweeper types and sweeping priorities, as well as continued visual observations from field personnel and local partners.

An analysis of covariance (ANCOVA) was implemented using a general linear model to test the predictive capability of road attributes and rapid measurements/observations (i.e., predictor variables) on 94 measured FSP concentrations (i.e., response variable) from controlled experiments during winter sampling events (January, February and March). Table 6.3 presents the results of the initial model, which included all potential predictor variables, and the final model, after the completion of a stepwise procedure to remove insignificant predictor variables. The F statistics indicate which individual predictor variables have a significant effect in the best predictive model for the response variable; *the higher the F statistic value the lower the unexplained variance*. The p-value (or alpha level) tells us the probability of incorrectly rejecting the null hypothesis that the predictor variable has no effect on the response variable; *the smaller the p-value the greater the significance the variable is as a predictor variable in the model*. For example, a p-value of 0.10 indicates there is a 10% chance that the effect on the response variable is due purely to random chance, and inversely, there is a 90% confidence level that the predictor variable has a significant and consistent effect on the response variable.

Table 6.3. Statistical results from ANCOVA analysis of controlled experiment winter FSP concentrations.

Predictor Variable	F	p-value
Initial Model Results Model Performance[1]: R^2 = 88.43%, Adjusted R^2 = 84.28, S = 0.376		
Degree of Fines	57.51	0.000
Dry Mass	14.74	0.000
PLRM Road Risk Category	1.35	0.262
Road Shoulder Condition	2.26	0.089
Road Surface Integrity	0.72	0.492
Month	0.16	0.854
Jurisdiction	1.15	0.342
Abrasive Application Priority	1.91	0.156
Sweeping Effectiveness	3.42	0.039
Final Model Results Model Performance[1]: R^2 = 84.99%, Adjusted R^2 = 83.73, S = 0.383		
Degree of Fines	20.48	0.000
Dry Mass	5.94	0.004
Abrasive Application Priority	9.08	0.000
Sweeping Effectiveness	108.38	0.000

[1] Model performance measures include R^2 (the proportion of variation in the response data explained by the predictors), Adjusted R^2 (R^2 modified for the number of terms in the model), and S (the standard distance of the observed from the predicted values, measured in the units of the response variable [mg/L]).

As the final model results of Table 6.3 indicate, the field observations ('Degree of Fines' and 'Dry Mass') and road maintenance practices ('Abrasive Application Priority' and 'Sweeping Effectiveness') explain 83.7% of the variance in the measured winter FSP concentrations and all of the predictors are significant to the 99.5% confidence level. The spatial extrapolation of Road RAM observations at discrete road segments is necessary to reduce the number of road segments evaluated within an urban catchment. In order to increase the confidence that the spatial extrapolation is representative of the road condition at a segment not specifically evaluated, the roads must be classified by characteristics that have the strongest influence on the urban road condition on any particular day. As the ANCOVA results indicate, abrasive application priority and sweeping effectiveness are strong indicators of likely urban road condition during the winter months.

Data Analysis

The winter and early spring road conditions provide the greatest opportunity to manage the risk to downslope water quality by local jurisdictions, since the greatest potential source of pollutants on roads is present during the winter and early spring seasons and the greatest risk of transport of these pollutants into the stormwater system is during the spring rains. The greatest FSP variation across roads and the highest FSP concentration are observed during the winter months (January, February and March; see Figure 6.3). Of the 238 controlled sampling observations conducted, 78% of the observations that exceeded 300[4] mg/L FSP were observed during the winter months. While the exact road maintenance practices conducted on the 29 sites that were below 300 mg/L during winter observations were difficult to obtain, the implementation of road maintenance practices that minimized abrasive applications and maximized sweeping frequency with more efficient sweepers were confirmed for the majority of the these 29 sites.

All jurisdictions apply road abrasives to roads where driver safety is a concern during winter storms, though the annual amount of material on a roadway that is FSP or is pulverized into FSP depends upon the miles of roads where abrasives are applied, the composition of the abrasives and the application strategies employed by the jurisdiction (see Figures 5.1 and 5.2). Similarly, there are significant differences in the winter road sweeping strategies (sweeper type and sweeping frequency) employed across Tahoe Basin jurisdictions during the winter months. As stated above, the longer abrasives remain on the road surface the greater risk of pulverization into particles smaller than 16μm (FSP). Thus it is assumed that frequency and effectiveness of sweeping actions to remove material from a winter road can reduce the potential FSP concentrations measured on a road segment. Figure 6.5 presents the integration of the controlled sampling results from 4 winter observations arranged from highest to lowest average FSP concentration for each Tahoe Basin urban jurisdiction. Sampling sites where abrasive applications were likely infrequent (flat residential roads with low traffic density) were removed from the data used to create Figure 6.5. There is a discernible trend in the maximum, average and minimum values observed across jurisdictions (see Figure 6.5), yet the distribution of road risk categories sampled for each jurisdiction is similar (see Table 6.1).

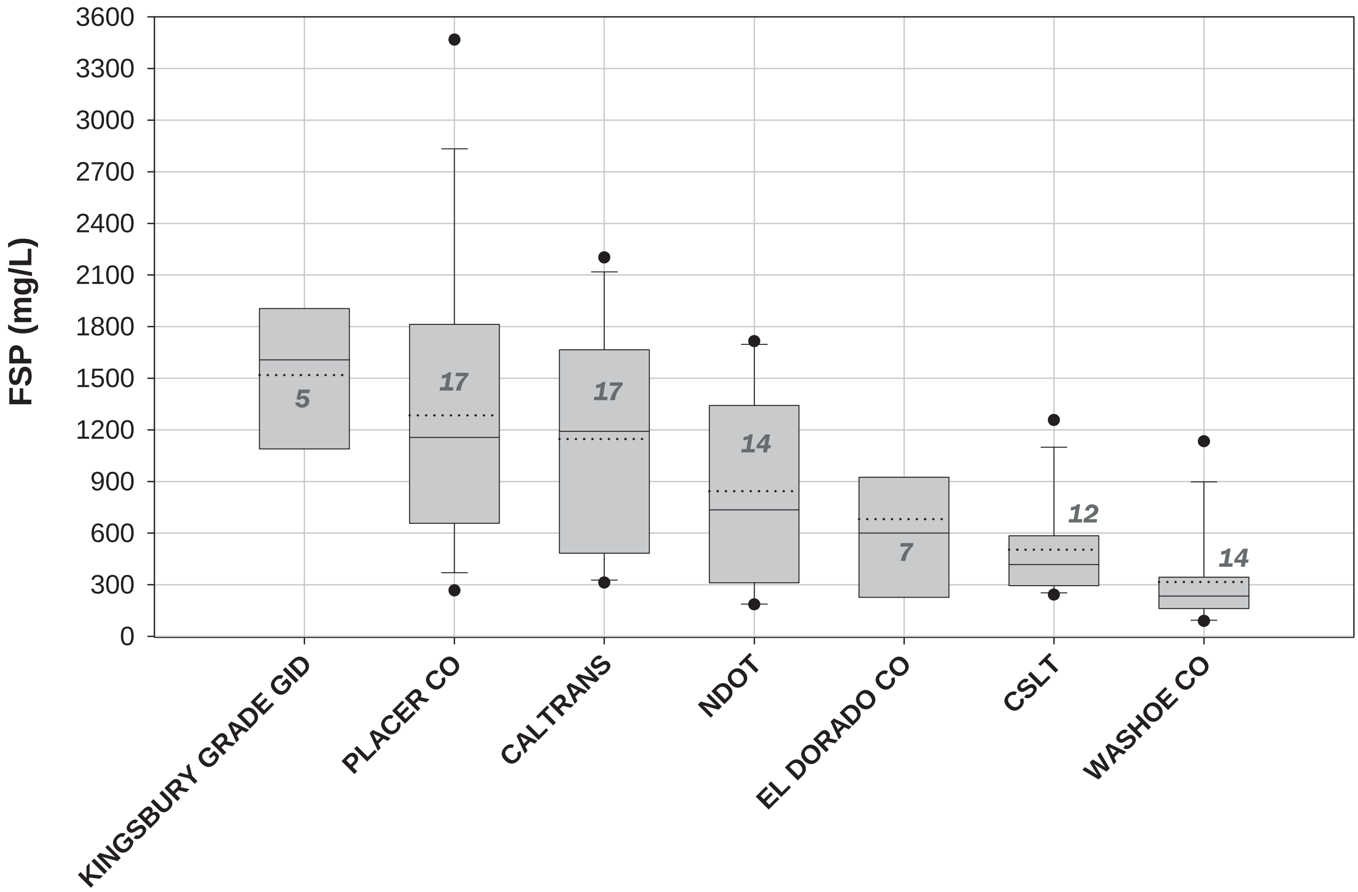
A specific example to illustrate the influence of road maintenance practices on road condition is the comparison of the average winter FSP concentration for roads maintained by the Kingsbury GID (1,520mg/L) and Washoe County (316 mg/L) (see Figure 6.5). Based on interviews with stormwater managers, these jurisdictions have very different road maintenance practices. Due to resource limitations, Kingsbury GID did not sweep any of the road segments included in the 2NDNATURE study, but abrasives were applied as necessary during winter storms to protect driver safety (M. Runtzell, pers. comm.). In contrast, Washoe County is well funded and is highly committed to minimizing the mass of road abrasives applied each year by limiting the number of abrasive application events each winter season, limiting the miles of road where abrasives are applied and minimizing the mass applied per unit area of road to the extent practical (D. Minto, pers. comm.). Washoe County's application rate per road mile is well below the Tahoe Basin average (see Figure 5.1) and Washoe continues to explore additional technology and strategies to decrease the annual amount applied (D. Minto pers.comm.). Washoe County also has a detailed sweeping program that includes route priorities, a tandem operation sweeper, and a commitment to frequent and on-going sweeping during the winter months when road conditions allow (D. Minto, pers. comm.).

Based on interviews and conversations with road maintenance personnel throughout the Tahoe Basin, availability of funding and level of effort in road maintenance practices by Washoe is much more intensive then other Lake Tahoe jurisdictions. The Washoe County commitment to road maintenance appears to result in consistently lower FSP concentrations measured on Washoe County roads than on similar roads throughout the Tahoe Basin based on controlled experiments results (see Figure 6.5). In addition, previous integration of urban catchment water quality

[4] The FSP value of 300mg/L is used a critical threshold, above which is considered a significant water quality risk of a road surface because 1) 300mg/L is the 60th percentile value given the existing 238 controlled road sampling data points, 2) field observations of a road surface that results in a FSP concentration > 300mg/L visibly appears to have an elevated amount of fine particles on the road surface, and 3) roads subjected to both road abrasive applications and high sweeping frequency have been observed to be consistently below 300mg/L during winter observations, therefore indicating that FSP values below 300mg/L on high risk roads are achievable during winter road conditions.

TAHOE BASIN CONTROLLED ROAD EXPERIMENTS

WINTER DATA
for all road sites where abrasives are applied (i.e., excluding SLR road sites)



Data above was obtained from March 2009, January 2010, February 2010 and March 2010 controlled road sampling efforts (2NDNATURE 2010a, 2010b).

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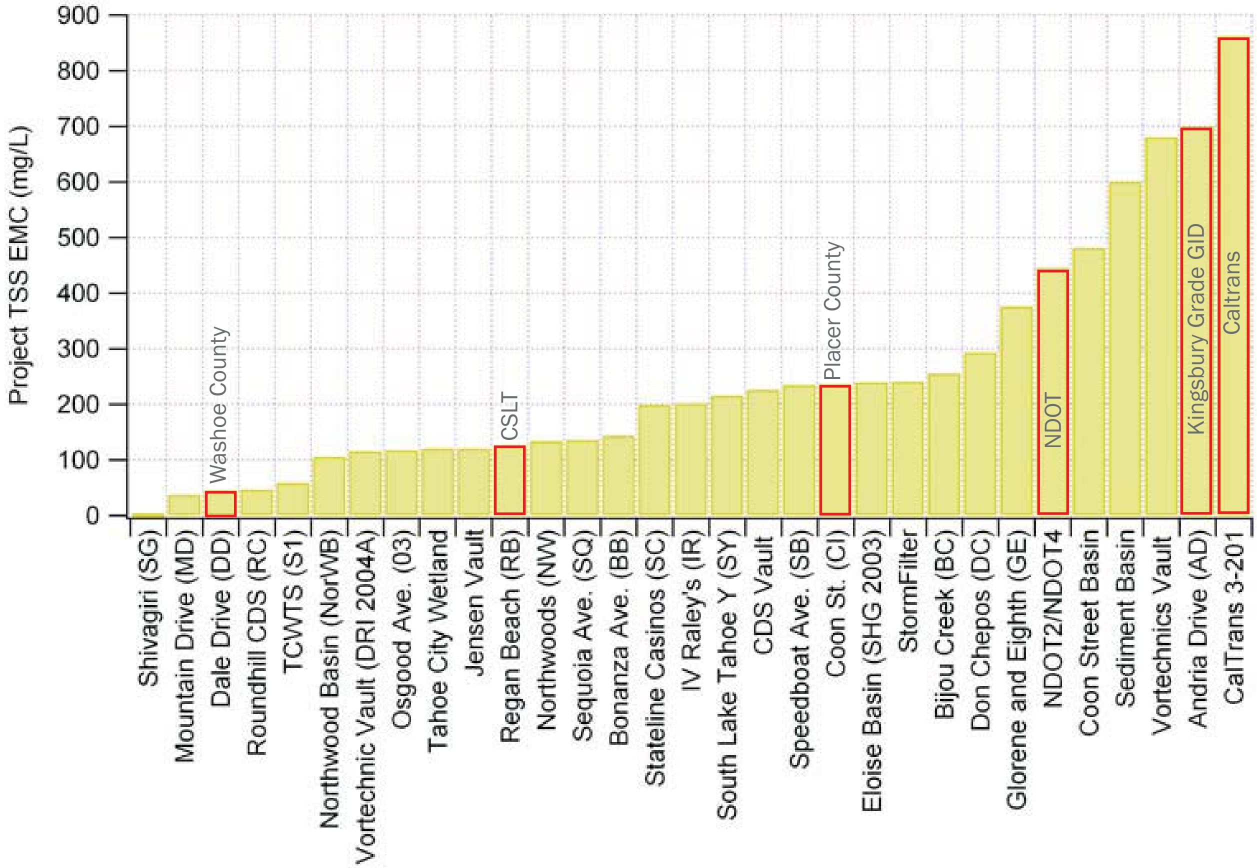
MEASURED WINTER FSP CONCENTRATIONS BY JURISDICTION

FIGURE 6.5

monitoring efforts for the TMDL and PLRM Road Methodology development also indicate lower pollutant event mean concentrations from mixed urban catchment sites in Washoe County (Figure 6.6; nhc et al. 2009b). Figure 6.6 also contains photos of representative winter road segments from both jurisdictions to illustrate the dramatic visual differences of road condition. The Washoe County practices are well documented and the road maintenance staff is eager to share their knowledge and collaborate with other jurisdictions to continue to identify the most effective and feasible road maintenance practices for the Tahoe Basin.

The general controlled experiment results across jurisdictions support existing literature and the mass balance concepts that a reduction in the source of FSP and/or an increase in the sink (i.e., effective road maintenance practices) will improve the critical winter road condition. Existing research on Tahoe Basin roads indicate that road condition is highly sensitive to road maintenance practices, and this finding is the basis for the road classification approach of the Road RAM. However, there is no question that focused and detailed road maintenance strategy effectiveness evaluations are needed to improve our understanding of how advanced road abrasive application strategies, sweeping effectiveness, snow haul and other road maintenance practices influence road surface condition and road land use water quality impacts on a catchment scale.

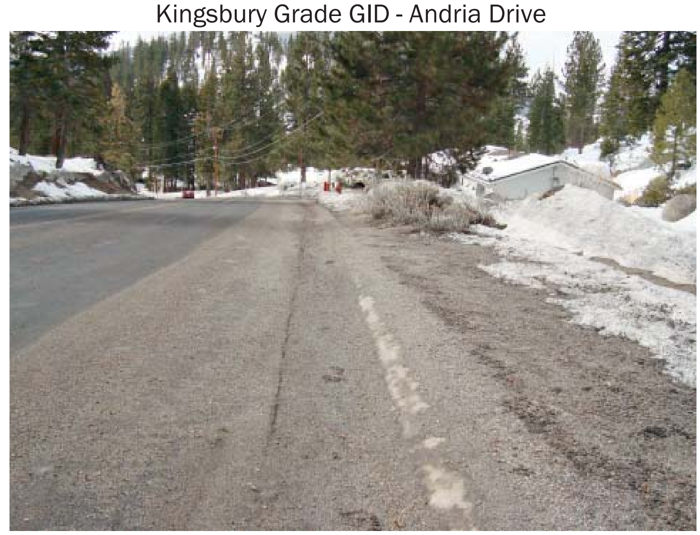
Reported TSS mean EMCs by respective researchers for several Tahoe Basin urban water quality monitoring studies representing runoff from mixed land use and primary road catchments conducted between 1999 and 2005. The six sites highlighted in red represent similarly-sized catchments with a similar urban road density distribution. The jurisdiction in charge of road maintenance within the catchment is also indicated. This Tahoe specific data informed the PLRM Road Methodology development (nhc et al. 2009a and 2009b).



Visual Comparison of Winter Road Condition - March 2009

Washoe County - Dale Drive

Kingsbury Grade GID - Andria Drive



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CHAPTER 7: ROAD RAM FIELD OBSERVATIONS

Road condition is simply defined as the relative risk to the immediate downslope water quality from the road segment of interest. The Road RAM tool employs rapid field observations to determine condition, expressed on a 0-5 scale. The RAM field observations focus on determining the relative amount of fine sediment mass present on the road segment using a series of simple, yet experimentally tested proxies to estimate the relative fine sediment mass, and thus the relative risk to downslope water quality. The differentiation between a road surface in poor (score = 0) versus desired (score = 5) condition can be determined with very high confidence using the visual proxies. The visual differentiation between intermediate RAM scores requires additional rigor, and therefore the RAM field observations include a series of detailed observations that, once trained, a user can complete relatively quickly with high precision.

The rapid observations presented below are experimentally tested proxies that have been determined to predict the measured FSP concentrations obtained by controlled road experiments with reasonable confidence (2NDNATURE and nhc 2010a, 2010b). Hundreds of side-by-side visual and controlled road samples have been collected to inform and validate the field observation protocols (STEP 4B) as detailed in *Chapter 6: Experimental Validation of Road RAM Concepts and Protocols*.

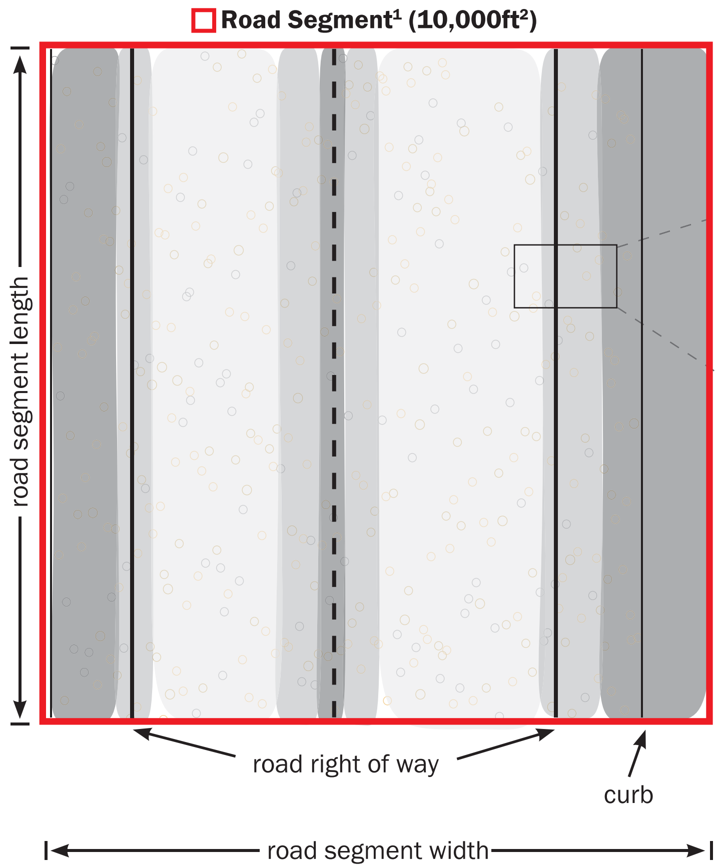
7.1 ROAD SEGMENT

A road segment is defined as a 10,000ft^2 road area. This is the road area within which field observations (STEP 4B) are performed and specific road segments are selected by the user in Road RAM STEP 4A. Horizontally, the road segment is defined by the width of the impervious road surface between the edges of pavement (see photo on right) and will include bike lanes or sidewalks if the impervious surface is continuous from the drive lane outward. Longitudinally, the road segment length is adjusted based on the horizontal width, such that wider roads have a shorter segment length. The area of 10,000ft^2 was chosen because it is large enough to be representative of a road, while still being small enough to allow rapid evaluations. A road segment can be either an intersection or road reach within the middle of a block.

Road Segment – defined by width of impervious surface and standardized to an area of 10,000ft^2

7.2 MATERIAL ACCUMULATION DISTRIBUTION

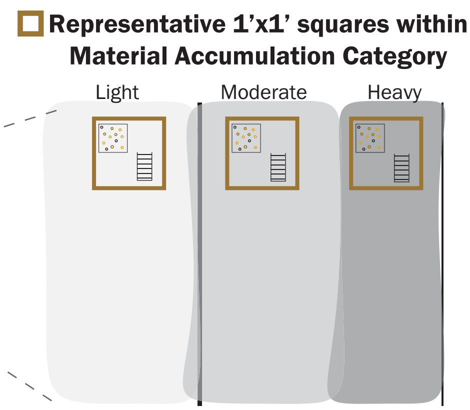
Material accumulated on roads has a typical pattern as a result of transport and sorting by vehicle traffic and wind. Due to this typical delineation, field personnel separate the road segment into 3 distinct areas based on the relative amount of visible material (i.e., sediment and particulate debris) present on the road surface. Consistent with the controlled road experiments, the 3 areas are classified heavy, moderate and light accumulation and the % areal contribution of each accumulation area is estimated (Figure 7.1A). The delineation of material accumulation



A. Road RAM Step 4B visual observations of material accumulation distribution on road segment:

% distribution of up to 3 categories:

- Heavy
- Moderate
- Light



B. Road RAM Step 4B visual observations of proxies for FSP concentrations:

- Volume/Mass of Material
- Degree of Fines

[1]Road segment is defined by the width of the impervious surface area between the two edges of pavement and will include bike lanes or sidewalks if the impervious surface is continuous from the drive lane outward. The road length is determined based on the road segment width and the standardized road segment area of 10,000ft².

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categories is unique to each distinct road segment and the categories are relative to one another for the specific day of observation. The field personnel then conduct a series of field observation on a representative $1ft^2$ in each of the 3 accumulation areas.

7.3 PROXIES FOR FSP CONCENTRATIONS

The rapid field observations within each area of accumulation (see Figure 7.1B) are:

- Volume measurement of the bulk mass of material from a $1ft^2$ area, and
- Relative degree of fines of material from adjacent area, including:
  - Rubbing fingers on road surface to characterize the amount, thickness and texture of material. A higher concentration of clay/silt material will hide the fingerprint and feel slimy to the touch.
  - Vigorous sweeping of the road surface with a hand broom to describe the height and hang time of resulting dust plume. Very fine particles <16μm or smaller will readily stay in suspension in air and the relative visual density of the plume is a proxy for concentration of fine particles.

See *Chapter 6: Experimental Validation of Road RAM Concepts and Protocols* for experimental and statistical validation of these proxies to predict the measured FSP concentration from the controlled road sampling experiments.

7.4 FIELD OBSERVATION LIMITATIONS

The Road RAM tool is designed to provide relatively accurate results where there is high confidence that a road segment with a higher segment score is in better condition and poses a lower downslope water quality risk than a segment that receives a lower segment score. The Road RAM observations have been developed to be rapid, standardized and repeatable to ensure consistency across all users to facilitate repeatable and precise results. However, there is a level of training and familiarity with the protocols that is required to minimize user errors. Trained field personnel will develop an "eye" for road condition and likely become highly efficient at completing Road RAM protocols and determining road segment condition. The areas within the field observations where the precision across users may be a concern are addressed below:

- Percent (%) distribution of each accumulation area will vary slightly across users. It is recommended that users enter the distribution in increments of 5%, walk the perimeter of the entire segment, and obtain general measurements (pacing) of each area to provide relative estimates as accurately as possible.
- The $1ft^2$ observations in each area of accumulation are intended to be representative of each heavy, moderate and light area. There exists inherent variability within each area of accumulation and the field personnel are encouraged to use their best judgment to identify a representative $1ft^2$ for each set of observations.
- Dry mass measurements are collected using a hand broom and dust pan and measured using graduated cylinders. Measurements should be recorded only to nearest volume demarcation on the cylinder used by field personnel.
- Wet roads or high wind conditions prevent Road RAM users from getting accurate or precise field observation results, and thus Road RAM is not recommended for use during these climatic conditions.

INFORMATION AND DATA LIMITATIONS

The road segment field observations are constrained to the impervious extent of the road surface and the adjacent bike lanes and/or sidewalks. Visual observations conducted at road segments over time suggest there can be a substantial amount of potentially mobile unconsolidated material accumulated beyond the area defined as the road segment by Road RAM. Below are a number of scenarios observed over the course of the controlled road sampling efforts and the development of the Road RAM tool where an additional downslope water quality risk is likely present, but the empirical data or observational protocols do not exist to consistently integrate these scenarios into the current road segment or Road RAM scoring procedures. However, the development team believes stormwater managers should be aware of and work towards solutions to minimize the occurrence of these scenarios. Future research is necessary to quantify and integrate these potential water quality implications into the Tahoe Basin stormwater modeling and rapid assessment methods.

Drainage flow paths inaccessible to mechanical pollutant recovery

In some instances, road abrasives, snow plow erosion or snow storage results in a significant accumulation of unconsolidated material beyond the impervious surface, which is therefore inaccessible to sweepers, snow haul or other mechanical pollutant removal techniques. Significant accumulation of unconsolidated material may occur in unpaved road shoulders or roadside swales that serve as drainage flow paths and this material may be transported downslope during stormwater runoff events. The transport efficiency increases as the area of the contributing catchment to the flow path of concern increases, such that a road shoulder that merely drains localized sheet flow from the adjacent road has relatively less transport power than a road shoulder that receives accumulated runoff from several road segments or serves as part of a drainage system. The effectiveness of sweeping to protect downslope water quality is likely reduced in these instances, yet we are not able to quantify the actual road condition impacts at this time. Conceptual models and focused data collection on the effectiveness of sweeping given a range of road factors including flow path accessibility, contributing drainage area, slope, etc. will improve our ability to incorporate these conditions into future versions of Tahoe Basin stormwater tools.

Road condition impacts on downslope conveyance

Roads and adjacent flow paths can accumulate a significant amount of pine needles during the summer and fall. Pine needles are not a downslope water quality threat, and thus the potential impacts of pine needle presence and accumulation is not included in Road RAM. However, summer and winter rains can result in mobilization of pine needles to the inlets of downslope culverts, Treatment BMPs or drop inlets, severely impairing intended stormwater conveyance and routing. Adequate performance of conveyance facilities is needed to ensure that stormwater infrastructure operates as intended. It is recommended that Road RAM field personnel use the opportunity on the ground to identify and improve road maintenance to minimize the potential conveyance impacts of pine needle accumulation.

CHAPTER 8: SPATIAL AND TEMPORAL EXTRAPOLATION OF OBSERVATIONS

The evaluation and tracking of Road RAM scores on impervious road surfaces is based on rapid field observations conducted on a series of road segments. Road segments can be evaluated independently to obtain and track discrete road segment scores over time. In order to spatially extrapolate road segment results, roads are classified into road class as defined by the relative road maintenance practices implemented by the respective jurisdiction. The road segments scores conducted for a series of segments belonging to the same class are averaged and extrapolated to represent the RAM score of all roads in the respective class. The critical components of the Road RAM spatial extrapolation concept are:

1. An adequate number of road segments are evaluated for any one observation period to provide a statistically reliable extrapolation to all roads of the same class.
2. The jurisdictional mapping of road class is representative of actual road maintenance practices.

Similarly, the inherent variability of road condition across seasons in the Tahoe Basin requires a temporal extrapolation of discrete observation periods to express an average annual road condition. The Road RAM tool provides a standardized approach to integrating discrete observations conducted over an annual time period to document the average annual road conditions for a specific water year that will meet both long-term road condition tracking goals as well as specifically align with the Crediting Program annual reporting requirements.

8.1 ROAD CLASS

The primary purpose of the road classification is to spatially extrapolate observations on road segments. Road class minimizes the number of necessary road segment observations for any particular observation period while maintaining reasonable confidence in the spatial extrapolation of the road segment condition results to a larger network of roads within a specific jurisdiction. Tahoe Basin research on roads has led to the hypothesis that within a single jurisdiction, road condition is highly sensitive to the relative intensity and effectiveness of road maintenance practices that control the magnitude of potential sources and actual sinks of FSP on the road (see *Chapter 6: Experimental Validation of Road RAM Concepts and Protocols*). Road maintenance practices vary significantly across jurisdictions and road class is not expected to result in a consistent categorization of road class across jurisdictions, but only within each respective jurisdiction.

Jurisdictions complete the road classification during STEP 3 of the Road RAM tool. Road class is defined by a jurisdiction’s specific maintenance practices that influence the sources and sinks of pollutants on the road surface. The primary categorization for pollutant sources that the jurisdiction controls on a short time scale is the relative frequency, intensity and type of abrasive applications during winter storm and freezing conditions. The primary categorization for pollutant sinks that the jurisdictions control on a short time scale is the relative sweeping type and intensity when road conditions allow for sweeper operation. The integration of actions that add and remove pollutants from the road surface result in a total of nine road class categories within Road RAM (Table 8.1).

The classification and definition of specific road maintenance practices conducted will greatly simplify record keeping of what actions are completed on which roads when. This record keeping is expected to be beneficial to the jurisdictions beyond the spatial extrapolation of Road RAM observations. Road classification is a two-step process where the practices related to the relative source of material applied to roads, which in most instances will be road abrasive application practices, are defined and categorized independently from the practices that result in removal of pollutants from the roads. Road class is the intersection of the source and sink practices as shown in Table 8.1. The only restriction in classification is that the source categories (A, B, C, etc) and sink categories (X, Y, Z, etc) are arranged such that the greatest potential annual source of abrasives is the A category and the lowest is C. Similarly, the road swept with the greatest potential annual removal of material is categorized as X and the lowest Z. This preservation of relative source and sink magnitude is important when applying recommendations on the minimum number of road segments selected and tolerance of condition variability across sites, as discussed later in this chapter. The *Road RAM User Manual* provides additional details on how a jurisdiction defines and delineates road class.

Table 8.1 provides a simple structure for jurisdictions to classify their roads, however there is flexibility in both the number of road classes used and how each is defined. It is likely that certain classes (such as AZ or CX) do not accurately represent the actual combination of road abrasive application and sweeping effectiveness practices implemented by the jurisdiction. For instance, it is likely not advised to prioritize frequent sweeping with the jurisdiction's most effective sweeper on road segments subjected to very infrequent abrasive applications (Road Class CX, see Table 8.1). In addition, the jurisdictions may wish to divide the relative source categories more specifically, for example: A for roads treated with volcanic bulk abrasives; B for roads treated with washed and processed high-durability abrasives; and C for roads rarely treated with any abrasives. As long as the jurisdiction preserves the relative high to low source and sink categories, the Road RAM tools provides flexibility for jurisdictions to define exactly the combination of road maintenance practices implemented on the different road classes.

TABLE 8.1. Road class based on pollutant source and sink controls as defined by the jurisdictional road maintenance practices. The table is structured to classify roads based on relative frequency/intensity of abrasive applications and sweeping effectiveness, but jurisdictions can specifically define each road class category as appropriate as long as the relative sources and sinks structure is preserved (i.e., AX is the combination of road maintenance practices that has expected greatest relative source and sink of FSP).

Sweeping effectiveness (*sinks*)	**Abrasive application priority (*sources*)**		
	Intensive (A) *high sources*	Moderate (B)	Rarely to Never (C) *low sources*
Intensive (X) *high sinks*	AX	BX	CX
Moderate (Y)	AY	BY	CY
Rarely to Never (Z) *low sinks*	AZ	BZ	CZ

8.2 MINIMUM RECOMMENDED ROAD SEGMENTS

When the spatial extrapolation of road segment results to the respective road class is desired a minimum number of road segment observations for each road class is recommended based on the potential of each road class to be in relatively poor condition and the target precision of road segment scores obtained. By striking the right balance, Road RAM results can provide valuable information to increase the effectiveness of maintenance activities and represent average annual conditions, without diverting attention from the implementation of effective maintenance actions. When Road RAM is being used as a verification tool for Crediting Program reporting, a two-tiered approach is used to establish consistency of results every fifth year (calibration years), while minimizing effort in the interim four years (check up years). The computational approach and justification for the recommended minimum road segment observations for spatial extrapolation is provided below.

The recommended minimum number of road segments observed in each observation period balances the need to accurately characterize the conditions of roads in each road class with the practical need to limit the amount of staff time required to complete field observations. Given limited time and resources, RAM observations will focus on road classes that are more likely to be in relatively poor condition, and thus subjected to relative high sources of abrasives. Table 8.2 identifies the expected relative importance of each road class based on road maintenance practices and potential for poor road conditions and associated downslope water quality impacts.

TABLE 8.2. Relative importance of Road RAM observations based on road class. High, medium and low indicate the relative significance of each class when the user is selecting road segments for evaluation. Roads with higher importance are expected to have a greater number of segments measured. The road class ID is provided in parentheses.

Sweeping Effectiveness (*sinks*)	**Abrasive Application Priority (*sources*)**		
	Intensive (A)	Moderate (B)	Rarely to Never (C)
Intensive(X)	High (AX)	Medium (BX)	Low (CX)
Moderate (Y)	High (AY)	Medium (BX)	Low (CY)
Rarely to Never (Z)	High (AZ)	High (BZ)	Medium (CZ)

In addition to priority of road classes presented in Table 8.2, the following were considered in developing the recommendations for minimum number of road segments:

- It is hypothesized that if roads are properly classified and reflect consistent and actual maintenance practices, randomly selected observation points (i.e., road segments) will produce precise RAM scores by class.
- Precision of segment observation is evaluated using the standard deviation (SD) of the road segment scores for each class. Table 8.3 provides an acceptable SD for each road class based on achievable SD values during preliminary testing by the development team.
- Two trained field personnel can complete the required field observations (STEP 4B) in less than 10 minutes on one road segment and should be able to perform at least 30 observations during a work day, including set-up and travel time. The recommended minimum number of road segments considers 4 full working days to obtain RAM scores for all roads within one Tahoe Basin jurisdiction to be reasonable.
- The recommended minimum number of segments and acceptable SD (see Table 8.3) assume the user will conduct field observations across an entire jurisdiction, covering anywhere from 40 to 175 road miles. If, however, the user is conducting field observations on a smaller area of interest the actual number of road segments required to achieve the target SD may be less.
- In order to meet the regulatory requirements associated with the Tahoe TMDL and the associated Crediting Program, there are additional spatial and temporal considerations for urban jurisdictions.

Calibration years

Table 8.3 provides guidance regarding the recommended minimum number of observations of each road class and the target standard deviation related to each road class. The degree of statistical variability acceptable is based on the expected relative importance of each road class (see Table 8.2), preliminary precision testing of the RAM tool and level of effort required for completion across an entire jurisdiction. The statistical and spatial rigor as recommended for calibrations years is higher than the reduced effort for check up years. If resources are available, it is recommended to follow the number of segments and target standard deviation in Table 8.3.

TABLE 8.3. The recommended minimum number of road segments and target standard deviation for spatial extrapolation of road segments scores to all roads of the same class. These recommendations are also required for a calibration year level of effort for a jurisdiction to meet annual reporting requirements.

Sweeping Effectiveness (sinks)	**Abrasive Application Priority (*sources*)**		
	Intensive (A)	Moderate (B)	Rarely to Never (C)
Intensive (X)	15 /±0.5	12 /±0.75	8 /±1.0
Moderate (Y)	15 /±0.5	12 /±0.75	8 /±1.0
Rarely to Never (Z)	15 /±0.5	15 /±0.5	12 /±0.75

Check up years

If Road RAM is being used by a jurisdiction to meet Crediting Program annual reporting requirements, the jurisdiction has the option to reduce the level of effort required. Once a jurisdiction's implementation plans and operational activities are calibrated with Road RAM scores, the number of road segments per class are reduced and the associated target standard deviations are increased as presented in Table 8.4.

TABLE 8.4 Check-up year number of road segments and target standard deviation for road segment scores for each road class.

Sweeping Effectiveness	**Abrasive Application Priority**		
	Intensive (A)	Moderate (B)	Rarely to Never (C)
Intensive (X)	8 /±0.6	5 /±0.9	3 /±1.3
Moderate (Y)	8 /±0.6	5 /±0.9	3 /±1.3
Rarely to Never (Z)	8 /±0.6	8 /±0.6	5 /±0.9

The recommended number of observations for each road class should be sufficient to achieve the target SD if the road classification is representative of actual road maintenance practices. If the SD of road segments is found to be higher than the acceptable limits (see Table 8.3 or 8.4), the user should include additional segments to the field observations for that road class in the subsequent observation period. If the user has conducted 25 segment observations within a road class and the SD remains unacceptable, the user should critically evaluate the dataset to determine the potential causes of variability. The *Road RAM User Manual STEP 5* protocols provide a number of potential sources of error and appropriate solutions.

8.3 ROAD SEGMENT SELECTION GUIDANCE

The user is free to select the specific road segments to meet the minimum number required in a manner that fits their needs. While road maintenance practices are assumed to have the most statistically significant effect on the variability of observed road condition, there are a range of road attributes that may be of interest as jurisdictions plan and prioritize the use of Road RAM results. Road segments can be added to the Road RAM tool at any time, so as the user becomes more familiar with the analysis possibilities of the Road RAM tool and/or the users' needs change over time additional road segments can be selected. A discussion of potential considerations when selecting road segments by class for observations is provided in the *Road RAM User Manual STEP 4A* protocols.

8.4 TEMPORAL EXTRAPOLATION

Long-term tracking of Tahoe Basin road conditions via Road RAM results is best expressed on an average annual basis (see Figure ES.2). Consistent with long-term tracking needs, the Crediting Program requires reporting of average annual conditions. A standardized method to temporally extrapolate a series of discrete Road RAM observations over one water year must be conducted in order to express observed road conditions on an average annual basis. Below we provide the justification and recommended approach to temporally integrate Road RAM results over an annual time period.

The discrete Road RAM observations provide a snapshot of the road conditions at the time of observations and the Road RAM tool can be repeated at any time to quantify road condition. While road conditions will vary during winter storm events and freezing conditions, consistent implementation of pollutant control practices are expected to improve road conditions following storms and before spring runoff events. Table 8.5 presents the percent of the annual FSP loading to Lake Tahoe by season, indicating the most significant loading occurs during the spring due to the combination of spring snow melt and spring rain events.

Table 8.5. Summary of annual pollutant loading to Lake Tahoe by season.

Season (months)	% of annual FSP loading to Lake[1]
Fall (Oct-Dec)	8%
Winter (Jan-Feb)	13%
Late Winter/Early Spring (March-April)	33%
Spring (May-June)	42%
Summer (July-Sept)	4%

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

On an average annual basis, the late winter/early spring road conditions are expected to have the greatest potential water quality impact (and provide the greatest opportunity for improvement) due to the combined high source inputs to the roads from recent winter conditions and the high probability of subsequent snowmelt and rain events that transport the pollutants off the roads, into the stormwater infrastructure and eventually to Lake Tahoe (see Table 8.5 and Figure 6.3). The temporal distribution of Road RAM observation periods estimates average annual road conditions as they relate to pollutant transport and the resulting threat to downslope water quality loading.

Minimum number of observation periods

Road RAM observation can be conducted as frequently as the user desires and increased observation periods will increase confidence in the road condition results as they are extrapolated to an annual average. However, when the Road RAM is being used by jurisdictions as a Crediting Program reporting tool, a minimum number of observation periods have been determined. Table 8.6 presents the minimum number of Road RAM observation periods necessary per season for calibration and check up years, based on the annual time step defined as one water year (October 1 – September 31). The recommended temporal distribution of annual Road RAM observations proportionally weights the road conditions in the late winter/early spring as the priority season. The timing of observations recommended in Table 8.6 provides information to inform road maintenance decisions and characterize road conditions before periods with expected runoff events that transport pollutants to surface waters and wash roads clean of pollutants in the process.

Additional observations may be made and incorporated into the annual summary and temporal integration as desired, but the *Road RAM Database* will integrate annual Road RAM results based on the weighting provided in Table 8.6.

TABLE 8.6. Minimum Road RAM observation periods by season to obtain the average annual RAM score over one water year. Road RAM scores are distributed and results weighted based on the seasonal distribution of runoff (see Table 8.5) and the increased need for road maintenance actions to sustain good road conditions.

Season (months)	CALIBRATION YEAR Minimum # of Observation Periods (% weighting)	CHECK UP YEAR Minimum # of Observation Periods (% weighting)	Specific Timing and Rationale
Fall (Oct-Dec)	1 (20%)	0 (0%)	Observations should occur prior to first winter rain event. Stormwater runoff event probability of occurrence is high.
Winter (Jan-Feb)	1 (20%)	1 (33%)	Road condition expected to be at annual low when abrasive application to protect driver safety occurs frequently. Larger stormwater runoff event probability of occurrence is low; typical runoff is gradual localized snowmelt.
Late Winter/ Early Spring (March-April)	2 (40%)	2 (66%)	Air temperature increases and snow fall frequency decreases, providing opportunity for aggressive sweeping. Stormwater runoff event probability of occurrence increases to moderate/high. All observations must be conducted prior to first significant (1 in/12hr) rainstorm event washes roads clean.
Spring (May-June)	1 (20%)	0 (0%)	Snowmelt and spring snow and rain events with frequent runoff. Temperatures provide opportunity for sweeping. Probability of roads being washed by a spring rain event is high.
Summer (July-Sept)	0 (0%)	0 (0%)	Road conditions expected to be at annual high due to extended duration since last abrasive applications and road cleaning by spring/summer rains.

The timing of RAM observation periods by jurisdictions could raise concerns about the potential tradeoff between performing the Road RAM versus doing necessary maintenance. It is important to understand that the Road RAM can be used at many time scales but that road conditions are assumed to change slowly between condition-changing events such as precipitation, abrasive application or sweeping. Thus is it not necessary to consider if a jurisdiction should choose maintenance or the Road RAM before/after specific events: timing of the Road RAM is flexible and should not preclude maintenance activities. However, the best-condition roads are observed in urban jurisdictions with maintenance plans that minimize abrasive application magnitudes and frequency and call for recovery of abrasives as soon as practicable after conditions and workloads allow.

CHAPTER 9: ROAD RAM SCORING

The *Road RAM Database* generates a Road RAM score based on the series of field observations performed by the user at a number of road segments belonging to a single road class. It is a fundamental hypothesis of the Road RAM that a reduction in the condition of the road, expressed on a 0-5 scale, corresponds to a simultaneous increase in the risk to downslope water quality with the next stormwater runoff event. The Road RAM scoring scale of 0-5 has been exponentially correlated to the observed range of FSP concentrations measured on Tahoe Basin roads during WY09 and WY10 using the existing controlled road experimental dataset (2NDNATURE and nhc 2010a, 2010b). Table 9.1 defines Road RAM scores and how they relate to the expected FSP concentration and the condition of a road.

The expression of road condition on an absolute scale of 0-5 and the road specific testing of FSP concentrations on hundreds of road segments over a 2 year period in the Tahoe Basin (2NDNATURE and nhc 2010a, 2010b) has provided a preliminary link between RAM score and water quality immediately downslope. Consistent with the BMP RAM tool (2NDNATURE et al 2009), a RAM score of 2 is identified as the **threshold value**, below which there is high confidence that the road is an immediate risk to downslope water quality. A Road RAM score of 2 equates to a predicted FSP concentration of 291 mg/L generated from the road segment (see Table 9.1). Based on observations across Lake Tahoe jurisdictions and over a range of seasons, it is assumed that the condition of a road with a Road RAM score of 2 can be improved in the future with the implementation of a combination of road maintenance practices.

Table 9.1 Road RAM scores relative to road condition and relative risk to downslope water quality.

Road RAM Score	Condition	FSP concentration (mg/L) range[1]	Description
0 - 1.0	Poor	1,592-680	• Significant potential risk to downslope water quality should runoff event occur • Road maintenance practices require immediate improvements • Capital improvement projects downslope may need to be considered to capture road generated pollutants
>1.0 - ≤ 2.0	Degraded	679-291	• Likely potential risks to downslope water quality • Road maintenance practices require immediate improvements • Capital improvement projects downslope may need to be considered to capture road generated pollutants
> 2.0 - ≤ 3.0	Fair	290-124	• Road condition is closer to degraded than desired, may pose downstream water quality risk • Road maintenance should be prioritized as needed if time and resources permit
> 3.0 - ≤ 4.0	Acceptable	123-53	• No immediate risk to downslope water quality should runoff event occur • Minimal need to improve road maintenance practices
> 4.0 – 5.0	Desired	52-23	• Maximum achievable road condition • No need to improve road maintenance practices

[1] FSP concentration (mg/L) range predicted for respective Road RAM score range based on 238 controlled road experiments conducted over a 2 year period in Tahoe Basin (2NDNATURE and nhc 2010a, 2010b).

9.1 ROAD RAM DATABASE AND SCORING PROCESS

The online *Road RAM Database* is a custom relational database that stores spatial and field observation data, calculates road segment and Road RAM scores, and manages all of the Road RAM information over time. Version 1 of the database contains a number of user-friendly features to minimize user error and confusion. The user interacts with a series of data entry menus and forms to populate data fields with the required information. This data is stored within underlying database tables and the database uses queries to perform calculations and generate reports that the user can print to summarize RAM data. The *Road RAM User Manual* provides all protocols necessary for complete operation of all Road RAM Database functions.

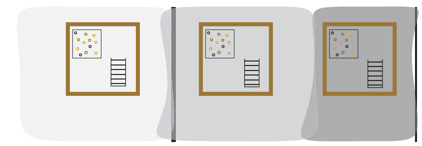
The Road RAM scoring process is completely automated by the database following the field datasheet entry by the user in STEP 4B. The generation of a score for a specific road segment is completed by a step-wise integration of field observation results from the $1ft^2$ squares to the expected road segment FSP concentration using simple spatial distribution weighting based on the conservation of mass. The road segment FSP concentration is then converted to a 0-5 score. Road segment scores obtained from roads of the same class are averaged to determine the Road RAM score for that class for the discrete observation period. Figure 9.1 summarizes the step-wise process the database follows to provide the user with road segment and Road RAM scores based on their field observations.

A. MATERIAL ACCUMULATION CATEGORY FSP CONCENTRATION

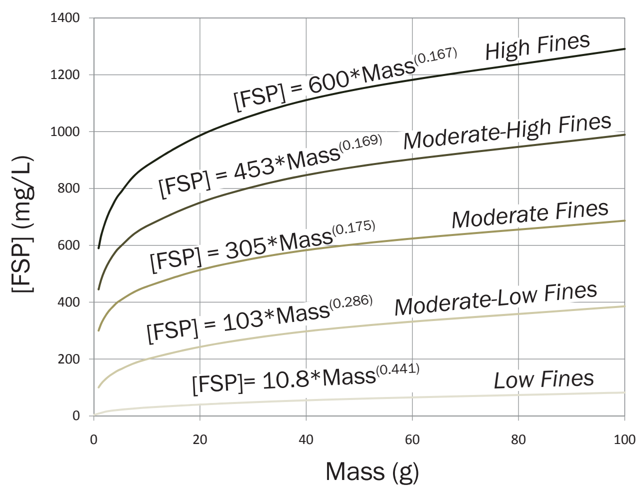
The database converts the user observation results for each $1ft^2$ into FSP concentration to represent each of the designated material accumulation areas. The conversion of observations to concentration is based on the predictive model developed using 238 experimental data points. The graph below provides the equations of the model used to calculate the expected FSP concentration for the $1ft^2$ area as a function of dry mass and degree of fines determined by the user observation results.

Material Accumulation Category
- Heavy
- Moderate
- Light

Representative 1'x1' square



Visual Observations
- Volume/Mass of Material
- Degree of Fines



$[FSP]_{HEAVY}$

$[FSP]_{MODERATE}$

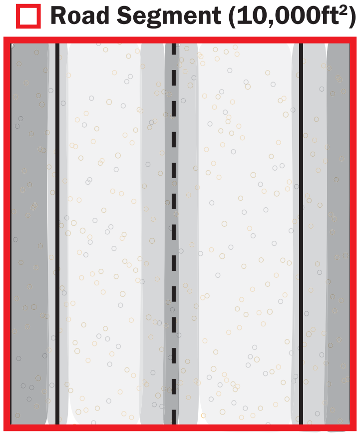
$[FSP]_{LIGHT}$

*Mass + Degree of Fines = FSP Concentration [**FSP**] (mg/L)*

B. ROAD SEGMENT FSP CONCENTRATION

The FSP concentrations obtained for each $1ft^2$ are weighted based on the percent distribution of the material accumulation determined by the user to calculate a road segment FSP concentration.

Road Segment ($10{,}000ft^2$)



Visual Observations
- % Heavy
- % Moderate
- % Light

$$([FSP]_{HEAVY} * \%\ HEAVY) + ([FSP]_{MODERATE} * \%\ MODERATE) + ([FSP]_{LIGHT} * \%\ LIGHT) = [FSP]_{ROAD\ SEGMENT}$$

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FIGURE 9.1

C. ROAD SEGMENT SCORE

The road segment score represents the observed condition of the road segment at the time of observation. The road segment FSP concentration is converted to a road segment score by the database using PLRMv1 road methodology CRC to score equation that has been and continues to be validated using land use specific controlled experiments (2NDNATURE 2010a, 2010b). After 238 controlled road samples, the range, shape and distribution of the PLRM v.1 Road Methodology equation appears representative of Tahoe Basin roads.

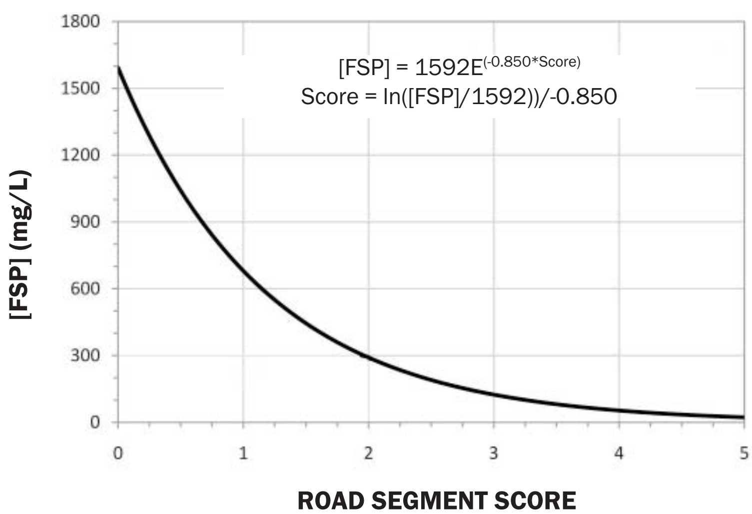

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FIGURE 9.1

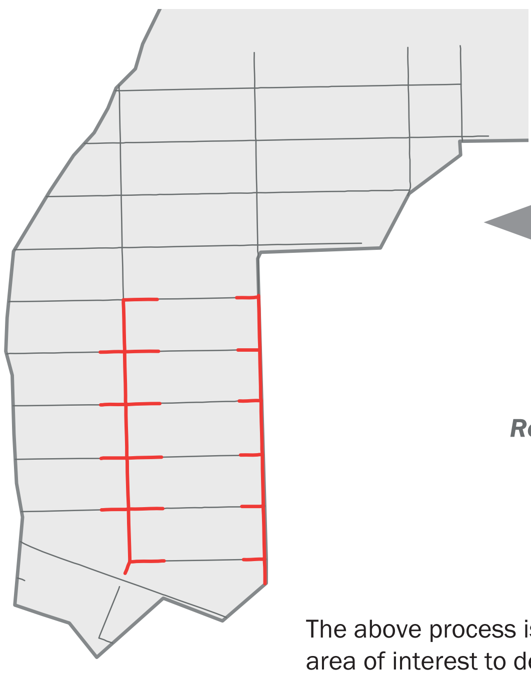
Hypothetical Example

D. ROAD RAM SCORE

The database calculates the average and standard deviation of all road segment scores within the same road class for an observation period (table to right), and spatially extrapolated as the Road RAM score for all roads of the respective class (graphic below). If the standard deviation is outside the recommended range (see Table 8.3), the Road RAM score is flagged in the database.

Road segment scores for AX roads March 10 2010	
Road Segment ID	**$SCORE_{RS}$**
Coon_01	1.6
Coon_02	2.2
Coon_03	1.8
Coon_04	1.8
Coon_05	2.2
Coon_06	1.5
Coon_07	2.0
Coon_08	1.9
Coon_09	1.3
Coon_10	1.8
Coon_11	2.2
Coon_12	2.3
Coon_13	1.7
Coon_14	1.0
Coon_15	2.4
average = AX RAM score	**1.8**
standard deviation (SD)	0.39

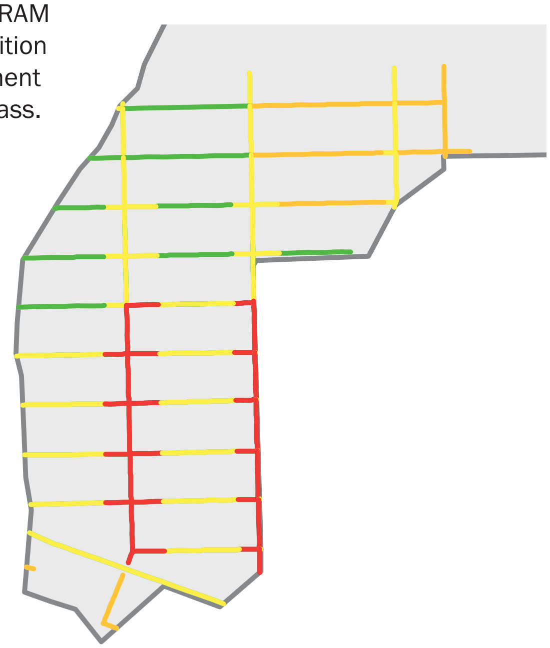
RAM SCORE - AX Roads



Repeated for all classes.

The above process is repeated for all roads within the area of interest to determine the Road RAM scores for the respective observation period. The Road RAM score represents the spatially extrapolated condition of the road class based on a series of road segment observations belonging to the respective road class.

RAM SCORE - All Roads



LEGEND	
Condition of Road Segment	
Red	Poor/Degraded (RAM ≤2)
Orange	Fair (2< RAM ≤3)
Yellow	Acceptable (3< RAM ≤4)
Green	Desired (RAM >4)

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ROAD RAM SCORING PROCESS (PAGE 3 OF 3)

FIGURE 9.1

CHAPTER 10: APPLICATION OF ROAD RAM DATA AND RESULTS

The Road RAM tool establishes a standardized methodology for evaluating the road condition that can be used to track and inform changes in road condition over time. The overlay of RAM results with different road attributes can provide valuable spatial information on pollutant sources, sinks and transport risk. These spatial and temporal changes can be used to prioritize future water quality improvement actions, improve the scientific basis for numerous Tahoe urban stormwater tools, evaluate and test the effectiveness of various road maintenance practices, and address other gaps in our knowledge of pollutant generation and transport from this land use. Below is a discussion of key analysis techniques that can be used to inform future urban stormwater management decisions in the Tahoe Basin.

10.1 ROAD RAM SCORES OVER TIME

Road RAM scores can be reduced to quantitative summaries of road conditions on a variety of time scales. It is assumed that future water quality improvement actions implemented in an effort to meet the Tahoe Basin TMDL goals will result in the overall improved condition of Tahoe Basin roads. Figure 10.1 provides a hypothetical visual and quantitative example of Tahoe Basin annual road conditions as measured by the implementation of the Road RAM tool over the next 20 years. Summary of the Road RAM results Basin-wide will provide a simple measure of what has been achieved for the money expended on improving road condition, a proxy for sustained pollutant load reductions from urban areas.

10.2 OVERLAY OF RAM SCORES AND ROAD ATTRIBUTES

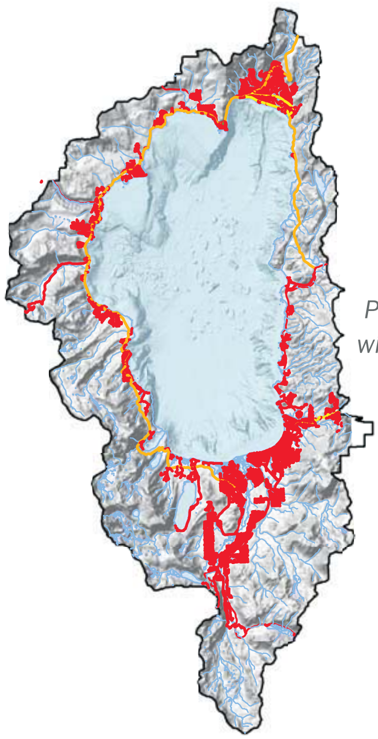
The *Road RAM User Manual* provides guidance to complete the spatial intersection of road attributes and Road RAM scores. This feature of the Road RAM tool provides a large amount of flexibility and opportunity for analysis of Road RAM scores with other road attributes. For instance, the user may want to evaluate the Road RAM scores based on road shoulder connectivity, such that the Road RAM score for directly connected roads is displayed spatially and analyzed to inform potential future improvements. Any attribute overlay spatial analysis can be completed for a discrete time period of interest (e.g., one Road RAM observation period, winter observation average, annual integration, etc.) and/or completed as a time series comparison to evaluate effects of specific attributes in Road RAM scores over time.

CURRENT ROAD ATTRIBUTE HYPOTHESES AND POTENTIAL ANALYSES

The following is a brief discussion of potential road attributes that may prove informative when analyzed with Road RAM results. The possibilities are extensive and, as users become more familiar with the Road RAM tool capabilities, the users can tailor analyses to meet a variety specific pollutant generation and transport questions.

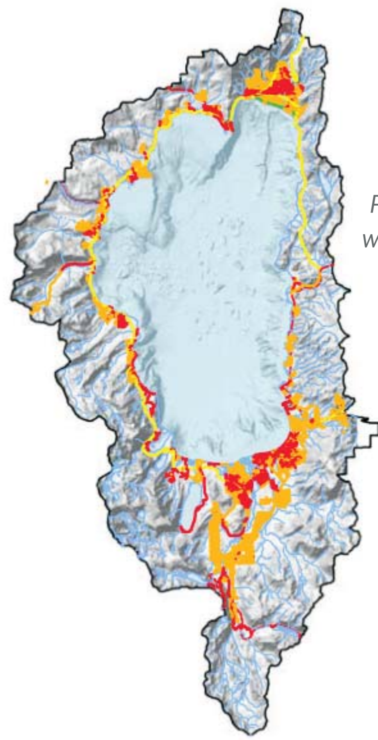
- <u>Road Shoulder Condition</u>: Road shoulder condition is defined in the PLRM User Manual (p. 58; nhc et al 2009a) and is considered a potential influence on the average annual condition of a road segment. Figure 10.2 is the PLRM user decision process used to define road shoulder condition. The following are water quality benefit assumptions of improving road shoulder condition, some of which are expanded from the PLRM documentation: (1) an unprotected road shoulder is subjected to traffic and human disturbance and can provide a chronic source of native material onto the impervious road surface; (2) an unstable road shoulder can result in erosion of the primary flow path parallel to the right of way during stormwater runoff events; (3) a stable road shoulder may reduce snow plow disturbance and associated erosion of the

2004



Percent of Tahoe Urban Roads with Road RAM Score ≤2 = 91% (~630 miles)

2015



Percent of Tahoe Urban Roads with Road RAM Score ≤2 = 33% (~225 miles)

2030

Percent of Tahoe Urban Roads with Road RAM Score ≤2 = 4% (~25 miles)

LEGEND

Condition of Road Segment

- Poor (RAM<1)
- Degraded (1<RAM<2)
- Fair (2<RAM<3)
- Desired (RAM>3)

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HYPOTHETICAL PROGRESSION OF TAHOE BASIN ROAD CONDITION OVER TIME

FIGURE 10.1

native soils; and (4) on roads where abrasives are frequently applied, a stable road shoulder may improve the efficiency of street sweepers to recover a greater fraction of abrasives applied.

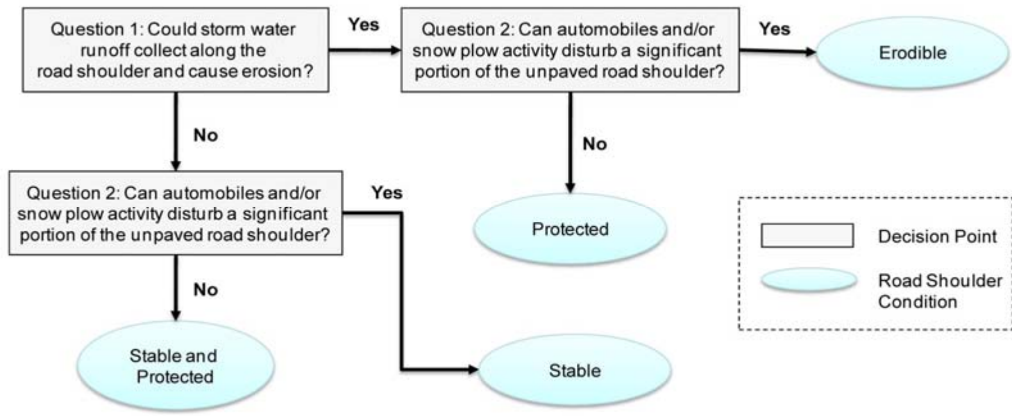

Figure 10.2 PLRM road shoulder condition decision process (nhc et al. 2009a)

Example analysis: Compare Road RAM scores to road shoulder condition during the summer months, when the pollutant generation from abrasive application is assumed to be minimal, to evaluate the contribution of material from unprotected road shoulders on road condition.

- Road Shoulder Connectivity: The amount of impervious area (e.g., roads) defined as directly connected impervious area (DCIA) significantly affects estimates of runoff volume and pollutant loading.
  Example analysis: Compare the spatial distribution of directly connected roads to Road RAM scores. Directly connected roads in poor condition are the most significant risk of the pollutants generated from the road surface reaching the Lake, and therefore this analysis could further refine jurisdictional road maintenance priorities to minimize source generation and transport from these roads.
- Road Surface Integrity: Poor road surface integrity can contribute to higher FSP concentrations in certain events due to trapping of sediment and FSP within the cracks and crevices that cannot be removed by road sweepers but can be effectively mined by stormwater runoff.
  Example analysis: Compare the road condition of road segments with poor and good road surface integrity at segments where sweeping is a priority to evaluate the impact road surface integrity has on sweeping effectiveness.
- Abrasive Application Improvements: The amount and quality of road abrasive applied to the road can affect the road condition. Potential improvements include: (1) reducing the amount of abrasives applied either by reducing the volume per each application, the spatial extent of each application and/or the number of applications per winter, (2) pre-washing the abrasives prior to application to remove any particles <16µm, and (3) using brands of abrasives that are more resistant to pulverization to decrease the accumulation of FSP on the road surface over time due to vehicular traffic.
  Example Analysis: Compare abrasive application practices on different road classes over a number of winters with Road RAM scores over time to evaluate if improvements to abrasive application practices correlate to improved Road RAM scores. Results will need to be evaluated with climatic differences across the winters evaluated.
- Sweeping Effectiveness Improvements: Several studies have shown that certain sweeper types are more effective at removing the priority pollutant (FSP) from the impervious road surface than others and that load reductions can increase as the frequency of sweeping increases.

Example analysis: Track sweeper type and sweeping frequency actions over time to compare observed Road RAM results and quantify road condition changes as a result of practice changes.

- PLRM Road Risk: The PLRM Road Methodology hypothesizes that slope, traffic density and adjacent land use influence the relative amount of road abrasives applied, the relative amount of road shoulder erosion, and the relative transport capability of the pollutants on the road. (See nhc et al. 2009a for details).
  Example analysis: Spatially compare distribution of road risk categories to abrasive application priority to improve the assumptions of the PLRM Road Methodology and/or improve jurisdiction road maintenance practices.

10.3 CATCHMENT SCALE ANALYSES

Road RAM scores can be spatially weighted based on the percent distribution of each road class within the catchment to calculate an overall RAM score for a specific area of interest. These catchment scores can be used to:

- Compare various locations within an urban jurisdiction and prioritize future storm water improvements.
- Inform road maintenance personnel of necessary adjustments to the current road maintenance practices and/or alert them to locations where Treatment BMPs may require less frequent maintenance to ensure proper treatment capability.

Winter Road RAM scores for roads within a catchment can be compared to the respective BMP RAM scores to assess the impact of road conditions on the influent water quality delivered to the Treatment BMP over time. If a Treatment BMP requires more frequent maintenance than expected, this comparison may provide insight regarding the impact of the catchment road conditions on pollutant generation within the contributing catchment.

10.4 UTILIZE ROAD RAM DATA TO INFORM ROAD MAINTENANCE PRACTICES

A large amount of insight can be gained by jurisdictions using the GIS road attribute layers created as part of Road RAM STEPs 2 and 3. Road RAM scores over time can then be used to test the effectiveness of road maintenance practices and their ability to improve seasonal and annual road condition over time. Some examples are included below, but likely stormwater managers can identify a number of other valuable uses of the Road RAM spatial datasets:

- Utilize abrasive application priority attribute layer to inform sweeping priority and effectiveness practices, targeting sweeping priorities on road network where abrasive applications are greatest on an average annual basis (A class roads).
- Overlay abrasive application priority and road shoulder condition attribute layers and use this information to target future water quality improvement projects (WQIP) to stabilize road shoulders where high abrasive applications occur to improve recovery efficiency and reduce the loss of pollutants into unstable primary flow paths.
- Overlay abrasive application priority and road surface integrity layers and target road resurfacing projects on roads where integrity is poor and abrasive application is high (A class roads).
- Overlay road slope and road surface integrity layers and prioritize road resurfacing projects on steeper roads due to more efficient transport of pollutants.
- Create a relative traffic density layer, and overlay with road slope and abrasive application priority to better inform abrasive application priorities and potential areas for reduced applications.

10.5 RELATIONSHIP OF ROAD RAM V1 TO PLRM V1

PLRM is used to determine the expected load reduction associated with specific water quality improvement actions and is approved for use to create a catchment credit schedule per the Crediting Program guidelines. The user inputs a variety of catchment, land use, hydrology, and stormwater treatment characteristics into PLRM to estimate the average annual pollutant loads generated from a catchment under baseline (2004) and expected condition scenarios. The modeled change in catchment pollutant loading from the baseline estimates is termed the expected pollutant load reduction and is used in the Crediting Program and associated TMDL Accounting and Tracking Tool to generate a catchment credit schedule. The catchment credit schedule documents the annual credits to be achieved by an urban jurisdiction within a selected catchment.

PLRM ROAD METHODOLOGY AND ROAD RAM

The PLRM Road Methodology was developed to provide the link between expected road land use condition and expected pollutant generation from this high priority land use, by integrating factors that are assumed to increase the amount of FSP on a road surface with actions that are assumed to reduce FSP. The PLRM Road Methodology provides a flexible approach that integrates physiographic characteristics, pollutant source control efforts and pollutant recovery actions to predict the likely condition and associated characteristic runoff concentrations (CRCs) from roads on an average annual basis. Baseline road condition is estimated by integrating road risk, reductions of abrasive application practices, road shoulder condition and pollutant recovery effectiveness (i.e., sweeping frequency and type) for the road network within the urban catchment of interest (Figure 10.3). The PLRM user estimates expected future road conditions by the commitment to any number of water quality improvement actions, such as decreased abrasive application frequency, distribution or changes in abrasive type, road shoulder improvements or increased effectiveness of road pollutant recovery actions that improve the average annual road condition.

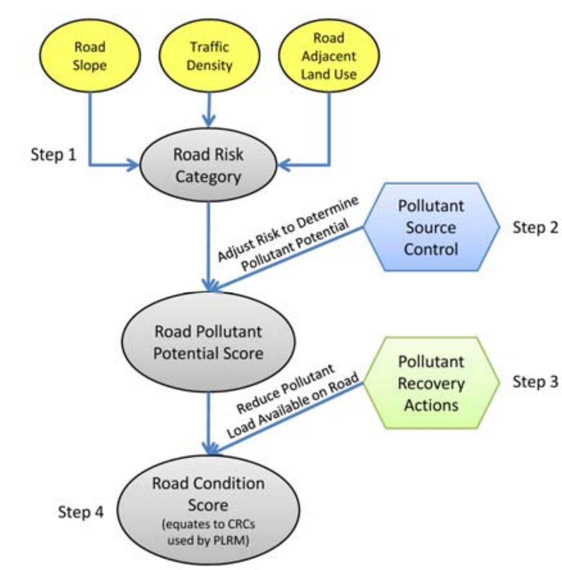

Figure 10.3 Simplified schematic illustrating PLRM Road Methodology approach

The PLRM Road Methodology was created in 2008 using an extremely limited dataset on the generation, fate and transport of FSP from roads, yet all hypothesis and assumptions are well documented. The general assumptions and approach to estimating road condition as employed by PLRM are consistent with recent research and observations (2NDNATURE and nhc 2010a, 2010b) regarding the seasonal variability of condition and primary sources and sinks. Below we review each of the PLRM Road Methodology components, present current knowledge and PLRM/Road RAM alignment, and clarify challenges associated with testing PLRM hypotheses.

Road Risk Category

Current research is pointing to winter road conditions as the greatest potential water quality risk per unit area from urban areas due to the chronic addition of anthropogenic road abrasives onto impervious road surfaces where this material is pulverized by traffic, generating particles < 16μm (see *Chapter 6.5: Measured Road Condition Variations*). In PLRM, road risk is the categorization method used to objectively estimate the relative magnitude of fine sediment particle generation spatially across the Tahoe Basin. The default PLRM Road Risk layer was developed by integrating three physiographic characteristics to infer the relative magnitude of pollutant generation (i.e., abrasive applications and native soil erosion) across roads and included: road slope, traffic density and adjacent land use density (see Figure 10.3). The default PLRM Road Risk layer was developed in this manner because comparable data on road maintenance operations for all Tahoe Basin roads does not exist. Given this limitation, the default PLRM Road Risk layer should be viewed as a first attempt to characterize the relative pollutant generation of roads throughout the Tahoe Basin. As anticipated, research conducted by 2NDNATURE after development of the default risk layer indicates that road maintenance operations markedly vary across jurisdictions (*Chapter 6.5: Measured Road Condition Variations*), including significance variance in abrasive application and recovery strategies. However, within each jurisdiction the concept of relative priority with respect to winter driver safety concerns and relative road risk with respect to abrasive applications does exist. The concept of road risk has been incorporated into the Road RAM road class attribute, where roads are categorized within a jurisdiction based on the relative intensity, frequency and type of abrasive applications, and in tandem with sweeping effectiveness to spatially extrapolate road segment scores.

Pollutant Source Controls

Temporal and spatial comparisons of road condition during WY09 and WY10 support the assumptions that the potential pollutant generation risk associated with abrasive applications can be mitigated by reducing the frequency and distribution of abrasives applied (see *Chapter 5: Road Condition* and *Chapter 6: Experimental Validation of Road RAM Concepts and Protocols*). In addition, it is reasonable to expect the implementation of advance abrasive application practices, such as the use of harder abrasives more resistant to pulverization and/or the pre-filtering of abrasives to eliminate particles < 16μm in the abrasives applied, will also result in improved road conditions, though these practices were not implemented on any of the road site studied to date. The implementation of advanced abrasive control strategies results in a PLRM CRC reduction and a corresponding improved average annual road condition.

Water quality benefits in PLRM are also achieved from road shoulder condition improvements that reduce the potential tracking of native material from shoulders onto the impervious road surface and subsequent pulverization (i.e., road shoulder protection) and reduce the source of native material generated from stormwater erosion of an unstable road shoulder. In addition, road shoulder improvements can reduce snow plow erosion of the road shoulder, which increases the source of native material available for stormwater transport. While not explicitly represented by a PLRM algorithm, a stable road shoulder can increase the effectiveness of pollutant recovery from sweeping. Winter field observations indicate significant accumulation of fine particles in the primary flow path of pervious road shoulders that are treated with abrasives, but cannot be recovered by sweeping and will be transported downslope during subsequent stormwater runoff events. The quantitative benefit of road shoulder condition improvements is constrained in PLRM, but a lower CRC is obtained if all roads within a catchment are stable and protected.

The water quality implications of road shoulder condition depend upon many interrelated factors for pollutant generation and stormwater routing, and considerations should include the annual sources of pollutants (including abrasives, road shoulder erosion by stormwater, snow plow erosion, etc.), the ability to effectively recover pollutants, and the road shoulder connectivity. There may be instances where a particular road shoulder stabilization method may not be a water quality benefit relative to the existing condition if stormwater runoff increases without a comparable improvement in the quality of runoff. The water quality benefits and implications of road shoulder condition are not completely understood and the benefits of road shoulder condition on protecting water quality must continue to be explored.

Road shoulder condition, abrasive application magnitude and sweeping effectiveness are all potential factors that could influence the road condition on any particular day. Road research indicates the FSP concentration measured on a road surface using controlled sampling methods is more sensitive to abrasive application priority and sweeping effectiveness (see *Chapter 6: Experimental Validation of Road RAM Concepts and Protocols* and Table 6.2) than it is to road shoulder condition. Thus road shoulder condition is not included in the road class spatial extrapolation technique to obtain Road RAM scores for a complete road network. However, the overlay of road shoulder condition and Road RAM scores can provide valuable insight on priority locations for future water quality improvement projects or priority areas where road maintenance practices may need to be modified to protect water quality.

Road RAM scores express the potential water quality risk downslope of a road segment based on the relative magnitude of fine sediment particles on the impervious surface at the time of observations. Road RAM observations and evaluations are limited to the impervious area, and the lack of incorporation of the amount of fine sediment particles within a road's pervious primary flow path into Road RAM is a known limitation of the tool (see *Chapter 7.4: Field Observation Limitations*), but not possible given existing data constraints.

Pollutant Recovery Actions

Estimates of the water quality benefits of sweeping type and frequency in PLRM relied upon available and existing research conducted outside of the Tahoe Basin. Continued road research in the Tahoe Basin suggests that good road conditions resulting from road maintenance practices require both source minimization (abrasive control) and sink maximization (sweeping frequency and type) as outlined in *Chapter 6: Experimental Validation of Road RAM Concepts and Protocols*. Site-specific measurements at high risk sites where advanced technology sweepers were applied (non-mechanical broom) consistently demonstrated lower FSP concentrations relative to high risk sites swept with mechanical broom units. For example, at the South Y site (EI; 2NDNATURE 2010a) known to have high abrasive applications, controlled sampling was conducted before and after passes with a mechanical broom sweeper. FSP concentrations were 854mg/L pre-sweeping and 690mg/L immediately following sweeping, with a site average of 771mg/L (March 2010). The previous March, the same site was observed to achieve a winter research minimum of 28mg/L (March 2009) during a trial sweeping program that used a regenerative air sweeper (2NDNATURE 2010a). PLRM incorporation of annual CRC reductions as a result of increased sweeping frequency and use of more efficient sweeper types is supported by existing data. However, additional research and development is necessary to understand how specifically sweeping activities modify average annual road conditions expressed as a CRC in PLRM. Road RAM incorporates pollutant recovery actions into road class, where roads are categorized by the relative magnitude of pollutant removal efforts conducted by the jurisdiction and in tandem with abrasive application priority used to spatially extrapolate road segment scores.

Characteristic Runoff Concentrations (CRCs)

As stated in *Chapter 6: Experimental Validation of Road RAM Concepts and Protocols* and presented in 2NDNATURE and nhc 2010a, the range of CRCs used by PLRM appear representative of measured road conditions in the Tahoe Basin, with PLRM maximum values exceeded and minimum values achievable. Both PLRM and Road RAM utilize the same CRC to score rating curve (see Figure 6.1).

PLRM RECOMMENDED IMPROVEMENTS

Preliminary validation of PLRM Road Methodology by the developers and Tahoe Basin jurisdictions indicate a number of potential improvements to the PLRM Road Methodology. As summarized above, research efforts continue to improve our understanding of factors influencing road condition. The Road RAM tool has been designed to better reflect our current understanding of the factors related to road maintenance operations that influence sources and sinks of FSP on Tahoe Basin roads and the relative role that road maintenance operation have on seasonal road condition. With the end goal of a more seamless integration between expected road conditions estimated by PLRM Road Methodology and actual road conditions observed using Road RAM, the following improvements to PLRM are recommended. The modifications below are not intended to be all inclusive nor highly detailed; rather they should provide the reader with a vision of how the Road RAM tool and the future PLRM Road Methodology will align.

- Road class as mapped by each respective jurisdiction and defined by the Road RAM may replace or augment the road risk categories used by the PLRM. While road risk was developed in an attempt to infer the potential for pollutant generation based on physiographic characteristics, additional road research confirms that actual road maintenance operations need to be defined and tracked to reliably estimate the potential for pollutant generation from roads.

- Road maintenance operations may be separated from road shoulder conditions in the PLRM Road Methodology to better align with Road RAM. Road maintenance operations such as abrasive application or road sweeping occur on short time scales and have a strong influence on road condition, especially during the winter. Road shoulder condition changes infrequently as erosion control or water quality improvement projects are implemented, and road shoulder condition improvement strategies should consider road maintenance practices to some degree.

- The simplicity of use between PLRM and Road RAM would be greatly improved if both tools reported expected and actual condition on a comparable and consistent scale. Besides outputting a CRC, the PLRM Road Methodology could also output a Road RAM score that can be compared to observed average annual Road RAM scores. In time, the user of the PLRM may have the option to commit to a Road RAM score by road class instead of defining specific water quality improvement actions. This approach would allow a PLRM user to explicitly commit to a road condition, which could be confirmed and track through Road RAM.

CHAPTER 11: INITIAL VERSION LIMITATIONS AND NEXT STEPS

The Road RAM version 1.0 has been developed to meet the goals, objectives and functions of the tool defined by at the onset of this effort. Tool development was conducted with limited resources and this initial version of the tool is ready for user testing and feedback (Fall 2010). All of the components of the initial Road RAM version have been implemented, tested and refined on a test catchment in Incline Village, Washoe County, Nevada. Hypothetical Road RAM results of the test catchment are included as Appendix A of the *Road RAM User Manual* to provide a tangible example for Road RAM users. It is anticipated that future resources will be secured to incorporate feedback into Road RAM version 2.0 and address some of the known limitations and potential improvements listed below.

1. The targeted research conducted on road segments on the same day across jurisdictions has provided preliminary data to suggest intensive winter and early spring road maintenance practices can maintain acceptable road conditions and reduce the potential downslope water quality risk. However, targeted research that quantitatively determines the effectiveness of a series of road maintenance strategies with respect to improved road conditions is drastically needed. Observations suggest that roads in very poor condition cannot be increased to an acceptable road condition (Road RAM score >3) by a few passes with a road sweeper during later winter following multiple winter storms and pulverization by cars. In addition, the Road RAM currently does not incorporate the potential water quality impacts of unrecoverable pollutants transported to drainage flow path where they are not accessible to mechanical removal techniques, nor does it include the potential downslope stormwater conveyance impacts of unmaintained roads. A well-designed effectiveness study on road maintenance strategies feasible in the Tahoe Basin are a high priority research need and will greatly improve our confidence and understanding of how road maintenance actions effectively improve road condition as well as stormwater quality.

2. The Road RAM tool has been designed to be as practical as possible while achieving the fundamental goal of rapidly evaluating the relative condition of a road at any particular day and tracking these conditions over time. The Road RAM is flexible to allow any user to determine the condition of specific road segment by completing a series of simple observations and database inputs. However, in order for the user to spatially extrapolate a series of road segment scores to large area of roads, the user will need the current road class map generated by the respective jurisdiction responsible for road maintenance actions.

3. One primary hypothesis of the Road RAM is that road condition improvements as measured by Road RAM scores correlate to relative pollutant load reductions as a result of pollutant source control and removal of FSP mass from the overall Tahoe Basin sediment budget. This quantitative link has been addressed through a series of targeted and controlled water quality research efforts, and there is relatively high confidence that there is a water quality benefit immediately downslope during a subsequent runoff event as a result of increased Road RAM scores. However, catchment scale validation testing needs to be performed to verify if significant changes in road conditions correspond to measurable changes in urban catchment pollutant loading.

4. The Road RAM was designed with the primary intent of providing a simple and consistent tool for local jurisdictions to determine and track the relative condition of roads in the Tahoe Basin. However, the developers also wanted to ensure RAM results met the annual road condition reporting requirements of the TMDL and Lake Clarity Crediting Program. Future versions of the Road RAM should continue to explore opportunities to better integrate the tool with other Tahoe Basin TMDL tools and needs. The future integration priorities are both programmatic and data management/operational improvements,

such as one single database that serves all of the data management needs of the Tahoe Basin TMDL tools (e.g., Road RAM, BMP RAM, PLRM and the A&T Tool). During the development of the Road RAM, necessary changes and updates to PLRM and the A&T Tool have been identified to improve the programmatic and functional synergy of these Tahoe Basin urban stormwater tools.

5. There is very high confidence that all trained Road RAM users can consistently discern roads from those in relatively good and poor condition (above 3.5 or below 2.0, respectively). The precision across users potentially declines as the road segment score increases and more variability across user results is expected for road segment scores above 3.5. It is desirable that Road RAM has a higher precision across users for conditions that are problematic (i.e. scores < 2). It must be stated that a Road RAM score of 3.5 or greater is a minimal potential risk to downslope water quality. In the future if all roads in the Tahoe Basin are observed to consistently be at a RAM score of 3.5 or higher and roads with a condition of 3 or lower become obsolete, the Road RAM tool could be refined to better resolve RAM scores for roads, by today's standards, pose little risk to downslope water quality. However, further testing of the field and scoring protocols is needed by other users and a QA/QC analysis of user precision should be performed.

6. The database is an essential component of the Road RAM tool to facilitate standardized data entry, storage, consistent analysis, and simplified presentation of results. The *Road RAM Database* v 1.0 has defined the main functions, field relationships, queries and user interaction platform. However, there are opportunities to improve the *Road RAM Database* functionality. The ultimate vision of the Road RAM tool is a fully functional online tool (operationally linked to other Tahoe Basin stormwater tools) that seamlessly integrates data entry from multiple users and presents real-time, interactive spatial summaries of Road RAM Scores. The current tool combines an online database with individual ArcGIS shapefiles. Data analysis must be manually exchanged between GIS and the database to perform Road RAM spatial calculations and present a Google® maps display of results. Future database versions would allow the user to spatially map road attributes online and perform spatial calculations internally, without requiring external GIS analysis. Additionally, the current built-in functionality of the database is limited to a select few automatic analyses of the Road RAM data. Future versions of the tool will expand this functionality and allow the user more flexibility to define the data analysis queries.

7. Throughout development of the tool, there have been decisions regarding statistical rigor of the field observation frequency and extrapolation of conditions to large areas. The final recommendations considered the need for jurisdictions to minimize their effort given resource limitations with a need for accuracy to meet the annual reporting requirements of the Crediting Program. After the Road RAM has been pilot tested, the decisions regarding minimum number of road segments, precision of RAM scores and number of required annual observations should be evaluated in light of the time it takes a typical jurisdiction to complete the Road RAM requirements under the Crediting Program.

8. Given the concern for the level of effort required for jurisdictions to perform Road RAM in conjunction with the Crediting Program, there may be some benefit for employing an autonomous entity to implement Road RAM for the entire Tahoe Basin. Potential benefits include increased number of observations and/or observation periods per water year; minimized risk of observation error; reduced costs and increased efficiencies by eliminating or reducing the need for audit observations as part of the Crediting Program; and improved consistency and comparability of results across jurisdictions. This opportunity should be discussed by regulators, project funders and jurisdictions to evaluate the potential for this to occur.

CHAPTER 12: ACRYONYMS AND GLOSSARY

LIST OF ACRONYMS

A&T Tool	TMDL Accounting & Tracking Tool
BMP RAM	Best Management Practice Maintenance Rapid Assessment Methodology
CRC	Characteristic Runoff Concentration
Crediting Program	Lake Tahoe Clarity Crediting Program
DCIA	Directly Connected Impervious Area
EMC	Event Mean Concentration
FSP	Fine Sediment Particles (<16µm)
LRWQCB	Lahontan Regional Water Quality Control Board
NDEP	Nevada Division of Environmental Protection
PLRM	Pollutant Load Reduction Model
RAM	Rapid Assessment Methodology
Road RAM	Road Rapid Assessment Methodology
SD	Standard Deviation
TMDL	Total Maximum Daily Load
WQIP	Water Quality Improvement Project

GLOSSARY

Abrasive Application Priority	The relative frequency and rate at which road abrasives are applied during winter storm and freezing conditions. Roads are designated as intensive, moderate, or rarely to never, where "intensive" roads receive the greatest annual mass per unit length of road abrasives during the year, and "rarely to never" roads receive the least.
Best Management Practices Maintenance Rapid Assessment Methodology (BMP RAM)	The BMP RAM was the first customized urban RAM tool developed for the Tahoe Basin stormwater community. The BMP RAM is a simple and repeatable field observation and data management tool to assist Lake Tahoe natural resource managers in determining the relative condition of an urban stormwater Treatment BMP. The tool consists of six distinct BMP RAM STEPs implemented by the user and a supporting database.
Calibration Year	Road RAM application to the Crediting Program. During the first year an urban jurisdiction is using the Road RAM and every fifth year thereafter the jurisdiction is expected to conduct a large number of Road RAM observations performed at many different times throughout the year in order to calibrate the jurisdictional road class categories. The purpose of calibration is to increase confidence in the spatial extrapolation techniques used during the check up years.

Characteristic Runoff Concentration (CRC)	A representative concentration for a pollutant of concern in stormwater runoff from a specific urban land use and its associated condition.
Check up Year	Road RAM application to the Crediting Program. Once a jurisdiction's implementation plans and operational activities are calibrated with Road RAM scores during a calibration year, a reduced number of observations focused on the most critical times of the year is sufficient to ensure that maintenance plans are being implemented effectively. Moderate statistical variability is acceptable during check-up years, but high variability is potentially an indication of a performance problem that should be investigated and addressed.
Directly Connected Impervious Area (DCIA)	See Road Shoulder Connectivity.
Field Observations (Road RAM STEP 4B)	A compilation of distinct rapid observations and/or measurements made at road segments over time to evaluate and track condition.
Fine Sediment Particles (FSP)	FSP refers to the mass fraction of the TSS (total suspended sediment) concentration that consists of particles 16µm or smaller, expressed as a % TSS by mass and allowing a concentration of FSP to be simply calculated.
Inventory (Road RAM STEP 2)	The user employs the provided Tahoe Basin road layer for the inventory of the roads within the designated area of interest. The user may also spatially map a variety of road attributes of the roads as desired using GIS and field mapping to later analyze road RAM scores relative to road attributes of interest.
Material Accumulation Category	Roads have a typical pattern of heavy, moderate and light material accumulation as a result of transport and sorting by vehicle traffic and wind. The distribution of material accumulation is unique to each distinct road segment and the categories are relative to one another for the specific day of observation.
Observation Period	The discrete period of time when Road RAM field observations are conducted to determine road condition and calculate Road RAM scores. If the area of interest is relatively large and requires a number of consecutive days to obtain results, all observations are lumped into one observation period and documented as the date of the first day Road RAM observations were initiated. Ideally neither road maintenance practices (e.g., sweeping or abrasive application) nor a stormwater runoff event occur during an observation period.
Pollutant Load Reduction Model (PLRM)	PLRM is a custom desktop stormwater model developed for Tahoe Basin stormwater managers to estimate the pollutant load reductions associated with catchment-scale water quality improvement actions. The PLRM Road Methodology was developed to predict the likely average annual road condition and associated characteristic runoff concentrations (CRCs) for the pollutants of concern by integrating road risk with general water quality improvement practices implemented by road risk category (nhc et al. 2009a).

PLRM Road Risk	A road attribute that incorporates road characteristics assumed to impact the relative risk of pollutant generation and transport downslope. Road risk is based on slope, traffic density, and adjacent land use, which are thought to influence the road's potential sources and transport capacity. A default road risk GIS layer has been created for the Tahoe Basin and is used in PLRM (nhc et al. 2009a).
Pollutants of Concern	The pollutants identified to have the greatest impact on the receiving waters' beneficial uses. In the case of Lake Tahoe, the continued decline in lake clarity is attributed to both the increased loading in fine sediment particles (FSP; <16µm in diameter) and algae production. Therefore the identified pollutants of concern are FSP and biologically available nutrient species: nitrate-nitrite (NO_x) and soluble reactive phosphorous (SRP).
Road Attribute	Any trait of a road network that can be spatially mapped and is expected to vary across an area of interest. Examples of road attributes include road shoulder condition, road shoulder connectivity, road surface integrity, road type, PLRM road risk, etc. The specific categorical designations within each attribute are called road attribute categories. Typically there are three to four categories associated with an attribute, defining the relative high and low bookend values and allowing for intermediate values. Depending on the road attribute, categories can be defined in absolute terms (e.g., PLRM road risk, road shoulder condition) or in relative terms (e.g, high, moderate and low sweeping priority). Road attributes of interest are inventoried by the user during Road RAM STEP 2 as desired. Road attributes can be overlain with Road RAM scores during STEP 6 to allow visual comparisons of attributes and road condition and inform maintenance actions or strategies, road improvement projects (e.g., resurfacing), water quality improvement projects, etc.
Road Class	Nine road classes are defined based on the combination of pollutant control practices employed on a particular road throughout the year, including the relative planned abrasive application priority during winter road conditions and relative planned sweeping priority when the weather is favorable for pollutant recovery. Road class is used to spatially extrapolate road segment scores to a greater area of roads to calculate Road RAM scores. The jurisdictions classify the roads in their jurisdiction based on actual maintenance practices during STEP 3.
Road Condition	The relative risk to downslope water quality from a road at the time of observations, quantitatively expressed as a Road RAM score. The primary pollutant of concern is fine sediment particles (FSP < 16µm), but total suspended sediment and nutrient species are also assumed to vary in relative magnitude with road condition. The condition of a road fluctuates over time due to the continual balance of pollutant sources and sinks based on a variety of factors, primarily physiographic characteristics and associated road maintenance practices. The Road RAM tool provides a quantitative measure of road condition on a 0-5 scale, with 5 being the best possible condition, with very low water quality risk downslope.

Road RAM	A simple and repeatable field observation and data management tool to assist Tahoe Basin natural resource managers in determining the relative condition and relative maintenance urgency of roads for water quality. The tool consists of six distinct RAM STEPs implemented by the user and the corresponding information stored in a custom *database*. Road RAM quantifies road condition for specific road segments using the Road RAM field protocols at a discrete point in time and spatially extrapolates the results to all of the roads within the subject area of interest. Road RAM results can be temporally extrapolated for comparison to expected annual road conditions.
Road RAM Database (database)	Version 1 of the database is an online database (www.tahoeroadram.com) with Google® Maps display that stores and manages all information necessary to implement, track and maintain Road RAM data and results over time. The Road RAM user generates data and/or information from GIS or field observations and enters it into the database.
Road RAM Score	A value between 0 and 5 that represents the temporally-discrete, spatially-extrapolated road condition as a result of Road RAM field observations conducted at one or more road segments. The Road RAM score is an average of road segment scores for roads of the same road class. A Road RAM score of 5 is the achievable score that results in a minimal downslope impact to water quality during a subsequent runoff event. The Road RAM score declines as the relative amount of available fine sediment particles present on the road segment increases, thus increasing the risk to downslope water quality should a runoff event occur.
Road Segment (Road RAM STEP 4A)	A 10,000 ft^2 road unit is the standardized road area evaluated by the user using the Road RAM field protocols during STEP 4. This size is assumed to be large enough to be representative of a road, while small enough that the road condition can be assessed rapidly (less than 10 minutes).
Road Segment Score	A value between 0 and 5 obtained from Road RAM field observations at one point in time for a 10,000 sq ft road unit. Road segment scores are obtained from a number of road segments belonging to the same road class. They are averaged to determine a Road RAM score for that road class.
Road Shoulder Condition	A road attribute defined by PLRM (nhc et al 2009a) to characterize the source control efforts to reduce road shoulder and primary flow path erosion along the side of the roadway. The road shoulder can be one of 4 conditions: erodible (neither protected nor stable), protected, stable or stable and protected. See Section 10.2 for summary of how road shoulder condition is determined for a specific road segment.
Road Shoulder Connectivity	A road attribute which defines the degree of hydraulic connection between the road surface and a surface water resource. Impervious area connectivity is defined using the following two terms: Directly Connected Impervious Area (DCIA) – impervious surfaces draining through a hydraulic connection (water flow is continuous) to a surface water drainage system. Where a surface water drainage system could be storm drain, a stream channel, a storm water treatment facility, or any receiving water. Indirectly Connected Impervious Area (ICIA) – impervious surfaces draining to pervious surfaces that promote sheet flow, infiltration, or storage prior to overflow discharging to a surface water drainage system.

Road Surface Integrity	A road attribute that defines the quality of the surface of the road segment. Asphalt integrity declines over time as a result of traffic wear, freeze/thaw cycles and other factors. Road observations in Tahoe Basin indicate that the relative distribution and severity of asphalt cracking and fissures can influence the road condition as a result of the storage of material within the cracks that may not be effectively recovered from sweepers.
Sweeper Type	A wide range of models and types of road sweeper types exist. Consistent with PLRM (nhc et al 2009a), Road RAM categorizes sweepers into 4 distinct types: mechanical broom, tandem operation (mechanical + vacuum assisted), regenerative air (dustless) and high efficiency vacuum assisted (dustless). The sweeper types are listed in increasing order of pollutant removal efficiency based on existing sweeper effectiveness research and summarized in nhc et al (2009b).
Sweeping Effectiveness	Sweeping effectiveness is relative ability to remove material from the road surface and improve road condition. Sweeping effectiveness is the combined implementation of sweeper type and frequency of sweeping. Sweeper types range from mechanical brooms that are not effective as removing small particulate material to vacuum-assisted units that have a relatively more effective at removing smaller particles from a road surface. Frequency of sweeping is a key component of effectiveness to improve road condition, as single and/or infrequent sweeping does not have the same ability to maintain road condition as more frequent efforts. See PLRM Development Document (nhc et al. 2009b) and Section 5.3 for more information.
Threshold Value	A Road RAM score of 2 is identified as the threshold value, below which there is high confidence that the road is an immediate risk to downslope water quality. A Road RAM score of 2 equates to a predicted FSP concentration of 291 mg/L generated from the road segment based on existing data (2NDNATURE and nhc 2010a, 2010b).
Total Suspended Sediment (TSS)	TSS is the mass of sediment contained in a known volume of water, and stormwater samples analyzed for TSS can be used to quantify the suspended sediment loads transported in runoff.

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