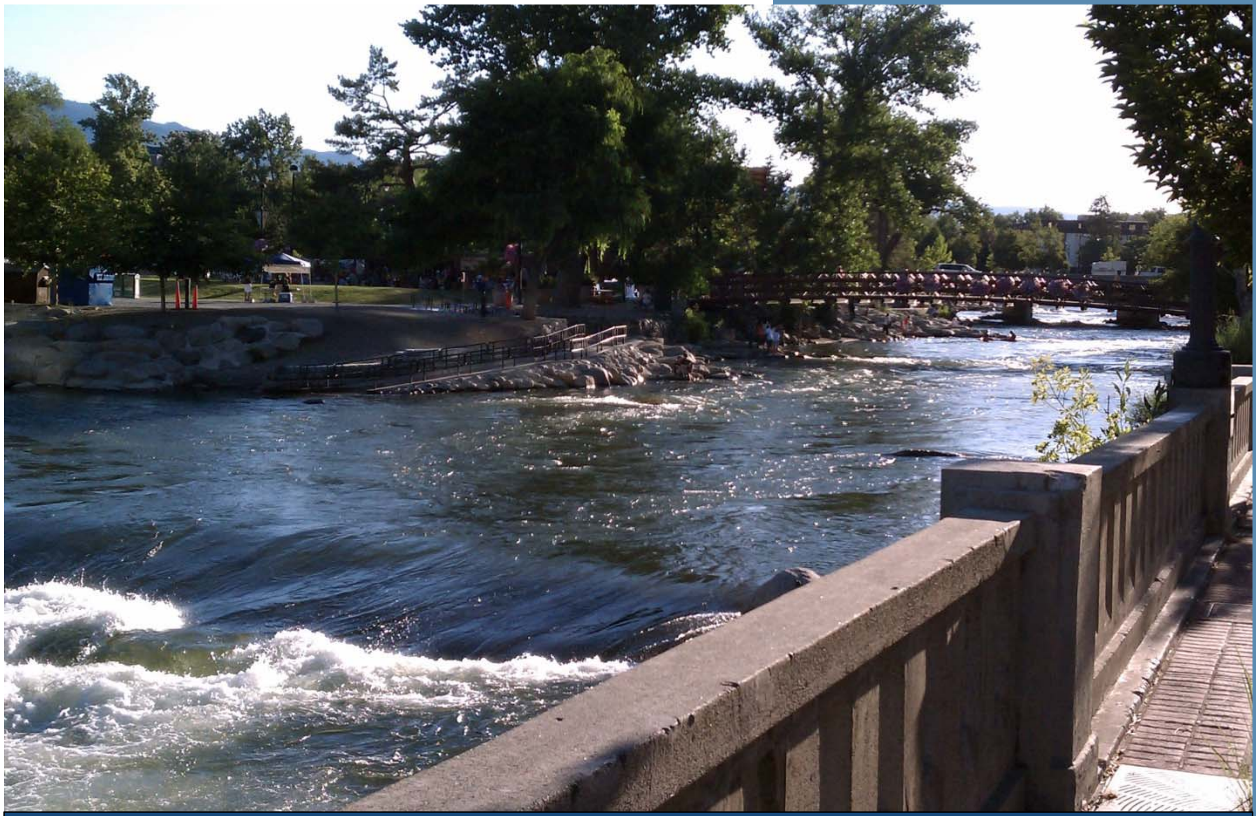

Technical Rationale for Review and Revision of Truckee River Nutrient Water Quality Standards

Prepared for:
Truckee River Third-Parties
City of Reno, City of Sparks,
Washoe County and
Truckee Meadows Water
Authority

FINAL REPORT

February 2014

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1
Executive Summary

Background

In, 2011, the Nevada Division of Environmental Protection (NDEP) issued notice of intent to conduct a triennial review of water quality standards (WQS). With this notice, NDEP solicited input from all interested parties on any aspect of Nevada's WQS that a person believes the NDEP should consider for potential revision. In response to the public notice, the City of Reno, City of Sparks, and Washoe County each submitted a letter stating their request for a review and potential revision of the total phosphorus (TP) and total nitrogen (TN) water quality standards for the Truckee River.

The Cities of Reno and Sparks, Washoe County and the Truckee Meadows Water Authority (TMWA) (the "third-parties") are jointly leading a third-party effort to review the Truckee River total nitrogen and total phosphorus Total Maximum Daily Load (TMDL) for the Truckee River. NDEP and the United States Environmental Protection Agency (U.S. EPA) have agreed that a third-party review of the 1994 TMDL is appropriate to determine whether the assumptions underlying the 1994 TMDL remain valid, and to identify new scientific and technical information and/or changes in conditions and river operations that may warrant a different approach to addressing nutrient issues in the watershed.

Further, NDEP and U.S. EPA have agreed to consider any third-party proposed revisions to the existing nutrient water quality standards in an effort to ensure that the water quality standards are the most appropriate criteria and that any TMDL revision be based on best available water quality standards. This third-party led effort, sponsored by the Western Regional Water Commission (WRWC), is designed to provide scientific support in the reassessment of water quality standards.

Technical Approach

The third-parties are collaborating with NDEP, U.S. EPA, and other stakeholders to review the existing nutrient water quality standards and develop a technical basis for any revisions. The focus of the technical effort is to examine the linkage between instream nutrient concentrations and response of the river in terms of dissolved oxygen (DO) concentrations. The third-parties, with funding from the WRWC, have retained LimnoTech to conduct the majority of the technical work, and this report serves as the primary technical documentation of this effort.

The foundation of the technical work is the development and application of a set of watershed and river water quality models that provide linkage between nutrient levels in the Truckee River and resulting dissolved oxygen levels:

- Watershed Analysis Risk Management Framework (WARMF) – watershed model
- Hydrological Simulation Program FORTRAN (TRHSPF) – river water quality model

The two linked models were run in conjunction to provide an understanding of how the Truckee River system assimilates nutrients and complies with dissolved oxygen criteria under representative flow conditions. The models simulate the complex relationship of how nitrogen and phosphorus, in combination with other factors such as temperature and light, can lead to excessive growth of algae and ultimately a situation of depleted dissolved oxygen. The use of the models developed specific to the Truckee River will help ensure that any proposed nutrient criteria reflect the site-specific response of the Truckee River to nutrient levels and are protective of beneficial uses.

Simulation results indicate that both models satisfactorily predict hydrology and water quality for an extended calibration/confirmation time period (2000 to 2011) and are suitable for use to support the third-party WQS and TMDL review efforts.

The linked and calibrated WARMF-TRHSPF models were used to evaluate potential nitrogen and phosphorus water quality criteria with the following steps:

1) Develop inputs from a flow management model;
2) Simulate baseline flow and water quality conditions for each representative flow condition;
3) Run iterative simulations to test a range of nitrogen and phosphorus concentrations that could be considered as potential water quality criteria; and
4) Post-process raw model results (dissolved oxygen concentrations) to calculate the level of DO criteria compliance, and translate this compliance into a nutrient-DO compliance relationship plot.

Stakeholder Outreach

Engagement with watershed stakeholders is an important element of the water quality standards review process in order to fully vet the interests, concerns, and potential impacts of any changes to water quality standards. At the beginning of the Truckee River WQS review process, a set of key watershed stakeholders was engaged on an individual basis. The purpose of engagement was to inform those potentially affected about the technical work being developed and give them an opportunity to ask questions and provide input. From this set of interested stakeholders, a Truckee River WQS Focus Group was formed and a series of workshops were conducted. All Focus Group members were encouraged to provide comments throughout the process via both written feedback forms and opportunities for verbal comments during the meetings.

Summary of Findings

Several observations were summarized from the water quality modeling effort which examined a range of nutrient concentrations over both low (10^{th} percentile) and average (50^{th} percentile) flow regimes.

In the Nevada region of the Truckee River (East McCarran Blvd. to Pyramid Lake Paiute Tribal Boundary), the level of DO criterion violation is low over the entire range of annual average nutrient concentrations examined. Additional observations include:

- For both low and average flow regimes, the DO criterion compliance does not show a sensitivity to increasing phosphorus concentrations;
- For the low flow regime, the DO criterion compliance shows a slight sensitivity to increasing TN concentrations; however, this response does not occur unless the annual average TN concentration is greater than approximately 0.80 mg/L; and

In the Pyramid Lake Paiute Tribal region of the Truckee River, the level of DO criterion violation varies depending on the annual average nutrient concentration and the flow regime. Additional observations include:

- For the low flow regime, the level of DO criterion violation in the Truckee River is sensitive to the annual average phosphorus concentration; however, no DO criterion violations were calculated for the average flow regime;

- For both the low flow and average flow regimes, DO criterion violation in the Truckee River does not show sensitivity to the average annual TN concentration over the range examined; however, for the low flow regime the DO criterion violations ranged from approximately 3% of days to 6% of days depending on the phosphorus concentration;
- For the average flow regime, no DO criterion violations were calculated for the Truckee River regardless of the annual average nutrient concentrations; and,
- DO criterion violations in the Truckee River are seen to be sensitive to other factors beyond the instream phosphorus concentration such as flow condition, channel geometry and stream temperature.

The purpose of the process and analysis described in this report is to provide NDEP and U.S. EPA with technical information to support their triennial review of the nutrient water quality standards for the Truckee River in Nevada. Any proposed recommendations for changes from the existing nitrogen and phosphorus numeric nutrient criteria will be developed by and documented by NDEP in a rationale document which will be available for public comment. Any proposed changes will need to be approved by the State Environmental Commission and U.S. Environmental Protection Agency before becoming effective under the federal Clean Water Act.

Two alternate scenarios for Nevada nutrient standards were given detailed examination: 1) Maintenance of existing standards, and 2) Switching the phosphorus standard from the existing TP=0.5 mg/L to the PLPT standard of OP=0.05 mg/L. Results shows that if the Nevada phosphorus criterion were changed to be consistent with the current PLPT criterion, there would be no expected increase in DO violations in the Truckee River under either low flow or average flow conditions compared to conditions under existing standards.

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2
Introduction

2.1 Watershed Background

The Truckee River watershed covers approximately 3000 square miles in California and Nevada and is unique due to its lake-to-lake configuration. The headwaters of the Truckee River begin at the northern end of Lake Tahoe (Figure 2-1). The Truckee River flows approximately 140 miles, first through the Sierra Nevada mountain range in California, and then into the plains and desert of Nevada, passing by the Cities of Reno and Sparks. As the Truckee River turns north near Wadsworth, Nevada, it flows through Pyramid Lake Paiute Tribal Reservation and terminates in Pyramid Lake.

The Truckee River is a highly controlled system in which water is released from California reservoirs in order to maximize water availability for competing municipal, agricultural, industrial, recreational, and fish habitat uses. A large amount of river flow is diverted downstream of Reno and Sparks at Derby Dam into Lahontan Reservoir via the Truckee Canal. The purpose of this federal inter-basin transfer is to augment the flows available from the Carson River to provide irrigation water for the Newlands Project, a Bureau of Reclamation program initiated in 1903. While the Truckee River needs adequate flows to support human enterprise, it also needs adequate flow with acceptable water quality to support aquatic life. In the Truckee River – Pyramid Lake system, the life cycle patterns of Cui-ui (an endangered fish species) and the Lahontan cutthroat trout (a threatened fish species) are affected by factors such as low dissolved oxygen, elevated temperatures, and reduced stream flow, particularly below Derby Dam.

Within the state of Nevada, the Truckee River historically has been challenged by a limited water supply, competing water demands, and difficulty meeting aquatic life uses under existing water quality standards and TMDLs. In the 1980's, water quality sampling indicated that the Truckee River was impaired for low dissolved oxygen. An overabundance of benthic algae (attached algae that grow on solid surfaces such as river bed rocks and submerged logs) was determined to be the primary cause of low dissolved oxygen. Benthic algae, also called periphyton, thrive in conditions with ample bioavailable nutrients (nitrogen and phosphorus) and shallow water depth (allowing for light penetration to the bottom) and increased opportunity for photosynthesis. Primary sources of nutrients to the Truckee River include natural background sources, nonpoint sources (e.g., stormwater, irrigation return flows, septic systems), and point source discharges. The largest point source in the watershed is the Truckee Meadows Water Reclamation Facility (TMWRF) that serves the cities of Reno and Sparks and portions of Washoe County.

Total nitrogen (TN) and total phosphorus (TP) water quality criteria for the Truckee River were developed by the Nevada Division of Environmental Protection (NDEP) in the 1970's and have been refined over time, with the current standards set in 1984. In 1994, NDEP established Total Maximum Daily Loads (TMDLs) for TN and TP in the Truckee River (NDEP, 1993). The 1994 Truckee River TMDL resulted in a total nitrogen allocation of 1000 lb/day, with half of the load (500 lb/day) allocated to TMWRF and the bulk of the remainder to nonpoint sources. The TMDL also specifies a total phosphorus allocation of 214 lb/day, with 134 lb/day allocated to TMWRF and the remainder to nonpoint sources.

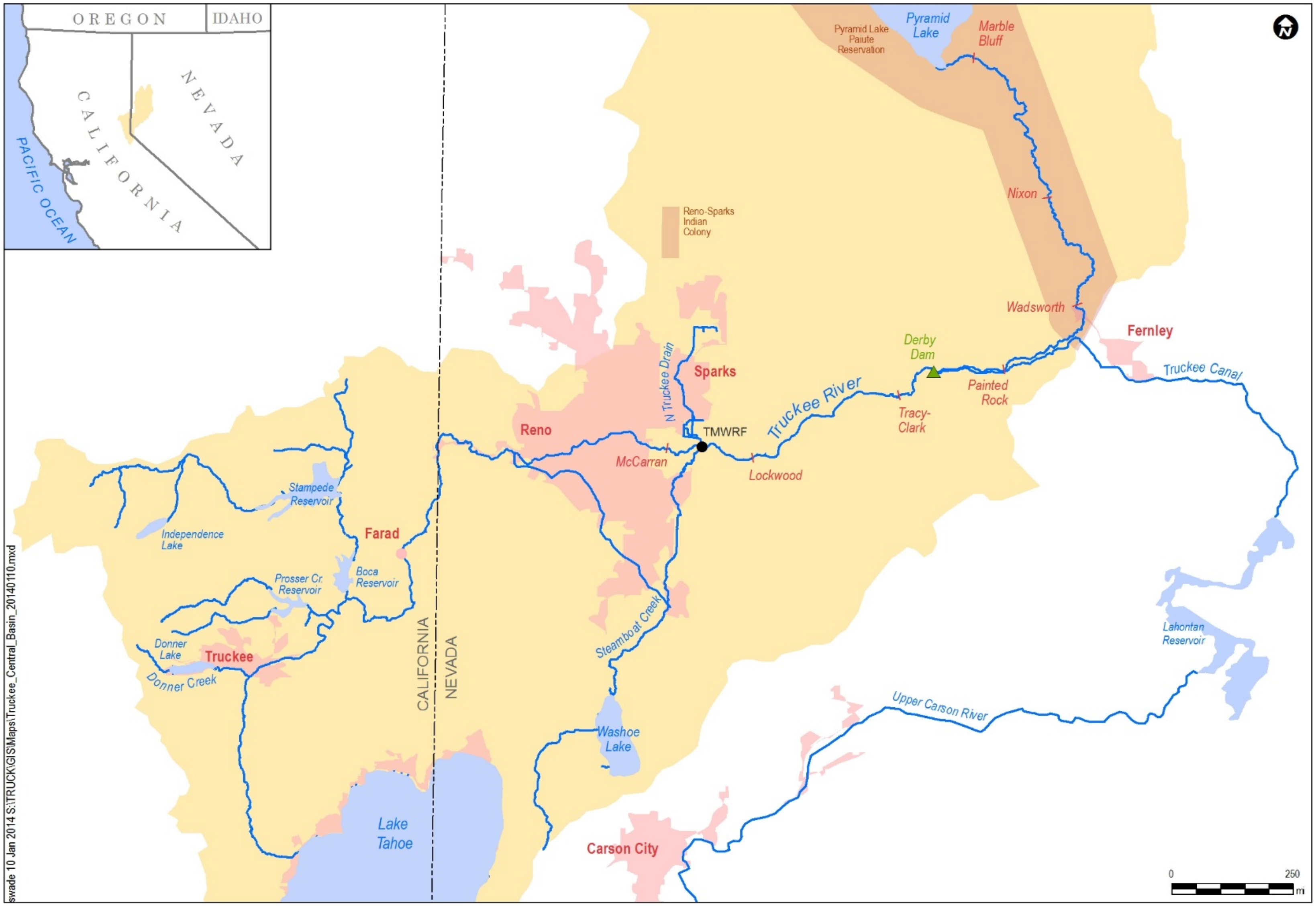

Figure 2-1. Truckee River in California and Nevada

TMWRF is currently able to comply with the waste load allocation (WLA) designated by the 1994 TMDL. The ability of TMWRF to meet this WLA and serve future growth of the service area may require very costly advanced treatment technologies.

2.2 Justification and Drivers for WQS Review

The Cities of Reno and Sparks (Cities), Washoe County and the Truckee Meadows Water Authority (TMWA) are jointly leading a third-party effort to review the Truckee River total nitrogen and total phosphorus TMDLs. In addition to regional growth, other driving factors which have motivated the TMDL review include improved river flow operations, advances in the science of river processes, and a desire for more flexible solutions to water quality management. NDEP and the United States Environmental Protection Agency (U.S. EPA) have agreed that a third-party review of the 1994 TMDL is appropriate to determine whether the assumptions underlying the 1994 TMDL remain valid, and to identify new scientific and technical information and/or changes in conditions and river operations that may warrant a different approach to addressing nutrient issues in the watershed.

Further, NDEP and EPA have agreed to consider any third-party proposed revisions to the existing nutrient water quality standards (WQS) in an effort to assure that the water quality standards are the most appropriate criteria and that any TMDL revision be based on best available water quality standards. The existing nutrient water quality criteria were based on limited information such as algal growth studies conducted in the late 1970's (before TMWRF upgrades) and U.S. EPA's "Red Book" (U.S. EPA, 1976). NDEP has recognized that these criteria are in need of improvement and has identified "improve numeric water quality criteria" to be one of their goals related to NDEP Standards Activities (NDEP, 2006).

2.2.1 Third Party Letter Proposing Review of Water Quality Standards

On January 6, 2011, NDEP issued notice of intent to conduct a triennial review of water quality standards. With this notice, NDEP solicited input from all interested parties on any aspect of Nevada's WQS that a person believes the NDEP should consider for potential revision. NDEP Bureau of Water Quality Planning (BWQP) opened a public comment period (January 6 through February 25, 2011) and held 3 public workshops to receive public comment on Nevada's surface water quality standards, particularly standards that BWQP should consider for review, revision and/or development during the next triennial review period (2011 through 2014/15).

In response to the public notice, the City of Reno, City of Sparks, and Washoe County each submitted a letter (dated February 22, 2011) stating their request for a review and potential revision of the TP and TN water quality standards for the Truckee River. The letter states three primary reasons for requesting this review:

1) The phosphorus TMDL currently in place is insufficient to meet the existing WQS. Nevada's 2006 303(d) Impaired Waters List indicates that three reaches of the Truckee River from East McCarran Blvd. to Wadsworth have been delisted for total phosphorus impairment because there is an EPA approved TMDL; however, it is noted that, periodically, the phosphorus concentration in the river "does not meet water quality standards";

2) A review of the nutrient WQS is consistent with goals identified in NDEP Bureau of Water Quality Planning's (BWQP) 5-Year Plan: July 2006 – July 2011 (NDEP, 2006). The plan recognizes NDEP's support of a Truckee River Third-Party TMDL review and notes that Nevada desires to first address any issues associated with inappropriate beneficial uses and numeric criteria before developing a TMDL; and

3) Legal, technical and operational changes that have occurred in the watershed since the adoption of the current WQS (1984) and the current TMDL (1994) warrant a review of the nutrient WQS. Conditions that have changed include development of improved databases and modeling tools for analyzing river conditions, upgrades to TMWRF operations, the adoption of Pyramid Lake Paiute Tribe (PLPT) water quality standards (PLPT, 2008), adoption of the Truckee River Water Quality Settlement Agreement, progress towards implementation of the Truckee River Operating Agreement (TROA), purchase and control of river water rights by the municipalities, and changes in the status and operation of the Truckee Canal.

In response to public workshop comments and the third-party letter, NDEP stated that ***"BWQP will review the nutrient standards in conjunction with the TMDL review currently underway by the Cities of Reno and Sparks, Washoe County, Truckee Meadows Water Authority, NDEP and USEPA"*** (NDEP, undated).

2.3 Existing Water Quality Standards

A water quality standard is comprised of three components. The first component of a WQS is the designated (or beneficial) use, which considers the value of the water body for uses such as public water supply, fish protection, recreation, agriculture, industry, and navigation. A particular water body may have multiple designated uses. Water quality criteria are a second component of a WQS which are established to protect each designated use. Designated uses such as recreation typically have water quality criteria for bacteria that protect human health. An aquatic life designated use may be supported by criteria for temperature or dissolved oxygen. Criteria may be expressed numerically (as pollutant concentrations) or as narrative requirements (qualitative statements that establish water quality goals). For each pollutant, criteria are established with the intent to protect the most restrictive designated use. It is assumed that all other designated uses will be protected if criteria are met for the most stringent designated use. Antidegradation is a third component of a WQS designed to protect water quality conditions that are better than the beneficial use criteria requirements.

Water quality standards for the Truckee River in the State of Nevada are designated under two jurisdictions: the NDEP and the Pyramid Lake Paiute Tribe (PLPT) Environmental Department. The NDEP water quality standards only apply for waters within the State of Nevada but not within the PLPT lands. The water quality standards established by the PLPT only apply for those portions of the Truckee River within PLPT lands (Figure 2-1).

Nitrogen and phosphorus numeric criteria have been developed for both jurisdictions to help control the potential growth of algae which could in turn result in reduced dissolved oxygen concentrations. Water quality models can simulate the complex relationship of how various levels of nutrient concentrations, in combination with other factors such as temperature and light, can lead to excessive growth of algae and ultimately a situation of depleted dissolved oxygen. The use of water quality models as part of the nutrient water quality standards review will help ensure that any proposed nutrient water quality criteria reflect the site-specific response of the Truckee River to nutrients and provide protection of the beneficial uses.

The focus of this water quality standards review effort is to specifically evaluate the **numeric nutrient criteria** that have been set for the Truckee River **within the state of Nevada** to protect the **aquatic life beneficial use**. This effort will not examine the appropriateness of any beneficial use or other numeric criteria. The effort will not examine the appropriateness of any beneficial uses or water quality standards developed for the portions of the Truckee River under the jurisdiction of the PLPT.

In reviewing the appropriateness and possible revisions of numeric nitrogen and phosphorus criteria, it is necessary to evaluate compliance with the existing numeric dissolved oxygen criteria. For this effort, the dissolved oxygen criteria are the primary biological endpoint of interest to evaluate the river's ability to meet the beneficial use of aquatic life. Although only the NDEP-derived numeric criteria are considered for revision, the effort will also consider compliance with downstream (i.e., PLPT) water quality nutrient criteria to ensure protection of beneficial uses specified for downstream waters.

As background, the sections below present a summary of the existing numeric nitrogen, phosphorus, and dissolved oxygen criteria for the Truckee River within both Nevada and PLPT jurisdictions.

2.3.1 Total Nitrogen

In Nevada, the total nitrogen numeric criteria for the Truckee River include both an annual average and single value concentration. As documented by NDEP, the current TN criteria for the Truckee River below East McCarran Blvd. were established in 1984 (NDEP, 2010). Both the annual average criterion of 0.75 mg/L (as N) and single value criterion of 1.2 mg/L were based upon criteria established in 1980. While these criteria were set to protect beneficial uses, records suggest that they may have been based upon observed local water quality that existed at that time. Little documentation has been found to explain the source of these criteria (NDEP, 2010). In the upper Truckee River (CA/NV Stateline to East McCarran Blvd.), annual average and single value TN RMHQ (requirement to maintain existing higher quality) criteria also were set to be consistent with 1980 criteria.

In 2008, the PLPT established total nitrogen criteria that were the same as the existing NDEP criteria (PLPT, 2008). A summary of the existing Truckee River total nitrogen criteria are shown in Figure 2-2.

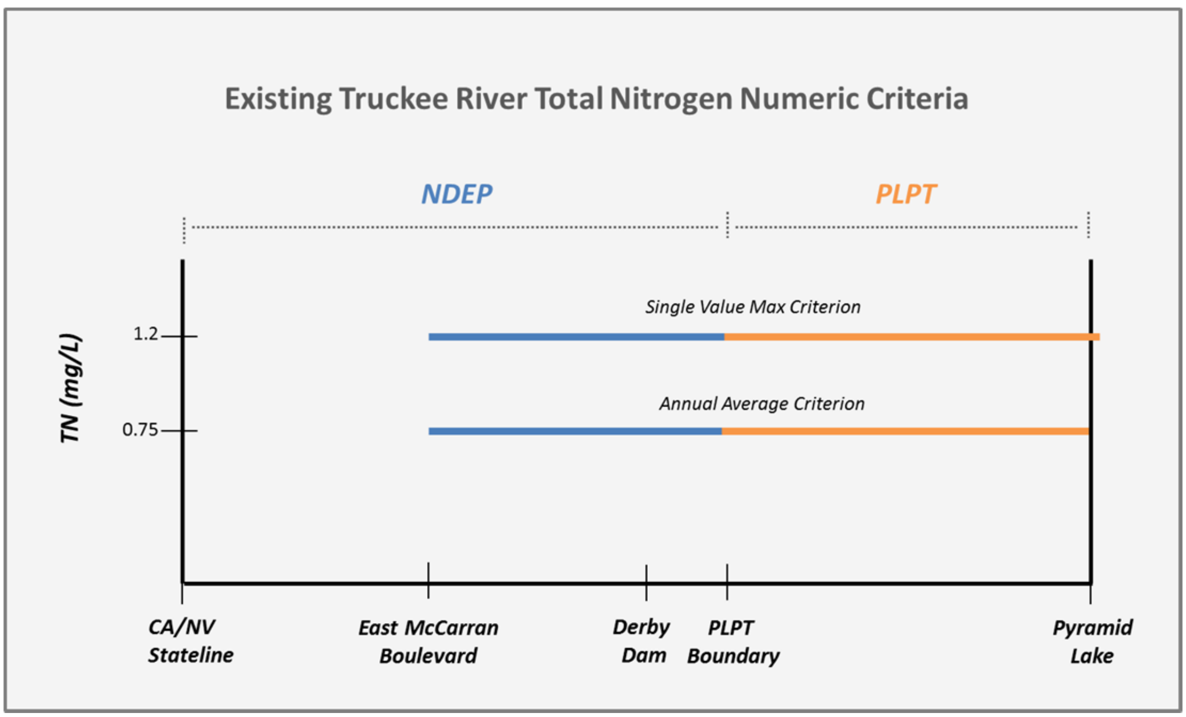

Figure 2-2. Schematic of existing total nitrogen numeric criteria in the Truckee River

2.3.2 Phosphorus

Phosphorus typically exists in natural waters as living and dead plankton, precipitates of phosphorus, phosphorus adsorbed to particulates, and dissolved inorganic and organic phosphorus. For different regions of the Truckee River, phosphorus numeric criteria are established as either annual average total phosphorus (TP) or dissolved reactive phosphorus (DRP), which is essentially equivalent to orthophosphate (OP). In 1984, NDEP established an annual average TP criterion of 0.05 mg/L (as P) for the Truckee River below East McCarran Blvd. The origin of the criterion is not well documented but it corresponds to a 1980 criterion of 0.15 mg/L (as PO_4). The numeric difference between the two standards is due to a unit conversion, as total phosphorus concentrations reported "as PO_4" are three times larger than total phosphorus concentrations reported "as P" (NDEP, 2010). NDEP also established TP and orthophosphate criteria for the Truckee River upstream from East McCarran Blvd. in 1984. An annual average TP criterion of 0.1 mg/L (as P) was set based upon USEPA's 1976 Red Book and a single value orthophosphate criterion of 0.05 mg/L (as P) was set based upon "best available" site specific information. According to the Rationale document in NDEP files, "*laboratory algae growth potential studies have concluded that nitrogen and phosphorus added in combination to Truckee River water will stimulate the growth of algae. The best available site specific information suggest that with a sufficient amount of nitrogen present in the water, single value orthophosphate concentrations in excess of 0.05 mg/l will stimulate algae growth.*" (NDEP, 2010). RMHQ standards were also set for this region of the Truckee River based on 95% confidence interval of the mean (assuming normal distribution) of the existing data.

For the Truckee River from the PLPT reservation boundary down to Pyramid Lake, PLPT set a numeric criteria that the annual average flow-weighted average concentration of DRP must not exceed 0.05 mg/L. Based on the assumption that the Truckee River is nitrogen-limited, the PLPT established a DRP standard rather than a total phosphorus standard recognizing that phosphorus is a nutrient of secondary importance in regulating algal growth, and that DRP is the bioavailable fraction of total phosphorus (PLPT, 2008). Because DRP is only one component of TP, DRP concentrations will always be less than TP concentrations. The existing NDEP TP criterion is more stringent than the PLPT DRP criterion.

A summary of the Truckee River annual average phosphorus criteria is shown in Figure 2-3.

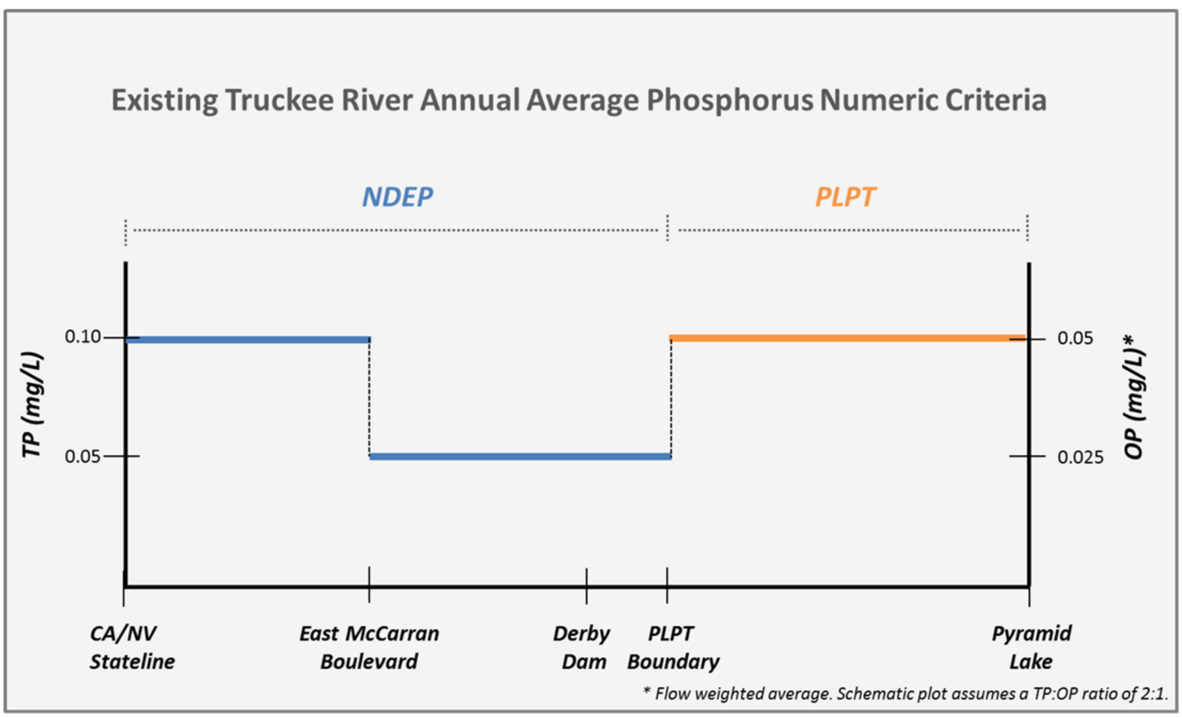

Figure 2-3. Schematic of existing annual average phosphorus water quality standards in the Truckee River

2.3.3 Dissolved Oxygen

Dissolved oxygen (DO) is a measure of oxygen dissolved in water and is an important indicator of a water body's ability to support aquatic life. The two primary sources of oxygen in the aquatic environment are aeration and photosynthesis. Dissolved oxygen depletion occurs when water's capacity to hold oxygen decreases or oxygen is used by another chemical or biological process and is not available for aquatic organisms (e.g., insects and fish). Several processes cause dissolved oxygen depletion including increased water temperature, nitrification (the conversion of ammonia to nitrate), impoundments (which can reduce aeration), organic matter decay, and algal decay and respiration. While aquatic plants produce oxygen during the process of photosynthesis, they also consume oxygen through the processes of decay and respiration. During most periods, plants add more oxygen than they consume. During certain periods of time (e.g. low-light conditions, end of the growing season), plants consume more oxygen than they produce. During these conditions, excessive levels of plants caused by high nutrient concentrations can lead to significant decreases in dissolved oxygen during these periods.

The dissolved oxygen criteria for both NDEP and PLPT require that dissolved oxygen must be greater than 6 mg/L from November through June, and greater than 5 mg/L from July through October for the portion of the Truckee River downstream of Derby Dam. Upstream, from the CA/NV Stateline to Derby Dam, the NDEP DO criteria require that dissolved oxygen must be greater than 6 mg/L from November through March and greater than 5 mg/L from April through October. The dissolved oxygen standard is more restrictive downstream of Derby Dam from April through June to provide a higher level of protection for Cui-ui and Lahontan cutthroat trout egg incubation and fry. The most recent 303(d) list indicates no impairment for dissolved oxygen along the entire length of the Truckee River within the State of Nevada (NDEP, 2012).

2.4 General Process for Truckee River Nutrient Water Quality Criteria Review

The Truckee River nutrient water quality standards review is a third-party effort driven by a collection of water agencies with interests in the Truckee River (Cities of Reno and Sparks, Washoe County, and TMWA). The third-parties are collaborating with NDEP, U.S. EPA, and other stakeholders to review the existing nutrient water quality standards and develop a technical basis for any revisions. Efforts to review the nitrogen and phosphorus criteria will examine the linkage between instream nutrient concentrations and response of the river in terms of DO concentrations. The process will ensure that any proposed nitrogen or phosphorus numeric criteria will result in compliance with the DO criteria set for the Truckee River by NDEP. This report serves as the primary technical documentation of this effort.

2.4.1 Third-Party Process for Technical Evaluation

The third-parties, with funding from the Western Regional Water Commission (WRWC), have retained the services of the consulting firm LimnoTech to conduct the majority of the technical work. The foundation of the technical work is the development and application of a set of watershed and river water quality models that provide linkage between nutrient levels in the Truckee River and resulting dissolved oxygen levels. The models incorporate other important factors that can influence dissolved oxygen levels such as temperature, sunlight, organic matter, and aeration. The use of the models developed specific to the Truckee River will help ensure that any proposed nutrient criteria reflect the site-specific response of the Truckee River to nutrient levels and are protective of beneficial uses.

This nutrient water quality standards review process involved close collaboration of a Truckee River WQS/TMDL Working Group (Working Group) which includes representatives from the following organizations:

- City of Reno (third-party)
- City of Sparks (third-party)
- Washoe County (third-party)
- TMWA (third party)
- Western Regional Water Commission
- NDEP
- U.S. EPA Region 9
- LimnoTech (consultant)
- Stantec (consultant)

Development of the technical work and preparation of this report has included the following general activities which have occurred over several years:

- Preliminary development and calibration of watershed and river water quality models (1998 – 2011)
- Collaboration of the third-parties, NDEP and U.S. EPA to develop and finalize a TMDL/WQS Review Work Plan to describe process for the review including roles, responsibilities and expectations (2011)
- Water quality model updates and refinement (2011-2013)
- Focus Group Stakeholder outreach and coordination (2011-2013)
- Working Group development of technical work (2011 – 2013):
  - Review of model calibration/confirmation
  - Development of model application approach
  - Establishment of major assumptions for analysis, conduct model simulations
  - Interpretation of model results
- Documentation of technical analysis (2013)

2.4.2 NDEP Process for Water Quality Standards Adoption

Nevada's Continuing Planning Process (NDEP, 2007) outlines the water quality standards adoption process. The State Environmental Commission (SEC) has the authority to adopt and amend water quality standards. The process involves the submittal of a proposal for water quality standards revisions in the setting of a public hearing. Two public notices are required 45 and 30 days prior to the hearings and all data analysis and rationales must be available to the public not later than at the time of the 30 day notice.

Prior to the public hearing, a public participation process must occur. This must include a public workshop, conducted by NDEP, to solicit comments from interested persons. A public notice of this workshop is required at least 30 days prior to the workshop and any proposed regulatory changes should only be in draft form at the time of the workshop.

The Legislative Council Bureau (LCB) must receive a package including the existing and proposed regulations at least 60 days prior to the SEC hearing. The LCB will review the proposed regulations to determine if the language is clear, concise, and suitable for incorporation into the Nevada Administrative Code (NAC).

After the SEC hearings, the U.S. EPA will review the State Attorney General certification stating that the standards were adopted in accordance with State and Federal laws. U.S. EPA will also review the adopted standards, rationale, and antidegradation policy. Federal regulations requires that changes to State water quality standards must be approved by U.S. EPA before they can be implemented by the State for Clean Water Act purposes.

This report, prepared on behalf of the third-parties, serves as the basis for NDEP and U.S. EPA to develop a technical rationale for any proposed changes to the Truckee River nitrogen and/or phosphorus numeric criteria. The analysis and development of the technical information presented in this report was produced in a cooperative manner between the 3rd Parties, NDEP, and U. S. EPA. NDEP and U.S. EPA reviewed and guided the development of the technical material throughout the process. The draft rationale will be presented at open public workshops will serve as the basis for the SEC hearings. Throughout the development of the technical analysis, the third-parties have conducted outreach with and solicited input from key watershed stakeholders.

2.5 Stakeholder Outreach – Truckee River WQS Focus Group

An important element of the water quality standards review process is engagement with watershed stakeholders in order to fully vet the interests, concerns, and potential impacts of any changes to water quality standards. At the beginning of the Truckee River WQS review process, a set of key watershed stakeholders were engaged on an individual basis. The purpose of engagement was to inform those potentially affected by or interested in the review of the water quality standards and give them an opportunity to ask questions and provide input. From this set of interested stakeholders, a Truckee River WQS Focus Group (Focus Group) was formed and a series of workshops were conducted. In addition to members of the Working Group, the Focus Group includes representatives from the following organizations:

- Churchill County
- City of Fernley
- Pyramid Lake Paiute Tribe
- Truckee River Irrigation District (TCID)
- U.S. Fish and Wildlife Service
- Nevada Department of Wildlife (NDOW)

A series of six Focus Group Workshops were conducted from 2011 through 2013[1]. A seventh Focus Group workshop is planned for January 2014. Appendix A provides a brief overview of topics covered at each workshop and Appendix B includes a list of the Focus Group participants and attendance at each meeting. All materials provided at the Focus Group workshops were posted to the Truckee River Information Gateway website and are publically available (http://truckeeriverinfo.org/tmdl). Information distributed to the Focus Group included technical fact sheets, PowerPoint presentations, technical memorandums and model calibration reports.

All Focus Group members were encouraged to provide comments throughout the process via both written feedback forms and opportunities for verbal comments during the meeting. The Focus Group was specifically asked to review and provide comment on the water quality model confirmation report: ***Model Confirmation & Database Extension for WARMF and TRHSPF*** which was provided on July 23, 2013 (LimnoTech, 2013). The Focus Group will also be given the opportunity to review and provide comment on this report. Appendix C includes a summary of comments received by Focus Group members and the Working Group's general response to each comment.

[1] A period of inactivity occurred during 2012 due to a recommendation from NDEP that the Truckee River water quality standards review should wait to proceed until the Lahontan Reservoir water quality standards review is complete. It was later determined by U.S. EPA and NDEP that the two efforts could proceed in parallel, so the Truckee River WQS process was restarted in early 2013.

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3
Summary of Water Quality Models

3.1 Model Development

In efforts that began in the late 1990's, two modeling tools were developed to simulate watershed processes, stream hydrology, and water quality to support a proposed third-party TMDL review and possible revision for the Truckee River:

- Watershed Analysis Risk Management Framework (WARMF) – watershed model
- Hydrological Simulation Program FORTRAN (TRHSPF) – river water quality model

The combination of extensive data and improved computer tools has greatly increased the general understanding of the Truckee River and related watershed processes as well as improved the ability to better simulate the river and watershed under contemporary conditions. Thus, the modeling and analysis performed for the current water quality standards review (and potentially a later TMDL review) will be an improvement over the 1994 TMDL analysis.

The two linked models were run together to provide an understanding of how the Truckee River system assimilates nutrients and complies with dissolved oxygen criteria under a representative flow condition. The models simulate the complex relationship of how nitrogen and phosphorus, in combination with other factors such as temperature and light, can lead to excessive growth of algae and ultimately a situation of depleted dissolved oxygen. The following sections provide a brief summary of both models.

3.1.1 Watershed Model – WARMF

WARMF is a watershed model adapted to the Truckee River basin that provides capabilities to simulate nonpoint source pollution loads under current and/or future land use and management practices. The spatial domain of WARMF encompasses the entire Truckee River basin from the tributaries flowing to Lake Tahoe downstream to Pyramid Lake (Figure 3-1). Within this broader model domain, sub regions of the model are relevant for linkage to the river water quality model (TRHSPF).

WARMF is a physically-based model which represents the watershed as a network of land catchments, stream segments, and (as necessary) lake layers. WARMF is a public domain model available from U. S. EPA and has been applied to other arid, heavily managed watersheds such as the Santa Clara and San Joaquin basins of California. The model simulates all standard constituents including flow, temperature, nitrogen, phosphorus, organic carbon, suspended sediment, and total dissolved solids. WARMF distinguishes between storm water and non-storm water nonpoint sources when calculating pollution loads and can also simulate potential reductions of nonpoint source loads due to changes in the watershed such as BMPs, conversion of agricultural lands, and removal of septic systems.

The model uses land use and land cover data, topography, and precipitation records to calculate a mass balance of pollutants as transported in snow and soil hydrology, overland flow, and groundwater accretion to river segments. WARMF has capabilities to model the impacts of diversions and irrigation withdrawals. The model diverts water out of rivers, applies a portion of the diverted water and irrigation to specified land areas, and computes infiltration and runoff. WARMF data inputs include meteorology, land use, and managed flows (which can be based on either historical records or projected by a flow management model). The model also incorporates point source inputs based on historic flows and loads.

WARMF was originally adapted to the Truckee River Basin during 1998 to 2001. The model adaptation included data compilation, model enhancements (to account for diversions and irrigation, periphyton, and septic systems), model setup, calibration, and confirmation. WARMF uses existing regional data including land use, water quality and quantity as well as data collected through the Coordinated Monitoring Program. The model accounts for municipal and agricultural diversions, irrigation, periphyton, septic tank loading, fertilizer application to farms and golf courses, and livestock loading to the land as well as rivers. Regional stakeholders participated in the model development by providing input data and feedback through a series of workshops. The initial WARMF-Truckee model adaptation and calibration was completed and documented by Systech Engineering (Systech Engineering, 2007). In 2011, LimnoTech extended the WARMF databases and conducted model confirmation simulations through the year 2008. In 2012 and 2013, LimnoTech further extended the WARMF database and conducted model confirmation simulations through the year 2011 (LimnoTech, 2013).

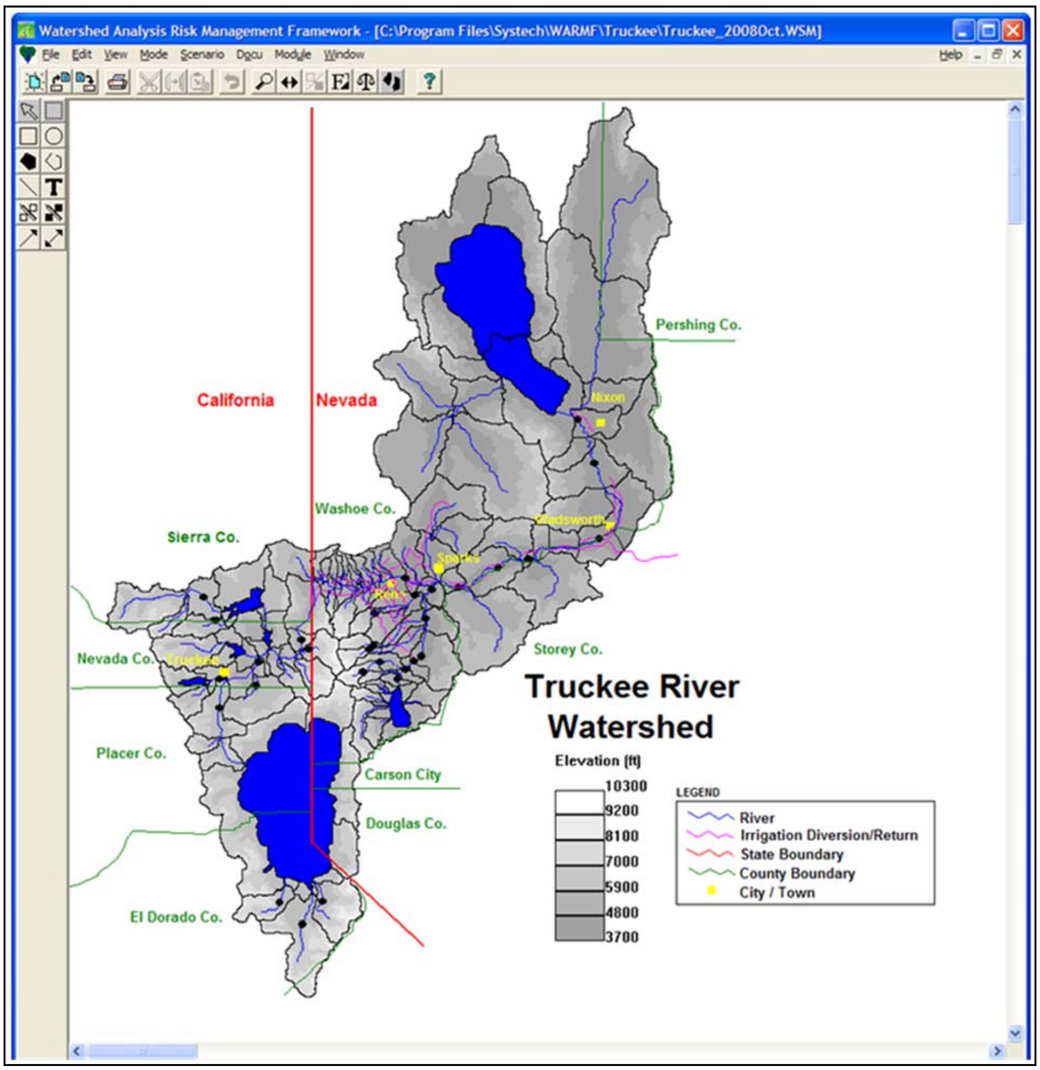

Figure 3-1. Spatial domain of WARMF applied to the Truckee River

3.1.2 River Water Quality Model – TRHSPF

TRHSPF is an instream water quality model used to predict occurrences of low dissolved oxygen resulting from benthic algae, low flow, and other pollutants. It is an enhanced version of the USEPA supported and publically available Hydrological Simulation Program – FORTRAN (HSPF) model and incorporates peer-reviewed empirical and theoretical equations related to the growth, death, nutrient preferences, and removal of benthic algae based on the DSSAMt model, which is a variation of the DSAMM III model used for the 1994 Truckee River nutrient TMDL.

Through a model review process, it was determined that algal subroutines in the DSSAMt were the best currently available for the Truckee River system. LimnoTech was contracted to develop TRHSPF as the long-term management tool for river water quality by enhancing the HSPF model with the periphyton routines from DSSAMt, and improving other select routines. TRHSPF is based on the modeling work completed by Lynn Taylor of the United States Geological Survey (USGS) in 1998, which resulted in a calibrated and validated HSPF model for flow, stream temperature, and total dissolved solids (TDS) in the Truckee River (Taylor, 1998).

From 2001 to 2004, LimnoTech expanded the HSPF framework to better describe nutrients and benthic algae growth and set up the model to simulate several different time periods including 1990, 1995, 1996, and July 2000 to September 2002. The enhancements made to HSPF included adding additional growth limitation terms, additional loss terms, and increasing the number of benthic algal types that can be simulated. The additional growth terms include a temperature limitation, standard Michaelis-Menton nutrient limitation terms, a stream velocity limitation term on nutrient availability, a light limitation term using the Steele equation, and a density limitation. Loss terms include both basal and photo-respiration, a grazing and disturbance loss, and a scour loss. In addition, other routines were improved in HSPF and included a macroinvertebrate grazing/removal function; insignificant nutrient concentrations were changed from being hardwired into the model to being user selected parameters; total solar radiation was adjusted to better represent photosynthetically active solar radiation (PAR); the hydraulic representation was improved; and the capability to simulate nitrogen-fixing algae and multiple algal groups was incorporated. The selection, development, and enhancements made to HSPF are documented in the January 2008 calibration report (LimnoTech, 2008). The improved model, which is now being applied to the Truckee River, is referred to as TRHSPF. The primary water quality algorithms of TRHSPF were documented in a technical memorandum and were provided to the Focus Group in 2011 (LimnoTech, 2011) and the document is available on the *Truckee River Information Gateway* website.

TRHSPF simulates water quality and flow in the Truckee River from McCarran Bridge in Reno to Marble Bluff Dam, just upstream of Pyramid Lake (Figure 3-2). The model domain covers a 55-mile section of the Truckee River and the system is divided into 43 linked segments. The model runs with a 0.5 hour time step and provides time series output for the following parameters at each model reach from Reno to Pyramid Lake: flow, temperature, dissolved oxygen, BOD, nitrate, ammonia, phosphate, total nitrogen, total phosphorus, pH, total dissolved solids, alkalinity, and benthic algae biomass. TRHSPF inputs include flows and constituent loads at the upstream boundary (Truckee River at East McCarran Blvd), tributary inputs (e.g., Steamboat Creek and North Truckee Drain), and nonpoint source load contributions along the length of the river. These inputs can be based on either historical data or output from the watershed model, WARMF. TRHSPF also requires inputs to represent diversions and point sources, which can be based on either historical data or output from a flow management model.

Calibration and confirmation of the enhanced TRHSPF model was conducted by LimnoTech using data collected by USGS, NDEP, Truckee Meadows Water Reclamation Facility (TMWRF), and the Truckee River Coordinated Monitoring Program (CMP) (LimnoTech, 2008). The calibration period focused on July 2000 through September 2002 because monitoring data from this time period included comprehensive benthic algae measurements. A model confirmation was also conducted by comparing model output to observed data for three other years to add additional confidence in the model parameters selected. The additional years used for model confirmation were 1990, 1995, and 1996. These years were selected because they represent low, medium, and high flow periods. Truckee River watershed stakeholders participated in TRHSPF training workshops that were conducted by LimnoTech and sponsored by the City of Reno and City of Sparks in 2003, 2006, and 2009.

In 2011, LimnoTech extended the TRHSPF database and conducted model confirmation simulations through the year 2008. In 2012 and 2013, LimnoTech further extended the TRHSPF database and conducted model confirmation simulations through the year 2011 (LimnoTech, 2013).

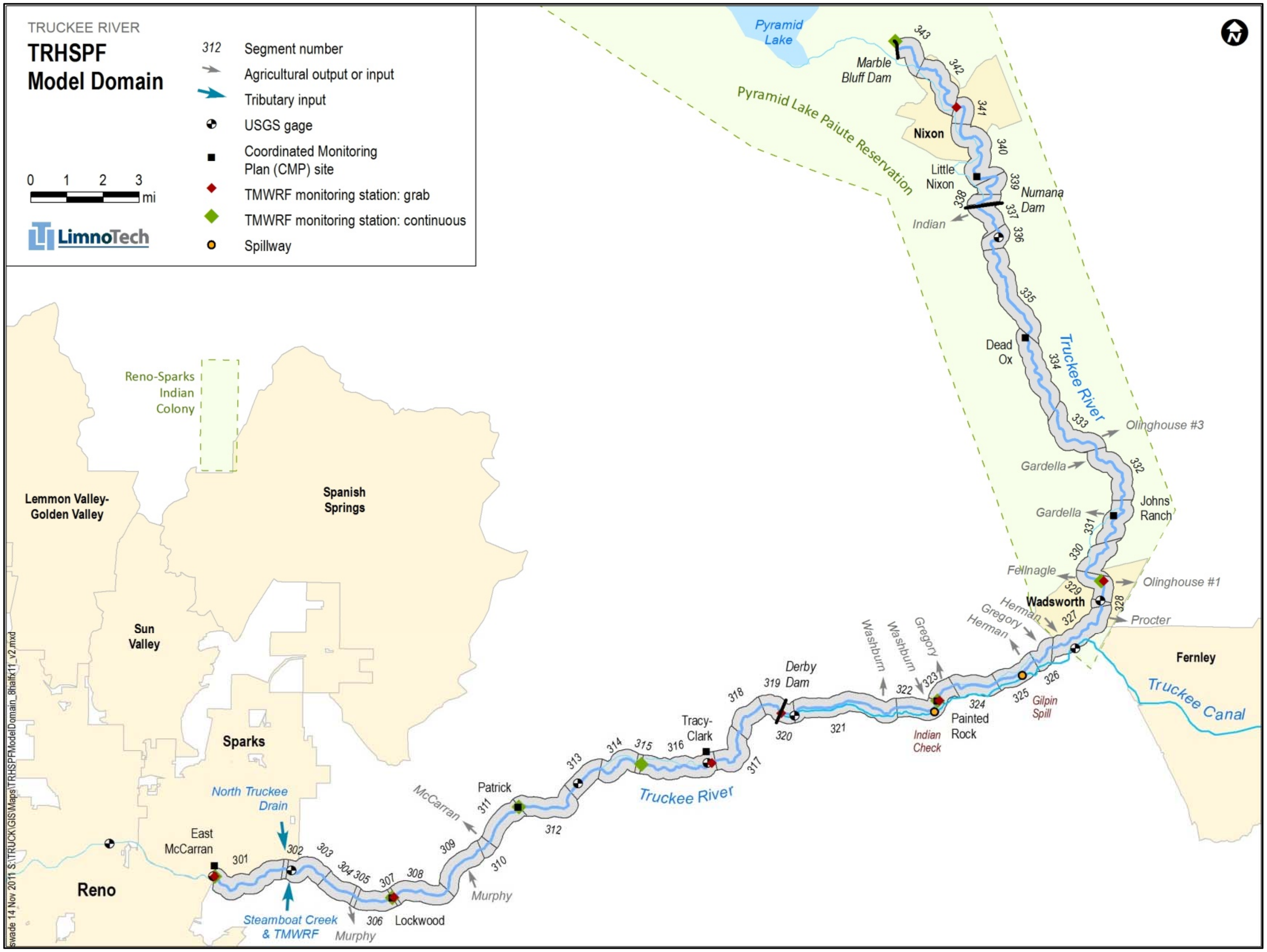

Figure 3-2. TRHSPF model domain and spatial segmentation

3.2 Model Updates and Calibration Confirmation

Model calibration was previously conducted for both models and focused on time periods through 2002 (TRHSPF) and 2004 (WARMF). Detailed descriptions of both models can be found in the original calibration reports (Systech Engineering, 2007; LimnoTech, 2008). In the time period from 2011-2013, an additional model confirmation exercise was undertaken to extend the simulation, for both models, to more recent time periods (LimnoTech, 2013). The model update process included an extension of databases to include more recent data such as land use/land cover, climate, point source discharge, diversions, observed streamflow, and observed water quality. The simulation time periods of both models were extended and models were run for the historical period of January 1, 2000 through December 31, 2011. Simulation results indicate that both models satisfactorily predict hydrology and water quality for the entire extended time period (2000 to 2011) and are suitable for use to support the third-party WQS and TMDL review efforts (LimnoTech, 2013). Both the Working Group and the Focus Group were invited to review and comment on the documentation for the original model calibration efforts as well as the more recent model update and confirmation.

3.3 Water Quality Model Linkage

One objective of using improved modeling tools to review nutrient WQS and TMDLs in the Truckee River is the use of a linked (coupled) watershed-receiving water model. A linked tool provides the capability to evaluate the Truckee River water quality response to changes in watershed activities (e.g., land development, BMPs) in addition to changes in point source loadings. For purposes of the WQS review, WARMF is used primarily to provide insight on the time-variability and speciation of nutrients being delivered to the Truckee River. As described in their respective calibration reports, WARMF and TRHSPF were initially developed and calibrated independently of one another. TRHSPF was originally calibrated using monitoring data to specify flow and water quality at all upstream boundaries, tributary inputs and nonpoint source loading contributions along the length of the river. However, the WQS and TMDL review and revision requires that the modeling tools work in conjunction with each other. To create a linked (coupled) model system, TRHPSF was re-run using WARMF-generated output to specify the upstream flow and load boundary conditions for Truckee River (at East McCarran Blvd.), Steamboat Creek, and North Truckee Drain. WARMF output was also used as the flow and load boundary condition for sub-catchment runoff adjacent to the Truckee River. Figure 3-3 shows the linkage of WARMF and TRHSPF for model calibration and confirmation simulations.

A tool was developed to convert WARMF output into a format that could easily be read by TRHSPF. Water quality constituents were converted from the constituents in WARMF to the constituents needed by TRHSPF. All constituents were converted using 1:1 ratios with the exception of total nitrogen (TN) and total phosphorus (TP) which required further delineation of the fraction of organic nutrient in labile and refractory forms. These two constituents were split 50:50 between organic labile and organic refractory components after subtracting off the dissolved inorganic components. The distribution of organic matter between refractory and labile forms is not readily measured, and is known to vary between sources. LimnoTech (2008) reviewed several modeling applications and found that the assumption of the split between refractory and labile forms ranged from 75% refractory : 25% labile to 25% refractory : 75% labile. A split of 50% refractory : 50% labile was used for this application as a mid-point between the ranges used in other model applications. For time periods that overlapped with the original TRHSPF calibration, the WARMF-driven linkage scenarios were compared to data-driven scenarios to verify linkage of the simulated parameters (LimnoTech, 2013).

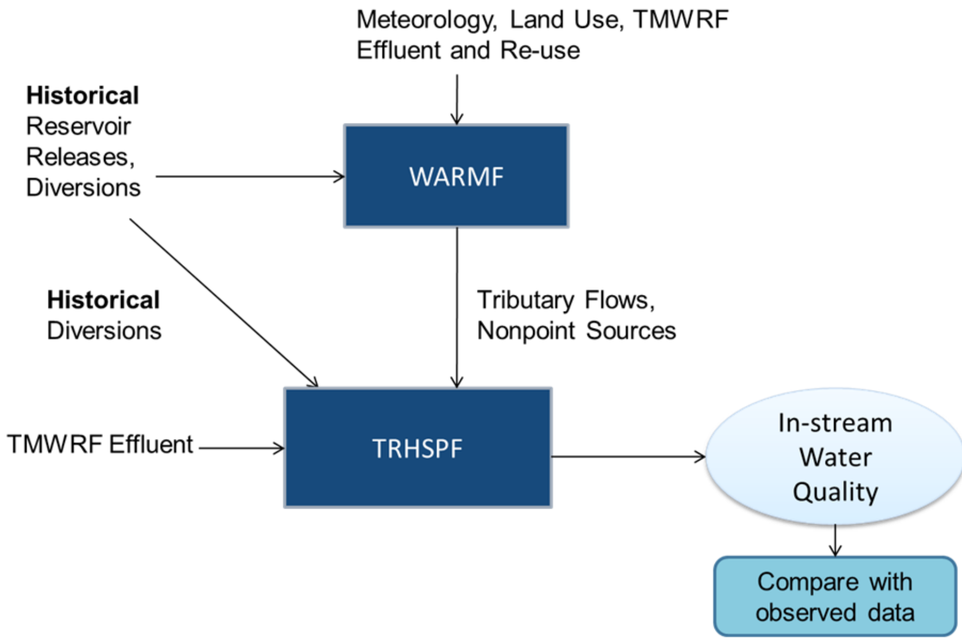

Figure 3-3. Model linkage for model calibration and confirmation to historical conditions

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4
Overview of Model Application Approach

4.1 Objectives of Model Application

The primary objective for the use of the linked WARMF-TRHSPF models to support the Truckee River nutrient water quality standards review process is to identify appropriate (site-specific) nutrient criteria for both nitrogen and phosphorus. Specifically, the models can be used to better understand the river's water quality response, in terms of a dissolved oxygen (DO) endpoint, to ranges of nutrient concentrations under a range of flow conditions. The models simulate the complex relationship of how nitrogen and phosphorus, in combination with other factors such as flow, temperature and sunlight, can lead to excessive growth of algae and ultimately a situation of depleted dissolved oxygen.

The relationship between flow, nutrients, benthic algae, and the resulting water quality (e.g., DO concentrations) is highly complex and can best be characterized through water quality modeling. A study published by the Water Environment Research Foundation (WERF, 2013) focused on the proper use of models to set water body-specific nutrient goals. The study identified both WARMF and HSPF as appropriate models capable of quantifying the relationship between nutrients and their impacts in terms of water quality or ecological response indicators. Figure 4-1 provides a schematic diagram of the relationship between nutrients and dissolved oxygen that the linked models were used to help quantify. The models can help determine if this relationship is a "flat" response (suggesting that an increased nutrient concentration would not lead to increased DO depletion) or if the relationship is sloped in a positive direction (suggesting that increased nutrients would lead to increased DO depletion). If the relationship were to show a "knee of the curve" (a point of maximum inflection), it would suggest that DO criteria violations are unresponsive to changes in nutrients at low levels, but become more responsive once a threshold (i.e., the knee) nutrient concentration is exceeded.

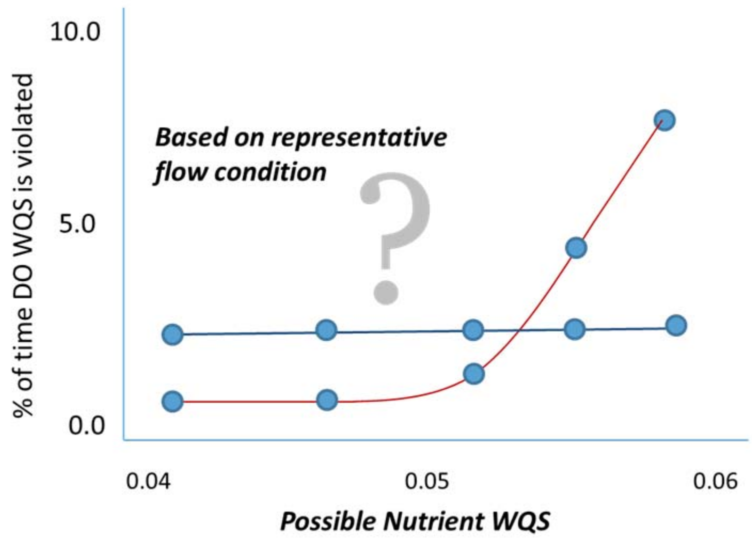

Figure 4-1. Schematic of the nutrient-DO response relationships derived from TRHSPF

Section 3 of this report and previous reports (LimnoTech, 2013; LimnoTech, 2008; Systech Engineering, 2007) documented the calibration and confirmation of TRHSPF and WARMF. The purpose of the calibration and confirmation simulations was to generate confidence that the models are capable of accurately simulating historical river conditions (i.e., flow and water quality).

In model *application mode*, the purpose is different and the models are used to predict the water quality response of the river under a set of hypothetical conditions. The models were used in application mode to calculate the Truckee River's response to a wide range of nutrient levels under representative low and average flow conditions, assuming current day river operational strategies. Flow in the Truckee River is highly dependent on the management of reservoirs in the upper watershed, and the operation of diversions and return flows throughout the system. The management of the water in the Truckee River for any given year is directly dependent on both climate conditions (i.e., precipitation and snowpack) and existing operational rules, policies and water rights agreements that are in place. Due to the complex management of the Truckee River flows, water quality simulations developed to represent a targeted, representative flow condition are best characterized using a flow management model rather than historical data. Figure 4-2 illustrates the linkage of a flow management model to the linked watershed (WARMF) and river water quality (TRHSPF) models to support the Truckee River water quality standards review process.

The application of the linked models to evaluate site-specific numeric nutrient criteria focused on evaluating a range of water quality *concentrations*. If future work leads towards a rigorous review of the Truckee River nutrient TMDLs, the models could be used in a similar manner to better understand possible balances of point and nonpoint *loads* which result in attainment with water quality criteria for nitrogen, phosphorus, and dissolved oxygen concentrations.

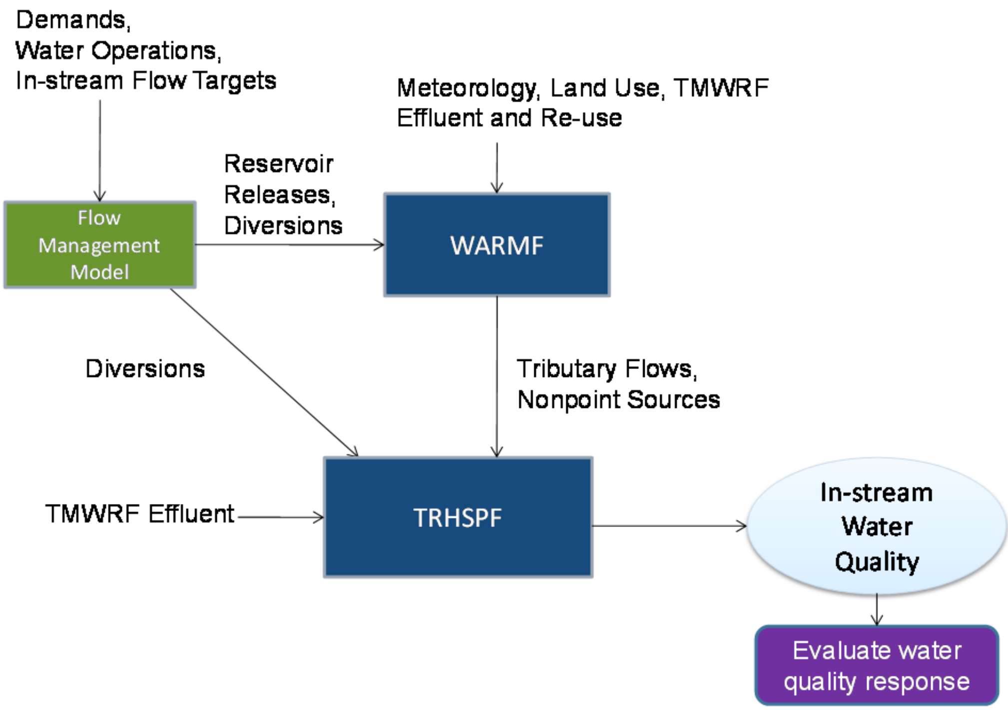

Figure 4-2. Model linkage for water quality standards analysis

4.2 Model Application Approach

An approach for using the linked WARMF-TRHSPF models to evaluate potential nitrogen and phosphorus water quality criteria was developed by the Working Group. The specific steps of the approach are described below:

1. **Develop Inputs from a Flow Management Model:** First the most appropriate flow management model was selected. Then, two representative (low flow and average flow) flow conditions were developed based on output from the flow management model.
2. **Simulate Baseline Conditions:** WARMF was used to simulate the baseline flow and watershed loading for each representative flow condition based on reservoir releases, diversions, and return flows specified by the flow management model. WARMF results were exported and linked to the TRHSPF river model to establish flow and concentration boundary conditions at key watershed locations: Truckee River at East McCarran Blvd, Steamboat Creek at the confluence with the Truckee River, North Truckee Drain at the confluence with the Truckee River, and smaller tributary and distributed nonpoint loads along the length of the Truckee River from East McCarran Blvd. to Marble Bluff Dam. A baseline TRHSPF simulation was conducted and results were evaluated to identify any issues.
3. **Run Iterative WQS Scenarios:** A series of iterative TRHSPF simulations were conducted to examine a range of nitrogen and phosphorus concentrations representing potential nutrient criteria. Figures 4-3 and 4-4 show two matrices of the target nitrogen and phosphorus concentrations that were examined through scenario analysis. Each "X" within the matrix represents a single simulation that examines a specific combination of potential nitrogen and phosphorus criteria concentrations. The "cross hairs" simulation for each set represents either the current NDEP numeric nutrient criteria

(TN = 0.75 mg/L and TP = 0.05 mg/L) or the current PLPT numeric nutrient criteria (TN = 0.75 mg/L and OP = 0.05 mg/L).

Each scenario was run for a one-year time period. To set up the run, all major incoming loads in the baseline simulation were scaled up or down so that the resulting instream concentrations were reasonably close to the target nitrogen and phosphorus levels. Instream concentrations varied temporally throughout the year (i.e., the concentration for a given season was higher or lower than the target value) with the specific variability being dictated by WARMF results; however, the objective was to match the target water quality concentration on an average annual basis. This provided consistency with the existing nitrogen and phosphorus water quality criteria, which are specified as annual average limits. River locations where the incoming loadings were scaled included: the upstream TRHSPF boundary of Truckee River at East McCarran Blvd., Steamboat Creek at the confluence with the Truckee River, North Truckee Drain at the confluence with the Truckee River, TWMRF discharge, and an agricultural nonpoint load in the vicinity of Indian Ditch just upstream of Marble Bluff Dam. For the nonpoint load in the vicinity of Indian Ditch, it was only necessary to scale the phosphorus loads in order to achieve an instream concentrations reasonably close to the target levels.

As noted in Figures 4-3 and 4-4, a range of TN target concentrations was evaluated at each of two different phosphorus levels: Ortho-P at 0.05 mg/L and Total P at 0.05 mg/L. These are the current average annual numeric criteria specified by PLPT and NDEP for their respective portions of the Truckee River below East McCarran Blvd (see Section 2.3 for more information).

4. **Post-Process Model Results:** For each iterative scenario, the hourly dissolved oxygen concentrations simulated for each river model segment and each day of the simulation were post-processed. Multiple methods were used to calculate the level of compliance with existing dissolved oxygen numeric criteria at each river model segment and each day of the one year simulation. The post-processed results were then translated into nutrient-DO compliance relationship plots similar to the one depicted in Figure 4-1.

		Total Phosphorus (mg/L)					
Total Nitrogen (mg/L)		0.030	0.040	0.050	0.075	0.100	0.125
	0.55			X			
	0.65			X			
	0.75	X	X	X	X	X	X
	0.85			X			
	1.00			X			

Figure 4-3. Matrix of ranges of TN and TP concentrations examined with a set of iterative simulations

Total Nitrogen (mg/L)	Orthophosphate (mg/L) 0.030	0.040	0.050	0.075	0.100
0.55			X		
0.65			X		
0.75	X	X	X	X	X
0.85			X		
1.00			X		

Figure 4-4. Matrix of ranges of TN and Ortho-P concentrations examined with a set of iterative simulations

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5
Major Assumptions for Model Runs

The main premise of the model application approach described above is to use a flow management model to drive the linked water quality models in order to evaluate a range of potential numeric nutrient criteria. The model application approach assumes climate and hydrological conditions that are reflective of a historical year of interest and assumes that the management of river water (operations of dam releases and diversions) are reflective of current day conditions to the extent possible. As model inputs were developed to conduct the matrix of simulations, a variety of assumptions had to be made. The following sections describe and document some of these model inputs and assumptions.

5.1 Water Quality Standards and Flow Considerations

One of the most important components of the model application approach described above is the establishment of the underlying flow condition for model simulation. Flow in the Truckee River is highly managed and can vary dramatically from wet years to dry years. Also, the many laws and water rights agreements that dictate the management of the water have evolved over time. The direct use of historical flow data as model input would be inadequate to represent a climate condition of interest under operating conditions that reflect current day practices to the extent possible.

The highest potential for algal growth and depleted DO is during low flow periods at low flow locations (e.g., downstream of large diversions). In the State of Nevada, water quality standards are set to protect beneficial uses throughout the expected range of flows; however, not during extreme high or low flows. As documented by NDEP [Nevada Administrative Code (NAC) 445.1.121(8)], water quality standards do not apply if flows are too low:

> *"The specified standards are not considered violated when the natural conditions of the receiving water are outside the established limits, including periods of extreme high or low flow"*

Nevada regulations do not clearly define how to specify a representative low flow condition for evaluation of potential water quality criteria. In some systems, a standard approach is to use a 7Q10 flow statistic to represent a low flow condition. The 7Q10 is the lowest stream flow measured for seven consecutive days that would be expected to occur once in ten years. It is based on a long record of measured streamflow data. There are two major drawbacks to using a 7Q10 approach in the Truckee River:

- The 7Q10 approach provides only a single, low flow value rather than a continuous flow record for a longer time period (e.g., season or year). It is necessary to simulate a longer time period across multiple seasons to comprehensively simulate the complexities of nutrient, periphyton and dissolved oxygen dynamics. For example, nutrient loads brought into the system during the high flows of spring will influence the extent of periphyton growth and DO depletion that occurs in the late summer, lower flow periods.
- The Truckee River is highly regulated and water rights agreements have changed in recent years. Therefore, a long period of record of measured streamflow does not provide a robust basis for calculating a 7Q10 flow statistic.

In coordination with NDEP and U.S. EPA, it was determined that the water quality standards review effort should not rely on historical flows to establish a representative low flow condition but rather use "best professional judgment" to define an alternative approach. The Working Group collectively determined that a previously developed flow management model should be used to derive appropriate flow conditions. First, model output generated from the flow management model for the longest period of record available should be examined. Then, one or more representative flow regimes should be selected from this dataset. The representative flow regime should cover a complete annual period, including both spring melt periods and low flow periods in the summer and fall. NDEP recommended that the nutrient water quality criteria evaluation be based on two primary flow conditions generated by a flow management model:

- Approximate 10th percentile lowest year from 100 years of flow management model output; and
- Approximate 50th percentile (average) year from 100 years of flow management model output.

Throughout the report the 50th percentile flow regime is referred to as the "average flow regime"; therefore, the "average flow regime" is actually representative of a median rather than a mean flow condition.

5.2 Selection of Flow Management Model and Most Applicable Scenario

The first two steps in defining representative low flow and average flow periods involved selecting the most appropriate flow management model and the most applicable scenario from that flow management model.

5.2.1 Flow Management Model

To support water quality modeling for the Truckee River numeric nutrient criteria evaluation, a flow management model is required to provide managed flow inputs throughout the system that reflect a representative flow condition and current river management practices. These include inputs to both the WARMF and TRHSPF models (Figure 4-1). For WARMF, the flow management model provides upstream reservoir releases and diversions within the domain of WARMF. For TRHSPF, the flow management model provides diversions within the model domain and TMWRF discharge flows. Two existing flow management models were reviewed for applicability to support the water quality standards modeling: TROM (Truckee River Operations Model) and RiverWare.

TROM: The Truckee River Operations Model (TROM) is a river operations model that projects regulatory flows (reservoir releases, diversions) under various flow management conditions. One of the main uses of TROM has been to support the development and approval process of the Truckee River Operating Agreement (TROA) (USBR, 2008). Inputs to TROM include historical hydrologic data for rivers tributary to reservoirs and local runoff; reservoir operation rules; historic and/or projected demands for municipal, industrial, and agricultural uses; and instream flow targets (e.g., Floriston Rates). For a given flow management condition, TROM simulates preferred operating conditions and calculates resulting reservoir releases and streamflows on a monthly or bi-weekly basis. The database for TROM scenarios includes 100 years of records from 1901 to 2000. TROM simulations include multiple scenarios for each of the 100 years under either a current (2002) or future (2033) time horizon for water demands. TROM has been used in the Truckee River basin since approximately 1975 (USBR, 2008).

RiverWare: RiverWare is a newer generation model that has been adapted to the Truckee-Carson River basins. It simulates complex river and reservoir operations in a generalized modeling environment (Zagona et al., 2001). RiverWare runs on a daily timestep and simulates operations within the Truckee and Carson basins according to all current basin policy including the 1935 Truckee River Agreement, the 1944 Orr Ditch Decree, the 1959 Tahoe Prosser Exchange Agreement, the 1994 Interim Storage Agreement, and 1997 OCAP (Coors, 2006). There are currently two versions of RiverWare applied to the Truckee Basin: 1) Operations Model representative of pre-TROA conditions with detailed operational data inputs, and 2) Long-Term

Planning Model representative of pre-TROA operations with more general operational data inputs and 100 years of records. RiverWare is currently undergoing revision to develop a third version of RiverWare which will simulate the TROA (Coors, 2006). It is expected that this version of RiverWare will be used to manage TROA once implemented.

In 2011, options for the most appropriate flow management model were discussed. MBK Engineers provided input on the advantages and disadvantages of using RiverWare in place of TROM to support the WARMF and TRHSPF modeling for the water quality standards review process (MBK Engineers, 2011a). MBK Engineers recommended the use of TROM for the following reasons (MBK Engineers, 2011a):

- Existing datasets generated by TROM are consistent with results used in the TROA Environmental Impact Statement (EIS) and recent hearings;
- TMWRF discharge flows in RiverWare do not adjust with changing scenarios;
- Accretions and depletions between Farad and Derby Dam are not yet finalized in RiverWare;
- Not all operational decisions are incorporated into RiverWare (in particular operations for water quality water and other below Derby Dam flows); and
- Truckee Meadows diversions and accretions/depletions are aggregated into reaches in RiverWare and would need to be disaggregated.

Based on these recommendations, LimnoTech proceeded with conducting preliminary water quality simulations based on output from TROM. In 2013, several members of the Focus Group recommended that the Working Group reconsider the use of RiverWare to support the water quality modeling because additional work had been conducted from 2011 to 2013 to further advance the Truckee River application of RiverWare. LimnoTech coordinated with two RiverWare experts: Shane Coors (Precision Water Resources Engineering) and Tom Scott (USBR). LimnoTech obtained a copy of the "Pre-TROA RiverWare" model for review. This version of RiverWare generally represents 2012 operations on the Truckee River, and it was noted that some of the previous limitations identified related to the potential use of RiverWare had been addressed: 1) better implementation of TMWA operations; and 2) better connectivity within the model between TMWA withdrawals and TMWRF discharges (Coors, 2013).

However, it was also communicated that USBR is still in the process of refining diversion numbers for the pre-TROA version of RiverWare (Scott, 2013). It was expected that USBR would conduct a TROM versus RiverWare comparison in the Fall of 2013 for the Department of Justice as part of a lawsuit. This would involve checking all diversion numbers within the model because diversions currently input in the model have not yet been fully confirmed. It was uncertain when the results of their comparison would be publically available (Scott, 2013).

Although Pre-TROA RiverWare is intended to represent roughly 2012 river operations, as of July 2013, the model is still under refinement. Given the time frame for submittal of a water quality standards review analysis, it was not feasible to wait for the vetted Pre-TROA RiverWare model to be available.

After discussing the options, the Working Group collectively agreed to proceed with TROM for the Truckee River water quality standards review effort. The Focus Group was in agreement with this approach. The Working Group and Focus Group discussed the possibility of transitioning to RiverWare as part of later water quality simulations to support a TMDL review effort.

5.2.2 Most Representative TROM Scenario

Selection of a TROM scenario was focused on identifying a scenario that reasonably represents current day river operations and has been used to simulate Truckee River flows and diversions over a long period of meteorological conditions. For each river operations scenario that is simulated, TROM provides 100 years of model output. TROM output that is used as input to both WARMF and TRSHPF includes reservoir releases, diversion flows and TMWRF discharge flows. Four existing TROM scenarios were evaluated for potential use to support the Truckee River water quality standards review process. All four scenarios were developed as part of the TROA EIS (USBR, 2008):

- ***Current:*** assumes municipal and agricultural demands and regulatory flow operations consistent with 2002;
- ***Current with TROA:*** assumes municipal and agricultural demands consistent with 2002, and allows for implementation of preferred TROA flow operations;
- ***Future No Action:*** assumes municipal and agricultural demands projected for 2033 (including conversion of water rights from agricultural to municipal), and assumes regulatory flow operations consistent with 2002; and
- ***Future with TROA:*** assumes municipal and agricultural demands projected for 2033 (including conversion of water rights from agricultural to municipal), and allows for implementation of preferred TROA flow operations.

Two of the four scenarios listed above are not applicable for use in assessing water quality standards because they represent the full implementation of TROA (*Current with TROA* and *Future with TROA*). Because TROA operations are not yet fully implemented for the Truckee River, it would be inappropriate to use flow regimes represented by TROA to develop the Truckee River water quality standards.

The Working Group considered the option of running a modified TROM scenario to represent conditions in between the *Current* and *Future No Action* scenarios that would potentially more closely replicate existing river operations. This idea was determined to be problematic because a great deal of effort would be involved to parameterize this scenario and vet all assumptions with relevant stakeholders. It was determined by the Working Group that the use of a TROM scenario that was already vetted through the TROA EIS process would be preferred.

The Working Group evaluated the two remaining TROM scenarios for applicability: *Current* and *Future No Action*. MBK Engineers, the consulting firm responsible for running TROM, participated in the discussion. It was noted that between the two scenarios, *Future No Action* is a closer representation of present-day operations than the *Current* scenario (MBK Engineers, 2011b). Specifically, many of the elements defined in the *Future No Action* scenario are already in place (e.g., purchasing of direct water rights). It was noted that the *Future No Action* scenario likely over estimates the TMWA demand as compared to existing demand; however, TMWRF discharge in the scenario directly corresponds with this demand, while accounting for a percentage of municipal consumption. Because TMWA water is diverted at Chalk Bluff and TMWRF discharge is returned downstream at the Steamboat Creek confluence, a higher than actual diversion for TMWA would represent a conservative assumption of reduced flows in the river segments between Chalk Bluff and Steamboat Creek.

In collaboration with NDEP and U.S. EPA, the Working Group recommended the use of the *Future No Action* scenario as a basis for the Truckee River nutrient water quality standards review process. During the low flow selection process (described in Section 5.3 below), the *Future TROA* scenario was also reviewed for comparison.

Two representative flow conditions were selected to form the primary basis of the water quality criteria scenarios: 10th percentile low flow and 50th percentile average flow. These flow regimes were established based on 100 years of climate data and simulated TROM flows. The following sections provide additional detail on the selection of the flow regimes and the corresponding flows that were run through the models.

5.3 Selection of a Representative Low Flow Condition

NDEP recommended that a 10th percentile low flow year would be a representative low flow condition. The development of a specific low flow condition was done in close coordination with NDEP, U.S. EPA, and the Working Group. The Working Group determined that the most robust approach would be to identify a single TROM output year that is most representative of this level of critical flows both above and below Derby Dam. After it was determined that *Future No Action* was the most appropriate TROM scenario available for consideration in the Truckee River water quality standards review process, NDEP conducted an analysis to further support a recommendation for selecting a representative low flow year from TROM output (NDEP, 2011). The review also included an evaluation of the *Future TROA* scenario for comparison purposes.

Predicted flows from six TROM scenarios runs conducted as part of the TROA EIS (USBR, 2008) were analyzed for applicability to the water quality standards review process:

- Future with TROA, Truckee Canal Capacity = 900 cfs
- Future with TROA, Truckee Canal Capacity = 500 cfs
- Future with TROA, Truckee Canal Capacity = 350 cfs
- Future No Action, Truckee Canal Capacity = 900 cfs
- Future No Action, Truckee Canal Capacity = 500 cfs
- Future No Action, Truckee Canal Capacity = 350 cfs

For each of the six TROM scenarios, 10th percentile flows were calculated for each of the 19 TROM time periods and three river locations: 1) Farad, 2) Vista, and 3) Below Derby Dam. TROM provides output for 19 time periods for each one year simulation. For the months of October through April, TROM provides a single, monthly flow value. For May, July, August, and September, TROM provides two flows per month and for the month of June, three flow values are provided.

The NDEP analysis verified that the 10th percentile flow targets for the *Future No Action* scenario were lower than the 10th percentile flows for the *Future TROA* scenario at the times and locations with greatest interest for the water quality standards review process (at Vista, Below Derby Dam and at Pyramid Lake during the summer months) (NDEP, 2011). It was also noted that the Truckee Canal capacities varying from 350 to 900 cfs appeared to have little impact on the 10th percentile flows and ultimate low flow year selection (NDEP, 2011).

After examination of several potential years, it was determined that 1926, 1929, and 1994 *Future No Action* scenarios appear to best match the Below Derby Dam 10th percentile values (both summer and overall) while providing a reasonable match with 10th percentile flows at Vista. Due to lack of available climate data for 1926 and 1929, those two years were removed from consideration (NDEP, 2011).

One noted shortcoming of 1994 *Future No Action* scenario is that the Vista summer flows are significantly lower than the 10th percentile target flows and this could have significant impact on the water quality standards evaluation. NDEP proposed consideration of two additional years, 1988 and 1977, because they both match the 10th percentile flow targets at Vista better than 1994. However, the flows for both 1988 and 1977 are higher than the 10th percentile targets below Derby Dam (NDEP, 2011).

The Working Group discussed the topic further and considered using a "fully synthetic" variation of a TROM *Future No Action* run where withdrawals and reservoir releases in WARMF would be highly modified to replicate 10th percentile target flows; however, this approach was eliminated because it would break the link between the modeled flow regime and the underlying historical meteorology data thus making the approach less defensible. After extensive review and discussion, the Working Group determined that the most robust approach would be:

- Use the 1977 *Future No Action* scenario because it provided the closest match to the 10th percentile targets at Vista during the critical summer and early fall months; and,
- Adjust the Truckee Canal diversions in the 1977 *Future No Action* scenario so that the flows below Derby Dam would be a closer match with the match the 10th percentile flow target.

This approach allows for straightforward use (and only slight modification) of an existing TROM scenario run that was already vetted through the TROA EIS process. It also retains the link between the 1977 flow regime and the historical meteorology.

Figure 5-1 shows a series of flows at Vista which summarize the development of the low flow condition. The flows in Figure 5-1 represent:

- 10th percentile low flow target values from TROM *Future No Action* output;
- 1977 *Future No Action* TROM output;
- Unadjusted flow from the linked WARMF-TRHSPF model; and
- Final adjusted flow from the linked WARMF-TRHSPF model.

Note that although the TROM output data (10th percentile targets and 1977 Future No Action flows) are provided on a monthly or bi-monthly basis, the WARMF-TRHSPF generated flows are daily values and therefore, have a more detailed temporal resolution.

In the process of applying the flow regime selection approach described above, it was noted that the 1977 *Future No Action* flows above Derby Dam (e.g., at Vista) were not well matched to the 10th percentile targets during the critical summer months of July through September. Therefore, a minor adjustment was made at the WARMF-TRHSPF interface to bring the modeled flows closer to the 10th percentile targets during this time period. Flows for January through April were not adjusted because this is a non-critical time period.

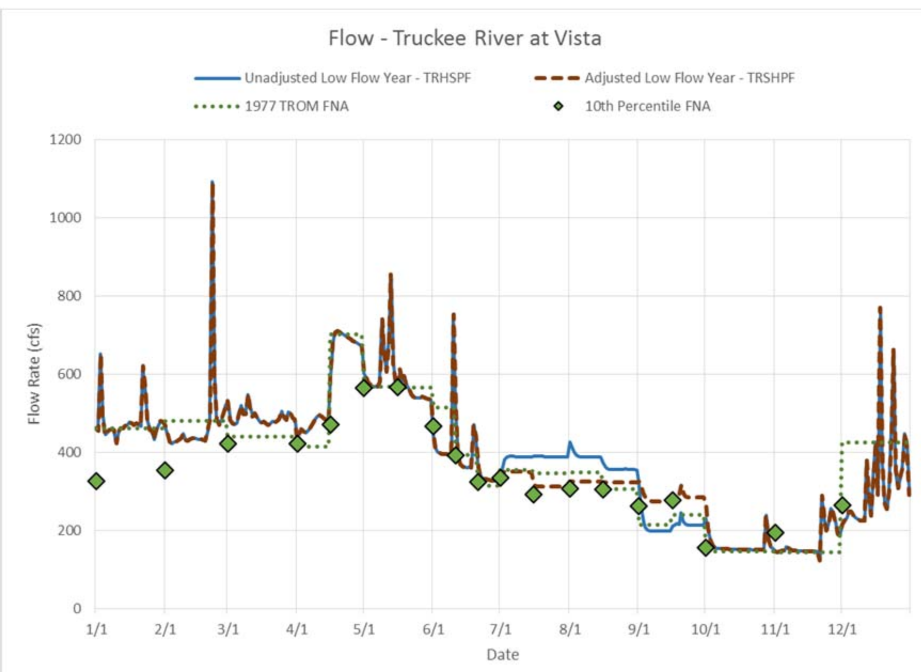

Figure 5-1. Comparison of 10th percentile (low flow) Truckee River flows at Vista

Figure 5-2 shows a series of flows below Derby Dam which summarize the development of the low flow condition. The flows in Figure 5-2 represent:

- 10th percentile low flow target values from TROM Future No Action output;
- 1977 Future No Action TROM output;
- Unadjusted flow from the linked WARMF-TRHSPF model; and
- Final adjusted flow from the linked WARMF-TRHPSF model.

The Truckee Canal diversion was adjusted from the original TROM flows for the time period from June 21 to December 31. This allowed for a much closer match to the 10th percentile flow targets for portions of the river below Derby Dam during the critical summer months, and greater model calculation stability during the months of December.

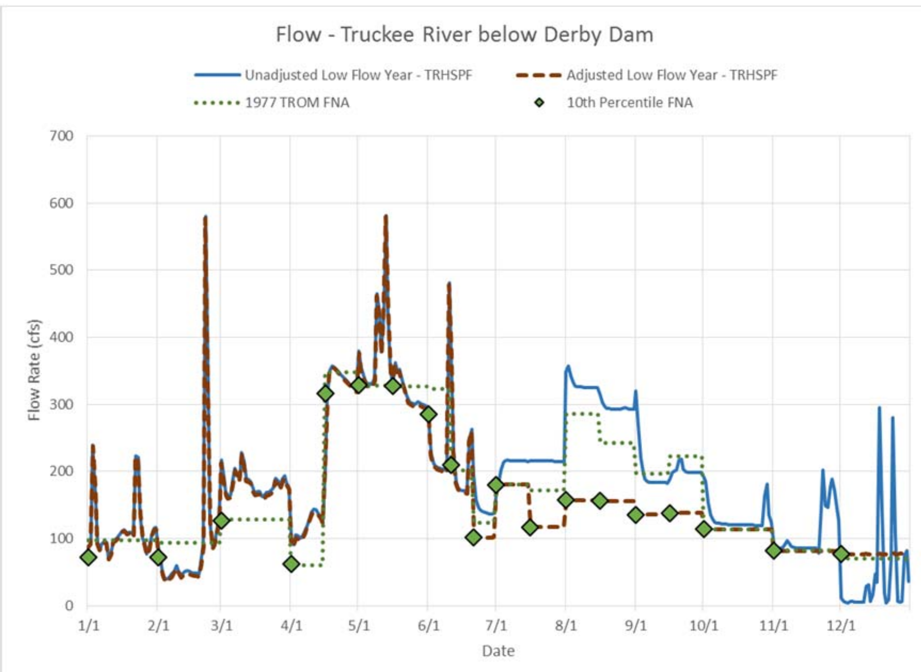

Figure 5-2. Comparison of 10th percentile (low flow) Truckee River Flows below Derby Dam

5.4 Selection of a Representative Average Flow Condition

A similar approach was used to identify a 50th percentile, average flow condition. TROM output for the *Future No Action* scenario were ranked for each flow period and the 50th percentile values were compiled for several river locations. Then TROM output flows for select years (1973, 1985, 1987, and 2000) were plotted against the targets. Based on visual inspection, it was determined that the 1985 *Future No Action* scenario had the best alignment with the 50th percentile flow targets both above and below Derby Dam. Figures 5-3 and 5-4 show the 1985 Future No Action flows and TRHSPF flows plotted against the targets at Vista and below Derby Dam. Because the TRHSPF model flows align reasonably well, although lower (which is conservative), with the 50th percentile flow targets, no additional adjustment was performed.

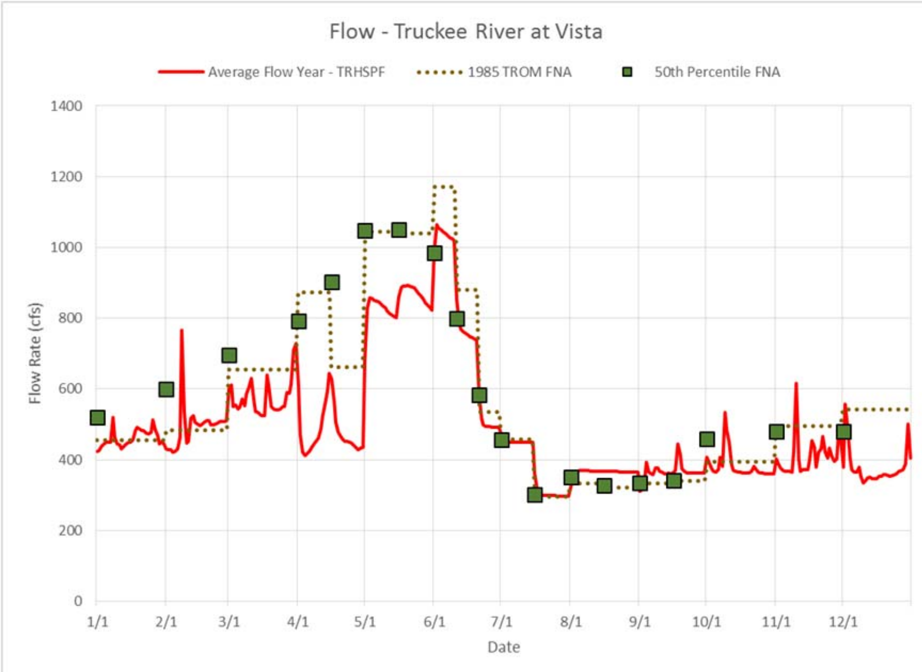

Figure 5-3. Comparison of 50th percentile (average flow) Truckee River flows at Vista

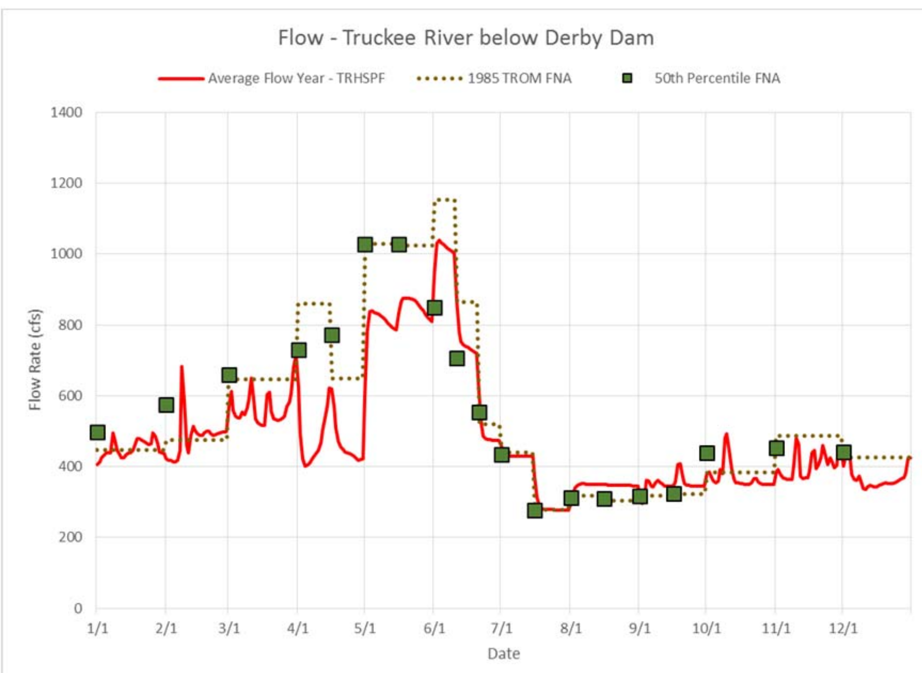

Figure 5-4. Comparison of 50th percentile (average flow) Truckee River flows below Derby Dam

5.5 Final Flow Regimes for Water Quality Standards Modeling

For each flow regime, the following set of TROM outputs was input to the water quality models:

- Reservoir releases from Lake Tahoe, Stampede Reservoir, Donner Lake, Prosser Creek Reservoir, and Boca Reservoir were input to WARMF;
- Diversion flows for municipal and industrial (M&I) and agricultural diversions along the Truckee River were input to WARMF and TRHSPF;

For most of the upper reaches of the Truckee River, the TROM output for agricultural diversions aligned directly with each diversion represented in WARMF. TROM aggregates diversion flows for the *Last Chance and Lake Diversions.* For agricultural diversions in the lower river, TROM aggregates diversion flows into two major regional diversions: *Vista Gage to Derby Dam* and *Derby Dam to Pyramid Lake*. TROM output for aggregated diversions was disaggregated into diversion records for each individual agricultural diversion represented in the water quality model. The disaggregation was developed to be proportional to current day diversion records. Note that TROM explicitly represents the Truckee Canal diversion and this was directly input to the water quality models.

To ensure an accurate flow balance, TROM river flows at key locations (e.g., Farad, Vista, Derby Dam, Pyramid Lake) were compared with river flows computed by WARMF and TRHSPF. As described above, adjustments were made for the low flow regime at the WARMF-TRHSPF interface and at the TCID diversion to achieve instream flows closer to the 10th percentile low flow target. Figures 5-5, 5-6, and 5-7 show the final flow regimes that were run through the WARMF and TRHSPF models to conduct the nutrient water quality standards review.

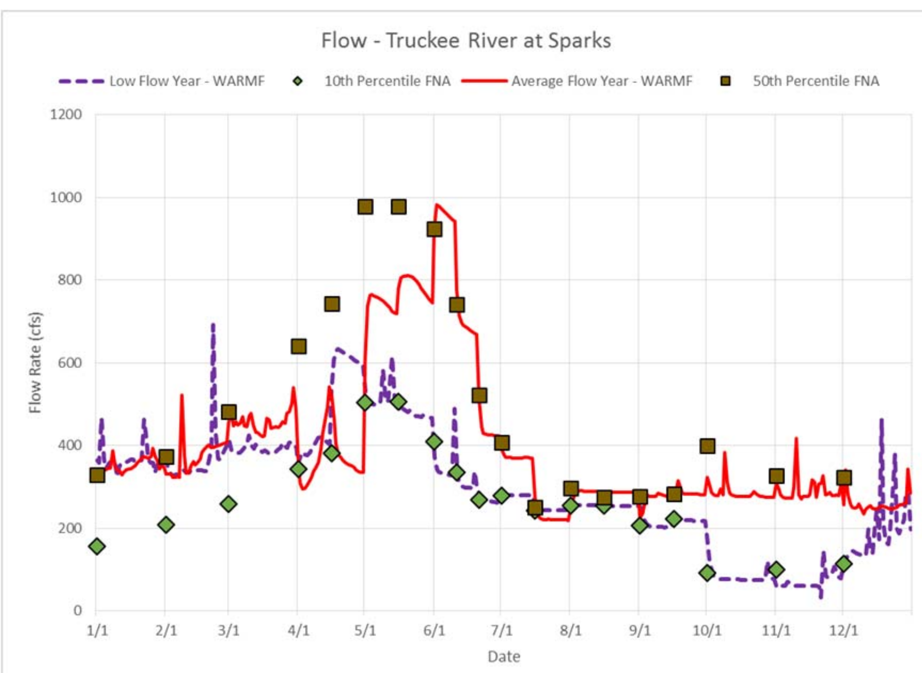

Figure 5-5. Truckee River modeled flows at Sparks for low flow and average flow regimes compared with 10th and 50th percentile target flows

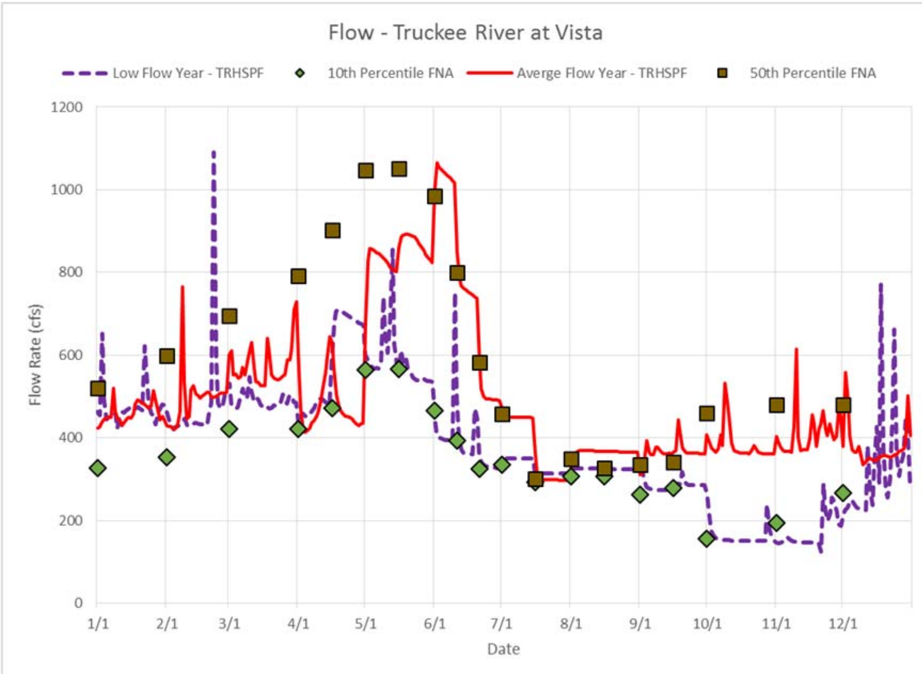

Figure 5-6. Truckee River modeled flows at Vista for low flow and average flow regimes compared with 10th and 50th percentile target flows

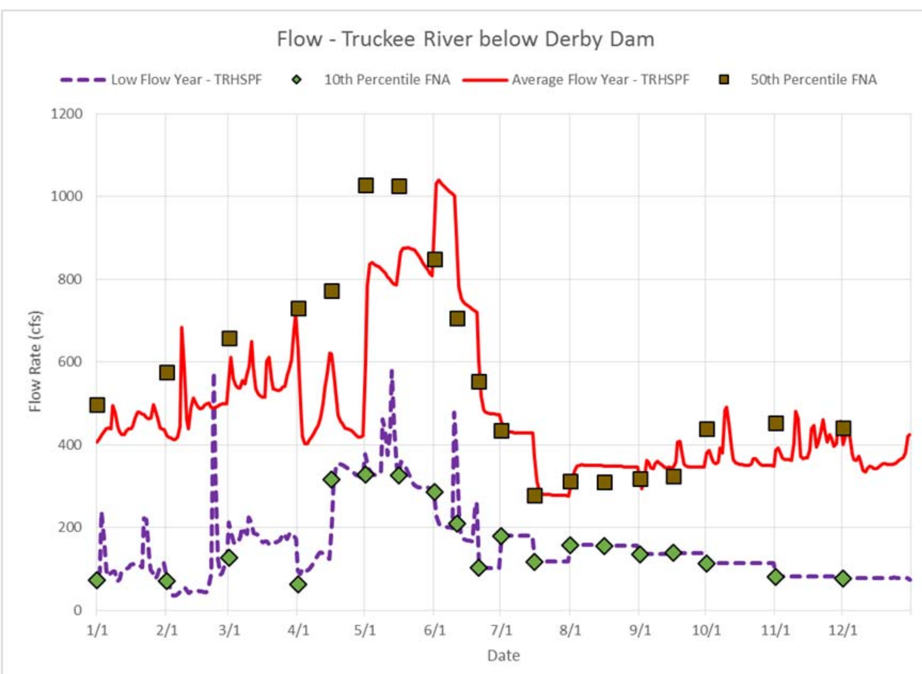

Figure 5-7. Truckee River modeled flows below Derby Dam for low flow and average flow regimes compared with 10th and 50th percentile target flows

5.6 Additional Assumptions for Model Runs

This section provides additional information on the following model inputs and assumptions:

- TMWRF flow and concentration for the "baseline" simulation
- Truckee Canal diversion and max capacity
- Land use / land cover input data
- Climate input data
- Start and end dates for simulation

Discharge flow from TMWRF was based on output from TROM. TROM also provided flows for the primary municipal withdrawal for the Truckee Meadows Water Authority (TMWA). Because both flows were from a single TROM scenario (i.e., Future No Action), they correspond with each other. For example, the TMWRF flow is a fraction of the TMWA withdrawal, accounting for municipal consumption. Figure 5-8 shows the TMWRF flow that was used for all scenarios (including both low flow and average flow regimes). Flows ranged from 29 MGD in July to 50.1 MGD in February, with lower summer discharges to the river due to effluent reuse. Note that the TROM *Future No Action* scenario assumed TMWA demands a future levels resulting in increased TMWRF flows above current permit levels.

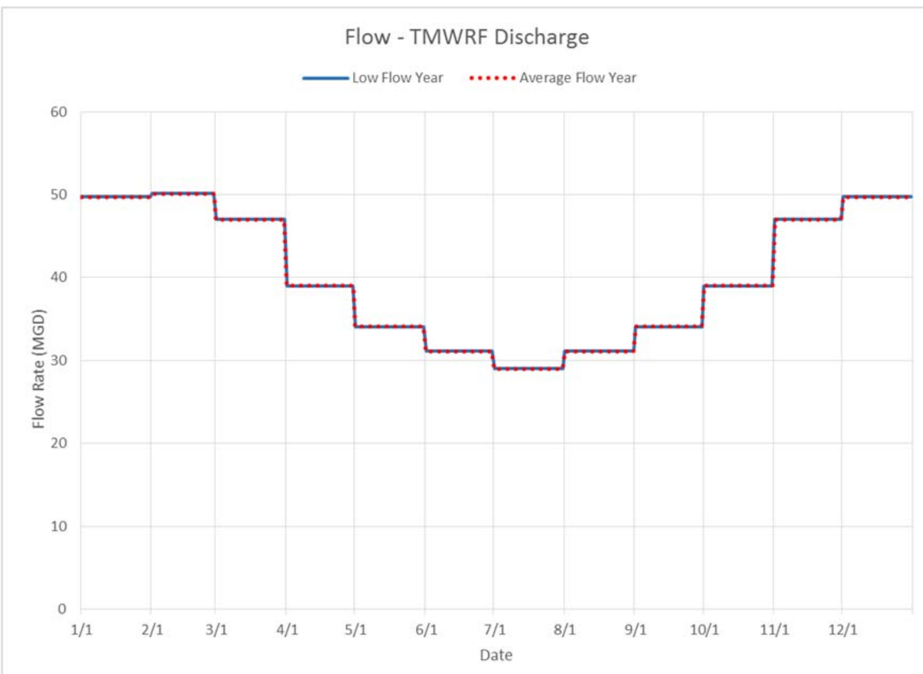

Figure 5-8. TMWRF discharge flow used for low flow and average flow simulations

For the preliminary baseline (i.e. pre-scenario) runs, the TMWRF effluent concentrations were set so that the nitrogen and phosphorus loads would reflect effluent loads measured for the time period of 2007-2008. The loads varied seasonally and resulted in annual average loads of 56 lbs/day of TP and 351 lbs/day of TN.

The proportion of individual nitrogen and phosphorus species (e.g., NH_3, NO_3, DON, OP, DOP) within the total nutrients (TN and TP) were first set based on observed data from 2007-2008 and then revised based on conversations with TMWRF and City of Reno personnel (Brisbin, Gray and Shumaker, 2009). It was recommended that model simulations use a TWMRF nutrient speciation that is reflective of operations and treatment capabilities that could be expected in the future, which may not necessarily reflect the level of treatment achieved during 2007-2008. Specifically, it was recommended that the proportion of dissolved inorganic nitrogen (which is bioavailable) and dissolved organic nitrogen (not readily bioavailable) reflect a higher proportion of nitrate and ammonia than was noted in observed data (Brisbin, Gray and Shumaker, 2009). Because nitrate and ammonia are the bioavailable forms of nitrogen, this adjustment results in a conservative assumption in the modeling.

As described in Step 3 of Section 4.1 above, the TMWRF effluent nutrient concentrations used for the baseline simulation were scaled up or down for each iterative WQS simulation so that the instream river concentration would match the target concentration for that scenario on an average annual basis.

The input data for the Truckee Canal diversion were initially set based on TROM output for the selected scenarios and years. For the two representative flow regimes simulated, the TROM Truckee Canal diversion flows ranged from approximately 13 cfs to 384 cfs for the low flow regime and from approximately 7 cfs to 114 cfs for the average flow regime. For the iterative model scenarios, the Truckee Canal diversion flows were adjusted slightly during the critical summer period to achieve a river flow downstream of Derby Dam that more closely reflects the target flow regime (i.e., 10^{th} percentile low flow or 50^{th} percentile average flow). Section 5 of this report provides additional detail on the selection of the flow regimes and the corresponding flows that were run through the models.

WARMF requires input for land use / land cover throughout the watershed. For the water quality criteria scenarios, the updated land use / land cover representative of regional growth up to 2006 was used to capture the growth since 2000. Details on the development of this data set are document in the model confirmation report (LimnoTech, 2013).

Both WARMF and TRHSPF require climate data as a model input. For each scenario, the climate data reflected the historical year upon which the targeted flow regime was based. For example, the low flow regime was based on the 1977 climate year and the average flow regime was based on the 1985 climate year. Additional information in Section 5 details how these particular years were selected to represent the low and average flow conditions. Climate inputs to WARMF included daily values of minimum and maximum air temperature, precipitation, wind speed, dew point temperature, and cloud cover from a total of eight stations throughout the watershed. Climate inputs to TRHSPF included hourly data for air temperature, dew point temperature, wind speed and cloud cover available from the National Climatic Data Center for the Reno Airport. Hourly solar radiation data for the North Reno Station were available from the Water Regional Climate Center (WRCC).

Each scenario run within TRHSPF was conducted for a one year time period from January 1 to December 31. Discussion with the Working Group led to the decision to use a "calendar year" basis for simulations rather than a "water year" basis (e.g., October 1 of previous year to September 30). Note that WARMF simulations were conducted for a longer time period which included both the water year and calendar year time frame (October 1 of previous year to December 31). This allowed for better parameterization of initial snow pack conditions in WARMF, when snow pack is at a minimum. However, within TRHSPF it was more appropriate to conduct simulations on the calendar year basis to more accurately set initial conditions for periphyton. January 1 is an optimal start date for TRHSPF because during that colder, higher flow time period the periphyton are the least sensitive to ambient nutrient levels in the river. It is also important to note that the low flow and average flow targets used to identify the most appropriate representative flow regime were based on a statistical calculation of flows for each month, independent of the next month. Therefore, the low and average flow targets were not based on a linked water year condition. Given this information, NDEP supported the use of calendar year for the basis of the iterative water quality simulations.

6
Simulation of DO Response to Nutrient Concentrations

6.1 Aggregation of Model Results

The TRHSPF model simulates dissolved oxygen concentrations for every hour of each simulation period at every model segment, resulting in several hundred thousand dissolved oxygen predictions for each scenario being examined. This massive amount of data needs to be condensed to be usable in supporting management decisions. This section first describes how the predicted hourly dissolved oxygen concentrations were translated into compliance with the dissolved oxygen criteria. It then describes how results were aggregated, both in terms of time (i.e., converting a year's worth of results at a single model segment) and space (i.e., combining results from multiple model segments into reach-wide averages).

6.1.1 Calculation of DO Criterion Compliance

The first step in the aggregation of model results consists of assessing the 8760 hourly results (24 hours x 365 days) for each simulation year in terms of compliance with water quality standards for dissolved oxygen. The water quality criterion for dissolved oxygen varies seasonally and with location, as shown in Table 6-1.

Table 6-1. Water quality criteria for dissolved oxygen in the Truckee River below Reno

Location	Daily Minimum Dissolved Oxygen (mg/l)
McCarran to Derby Dam	Nov. – Mar.: 6.0 Apr. – Oct.: 5.0
Derby Dam to Tribal Boundary	Nov. – Jun.: 6.0 Jul. – Oct.: 5.0
Tribal Boundary to Marble Bluff Dam	Nov. – Jun.: 6.0 Jul. – Oct.: 5.0

Each year of model results were assessed in terms of percent of noncompliance with the dissolved oxygen criterion, using two methods:

- Percent of days in noncompliance with water quality criterion
- Percent of hours in noncompliance with water quality criterion

These methods provide different results because the "percent of days" calculation is based on the assumption that presence of a violation of the water quality criterion *during any hour of the calendar day* results in that entire day being considered in violation. The specific calculation procedure used for each method is as follows:

Percent of Days

1. Assess each hourly dissolved oxygen prediction in terms of whether it is in compliance with the dissolved oxygen criterion in Table 6-1.
2. Divide the year into 365 calendar days
3. Count the number of days in which a violation occurs
4. Calculate the percent of days in noncompliance for each segment as:

Number of days in which a violation occurs / Number of days in the year x 100

Percent of Hours

1. Assess each hourly dissolved oxygen prediction in terms of whether it is in compliance with the dissolved oxygen criterion in Table 6-1.
2. Count the number of hours in which a violation occurs
3. Calculate the percent of hours in noncompliance for each segment as:

Number of hours in which a violation occurs / Number of hours in the year x 100

These multiple DO criterion compliance calculations were performed because there is currently no single accepted method for interpreting model results in terms of compliance with the dissolved oxygen criterion, nor is there a pre-specified “acceptable” percentage of time in which the dissolved oxygen criterion may be exceeded (as subsequent model results will indicate, some percentage of dissolved oxygen criterion violations are expected to occur regardless of the nutrient concentration evaluated). The “acceptable” percentage of time in violation is highly dependent on the spatial and temporal scale upon which the DO exceedance percentages are calculated. For this reason, results were evaluated at a range of different spatial and temporal scales to allow for an educated determination as to what is appropriate (NDEP, 2013).

Since the *percent of days* is the more conservative approach (results in higher percentage), the following discussion focuses on the results for that calculation method. Results in terms of *percent of hours* are presented in Appendix D. It is also important to note that the *percent of days* calculation is more compatible with NDEP’s assessment approach of continuous water quality data for their 303(d) List of impaired waters.

6.1.2 Spatial and Temporal Aggregation of Results

As described above, TRHSPF generates a massive amount of information. Each iterative TRHSPF water quality standard simulation that is run for a range of nutrient concentrations generates DO concentrations at each of the 43 model segment for each hour of simulation over the course of a year (365 days, 8,760 hours). This translated to approximately 17,327,280 dissolved oxygen modeled data points.

In order to efficiently review and interpret the model results to support decision-making, several types of post-processing as well as temporal and spatial aggregation must be conducted. The Working Group has been testing and revising the post-processing and aggregation methodology for the last two years.

For the temporal aggregation, DO criteria compliance results generated for each month and model segment were aggregated temporally in the following three ways:

- Annual aggregation: January - December
- Critical season: June - September
- Critical month

The critical month was selected based on a review of the model results. The month with the greatest number of days with DO criterion noncompliance was identified as the critical month.

For the spatial aggregation, DO criteria compliance results generated for each month and model segment were aggregated spatially into four reaches based on existing NDEP regulatory reaches used to define water quality standards in the region, and the portion of the river on PLPT lands (Figure 6-1):

- Reach 1 = model segments 301 – 306, McCarran Bridge to Lockwood Bridge
- Reach 2 = model segments 307 – 319, Lockwood to Derby Dam
- Reach 3 = model segments 320 – 326, Below Derby Dam to Wadsworth Gage
- Reach 4 = model segments 327 – 343, Pierson to Marble Bluff Dam

The DO criteria compliance results for each aggregated reach take into account the length of each individual segment using a length-weighted average calculation. For example, a segment with a length of three miles and a compliance of 95% would have more "weight" than a reach with a length of one mile with a compliance of 98%, where the overall compliance would equal 96% [e.g., 0.96 = (3 x 0.95) + (1 x 0.98)/(3+1)].

In addition to reviewing DO criteria compliance results for each aggregated reach, DO criteria compliance results were also examined for the most critical segment within each aggregated reach:

- Segment 304 at Vista (within Reach 1)
- Segment 315 at Tracy (within Reach 2)
- Segment 320 Below Derby Dam (within Reach 3)
- Segment 343 at Marble Bluff Dam (within Reach 4)

The critical segment for each reach was identified as the segment with the greatest number of days with DO criterion noncompliance based on a review of the model results.

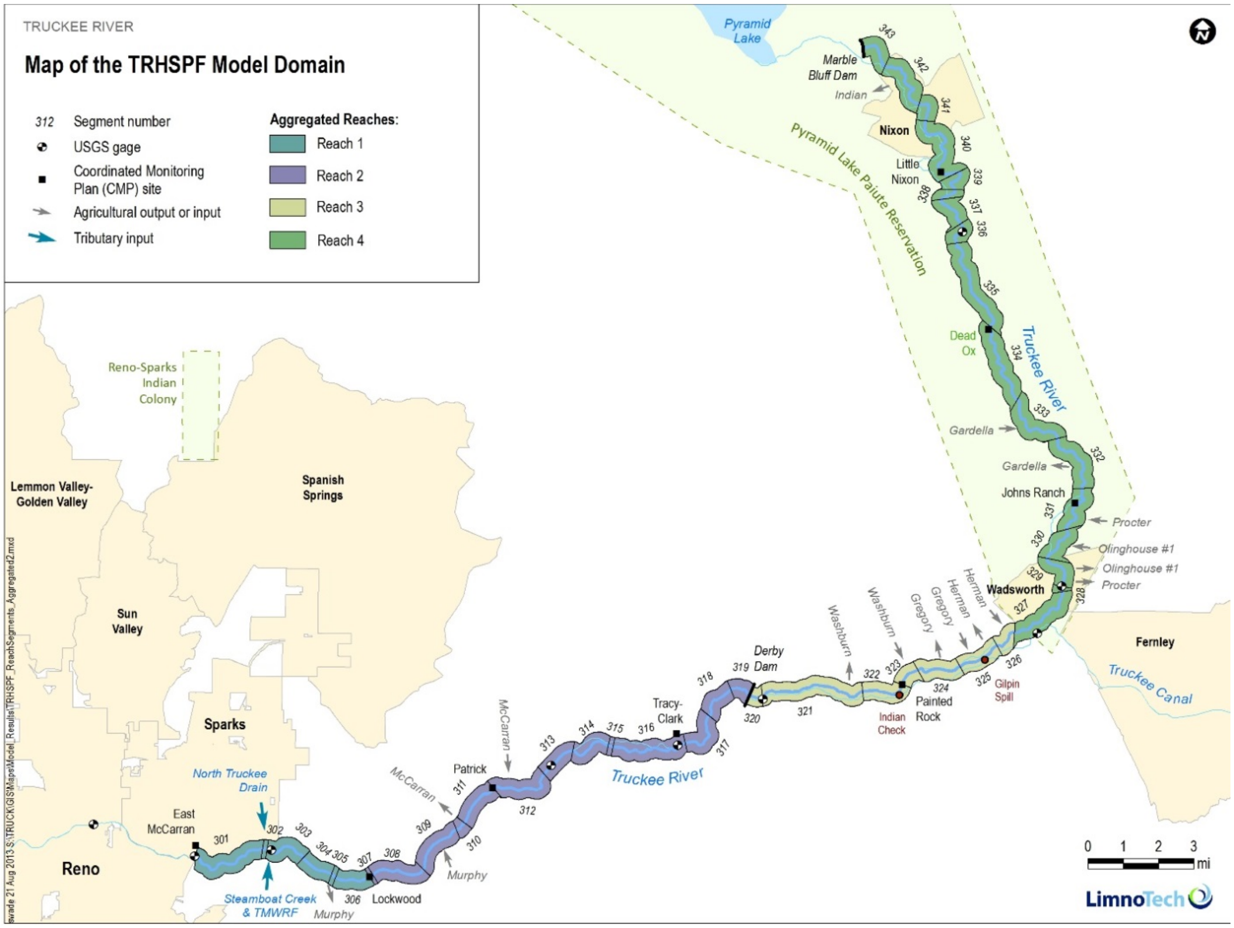

Figure 6-1. Map of the TRHSPF model domain showing aggregation of model segments into four reaches.

Figure 6-2 shows the progression of the model simulations, temporal/spatial aggregation and post-processing that was conducted with the TRHSPF model results for the suite of water quality standard simulations. With all of the permutations described above, approximately 192 nutrient – DO response curves were generated that compare a range of nutrient concentrations to a level of DO violation. Post-processing and plotting was for the suite of TRHSPF water quality simulations conducted as follows:

- **Flow Regime:** Separate sets of plots were generated for the 10th percentile and 50th percentile flow simulations.
- **Constituent:** Separate sets of plots were generated for each constituent examined (TN, TP and Ortho-P). TN was evaluated for a range of TN concentrations (0.55 to 1.00 mg/L) at two different levels of phosphorus: 1) TP set at 0.05 mg/L, and 2) Ortho-P set at 0.05 mg/L. TP was evaluated for a range of concentrations (0.03 to 0.125 mg/L) with TN set at 0.75 mg/L. Ortho-P was evaluated for a range of concentration (0.03 to 0.100) with TN set at 0.75 mg/L.
- **Compliance Method:** DO criterion compliance was evaluated using both the *percent of days* and *percent of hours* methods. The results were plotted separately both are included in this report (*percent of days* results in Section 6 and *percent of hours* results in Appendix D).
- **Temporal Aggregation:** Results for both annual and critical season DO criterion compliance results were plotted separately. The results in this report focus on DO criterion compliance on an annual basis.

- **Spatial Aggregation:** Results for DO criterion compliance were developed for both aggregated Reaches (1, 2, 3, and 4) and the four (4) critical segments are plotted together. The plots in this report focus on the aggregated reach results and tabulated results include both aggregated reach and critical segment DO criterion compliance results. Additional time series and longitudinal plots were created for specific water quality standard simulations.

Flow Regime	Constituent	DO Criterion Compliance Method	Temporal Aggregation	Spatial Aggregation
10th Percentile Low Flow Regime	TN	Percent of Days	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
		Percent of Hours	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
	TP	Percent of Days	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
		Percent of Hours	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
	OP	Percent of Days	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
		Percent of Hours	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
50th Percentile Average Flow Regime	TN	Percent of Days	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
		Percent of Hours	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
	TP	Percent of Days	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
		Percent of Hours	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
	OP	Percent of Days	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)
		Percent of Hours	Annual Aggregation	Aggregated Reaches (4)
				Critical Segments (4)
			Critical Season (Jun-Sep)	Aggregated Reaches (4)
				Critical Segments (4)

Figure 6-2. Summary of water quality standard temporal and spatial aggregation for post-processing

6.1.3 Normalization of Curves to Actual Concentrations

Model results presented later in this section are displayed to show the percent of time (hours or days) that the DO criterion was not met for a range of pre-specified instream nutrient concentrations. Presentation of these results was complicated by the fact that instream reaction processes led to nutrient concentrations varying over distance. Two types of normalization were required to allow results across model segments to be appropriately compared for a given set of target concentrations:

- Adjustment of instream nutrient concentrations to account for decreasing concentration over distance; and
- Adjustment of Reach 4 DO criterion percent noncompliance at different TN concentrations to account for the interrelationship between TN and OP concentrations.

This section describes each of these adjustments.

As discussed in Section 4, major nutrient loads to TRHSPF (e.g. upstream boundary at E. McCarran Blvd., North Truckee Drain) were directly adjusted in the model inputs to maintain annual average nutrient concentrations at the specific target concentration being evaluated for a given simulation. This approach assured that concentrations in the river exactly matched the desired target concentration at the location where these loads entered the river, but did not guarantee that concentration targets were maintained at all downstream locations. In actuality, predicted nutrient concentrations typically decrease downstream from the loading source, as indicated by the example shown in Figure 6-3. As seen in the figure, predicted total nitrogen concentrations exactly match the target concentration of 0.75 mg/l at the upstream boundary and in the segments near Vista that are influenced by North Truckee Drain, Steamboat Creek, and TMWRF. Predicted nitrogen concentrations gradually decrease downstream of Vista, because aquatic plants remove nitrogen from the water column and no major downstream nitrogen sources are represented in the model. At the downstream end of the system, predicted nitrogen concentration are approximately 0.60 mg/l, well below the target concentration of 0.75 mg/l.

Two potential methods exist for addressing the decrease in predicted nutrient concentration over downstream distance:

- Add new loads of nitrogen in the model at multiple downstream locations to maintain instream concentrations exactly at the target values; or
- “Normalize” results to the simulated instream levels

The first option was rejected because it represented an artificial condition (i.e. introducing nutrient loads to the river where none existed) and would be extremely computationally intensive. The normalization approach was therefore selected and is discussed below and illustrated in Figure 6-4.

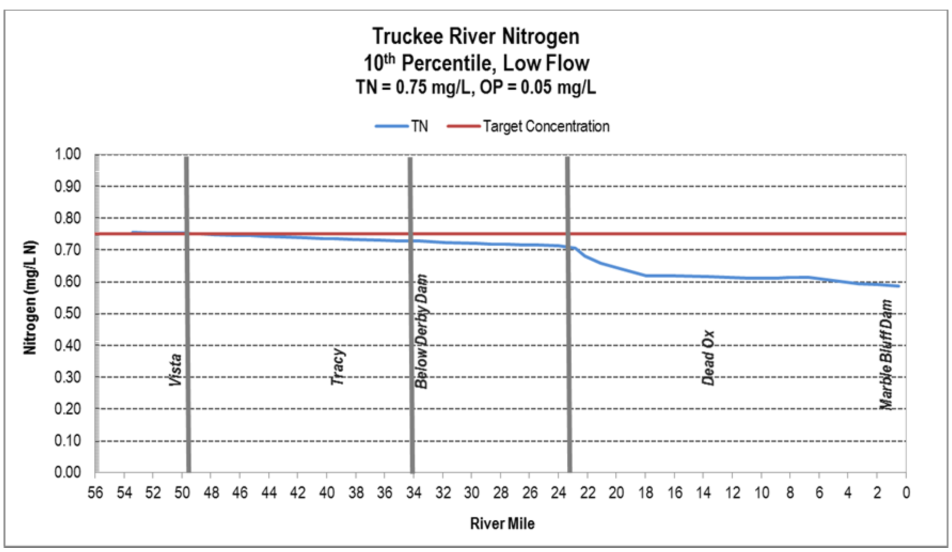

Figure 6-3. Example Plot Showing River Concentrations Decreasing Downstream below Target Concentrations

Figure 6-4 provides an example where simulated instream concentrations dropped below target levels in Reach 4, and the model results were adjusted (i.e., shifted to the left) to reflect the actual instream concentration, rather than the target concentration. The dashed line in Figure 6-4 shows the percent of days in violation for the range of target concentrations evaluated, referenced to the original *target* concentration for each simulation. The solid line shows the same percent of days in violation for each simulation; however, the line has been plotted against the *actual* model-predicted concentration. The normalization process accounts for the fact that predicted concentrations in the downstream portion of the river are less than the targets, and adjusts the concentration to represent the actual predicted concentration for that reach. In order to estimate the percent noncompliance for a given target concentration from the normalized curve, linear interpolation is conducted between the model results on either side of the target. For example, in Figure 6-4, the percent noncompliance for a target OP concentration of 0.05 mg/l is estimated at 5.5%, by interpolating between the DO compliance results for the predictions plotted against OP concentrations of 0.042 and 0.062 mg/l. In the remainder this report, all results for each of the simulations were shifted in a like manner, such that the x-axis value represents the actual predicted average concentration in each reach, rather than the target concentration.

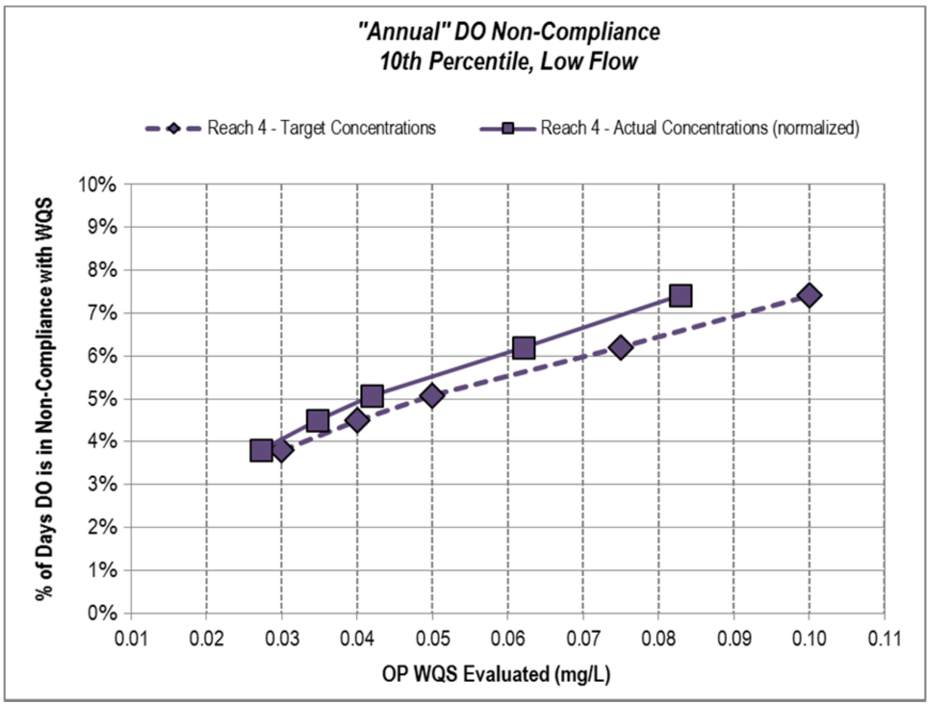

Figure 6-4. Example Plot Showing a DO Compliance Curve Normalized to Actual River Concentrations

The second aspect of normalization consisted of adjustment of Reach 4 percent noncompliance at different TN concentrations to account for the interrelationship between TN and OP concentrations. This was necessary because model results indicated that the rate at which OP concentrations decreased in the downstream direction varied as a function of the TN concentration being evaluated. This behavior is not unexpected, as higher TN concentrations in Reaches 1 through 3 cause more periphyton growth, which leads to lower OP concentrations. Figure 6-5 demonstrates this effect for the series of simulations reflecting OP = 0.05 mg/l for a range of TN concentrations. The Reach 4 OP concentration for the lowest evaluated TN concentration of 0.5 mg/l was 0.44 mg/l, while the Reach 4 OP concentration for highest evaluated TN concentration of 1.0 mg/l was 0.39 mg/l.

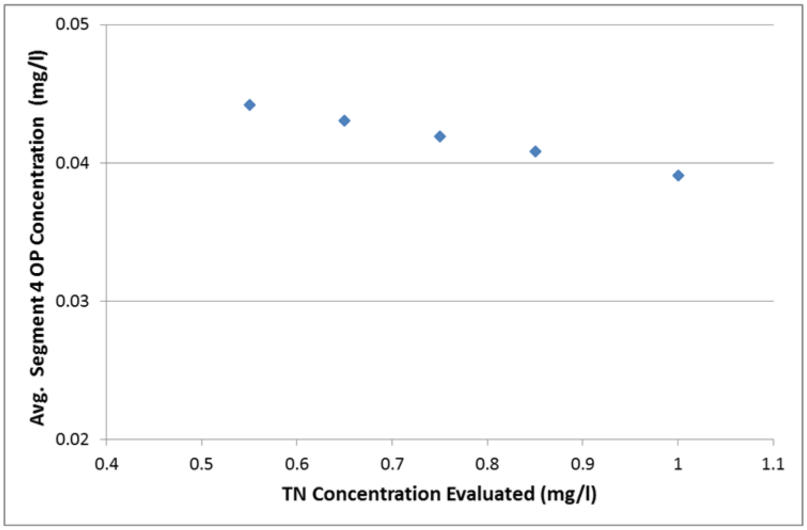

Figure 6-5. Example plot showing a predicted Reach 4 OP concentration decreasing in response to higher evaluated TN concentration

Because percent noncompliance in Reach 4 was seen to be strongly related to OP concentration, it was necessary to normalize the results of these TN simulations to account for the fact that each simulation has a different OP concentration. The normalization process was conducted as follows:

- A relationship was developed between percent noncompliance and Reach 4 OP concentration from model output, using the Trendline function in Microsoft Excel, as shown in Figure 6.6;
- Separate regressions were developed for % of days and % of hours; and
- The regression equations were used to normalize % violation for each of the TN runs to represent average OP in Reach 4 of 0.05 mg/l.

This normalization process was not required for Reaches 1-3, because model results presented subsequently (see Sections 6.2 and 6.3) indicate that dissolved oxygen concentrtions in these reaches are insensitive to variation in OP over the range of concentrations evaluated.

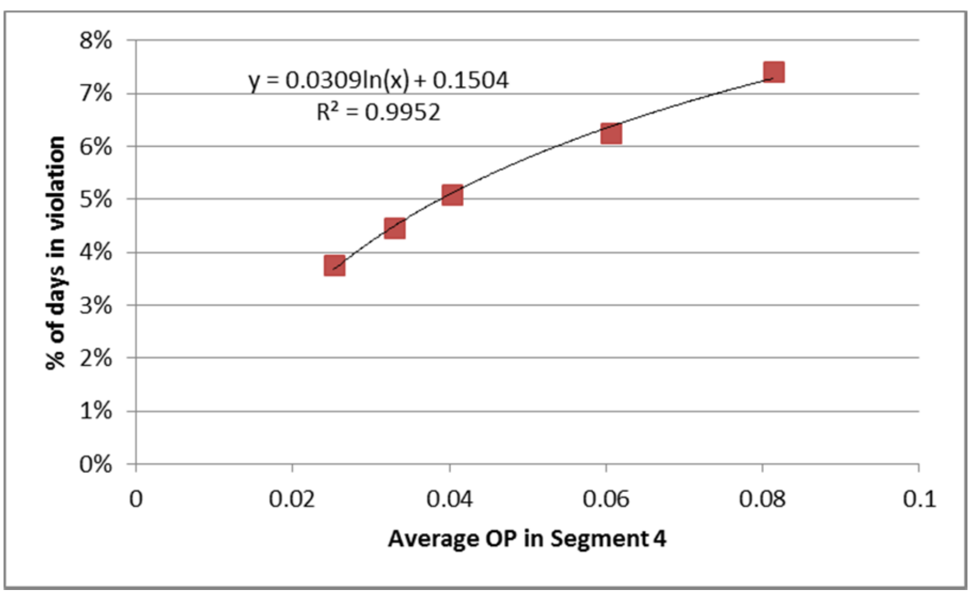

Figure 6-6. Relationship between Reach 4 OP Concentrations DO Compliance Used in Normalization Process.

Figure 6-7 demonstrates the effect of this normalization process. The un-adjusted results show a counter-intuitive situation of percent violation in Reach 4 decreasing in response to increasing nitrogen concentrations. The normalized results correct this counter-intuitive situation, and show that compliance in Reach 4 does not vary significantly with increasing nitrogen concentrations over the range examined.

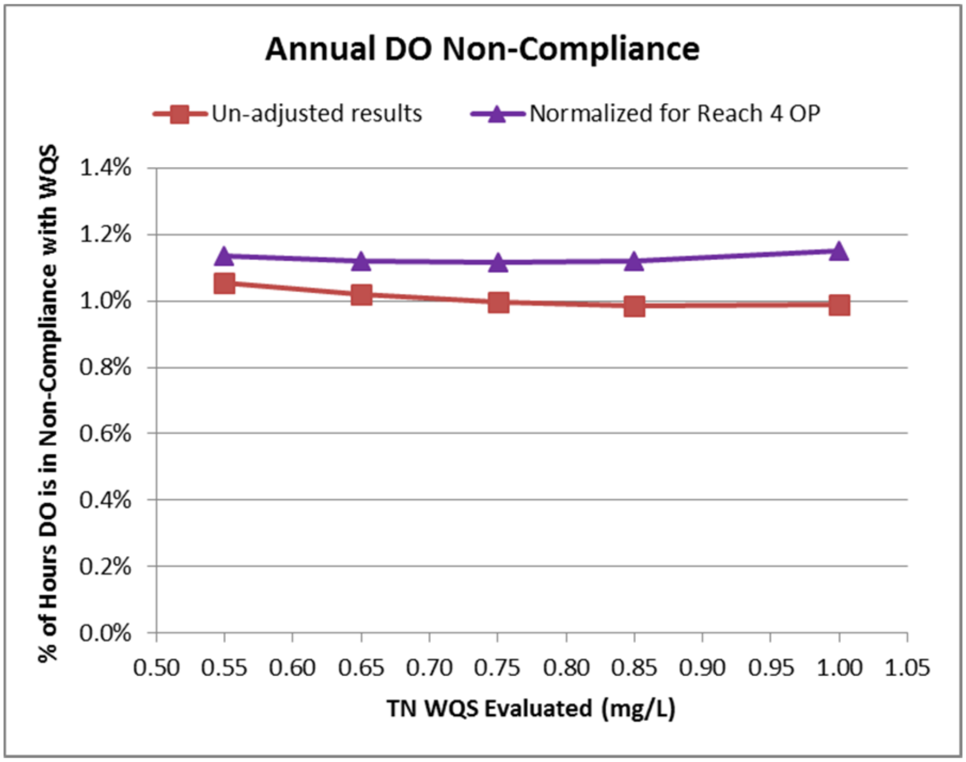

Figure 6-7. Example Plot Showing a Predicted Reach 4 OP Concentrations Decreasing in Response to Higher Evaluated TN Concentration.

6.2 Results for Low Flow Condition

Results for each of the low flow condition iterative scenarios are presented below in two forms for each nutrient that was examined (TN, OP, and TP):

- A curve showing the nutrient-DO response (criterion compliance) relationship for each aggregated reach; and
- A longitudinal plot showing the DO criterion noncompliance along the length of the river for each nutrient concentration that was examined.

For all of the results presented in this section, the DO criterion noncompliance was calculated based on *percent of days* that violated the criterion. As described in Section 6.1.1, this is a more conservative approach for examining DO criterion compliance. A similar set of results for the low flow condition simulations where DO criterion noncompliance was evaluated based on *percent of hours* violated is presented in Appendix D. The *percent of hours* approach provides a more accurate description of the amount of time the DO criterion is violated; however, the *percent of days* approach is more compatible with NDEP's assessment approach of continuous water quality data for their 303(d) List of impaired waters.

6.2.1 Total Nitrogen

Figures 6-8, 6-9, and 6-10 examine the response of noncompliance with Truckee River DO criteria to a range of TN concentrations in the river under a low flow condition. Figure 6-8 shows the percent of days that the DO criterion was violated for each aggregated reach across a range of annual average TN concentrations. This figure shows results for two sets of runs: 1) a case where the annual average TP target concentration was set at 0.05 mg/L (solid symbols), and 2) a case where the annual average OP target concentration was set at 0.05 mg/L (open symbols). Note that when OP is 0.05 mg/L, the TP concentration is roughly 0.09 mg/L (approximately twice the amount of phosphorus as compared to the TP 0.05 mg/L case).

For Reaches 1, 2, and 3, violation of the DO criterion occurs less than approximately 0.5% of days at a TN concentration of 0.80 mg/L or less. At higher TN concentrations, there is a slight increase in DO criterion violation. For Reaches 1, 2, and 3, the DO response curve for the TP at 0.05 mg/L case lines up very closely with the case when OP was set at 0.05 mg/L. This suggests that this portion of the Truckee River is not sensitive to increasing phosphorus concentrations during low flow conditions.

The results for Reach 4 show a very “flat” response of DO criterion violation regardless of the TN concentration examined. This suggests that this region of the river is not sensitive to increasing TN concentrations within the range tested during low flow conditions. In Reach 4, the TN-DO response curves for the two cases of phosphorus that were tested show different levels of DO criterion violation. At a TP concentration of 0.05 mg/L, the DO criteria was violated approximately 4% of the days of the year; whereas, at an OP concentration of 0.05 mg/L (almost twice the level of phosphorus), the DO criterion was violated approximately 5.5% of the days of the year. This suggests that dissolved oxygen compliance in this region of the river is sensitive to increasing phosphorus concentrations under a low flow condition.

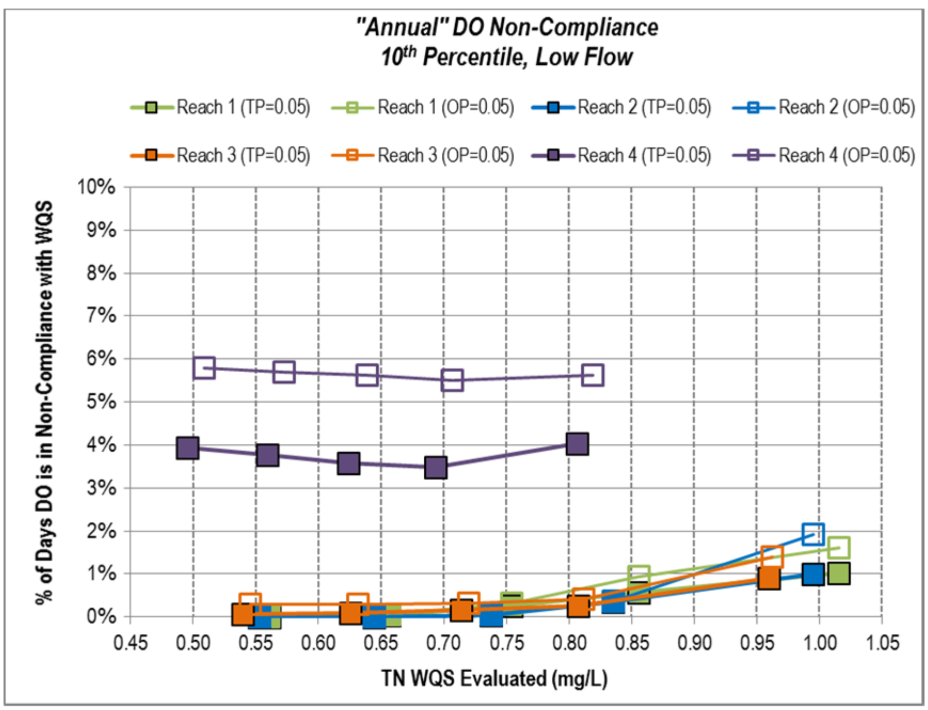

Figure 6-7. Nutrient-DO response relationship for TN in the Truckee River under a low flow condition (calculated for aggregated reaches and percent of days with DO criterion noncompliance)

Figures 6-9 and 6-10 show the same model output in the perspective of a longitudinal profile. Each symbol on the plot represents a different annual average TN target concentration that was examined. Figure 6-9 shows the case where the annual average TP target concentration was 0.05 mg/L and Figure 6-10 shows the case where the annual average OP target concentration was 0.05 mg/L.

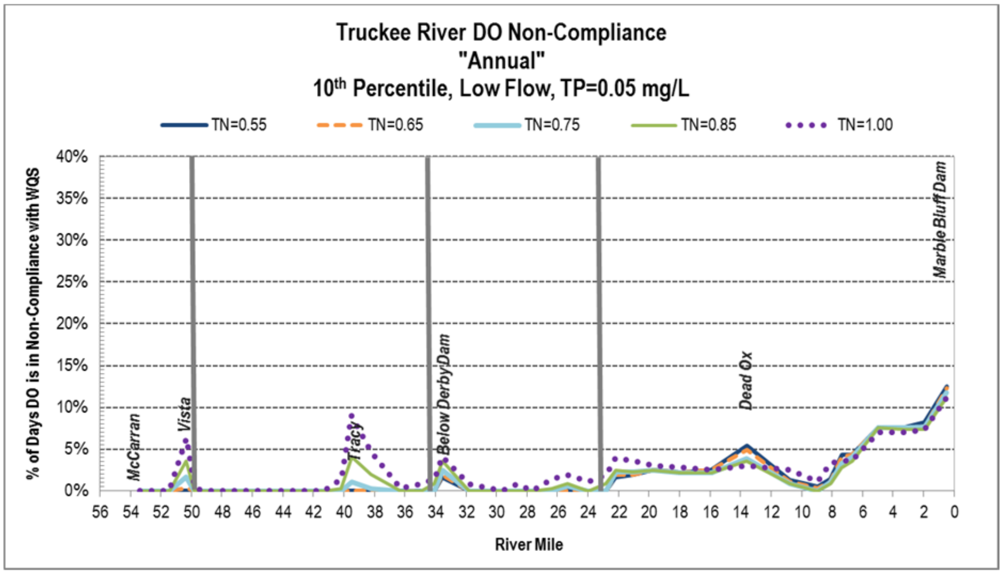

Figure 6-8. Longitudinal plot of the percent of days with DO criterion noncompliance for a range of TN target concentrations and a TP target concentration of 0.05 mg/L under a low flow condition

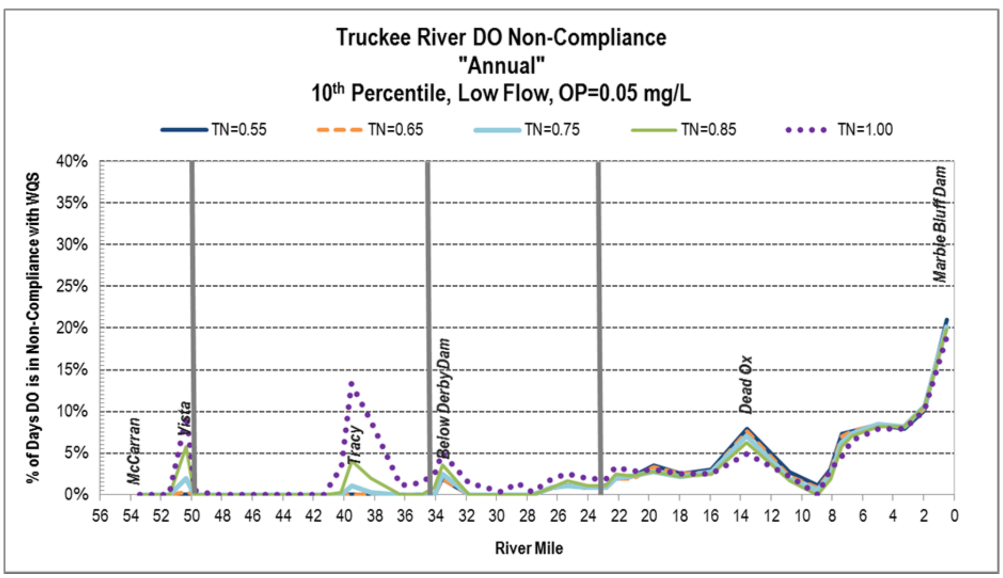

Figure 6-9. Longitudinal plot of the percent of days with DO criterion noncompliance for a range of TN target concentrations and a OP target concentration of 0.05 mg/L under a low flow condition

6.2.2 Total Phosphorus

Figures 6-11 and 6-12 examine the response of noncompliance with Truckee River DO criteria to a range of TP concentrations in the river under a low flow condition. Figure 6-11 shows the percent of days that the DO criterion was violated for each aggregated reach across a range of annual average TP concentrations and an annual average TN concentration of 0.75 mg/L.

For Reaches 1, 2, and 3, violation of the DO criterion occurs less than approximately 0.5% of days at all TP concentrations evaluated. The curve shows a very “flat” response indicating that dissolved oxygen compliance in this portion of the Truckee River is not sensitive to increasing phosphorus concentrations during the low flow condition. The results for Reach 4 show that DO criterion violations range from 3% to 6% of days across the range of TP concentrations that were examined. This suggests that dissolved oxygen compliance in this region of the river is sensitive to increasing phosphorus concentrations under a low flow condition.

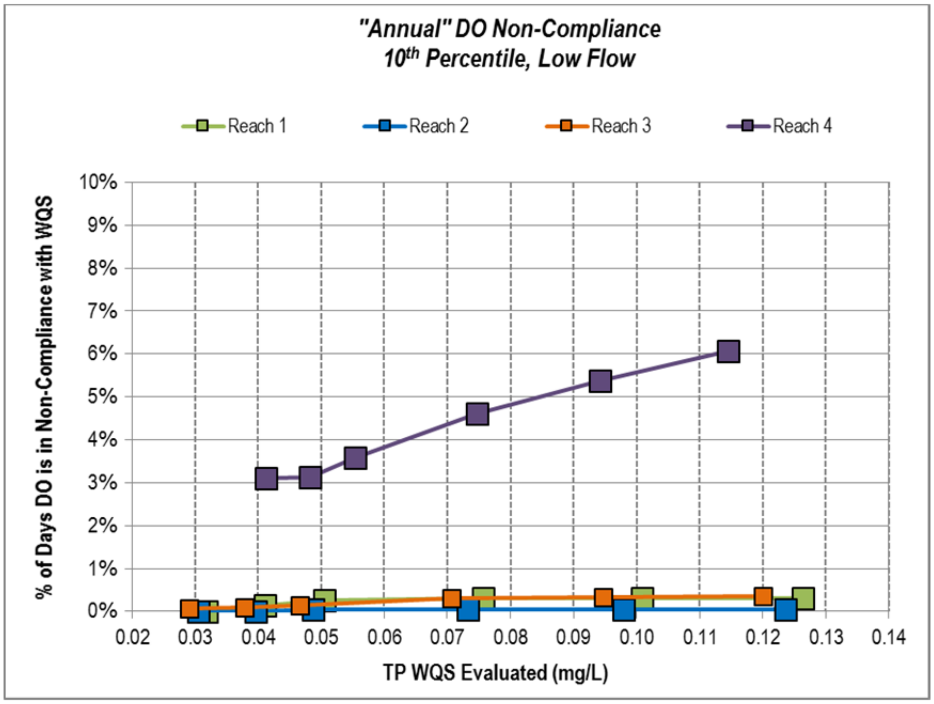

Figure 6-10. Nutrient-DO response relationship for TP in the Truckee River under a low flow condition and an annual average TN target concentration of 0.75 mg/L (calculated for aggregated reaches and percent of days with DO criterion noncompliance)

Figure 6-12 shows the same model output in the perspective of a longitudinal profile. Each symbol on the plot represents a different annual average TP target concentration that was examined. Noncompliance is consistently low for all TP concentrations from E. McCarran Blvd. down to River Mile 22 near Wadsworth, increase somewhat between River Mile 22 and Dead Ox, then increase dramatically over the last six River Miles for all TP concentrations evaluated.

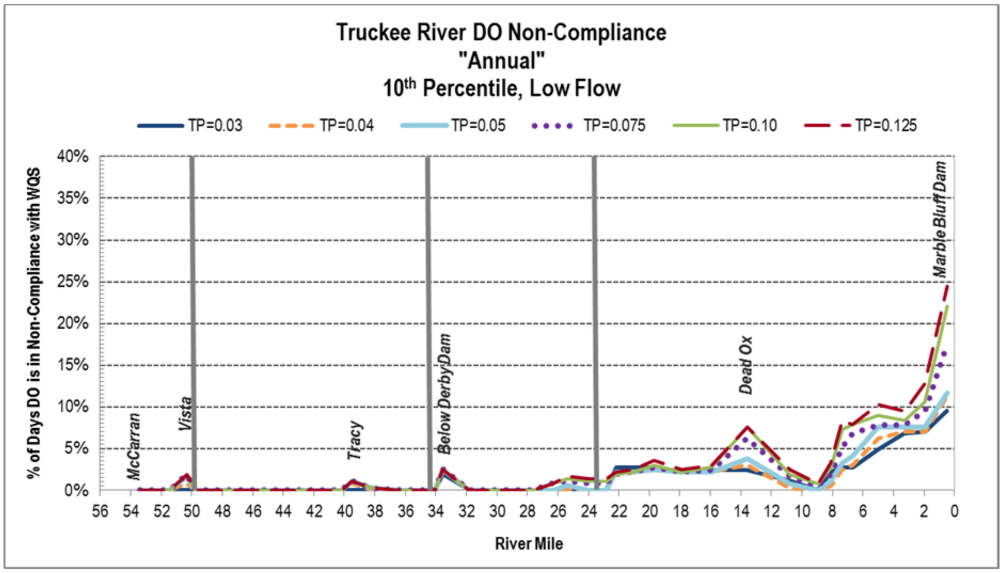

Figure 6-11. Longitudinal plot of the percent of days with DO criterion noncompliance for a range of TP target concentrations and a TN target concentration of 0.75 mg/L under a low flow condition

6.2.3 Ortho-phosphorus

Figures 6-13 and 6-14 examine the response of noncompliance with Truckee River DO criteria to a range of ortho-phosphorus (OP) concentrations in the river under a low flow condition. Figure 6-13 shows the percent of days that the DO criterion was violated for each aggregated reach across a range of annual average OP concentrations and an annual average TN target concentration of 0.75 mg/L.

For Reaches 1, 2, and 3, violation of the DO criterion occurs less than approximately 0.5% of days at an OP concentration of 0.1 mg/L or less. The curve shows a very “flat” response indicating that dissolved oxygen compliance in this portion of the Truckee River is not sensitive to increasing phosphorus concentrations. The results for Reach 4 show that DO criterion violations range from approximately 3.6% to 7.2% of days across the range of OP concentrations that were examined. This suggests that dissolved oxygen compliance in this region of the river is sensitive to increasing phosphorus concentrations under a low flow condition.

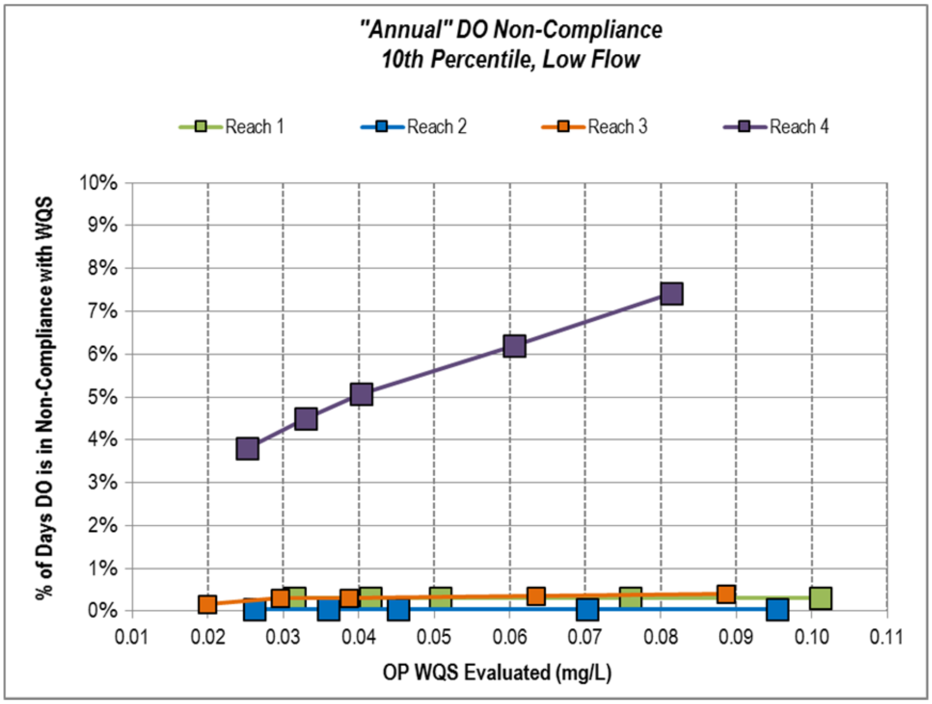

Figure 6-12. Nutrient-DO response relationship for OP in the Truckee River under a low flow condition and an annual average TN target concentration of 0.75 mg/L (calculated for aggregated reaches and percent of days with DO criterion noncompliance)

Figure 6-14 shows the same model output in the perspective of a longitudinal profile. Each symbol on the plot represents a different annual average OP target concentration that was examined. A similar longitudinal pattern is observed for OP as was for TP, violations increasing dramatically over the last six River Miles for all OP concentrations evaluated.

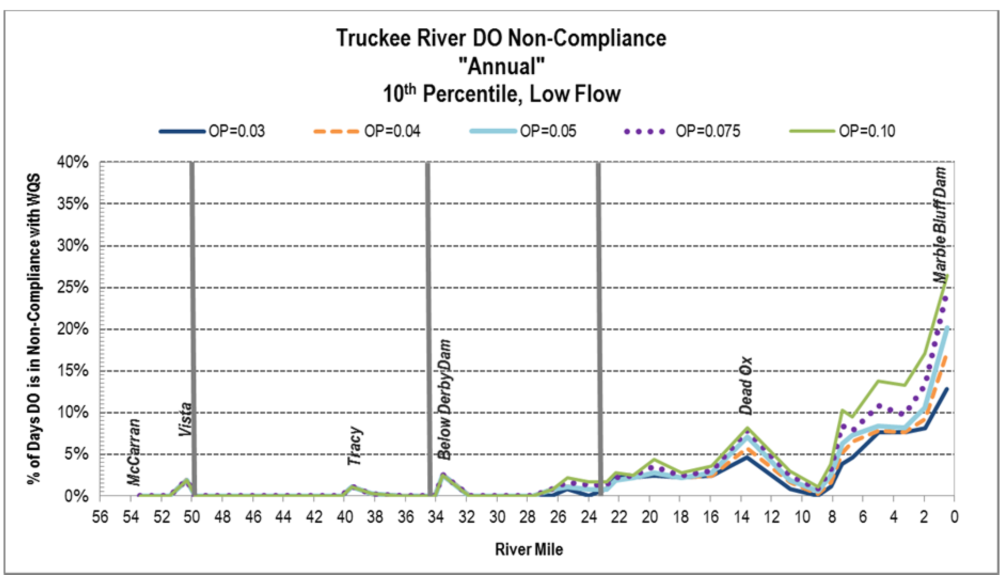

Figure 6-13. Longitudinal plot of the percent of days with DO criterion noncompliance for a range of OP target concentrations and a TN target concentration of 0.75 mg/L under a low flow condition

6.3 Results for Average Flow Condition

This section presents a similar set of results as were summarized in Section 6.2; however, the scenarios presented below were run for a *50th percentile (average flow)* condition rather than the low flow condition. Results for each of the average flow condition iterative scenarios are presented below in two forms for each nutrient that was examined (TN, TP, and OP):

- A curve showing the nutrient-DO response (criterion compliance) relationship for each aggregated reach; and
- A longitudinal plot showing the DO criterion noncompliance along the length of the river for each nutrient concentration that was examined

For all of the results presented in this section, the DO criterion noncompliance was calculated based on *percent of days* that violated the criteria. As described in Section 6.1.1, this is a more conservative approach for examining DO criterion compliance than the alternative measure of *percent of hours*. A similar set of results for the low flow condition simulations where the DO criterion noncompliance was evaluated based on *percent of hours* violated is presented in Appendix D. The *percent of hours* approach provides a more accurate description of the amount of time the DO criterion is violated; however, the *percent of days* approach is more compatible with NDEP's assessment approach of continuous water quality data for their 303(d) List of impaired waters.

6.3.1 Total Nitrogen

Figures 6-15, 6-16, and 6-17 examine the response of noncompliance with Truckee River DO criteria to a range of TN concentrations in the river under an average flow condition. Figure 6-15 shows the percent of days that the DO criterion was violated for each aggregated reach across a range of annual average TN concentrations. This figure shows results for two sets of runs: 1) a case where the annual average TP target concentration was set at 0.05 mg/L (solid symbols), and 2) a case where the annual average OP target concentration was set at 0.05 mg/L (open symbols). Note that when OP is 0.05 mg/L, the TP concentration is roughly 0.09 mg/L (approximately twice the amount of phosphorus as compared to the TP 0.05 mg/L case).

The DO response curves for Reaches 1 and 2 show that with increasing TN concentrations, there is a slight increase in DO criterion violation. For Reach 1 the DO criterion violations ranged from approximately 0.8% to 2.5% of days across the range of TN concentrations examined. For Reach 2, the DO criterion violations ranged from approximately 0% of days to 2.5% of days across the range of TN concentrations examined.

The results for Reaches 3 and 4 show a very "flat" response of DO criterion violation regardless of the TN concentration examined. This suggests that dissolved oxygen compliance in this region of the river is not sensitive to increasing TN concentrations within the range tested.

For all reaches, the DO response curves for the TP at 0.05 mg/L case lines up very closely with the case when OP was set at 0.05 mg/L. This suggests that dissolved oxygen compliance in all portions of the Truckee River are not sensitive to increasing phosphorus concentrations under the average flow condition.

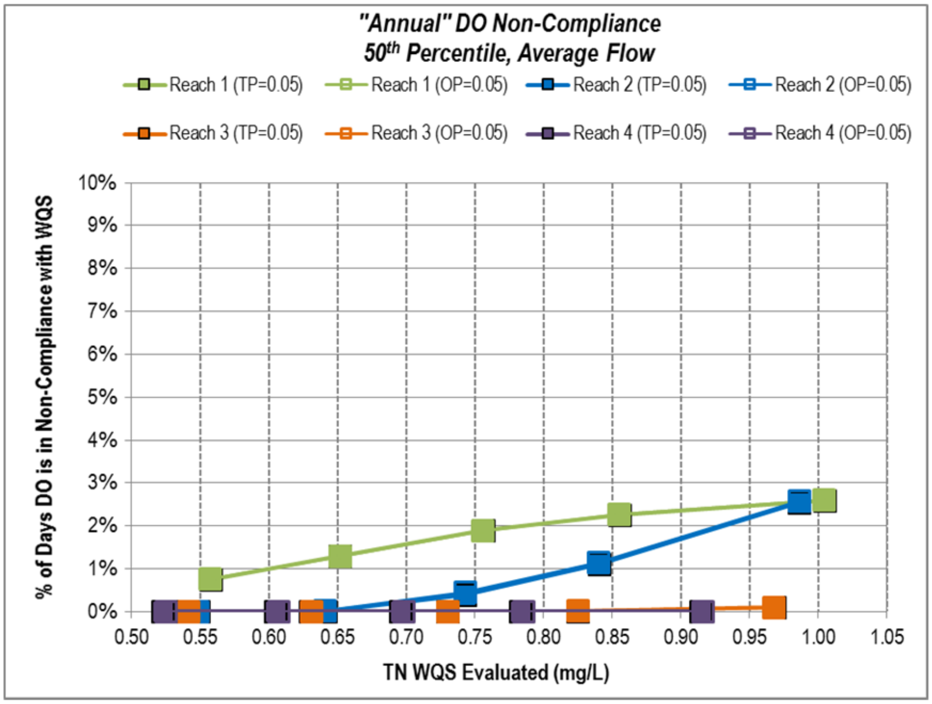

Figure 6-14. Nutrient-DO response relationship for TN in the Truckee River under an average flow condition (calculated for aggregated reaches and percent of days with DO criterion noncompliance)

Figures 6-16 and 6-17 show the same model output in the perspective of a longitudinal profile. Each symbol on the plot represents a different annual average TN target concentration that was examined. Figure 6-15 shows the case where the annual average TP target concentration was 0.05 mg/L and 6-16 shows the case where the annual average OP target concentration was 0.05 mg/L.

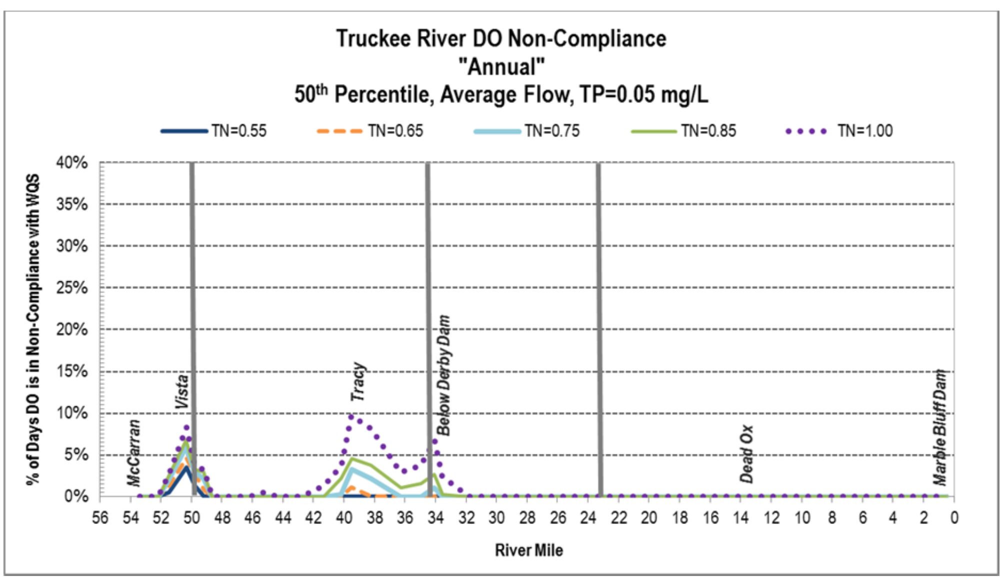

Figure 6-15. Longitudinal plot of the percent of days with DO criterion noncompliance for a range of TN target concentrations and a TP target concentration of 0.05 mg/L under an average flow condition

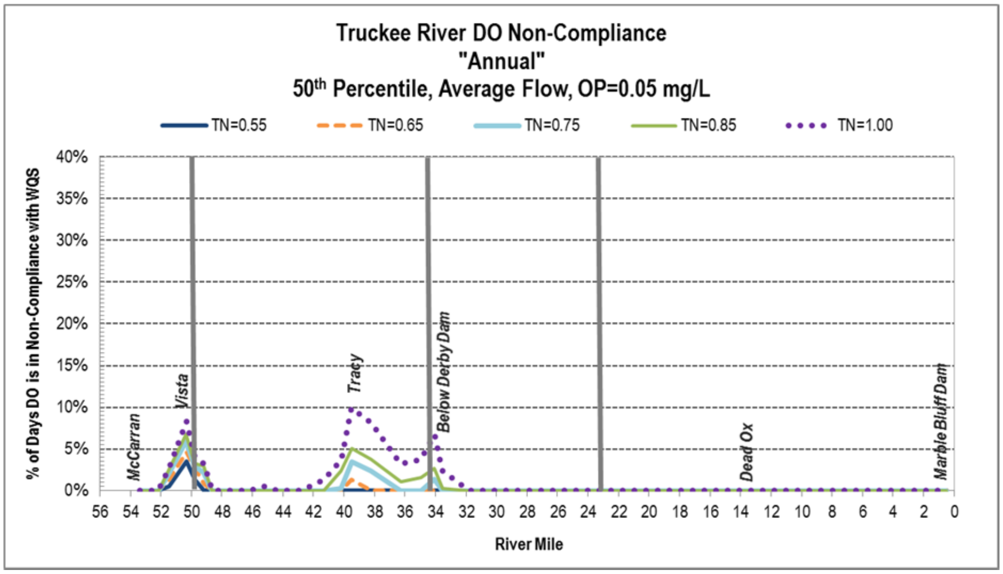

Figure 6-16. Longitudinal plot of the percent of days with DO criterion noncompliance for a range of TN target concentrations and a OP target concentration of 0.05 mg/L under an average flow condition

6.3.2 Total Phosphorus

Figures 6-18 and 6-19 examine the response of noncompliance with Truckee River DO criteria to a range of TP concentrations in the river under an average flow condition. Figure 6-18 shows the percent of days that the DO criterion was violated for each aggregated reach across a range of annual average TP concentrations and an annual average TN concentration of 0.75 mg/L.

For all reaches, the DO response curves show a generally “flat” response indicating that dissolved oxygen compliance in all portions of the Truckee River are not sensitive to increasing phosphorus concentrations under an average flow condition. For Reach 1, the DO criterion violation was less than approximately 2% of days at a TP concentration of 0.12 mg/L or less; whereas, for Reach 2 the DO criterion violation was less than approximately 0.5% of days. For Reaches 3 and 4 there were zero days with DO criterion violation under the average flow condition, regardless of the annual average TP concentration.

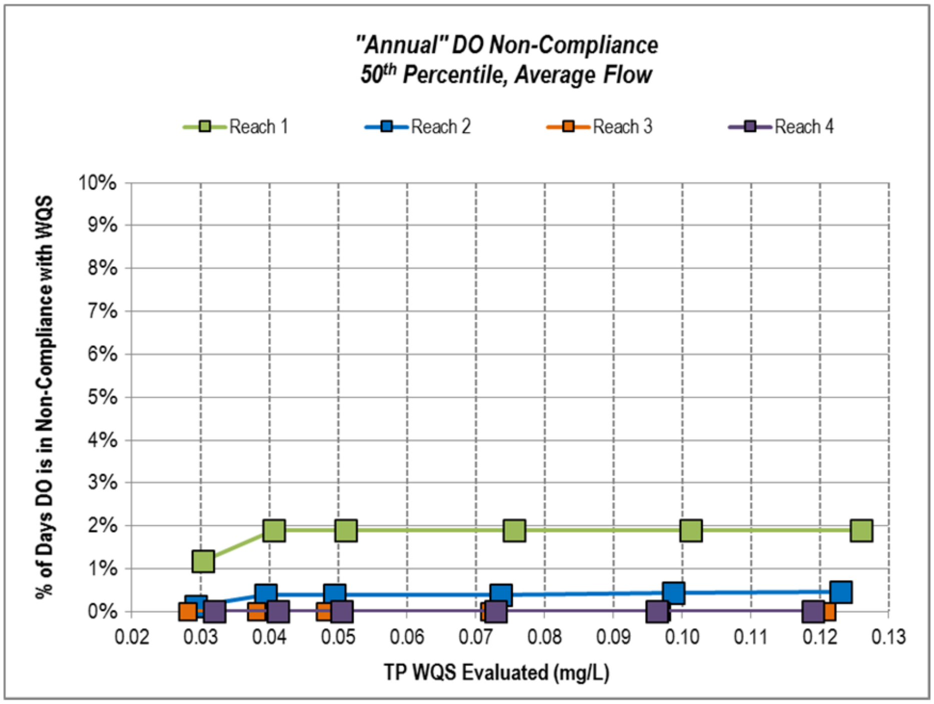

Figure 6-17. Nutrient-DO response relationship for TP in the Truckee River under an average flow condition and an annual average TN concentration of 0.75 mg/L (calculated for aggregated reaches and percent of days with DO criterion noncompliance)

Figure 6-19 shows the same model output in the perspective of a longitudinal profile. Each symbol on the plot represents a different annual average TP target concentration that was examined. Noncompliance percentages are near 5% at Vista and Tracy, and generally very low throughout the rest of the river for all TP concentrations evaluated.

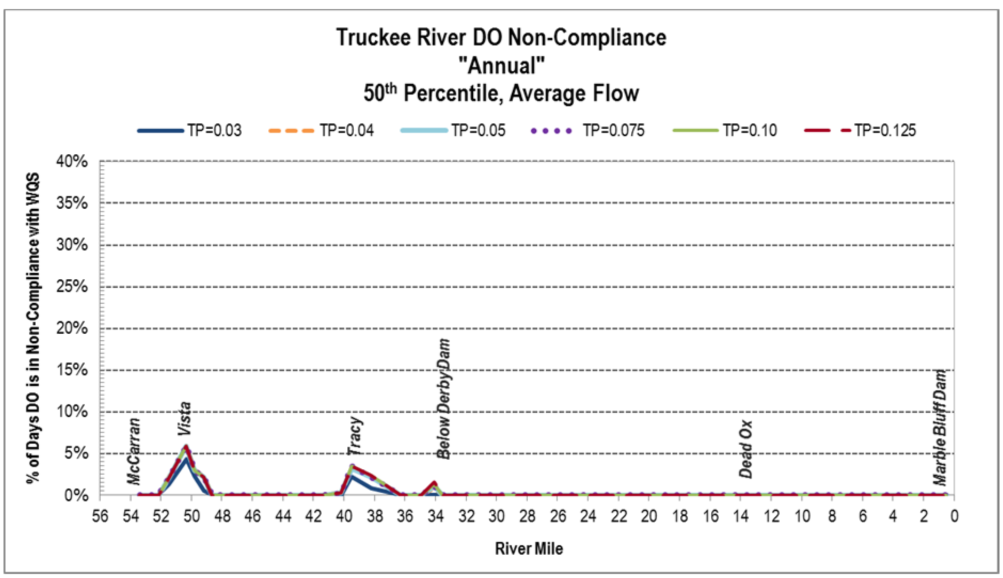

Figure 6-18. Longitudinal plot of the percent of days with DO criterion noncompliance for a range of TP target concentrations and a TN target concentration of 0.75 mg/L under an average flow condition

6.3.3 Ortho-phosphorus

Figures 6-20 and 6-21 examine the response of noncompliance with Truckee River DO criteria to a range of ortho-phosphorus (OP) concentrations in the river under a low flow condition. Figure 6-20 shows the percent of days that the DO criterion was violated for each aggregated reach across a range of annual average OP concentrations and an annual average TN target concentration of 0.75 mg/L.

For all reaches, the DO response curves show a generally "flat" response indicating that dissolved oxygen compliance in all portions of the Truckee River are not sensitive to increasing phosphorus concentrations under an average flow condition. For Reach 1, the DO criterion violation was less than approximately 2% of days for all OP concentrations evaluated; whereas, for Reach 2 the DO criterion violation was less than approximately 0.5% of days. For Reaches 3 and 4 there were zero days with DO criterion violation under the average flow condition, regardless of the annual average OP concentration.

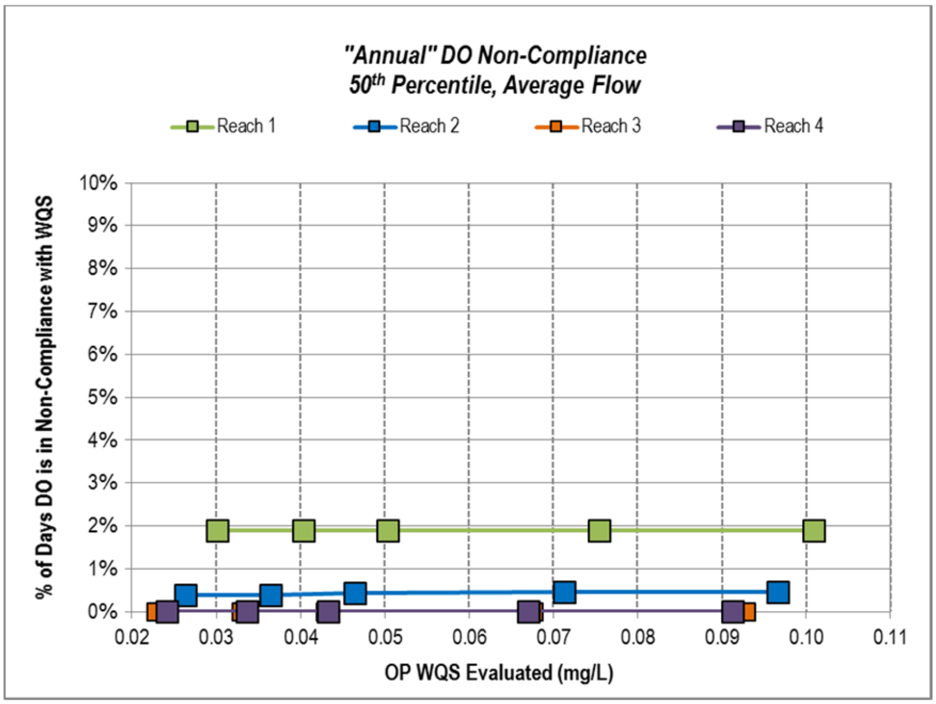

Figure 6-19. Nutrient-DO response relationship for OP in the Truckee River under a low flow condition and an annual average TN target concentration of 0.75 mg/L (calculated for aggregated reaches and percent of days with DO criterion noncompliance)

Figure 6-21 shows the same model output in the perspective of a longitudinal profile. Each symbol on the plot represents a different annual average OP target concentration that was examined. Results are essentially identical to those for TP shown in Figure 6-19. Noncompliance percentages are near 5% at Vista and Tracy, and generally very low throughout the rest of the river for all TP concentrations evaluated.

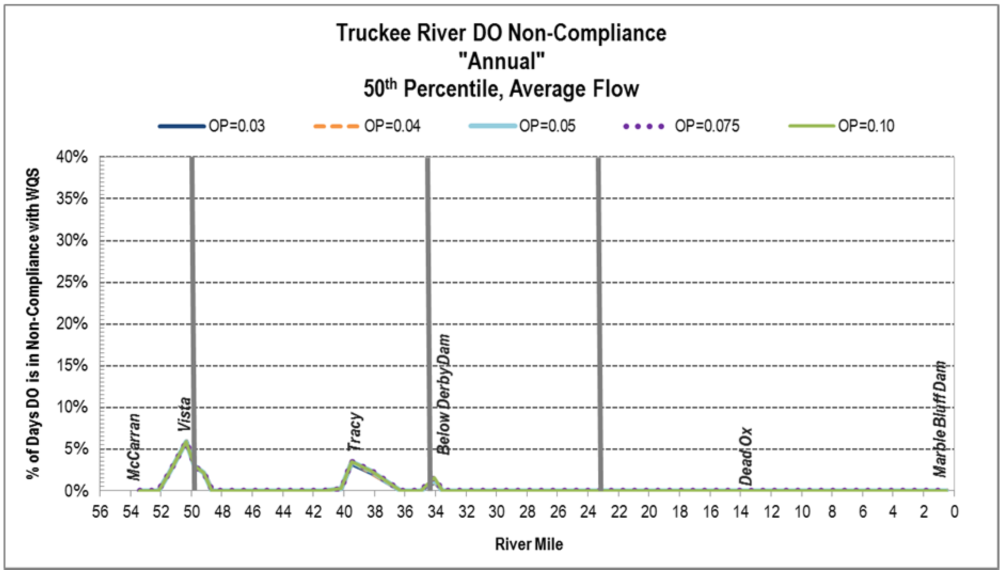

Figure 6-20. Longitudinal plot of the percent of days with DO criterion noncompliance for a range of OP target concentrations and a TN target concentration of 0.75 mg/L under an average low flow condition

6.4 Summary of Low Flow and Average Flow Scenario Results

This section provides additional summaries of the results presented above. Sections 6.2 and 6.3 show the level of DO criterion non-attainment across the full range of nitrogen and phosphorus concentrations examined. Another potentially useful way to examine the model results is to look at the level of DO criterion non-attainment for different nutrient criteria concentration combinations of interest under both flow regimes. Table 6-2 summarizes the numerical DO criterion attainment results three scenarios:

- **Scenario 1:** Current numeric nutrient criteria
- **Scenario 2:** Nitrogen levels at current numeric TN criteria; phosphorus levels at annual average TP = 0.05 mg/l; and
- **Scenario 3:** Nitrogen levels at current numeric TN criteria; phosphorus levels at annual average OP = 0.05 mg/l.

Note that the table provides DO criterion compliance as *percent of days* of violation. The nutrient-DO response curves and a summary table for the *percent of hours* calculation are provided in Appendix D. Along with the results for each aggregated reach which were presented in Section 6.2 and 6.3, Table 6-2 also includes DO criterion violation results for the most critical reach within each aggregated reach. Calculations of DO criterion compliance for all reaches and nutrient forms was done using annual averages of nutrient concentrations. For the OP evaluation at Reach 4 locations, an alternate calculation of DO violation is presented in terms of *flow-weighted* annual average OP, to be consistent with the averaging approach specified in the PLPT OP criteria. Figures 6-22 and 6-23 also present a comparison of the three scenarios in terms of a longitudinal plots. The results suggest that if the Nevada phosphorus criterion were changed to be consistent with the current PLPT criterion (Scenario 3), there would be no expected increase in DO violations in the Truckee River under either low flow or average flow conditions compared to conditions under existing standards.

In addition to examining the frequency of violation of the DO criterion, an analysis was also conducted of the magnitude of violation of the DO criterion (i.e., the difference between the DO criterion and the simulated DO concentration). For the three scenarios shown, the average magnitude ranged from 0.06 mg/L (Reach 1) to 0.8 mg/L (Reach 4) under the low flow condition. For the average flow condition, the average magnitude of violation ranged from 0 mg/L (Reaches 3 and 4) to 0.3 mg/L (Reach 1). This indicates that when DO criterion violations did occur, concentrations were not dropping so low as to cause major short-term impacts. Rather, the simulated DO concentration was generally just slightly below the numeric criterion for DO.

Table 6-2. Summary of percent of days of DO criterion violation for low flow and average flow

Location		Low Flow			Average Flow		
		Scenario 1: Existing Numeric Criteria	Scenario 2: TN=0.75 mg/L TP=0.05 mg/L	Scenario 3: TN=0.75 mg/L OP=0.05 mg/L	Scenario 1: Existing Numeric Criteria	Scenario 2: TN=0.75 mg/L TP=0.05 mg/L	Scenario 3: TN=0.75 mg/L OP=0.05 mg/L
Aggregated Reaches	Reach 1	0.27	0.27	0.31	1.9	1.9	1.9
	Reach 2	0.05	0.05	0.05	0.39	0.39	0.44
	Reach 3	0.17	0.17	0.34	0.0	0.0	0.0
	Reach 4	5.5* (5.6)	3.2	5.5* (5.6)	0.0* (0.0)	0.0	0.0* (0.0)
Most Critical Segments	Vista (within Reach 1)	1.6	1.6	1.9	5.9	5.9	5.9
	Tracy (within Reach 2)	1.1	1.1	1.1	3.2	3.2	3.5
	Below Derby (within Reach 3)	2.5	2.5	2.5	0.0	0.0	0.0
	Marble Bluff Dam (within Reach 4)	23* (23)	11	23* (23)	0.0* (0.0)	0.0	0.0* (0.0)

* The value in parentheses denotes the percent DO violation calculated using a flow-weighted average OP concentration. This is the method of calculation specified for the current OP numeric criteria in the PLPT jurisdiction (Reach 4).

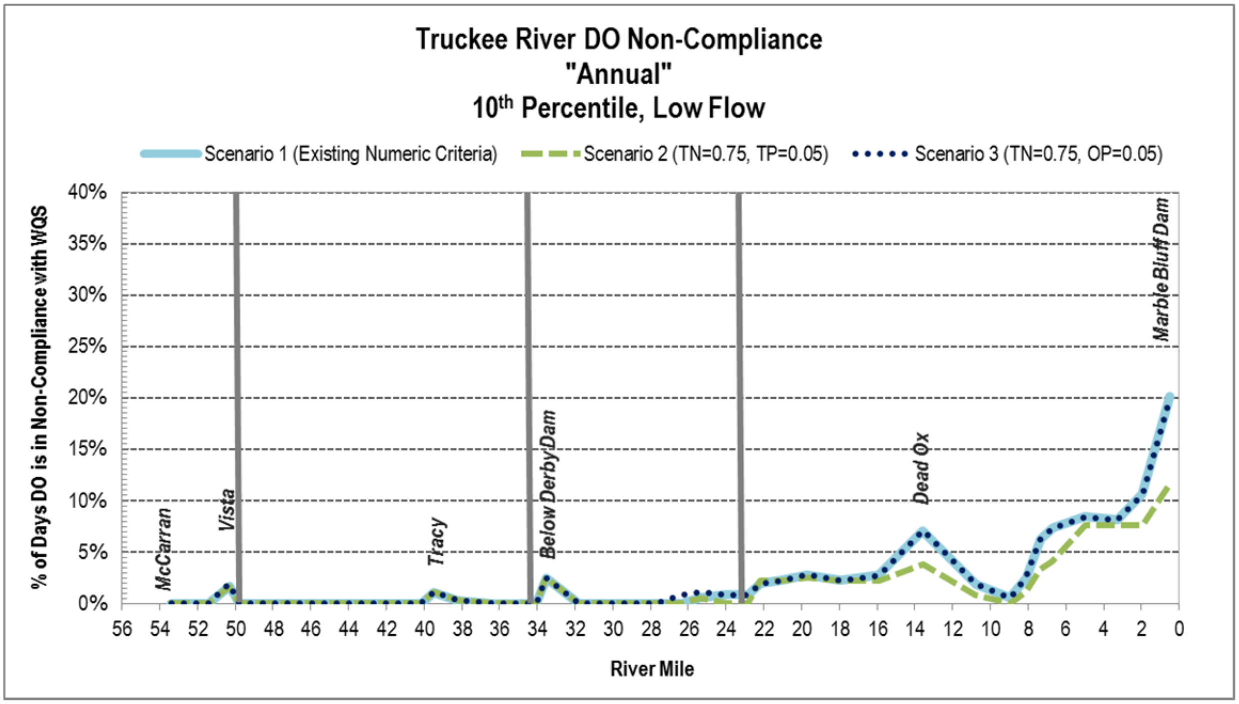

Figure 6-21. Longitudinal plot of the percent of days with DO criterion noncompliance for three scenarios under a low flow condition

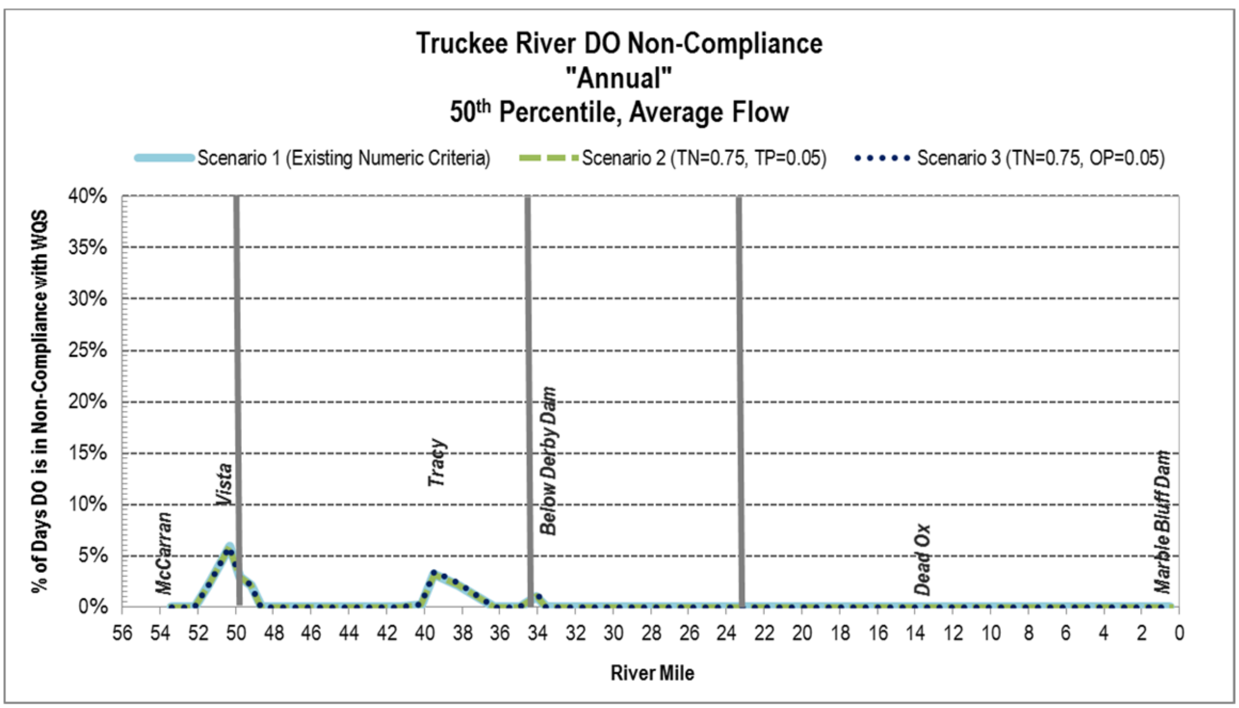

Figure 6-22. Longitudinal plot of the percent of days with DO criterion noncompliance for three scenarios under an average flow condition

All of the results presented above summarize DO criterion violation on an annual basis in terms of percent of days of violation. Inspection of the month-by-month DO criterion compliance output from TRHSPF provides information on which months were noted to be most critical (i.e., highest level of DO criterion violation) for each flow regime and each most critical results. The results of this inspection are shown in Table 6-3. For the low flow condition, the most critical months were noted to be June and July with the greatest amount of violations occurring in the Marble Bluff Dam model segment within Reach 4. For the average flow condition, the most critical month was July with the greatest amount of violations occurring in the Vista model segment within Reach 1.

Table 6-3. Summary of most critical months with highest DO criterion violation for the low flow and average flow simulations.

Critical Month Summary *for simulation where TN = 0.75 mg/L and TP = 0.05 mg/L or OP = 0.05 mg/L*				
FLOW CONDITION	**Most Critical Segments**			
	Vista (within Reach 1)	**Tracy (within Reach 2)**	**Below Derby (within Reach 3)**	**Marble Bluff (within Reach 4)**
10^{th} Percentile, Low Flow	Jun, Aug, Sep, Oct, Nov	Jun, Oct	Jun	**Jun, Jul**, Aug
50^{th} Percentile, Average Flow	**Jul**, Aug, Sep	Jul	--	--

BOLD – Most significant violations: greater than 10% of hours within the month

6.5 Integration over Full Flow Regime

The results presented in Section 6.4 are specific to one of two individual flow regimes, either the 10^{th} percentile (low flow) condition or the 50^{th} percentile (average flow) condition. It is instructive to examine results over the broad range of flow conditions that are expected to occur in the Truckee River, as opposed to considering only two individual conditions. This integrated assessment must be tempered by the fact that it is very time consuming to conduct additional TRHSPF simulations for additional flow conditions. The following assumptions were made to balance these competing demands and provide an estimate of expected DO criteria compliance for different nutrient criteria when assessed over an integrated flow regime:

- Results for an integrated flow regime can be represented as a weighted average of results across three individual flow regimes corresponding to low (10^{th} percentile), average (50^{th} percentile), and high (90^{th} percentile) flows; and
- Results for the high flow year can be conservatively approximated by the results from the average flow year.

Model simulations were conducted for the 10^{th} percentile (low flow) condition and the 50^{th} percentile (average flow) condition. It can be reasonably assumed that the average percent violation across the entire range of flow conditions can be approximated as a weighted average of results across three (i.e. low, medium, and high) individual flow regimes. Weighted averages are used to reflect the fact the high and low flow conditions represent relatively rare conditions, while the median represents the more commonly expected central tendency. It can also be reasonably assumed that the 10^{th} percentile low and 90^{th} percentile high flows each represent 20% of the observed conditions (i.e. the 10^{th} percentile low flow represents the conditions between 0 and 20th percentile low flows, while the 90th percentile high flow represents the conditions between 80 and 100th percentile high flows). This results in weighting factors of 0.2 for the low flow and high flow conditions, and a weighting factor of 0.6 for the median flow condition. The resulting equation for calculating percent of DO criterion noncompliance under an integrated flow condition is:

$$DOv_{all} = 0.2*DOv_{low} + 0.6*DOv_{ave} + 0.2*DOv_{high}$$

where

DOv_{all} = Percent noncompliance integrated over all flow conditions

DOv_{low} = Percent noncompliance for the low flow condition

DOv_{ave} = Percent noncompliance for the median flow condition

DOv_{high} = Percent noncompliance for the high flow condition

The second assumption made in conducting this integrated flow assessment is that results for the high flow year can be approximated by the results from the average flow year. This is clearly a conservative assumption, because noncompliance with DO criteria is expected to decrease as stream flows increase.

Tables 6-4, 6-5 and 6-6 summarize the integrated flow regime numerical DO criterion non-attainment results for three scenarios described above in terms of *percent of days*:

- **Scenario 1:** Current numeric nutrient criteria
- **Scenario 2:** Nitrogen levels at current numeric TN criteria; phosphorus levels at annual average TP = 0.05 mg/l; and
- **Scenario 3:** Nitrogen levels at current numeric TN criteria; phosphorus levels at annual average OP = 0.05 mg/l.

Tables 6-4, 6-5 and 6-6 include DO criterion violation results for the most critical segment within each aggregated reach. The results for the integrated flow condition are also graphed in Figures 6-24, 6-25 and 6-26. The key observation from these results is that the percent of DO criterion violations in Reach 4 (PLPT) are much lower when integrating over all flows than when only considering the low flow year, as no violations during the average and higher flow conditions. This highlights the importance of river flow in controlling compliance with the water quality criterion for dissolved oxygen in the lower river.

Table 6-4. Summary of integrated flow results for Scenario 1

		Scenario 1: Existing Numeric Criteria			
		% of Days in Violation			
	Location	**Low Flow**	**Ave Flow**	**High Flow**	**Integrated Flow**
Aggregated Reach	**Reach 1**	0.27	1.89	1.89	**1.57**
	Reach 2	0.05	0.39	0.39	**0.32**
	Reach 3	0.17	0.00	0.00	**0.03**
	Reach 4	5.5	0.00	0.00	**1.1**
Most Critical Segments	**Vista**	1.65	5.92	5.92	**5.07**
	Tracy	1.10	3.23	3.23	**2.80**
	Below Derby	2.50	0.00	0.00	**0.50**
	Marble Bluff Dam	23	0.0	0.0	**4.6**

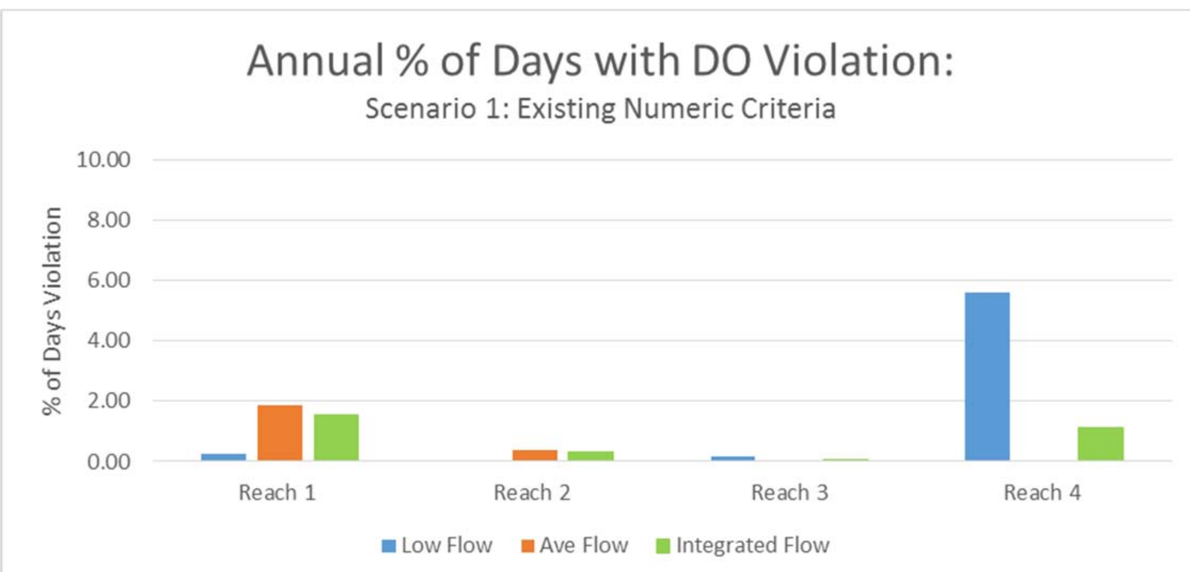

Figure 6-23. Integrated flow results for aggregated reaches for Scenario 1 (existing numeric criterion)

Table 6-5. Summary of integrated flow results for Scenario 2

	Location	Scenario 2: TN = 0.75 mg/L, TP = 0.05 mg/L			
		% of Days in Violation			
		Low Flow	Ave Flow	High Flow	Integrated Flow
Aggregated Reach	Reach 1	0.27	1.89	1.89	**1.57**
	Reach 2	0.05	0.39	0.39	**0.32**
	Reach 3	0.17	0.00	0.00	**0.03**
	Reach 4	3.24	0.00	0.00	**0.65**
Most Critical Segments	Vista	1.65	5.92	5.92	**5.07**
	Tracy	1.10	3.23	3.23	**2.80**
	Below Derby	2.50	0.00	0.00	**0.50**
	Marble Bluff Dam	11.30	0.00	0.00	**2.26**

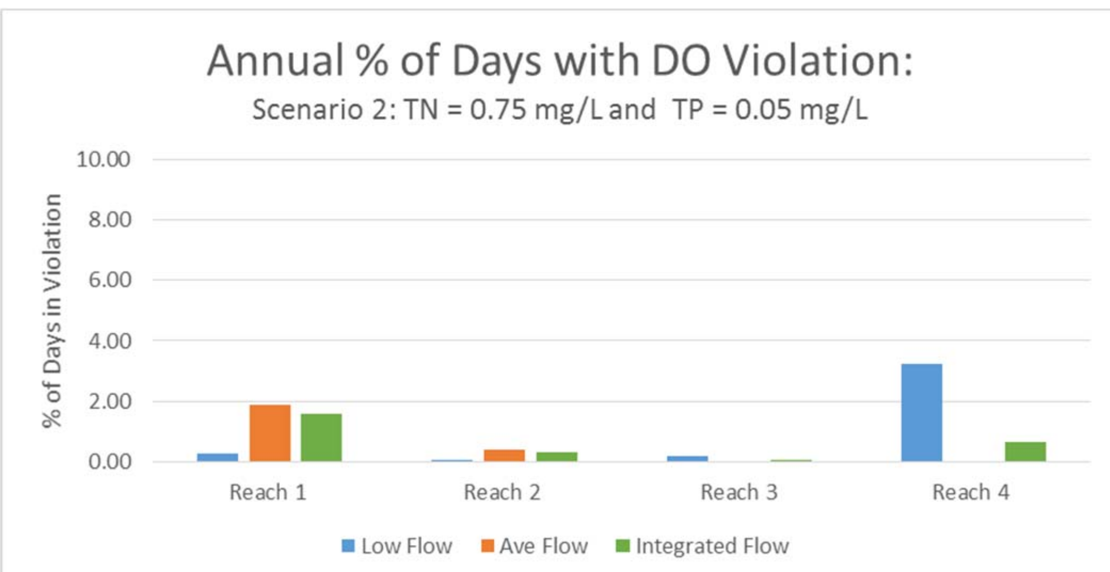

Figure 6-24. Integrated flow results for aggregated reaches for Scenario 2 (TN = 0.75 mg/L and TP = 0.05 mg/L)

Table 6-6. Summary of integrated flow results for Scenario 3

		Scenario 3: TN = 0.75 mg/L, OP = 0.05 mg/L			
		% of Days in Violation			
	Location	Low Flow	Ave Flow	High Flow	Integrated Flow
Aggregated Reach	Reach 1	0.31	1.9	1.9	**1.6**
	Reach 2	0.05	0.44	0.44	**0.36**
	Reach 3	0.34	0.00	0.00	**0.07**
	Reach 4	5.5	0.00	0.00	**1.1**
Most Critical Segments	Vista	1.9	5.9	5.9	**5.1**
	Tracy	1.1	3.5	3.5	**3.0**
	Below Derby	2.5	0.0	0.0	**0.5**
	Marble Bluff Dam	23	0.0	0.0	**4.6**

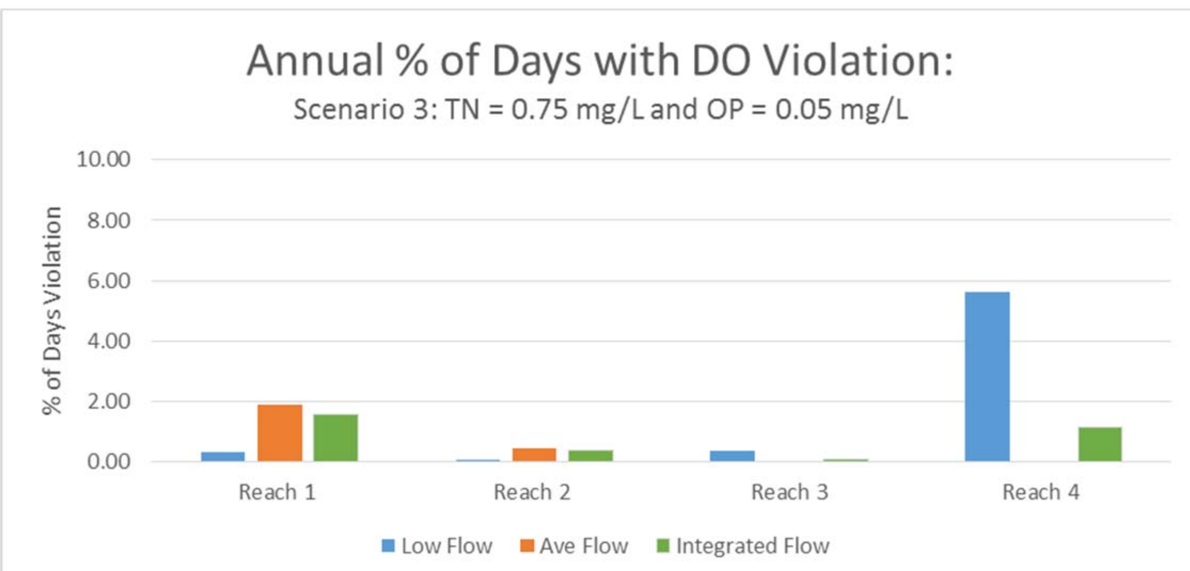

Figure 6-25. Integrated flow results for aggregated reaches for Scenario 3 (TN = 0.75 and OP = 0.05 mg/L)

7
Discussion of Results

Section 6 of this report presented a comprehensive summary of the response of DO criterion compliance in the Truckee River to a range of annual average nutrient concentrations that could be considered as numeric nutrient criteria. The response of the river is presented in terms of violation with the DO criterion for both low flow and average flow conditions. This section provides additional discussion of results as a summary of general observations and an evaluation of the existing single value maximum TN criterion which applies in Nevada portions of the Truckee River.

7.1 General Observations

From the comprehensive results presented in Section 6, the following general observations can be made:

- In the Nevada region of the Truckee River from East McCarran Blvd. to Pyramid Lake Paiute Tribal Boundary (Reaches 1, 2, and 3), the level of DO criterion violation is low regardless of annual average nutrient concentration:
  - For both low and average flow regimes, the DO criterion compliance in Reaches 1, 2 and 3 does not show a sensitivity to increased TP or OP concentrations;
  - Under the low flow regime, the DO criterion compliance in Reaches 1, 2 and 3 shows a slight sensitivity to increasing TN concentrations; however, this response does not occur unless the annual average TN concentration is greater than approximately 0.80 mg/L; and
  - Under the average flow regime, Reaches 1 and 2 show a slightly greater level of DO criterion violations than were calculated for the low flow regime; however, this phenomenon was attributed to inadvertent effects resulting from the synthetic approach used to scale incoming loads to match instream annual average nutrient concentrations to the target value under examination. These effects do not influence the primary observations noted for this region of the system (e.g., the flat DO response curve indicates a lack of sensitivity to phosphorus concentrations). Appendix E provides a detailed explanation of this phenomenon.

- In the Pyramid Lake Paiute Tribal region of the Truckee River (Reach 4), the level of DO criterion violation varies depending on the annual average nutrient concentration and the flow regime;
  - For the low flow regime, the level of DO criterion violation is sensitive to the annual average phosphorus concentration; however, no DO criterion violations were calculated for the average flow regime;
  - For both the low flow and average flow regimes, DO criterion violation in the Truckee River does not show sensitivity to the average annual TN concentration over the range examined; however, for the low flow regime the DO criterion violations ranged from approximately 3% of days to 6% of days depending on the phosphorus concentration; and
  - No DO criterion violations were calculated for Reach 4 for the average flow regime regardless of the annual average nutrient concentrations.

7.2 Evaluation of Single Value Maximum TN Criterion

The analyses presented in this report have primarily focused on evaluating the annual average total nitrogen and total phosphorus numeric criteria in the Truckee River. As discussed in Section 2.3, the Nevada and PLPT total nitrogen water quality standards also contain a component specifying a maximum single value criterion of 1.2 mg/L TN. Designated uses are more closely linked to the annual average component of the water quality standards than the single value maximum expression for two reasons:

1. Periphyton growth and subsequent depression of dissolved oxygen through periphyton respiration are driven more by long-term exposure to nutrients than to concentration occurring for a single day; and
2. The highest single value concentrations are typically observed during cold waters period of reduced periphyton growth and high dissolved oxygen. Approximately three quarters of the maximum observed TN data in a given year occurred during the period November through April, with December and January being the months where the highest concentration of the year were most likely to be observed. This is consistent with WARMF/TRHSPF results, which also show the highest concentration of TN to occur during cold weather.

Nonetheless, because the single value total nitrogen criterion exists, it is important as part of an overall review of water quality standards to evaluate whether modification of the annual average component of the standard would also require modification of the single value criterion.

Figure 7-1 examines the response of the Truckee River (DO concentration) to a range of predicted annual maximum TN concentrations in the river under a low flow condition, showing the percent of days that the DO criterion was violated for each aggregated reach across a range of TN concentrations. This figure shows results for two sets of runs: 1) a case where the annual average TP concentration was set at 0.05 mg/L (solid symbols), and 2) a case where the annual average OP concentration was set at 0.05 mg/L (open symbols). For Reaches 1, 2, and 3, DO criterion violation is less than 0.5% of days at a maximum TN concentration of 2.0 mg/L or less. At higher TN concentrations, there is a slight increase in DO criterion violation, although not exceeding 2% of days for any of the concentrations examined. DO compliance in Reach 4 was insensitive to variation in the maximum TN concentration, averaging around 4% of days for annual average TP concentration of 0.05 mg/l and 6% of days for annual average OP concentration of 0.05 mg/l.

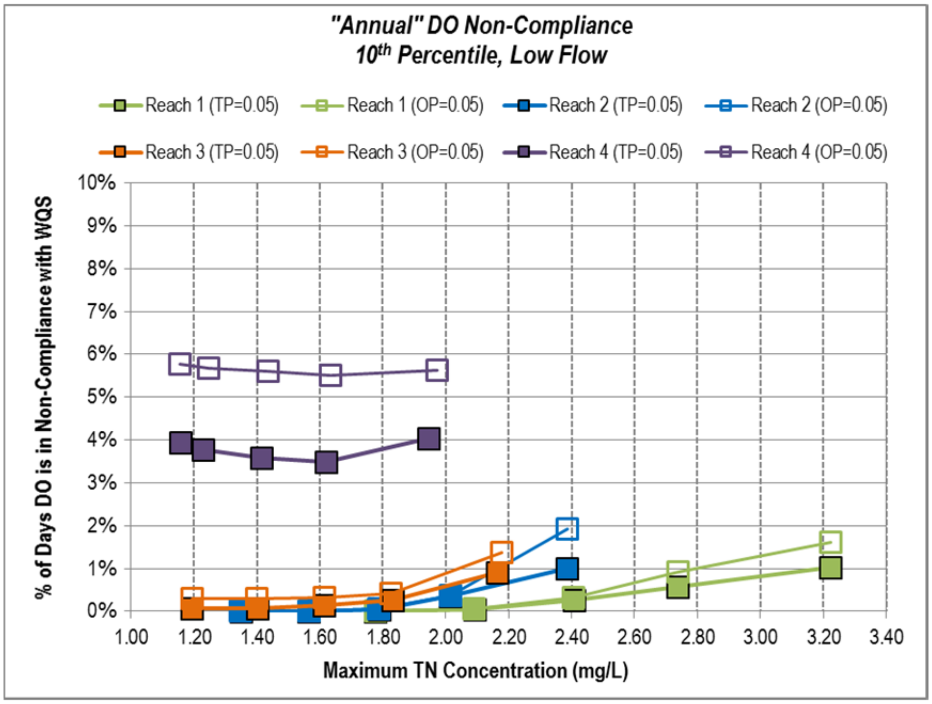

Figure 7-1. Nutrient-DO response relationship for Annual maximum TN in the Truckee River under a low flow condition (calculated for aggregated reaches and percent of days with DO criterion noncompliance)

Figure 7-2 examines the response of the Truckee River (DO concentration) to a range of maximum predicted annual TN concentrations in the river under the average flow condition. This figure shows results for two sets of runs: 1) a case where the annual average TP concentration was set at 0.05 mg/L (solid symbols), and 2) a case where the annual average OP concentration was set at 0.05 mg/L (open symbols). DO criterion violation in Reach 1 increases gradually as a function of maximum TN concentration, starting at less than 1% of days for a maximum TN of 1.05 mg/l and increasing to 2.8% of days for a maximum TN of 1.9 mg/l. DO criterion violation in Reach 2 is zero for maximum TN concentrations less than 1.1 mg/l, increasing to 2.8% of days for a maximum TN of 1.6 mg/l. DO compliance in Reaches 3 and 4 was insensitive to variation in the maximum TN concentration, remaining at zero for all maximum TN concentrations evaluated.

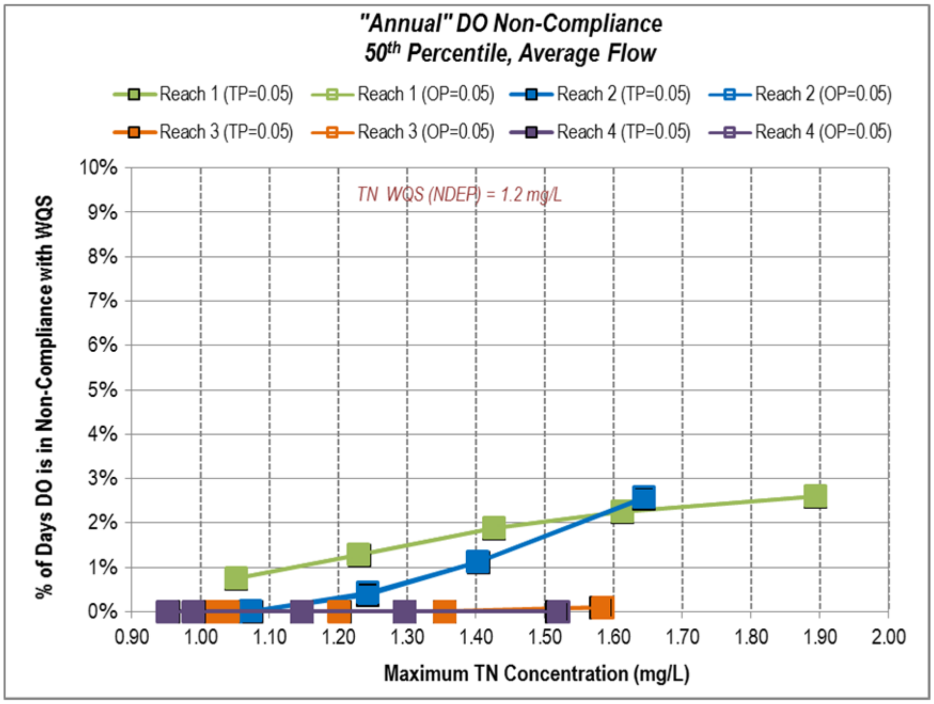

Figure 7-2. Nutrient-DO response relationship for Annual maximum TN in the Truckee River under an average flow condition (calculated for aggregated reaches and percent of days with DO criterion noncompliance)

7.3 Additional Observations to Support NDEP Recommendations

The purpose of the process and analysis described in this report is to provide NDEP and U.S. EPA with technical information to support their triennial review of the nutrient water quality standards for the Truckee River in Nevada. Any proposed recommendations for changes from the existing nitrogen and phosphorus numeric nutrient criteria will be developed by and documented by NDEP in a rationale document which will be available for public comment. Any proposed changes will need to be approved by the State Environmental Commission and U.S. Environmental Protection Agency before becoming effective under the federal Clean Water Act.

Two alternate scenarios for Nevada nutrient standards were given detailed examination: 1) Maintenance of existing standards (Scenario 1), and 2) Switching the phosphorus standard from the existing TP=0.5 mg/L to the PLPT standard of OP=0.05 mg/L (Scenario 3). Results shows that if the Nevada phosphorus criterion were changed to be consistent with the current PLPT criterion, there would be no expected increase in DO violations in the Truckee River under either low flow or average flow conditions compared to conditions under existing standards.

8
Additional Considerations

The review and evaluation of nutrient water quality standards in the Lower Truckee River warrants a few additional and important considerations. These additional considerations include the potential impact of river geometry, river restoration, and climate change on DO criterion noncompliance. These topics are discussed in the sections below. This section also provides discussion on limitations and caveats of this analysis.

8.1 River Geometry Properties

Flow, temperature, and algae (such as periphyton) are all factors that contribute to the dissolved oxygen levels in the Truckee River. The geometry or shape of a river channel can influence all of these factors. In particular, the shape of a river channel can determine how fast water moves, how warm the water can get, and how much algae can grow (i.e., wide and shallow reaches tend to move water slower, keep water warmer and serve as an ideal environment for algal growth). In order to understand how reach geometry may impact DO response in the Truckee River, a reach geometry analysis was performed.

The model is a conservative (i.e., worst case) representation of actual, present-day river conditions in those locations where the model channel geometry represents pre-restoration geometry conditions. To investigate the potential relationship between reach channel geometry and the most critical reach segments in terms of DO criterion noncompliance, as predicted by TRHSPF, selected reach geometry parameters were mapped for each model reach segment and included the following:

- Reach slope (Figure 8-1)
- Water depth (summer average; 10th percentile year) (Figure 8-2)
- Water velocity (summer average; 10th percentile year) (Figure 8-3)

The reach geometry parameters mapped were based on either model inputs (i.e., reach slope) or model outputs (i.e., water depth and velocity). The most critical segments, as predicted by TRHSPF, were identified for each aggregated reach (see Figure 6-1 and Section 6.1.2 for more details). The critical segments within each aggregated reach were identified as:

- Reach 1 = critical reach segment 304, Vista
- Reach 2 = critical reach segment 315, Tracy
- Reach 3 = critical reach segment 320, Below Derby Dam
- Reach 4 = critical reach segment 343, Marble Bluff Dam

A summary of the reach geometry analysis is provided below and is summarized by critical reach segments and aggregated reaches. The categories of preferred, okay and less preferred were used in the analysis to qualitatively describe how each reach geometry parameter may contribute either positively or negatively to dissolved oxygen concentrations. The categories are based on the distribution of values for each reach geometry parameter (i.e., slope, water depth, and water velocity). Reach geometry values were plotted from upstream to downstream and then breakpoints were identified in the distribution to assign the range of values associated with the qualitative category of preferred, okay and less preferred.

The preferred slopes for a healthy DO response tend to be higher slopes. A higher slope will tend to move water faster, improve reaeration (i.e., rate of transfer of oxygen from the atmosphere to a body of water), and potentially create a less than optimal environment for algal growth. The model segments with the less preferred slopes (in red) tend to overlap with the critical reach segments (Figure 8-1). This suggests that reach slope may be an important factor in reach specific DO response.

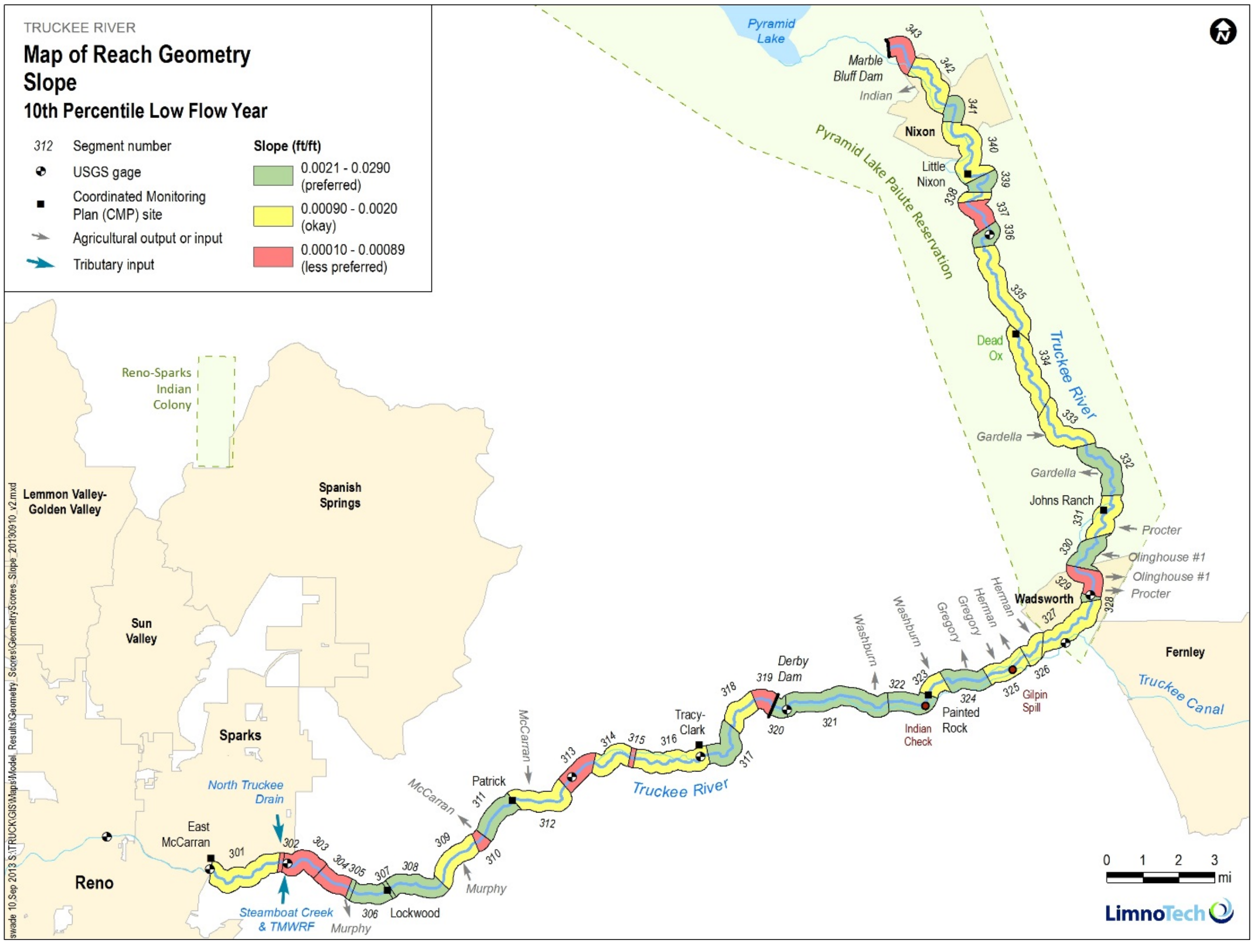

Figure 8-1. Map of TRHSPF model reach segment slope based on the 10th percentile low flow year

Deeper water is preferred in the summer for a healthy DO response. Deeper reaches will tend to have colder water and less light available for algae to grow. The model reach segments with the less preferred (i.e. shallower) depths occur in Reach 4, which tends to be the most sensitive during low flow conditions in regard to DO noncompliance (see Section 6.2). In particular, Marble Bluff Dam, which is the most critical reach segment in Reach 4, has a less preferred summer mean depth as well as the most of reach segments just upstream of this location (Figure 8-2).

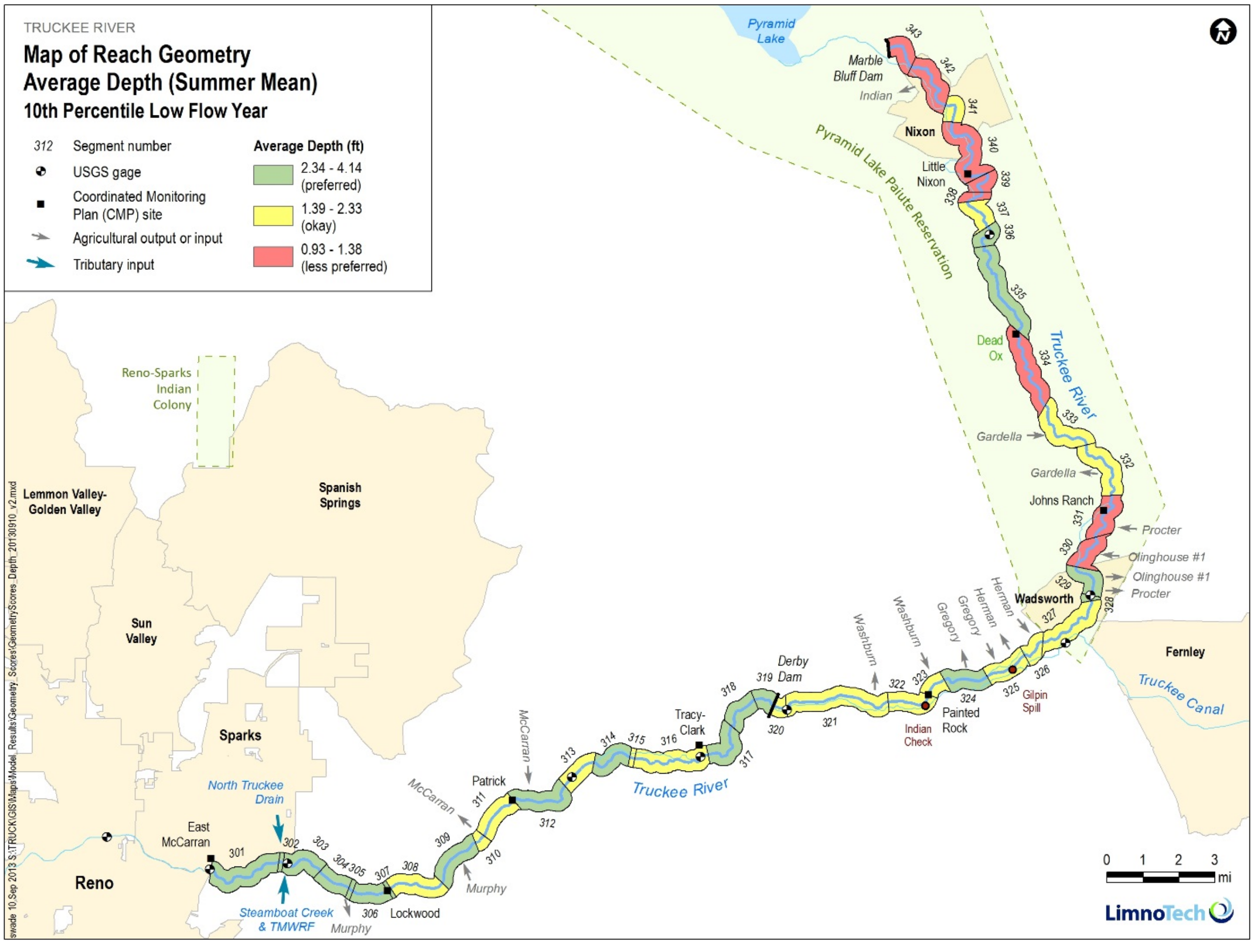

Figure 8-2. Map of TRHSPF model reach segment summer mean average depth based on the 10th percentile low flow year

Higher velocities are also preferred for a healthy DO response. Reaches where water tends to move faster likely have higher levels of reaeration. In addition, these reaches likely have less than optimal conditions for algae to grow. Again, the model reach segments with the less preferred velocities primarily occur in Reach 4 (Figure 8-3).

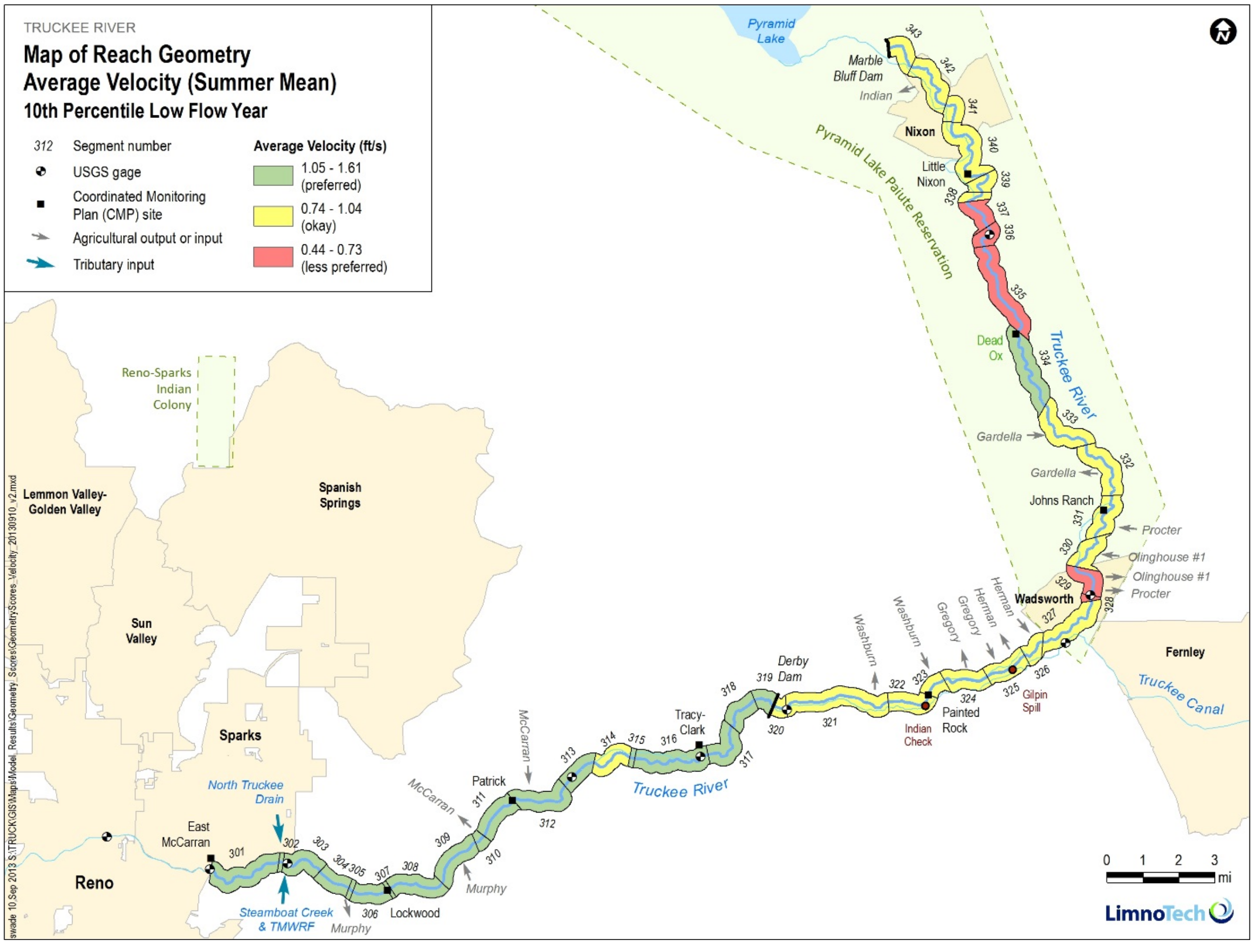

Figure 8-3. Map of TRHSPF model reach segment summer mean average velocity based on the 10th percentile low flow year

A *Reach Geometry Index* was created to better understand how slope, depth, and velocity may work together to affect the DO response on an individual segment or broader reach basis. Given similar algae (or periphyton) productivity across reach segments, the product of *depth* **x** *velocity* **x** *slope* should be a good indicator or index of segment-specific diurnal variation in dissolved oxygen. Excessive growth of algae in the Truckee River can cause large dissolved oxygen concentration swings over a single day due to photosynthesis and respiration. This pattern is often referred to as a "diurnal swing". Significant variations in dissolved oxygen levels may stress aquatic organisms, especially if dissolved oxygen levels drop below 5 mg/L.

The justification and logic for the *Reach Geometry Index* is outlined below:

- Violations are caused primarily by the magnitude of the diurnal swing
- The diurnal swing at steady state is directly proportional to gross plant productivity (g O_2/m^3/day) divided by **[reaeration rate]**
- Gross plant productivity equals areal productivity (g O_2/m^2/day) divided by **[water depth]**
- Reaeration is proportional to **[velocity * slope]**
- Diurnal swing equals areal productivity divided by **[depth * velocity * slope]**
- With similar algae (i.e. periphyton) productivity across segments, **[depth * velocity * slope]** should be a good indicator of segment-specific diurnal swing

The *Reach Geometry Index* was developed for the segment-specific diurnal swing by calculating a two-segment average to account for influence by the diurnal swing in the prior segment. The Truckee River is a spatially-varying system. The diurnal swing in a given segment is also influenced by the diurnal swing in the prior segment. To account for the diurnal swing created in the segment immediately upstream, a two-segment average of *depth* **x** *velocity* **x** *slope* was calculated.

It should be noted that the *Reach Geometry Index* does not account for other features (e.g., substrate) that will lead to different algae (or periphyton) densities or the effect that higher stream temperatures will have on DO saturation.

The preferred *Reach Geometry Index* for DO response tends to have higher index values. The model segments with the less preferred *Reach Geometry Index* values are shown in red in Figure 8-4. These segments tend to overlap with the critical segments identified through the water quality modeling (see Section 6). In addition, large sections of the aggregated Reach 4 are shown to have less preferred *Reach Geometry Index* values (Figure 8-4). The overlap between the less preferred *Reach Geometry Index* values and the critical segments suggests that reach geometry is an important factor in reach-specific DO response.

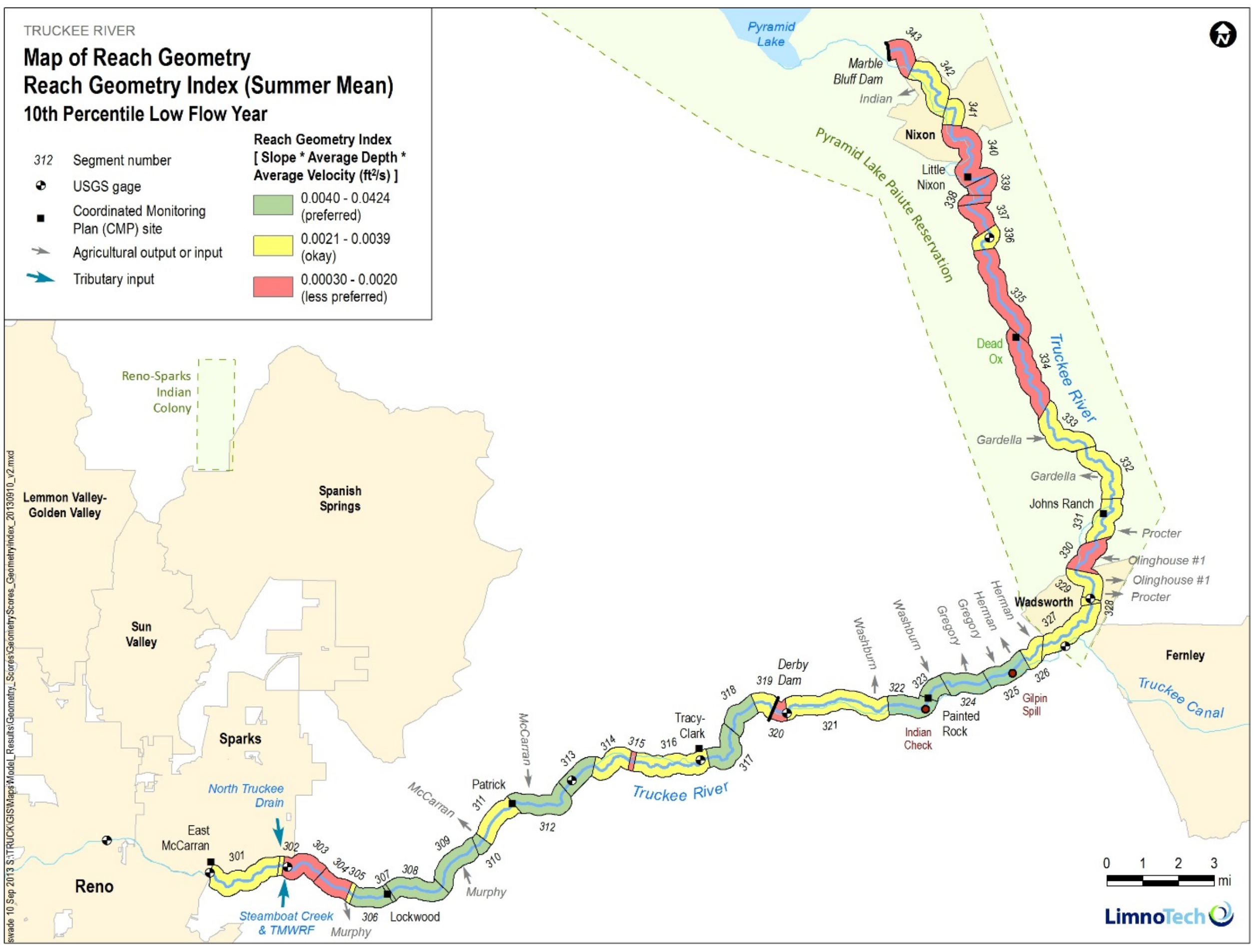

Figure 8-4. Map of TRHSPF model reach segment summer mean Reach Geometry Index based on the 10th percentile low flow year

Based on the reach geometry analysis described above, DO criterion noncompliance in the critical segments, as well as Reach 4, appears to have characteristics (such as reach geometry parameters like slope, depth, and velocity) which contribute to an increased sensitivity to algal growth in the presence of phosphorus.

8.2 River Restoration

The Lower Truckee River has undergone restoration in specific locations over the last decade. Restoration efforts led by The Nature Conservancy (TNC) have focused on building new meanders to reconnect the river to the floodplain, creating instream riffles to provide habitat for native fish, creating wetland habitat along the river to provide habitat for birds, frogs, and other wildlife, and replacing invasive plants with native plants (TNC, 2013). Restoration projects completed in the Lower Truckee River include McCarran Ranch, Lockwood, 102 Ranch, and Mustang Ranch (TNC, 2013). The restoration work includes nearly nine river miles, 19 new wetlands, 13 new river meanders, 31 instream riffles, and approximately 400 acres of re-vegetation (TNC, 2013). Currently, restoration of the Tracy Reach is in progress (TNC, 2013). A map of the completed as well as ongoing and planned restoration projects led by TNC as well as other groups is provided below in Figure 8-5.

It is important to note that the river model, TRHSPF, does not represent the completed restoration projects indicated in the map below (Figure 8-5). Therefore, the model is a conservative representation of actual river geometry as it is parameterized for the pre-restoration geometry conditions.

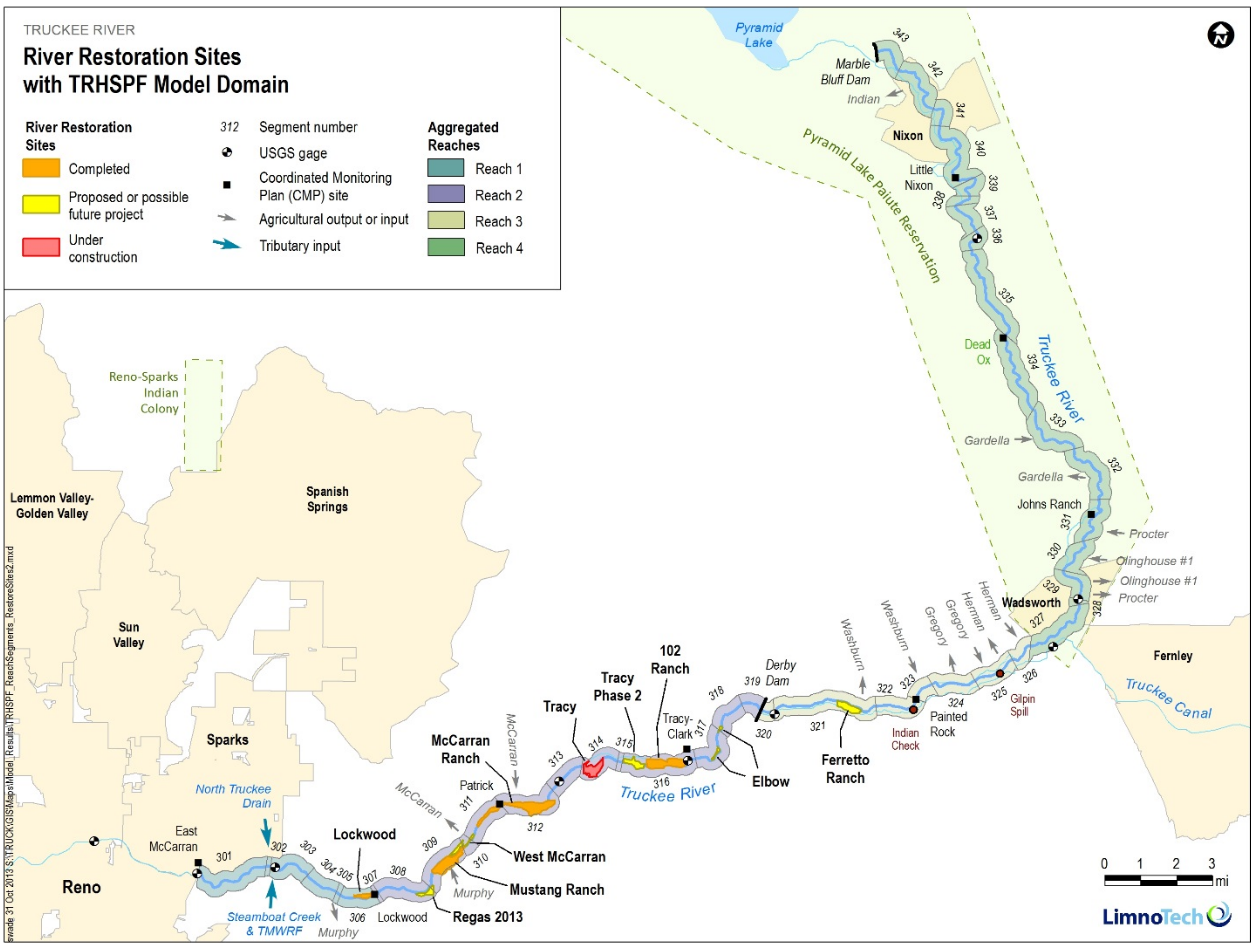

Figure 8-5. Map of river restoration sites located within the TRHSPF model domain.

8.3 Climate Change Sensitivity

The potential impact of climate change was identified by the Focus Group as an important consideration in the review of the nutrient water quality standards. A sensitivity analysis was conducted to understand how DO criterion noncompliance may change in the future with an increase in air and water temperature. The sensitivity runs only focused on the potential impacts of an increase in air and water temperature (without explicitly considering changes in precipitation) for the following reasons:

- Given the highly managed nature of flows throughout the system, reservoir management could override climate change influences on flow in upper watershed;
- Climate forecasting models predict a wide variation in precipitation changes, resulting in a wide range of uncertainty regarding how precipitation patterns may change in the future; and
- An extensive climate change sensitivity analysis that includes direct linkage with climate projection models is beyond the scope of this effort.

The general approach for climate sensitivity runs included the following steps:

1) A 1° C air temperature increase was applied across an entire year. The selection of a 1° C air temperature increase for the climate sensitivity runs was based on the United States Bureau of Reclamation (USBR) Truckee River Basin Study (2012-2014) (USBR 2013). The study evaluated a range of potential changes in water demands due to growing population and compared demands to existing supply under potential future uncertainties, including climate change (Figure 8-6).

2) Based on the results of the 1° C air temperature increase, the location of the maximum water temperature increase was determined. The maximum increase was used to set the water temperature increase for the upstream boundary conditions. The maximum water temperature increase simulated by the model occurred near Marble Bluff Dam.

   – 10^{th} percentile, low flow: 0.48 ° C

   – 50^{th} percentile, average flow: 0.37 ° C

3) The water temperature increase calculated in Step 2 was applied to the upstream boundary conditions at the WARMF /TRHSPF interface (McCarran Blvd., North Truckee Drain, Steamboat Creek).

4) The model was run with the combined air temperature (1° C) and water temperature increase for the “cross-hairs” run (TN 0.75 mg/L, Ortho-P 0.05 mg/L) for the low (10^{th} percentile) and average (50^{th} percentile) flow regimes.

5) The DO criterion noncompliance” water quality runs based on historical climate were compared with output from the climate change “cross-hairs” runs to evaluate the potential impact of climate change.

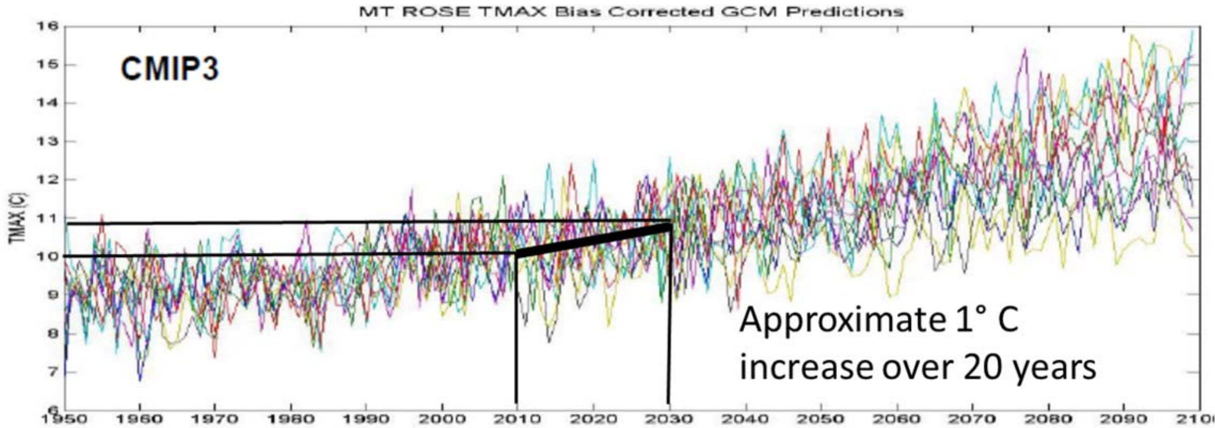

Figure 8-6. Maximum temperature predictions at Mt. Rose

Adapted from the *Truckee Basin Study,* Technical Advisory Group Water Supply Workshop, June 24, 2013 (USBR 2013).

The results of the climate change sensitivity results are shown below in Figures 8-7 and 8-8. Note that these simulations are referenced to "target" nutrient concentrations of TN = 0.75 mg/L and OP = 0.05 mg/L; however, no adjustment was made to simulated instream concentrations (as described in Section 6.1.3). Therefore, the results for the "historical climate" simulation will not directly match results shown in Table 6-2. What is important to note is the relative change in DO violation between the two scenarios.

For the low flow regime (10th percentile), the increase in DO noncompliance between the "historical climate" and the "climate change" run is less than 0.5% for Reaches 1, 2, and 3 and is less than 1% for Reach 4 (Figure 8-7). The overall DO noncompliance for both runs is less than 1% for Reaches 1, 2, and 3 and is less than 6% for Reach 4. For the average flow regime (50th percentile), the increase in DO noncompliance between the baseline and the climate change run is less than 0.5% for Reaches 1 and 2 (Figure 8-8). For Reaches 3 and 4, the DO noncompliance between the baseline and the cross-hairs climate change run does not change, and remains at 0% for both climate conditions.

The low flow regime shows slightly better DO noncompliance in Reaches 1 and 2 compared to the average flow regime, which may be counterintuitive. However, this phenomenon can be attributed to the synthetic approach used to scale incoming loads to match instream annual average nutrient concentrations to the target value under examination. See Section 7 and Appendix E for a more detailed explanation of this phenomenon. Overall, the climate change sensitivity analysis indicates that an increase in air and water temperature results in a minimal increase in DO noncompliance for Reaches 1, 2, 3, and 4 in both the low flow and average flow regime runs.

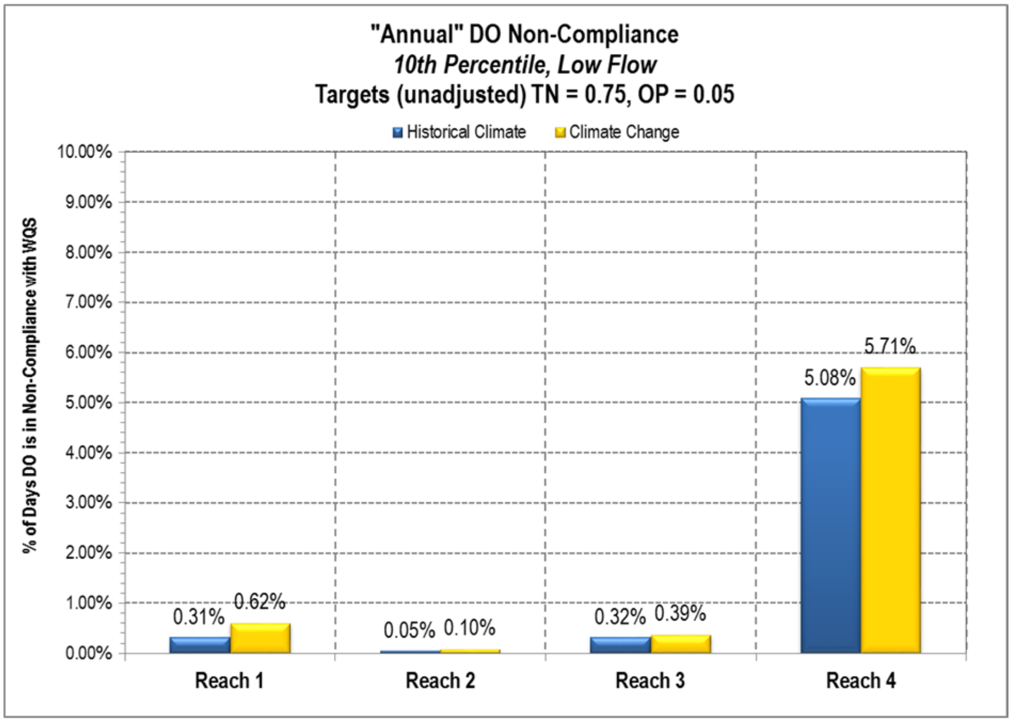

Figure 8-7. Annual DO noncompliance for a representative 10th percentile low flow simulation (target TN 0.75 mg/L, Ortho-P 0.05 mg/L) under "historical climate" and "climate change" conditions

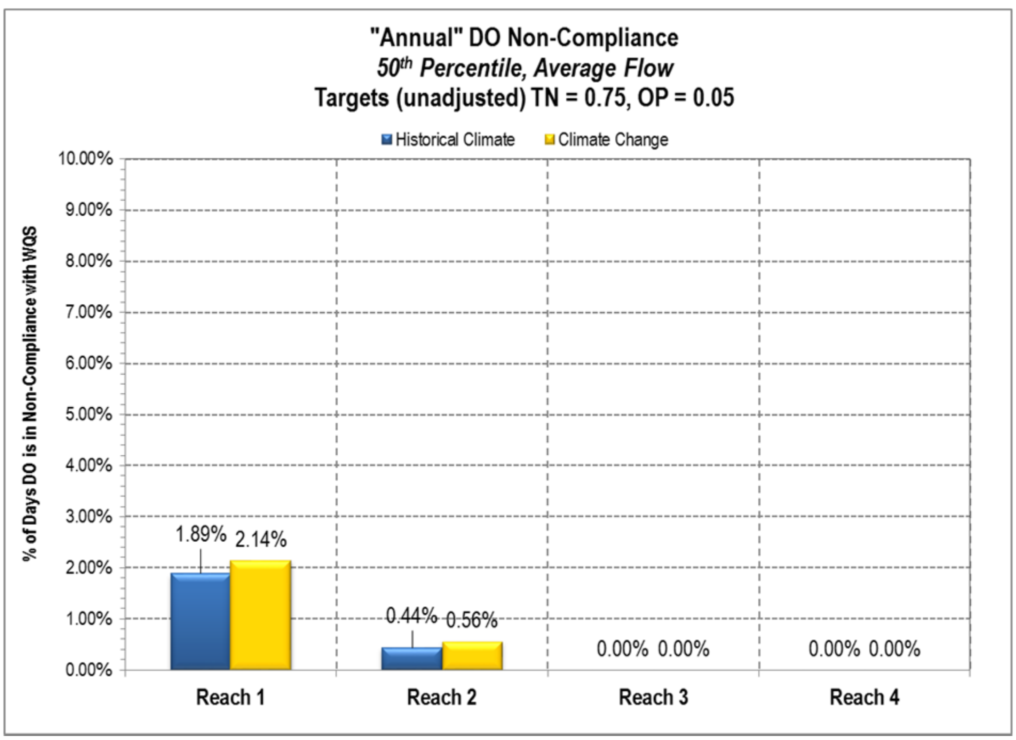

Figure 8-8. Annual DO noncompliance for a representative 50th percentile average flow simulation (target TN 0.75 mg/L, Ortho-P 0.05 mg/L) under "historical climate" and "climate change" conditions

8.4 Limitations and Caveats

It is recognized that the results of simulations from these models are not an exact prediction of future conditions. Water quality models are simplified representations of the real world, and their results contain a degree of uncertainty. Furthermore, there is no guarantee that future flow and climate will match the conditions used as input to these simulations. Although the results presented here contain some degree of uncertainty, they also represent the best available understanding of the expected response of the Truckee River to different nutrient criteria, and can serve as a valuable tool for evaluating alternative nutrient criteria.

There are some assumptions inherent to the model application that can be considered conservative, i.e. resulting in a prediction of greater water quality impacts than might be expected to occur. As described in Section 4.2, the nitrogen speciation of TMWRF effluent was set to reflect a higher proportion of bioavailable nitrogen (ammonia and nitrate) than recent observed data. Also, the channel geomorphology (widths, depths) specified in TRHSPF represents conditions prior to the initiation of currently-ongoing restoration efforts. These restoration efforts are expected to improve dissolved oxygen conditions in the Truckee River, such that the amount of time that water quality standards are not met after restoration should be less than what is predicted here for pre-restoration conditions. Another conservative assumption is used during the integration of results across a range of flow years. The results presented here are based on the assumption that the percent of time in noncompliance during a high flow year is the same as for an average flow year, while in reality it is expected that the rate of noncompliance should decrease at higher flows.

It is often worthwhile when examining uncertain model results to focus more on relative differences between results than absolute values. For example, if the percent of time of standards violations for two different candidate nutrient criteria are 2% and 4%, the observation that one criterion results in twice as many violations than the other is likely more robust than assuming the percent of time in violation is exactly 2% or 4% for each alternative.

9
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Appendix A: Summary of Focus Group Outreach Meetings

Focus Group Workshop #1 (November 2nd, 2011): Provided background on, justification for, and objectives of the water quality standards review process. Introduced the two models used for the WQS review process (TRHSPF and WARMF) and summarized recent model updates. Discussed model updates such as recent land use data, updated input databases, and model confirmation runs to simulate more recent historical conditions.

Focus Group Workshop #2 (December 14th, 2011): Recap of NDEP Triennial Review and Standard Setting. Overview of WQ model updates. Discussion of model application process to conduct the water quality standards review. Overview of Truckee River flow management models: TROM and Riverware. Discussion of basis for the representative flow condition, a key modeling assumption.

Focus Group Workshop #3 (July 17th 2013): Restart of stakeholder engagement process. Review of the basis for the water quality standards review. Recap of models to support WQS review process including recent updates and the model confirmation report. Overview of the general approach for model application to support the WQS process. Introduction to technical decision points (flow model, flow year selection, DO compliance calculation methods, aggregation and interpretation of model results). Anticipated schedule and milestones.

Focus Group Workshop #4 (August 28th 2013): Discussed feedback on model confirmation report. Review of approach for model application. Establishment of representative flow regimes. Analysis and interpretation of model results. Presented and discussed preliminary model results demonstrating the response of the Truckee River in terms of dissolved oxygen criteria compliance to a range of nitrogen and phosphorus concentrations.

Focus Group Workshop #5 (September 27th 2013): Reviewed development of representative flow regime. Presented and discussed preliminary model results demonstrating the response of the Truckee River in terms of dissolved oxygen criteria compliance to a range of nitrogen and phosphorus concentrations. Presented preliminary results of climate change sensitivity runs. Examined considerations of river geomorphology characteristics in the context of water quality modeling.

Focus Group Workshop #6 (November 12th 2013): Presented and discussed draft final water quality model results. Presented updates to the climate change sensitivity runs. Examined mapping of restoration sites in the context of the model domain. Presented next steps for the Focus Group involvement and the NDEP process for WQS review.

PLANNED Focus Group Workshop #7 (~January 15th 2014): Provide an overview of the "Technical Rationale for Review and Revision of Truckee River Nutrient Water Quality Standards" (this report). Request feedback from Focus Group on draft report. Comments due 2/15/14.

Appendix B:
Focus Group Meeting Attendance

	Name	Organization	11/2/11	12/14/11	7/17/13	8/28/13	9/27/13	11/12/13	
Truckee WQS Focus Group	Michael K. Johnson	Churchill Co			x	x	x	x	
	Brad Goetsch	Churchill Co	x	x					
	Chris Mahannah	Churchill Co		x					
	Shari Whalen	City of Fernley	x	x	x		x		
	Jennifer Derley	City of Fernley				x			
	Matt Maples	NDOW		x					
	Nancy Vucinich	P.L. Fisheries			x	x		x	
	Brian Wadsworth	PLPT			x			x	
	Olin Anderson	PLPT	x	x		x	x		
	Fannie Ely	PLPT	x	x					
	John Mosley	PLPT	x	x					
	Rusty Jardine	TCID	x		x		x		
	Walter Winder	TCID	x		x		x	x	
	Kerensa King	USFWS	x	x	x			x	
	Mike Cotter	USFWS	x						
	Randy Pahl	NDEP	x	x	x	x	x	x	Truckee River WQS Working Group
	John Heggeness	NDEP	x			x	x	x	
	Jean Stone	NDEP	x			x	x	x	
	Stephanie Wilson	USEPA	x		x	x	x	x	
	Terri Svetich	City of Reno	x	x	x	x		x	
	Lynell Garfield-Qualls	City of Reno			x		x	x	
	Niki Linn	City of Reno	x						
	John Martini	City of Reno		x					
	Andy Hummel	City of Sparks					x		
	Ron Penrose	TMWA	x						
	Michael Drinkwater	TMWRF					x	x	
	David Bruketta	TMWRF	x						
	Helene Decker	TMWRF	x						
	Jim Smitherman	WRWC/NNWPC	x				x	x	
	John Buzzone	Washoe County		x	x				
	Dave Dilks	LimnoTech	x		x	x	x	x	
	Laura Weintraub	LimnoTech	x	x	x	x	x	x	
	Alan McKay	DRI	x	x					
	Tami Thompson	MBK Engineers		x					
	John Buzzone	Stantec					x	x	

Appendix C: Summary of Comments Received and Response to Comments

Below is a summary of many of the comments and questions raised by Focus Group participants during the series of meetings. When applicable, the response to a question is noted.

11/2/2011

Questions were asked about if/how bedload was incorporated into the models and whether core samples from the river were used. (USFWS)

> Response: No core samples were taken because although central for habitat, it is not a driver of dissolved oxygen. Bed load is implicitly (but not explicitly) included in the models.

Questions about whether recent population data (downward trend since 2006) were included in the models. (USFWS)

> Response: Population inputs and growth through the 2006 were incorporated into the model via land use / land cover and municipal demand data. Information on recent population trends will be important in making future predictions.

Recognition that the model updated is needed. Felt that initiation of the Focus Group was important. Hopes to see updates to WQS to be consistent with PLPT WQS. Dissolved oxygen needs to be incorporated into the TMDL. (PLPT)

> Response: none.

A comment that this was a good initial meeting to look ahead to the TMDL process. The link between WARMF and TRHSPF is valuable. It could be useful to examine how knowledge in Truckee Meadows has evolved since early 1990's (when the DSAMMt model was used). (DRI)

> Response: a rigorous literature review was performed in early 2000's to determine best science for predicting periphyton growth in rivers. DSAMMt algorithms selected and incorporated into TRHSPF. LimnoTech deveoped a memorandum summarizing the periphtyon algorithms and kinetics (LimnoTech, 2011).

A comment that understanding the impacts of changing water quality standards to the City of Fernley will be a priority. (City of Fernley)

> Response: none.

City of Fallon relies 99.9% on water from Truckee and Carson Rivers. Would like open and objective process. Would hope that toxins from pharmaceuticals would be addressed in process. Recognized that unique flows and dilution rates important upstream but not for Fallon. Would like to see that State's water quality program would examine accumulated total load versus flow rate as snapshots along small river segments. Appreciates better development of models and linkage of models. (Churchill County)

Response: Although toxins from pharmaceuticals are in important issue, this topic falls outside the current effort focused on the nutrient / dissolved oxygen relationship for the Truckee River.

12/14/2011

Questions were raised about the slight underprediction of nutrients in TRHSPF and possibility of further adjustment of model to resolve.

> Response: LimnoTech proceeded with further refinement of WARMF and TRHSPF. Some of the issues were addressed and final calibration results are presented in the model confirmation report (LimnoTech, 2013).

Are there adequate data for model comparison and were all data collected by TMWRF? Should data be validated by outside party? (Churchill County)

> Response: TMWRF provides some of the data which is reviewed by an independent agency for validation. For many time periods, there is a second set of data collected by DRI that overlaps. Recent monitoring effort for TMWRF has been run by DRI.

Some expressed opposition to using TROM. Issues about TROM raised in court have not been resolved. Concerned that TROM could only be run by one person (who has passed away). Would like to see a re-run of TROM. (Churchill County). Questions about calibration of TROM (City of Fernley).

> Response: USBR is keeper of TROM. MBK Engineers, USBR, and Stetson can all run TROM. Third parties will evaluate RiverWare as a possible alternative to TROM. It was noted that other Focus Group members (PLPT) did not have major objections to TROM. MBK Engineers verified that a TROM calibration was conducted prior to use for the TROA EIS. The TROA EIS document (USBR, 2008) describes TROM in further detail.

Nutrient loading from nonpoint sources is important and a major component of loading to the system. A little more effort on refining the water quality models may be justified; however, not good to force calibration of the model. (PLPT)

> Response: LimnoTech proceeded with further refinement of WARMF and TRHSPF. Some of the issues were addressed and final calibration results are presented in the model confirmation report (LimnoTech, 2013). Stormwater sampling data at stream sampling sites were incorporated into the modeling.

7/16/2013

Worried about potential personnel capacity issues with being part of both the Truckee River and Lahontan Reservoir water quality standards review efforts. (USFWS)

> Response: NDEP clarified timing of the two efforts. There will be some staggering of materials for review and public outreach meetings.

PLPT appreciates the effort to collaborate and would like to have a 1:1 meeting with Tribal Council or other relevant PLPT representatives:

> Response: NDEP and EPA are scheduled to attend a PLPT IDT meeting on December 3, 2013 and City of Reno is scheduled to a 1:1 meeting with PLPT representatives on December 6, 2013.

8/28/2013

A question was raised about if the model being designed to predict future water quality issues. Need clarification on use of model. (Churchill County)

> Response: Clarified that the model will be used to assess alternative water quality standards.

Questions were raised about why dissolved oxygen endpoint is focus of effort rather than other biological endpoints. (PLPT)

> Response: Clarified that the goal of the effort is to set water quality standards the protect habitat in critical reaches of the Truckee River and the best way to represent habitat related to nutrients is to look at dissolved oxygen concentrations.

Questions were raised about whether use of an annual average nutrient water quality criteria is the best approach. Should the standard be set for a critical period or provide for seasonal variation? (PLPT)

> Response: NDEP does not want to develop an overly complicated standard that would be difficult to implement and so an annual average nutrient criteria is recommended. It is better to build seasonal complexity into a TMDL rather than a water quality standard. It was noted that process will also evaluate the current single value TN maximum criteria. It was noted that the existing TMDL and the TMWRF NPDES permit both allow for seasonal variation (e.g., more restrictive during the critical summer period).

Interest in evaluating the potential impacts of climate change. (PLPT)

> Response: A set of climate change sensitivity model runs were conducted (see Section 8.3)

Questions about internal cycling of nutrients and how solar radiation is handled in TRHSPF. (PLPT)

> Response: Confirmed that model does handle shading and nutrient cycling with periphyton. Clarified that TRHSPF does not simulation macrophytes.

Question about the selection of the TROM Future No Action scenario. (PLPT)

> Response: The Working Group collectively selected this scenario with input from NDEP and U.S. EPA. It was determined that it was best to use an existing scenario that was already vetted for TROA EIS. Of the three scenarios that were available, Future No Action was the best option (see Section 5.2).

There is interest to evaluate most critical reaches and profile plots in addition to aggregated reach results.

> Response: This information is included in Section 6 of this report.

9/26/2013

The group discussed the relevance of a recently issued U.S. EPA document: *Guiding Principles on an Optional Approach for Developing and Implementing a Numeric Nutrient Criterion that Integrates Causal and Response Parameters* (USEPA, 2013). Focus Group members wanted to know if the bioconfirmation method suggested was relevant to the Truckee River water quality standards review.

> Response: It was noted that the recommendations presented by U.S. EPA are consistent with the approach for the Truckee River which includes looking at a biological endpoint (dissolved oxygen) in addition to causal endpoints (nitrogen and phosphorus). The U.S. EPA recommendations do not preclude the need to have numeric nitrogen and phosphorus criteria for the Truckee River. LimnoTech provided the Focus Group with a link to the document that was discussed.

It was noted that at the low flow condition, it is not surprising to see some DO violations in the lower river. It is consistent with observations from the field. It was noted that the geomorphology indicator mapping may be helpful to target areas that would benefit from shading and deeper water. (PLPT)

> Response: none

Focus Group is satisfied with approach for evaluating climate change impacts. Questions about the possible changes of storm events (e.g., extreme events) under future conditions. Additional evaluation not needed now but maybe should be considered in the future. (PLPT)

> Response: NDEP noted that the water quality standards can be revisited in the future (e.g., in 10-20 years) and that process could incorporate any increase variability in storms that has occurred.

11/12/2013

Wanted clarification on who participated in Working Group in addition to Focus Group. (Churchill County)

> Response: clarification was provided.

Many Focus Group participants expressed general support of modeling efforts and water quality standards review process. (TCID, USFWS, and Churchill County)

Appendix D: Model Results for Percent of Hours Compliance

As a complement to results presented in Section 6.2 and 6.3, this appendix presents figures and tables for the low flow and average flow condition simulations where the DO criterion noncompliance was calculated based on the *percent of hours* that violated the criterion. As described in Section 6.1.1, this is a less conservative approach for examining DO criterion noncompliance as compared to evaluation based on *percent of hours* violated, but is more descriptive of the actual time the DO is noncompliant with the criterion.

D.1 Low Flow Condition

Results for each of the low flow condition iterative scenarios are presented as a curve showing the nutrient-DO response (criterion noncompliance) relationship for each aggregated reach and each nutrient that was examined (TN, OP, and TP). For all of the results presented in this section, the DO criterion noncompliance was calculated based on *percent of hours* that violated the criterion.

Figure D-1 examines the response of noncompliance with Truckee River DO criteria to a range of TN concentrations in the river under a low flow condition. It shows the percent of hours that the DO criterion was violated for each aggregated reach across a range of annual average TN concentrations. This figure shows results for two sets of runs: 1) a case where the annual average TP concentration was set at 0.05 mg/L (solid symbols), and 2) a case where the annual average OP concentration was set at 0.05 mg/L (open symbols). Note that when OP is 0.05 mg/L, the TP concentration is roughly 0.09 mg/L (approximately twice the amount of phosphorus as compared to the TP 0.05 mg/L case).

For Reaches 1, 2, and 3, DO criterion violation is less than approximately 0.2% of hours at a TN concentration of 0.80 mg/L or less. At higher TN concentrations, there is a slight increase in DO criterion violation. For Reaches 1, 2, and 3, the DO response curve for the TP at 0.05 mg/L case lines up very closely with the case when OP was set at 0.05 mg/L. This suggests that dissolved oxygen compliance in this portion of the Truckee River is not sensitive to increasing phosphorus concentrations.

The results for Reach 4 show a very “flat” response of DO criterion violation regardless of the TN concentration examined. This suggests that dissolved oxygen compliance in this region of the river is not sensitive to increasing TN concentrations within the range tested. In Reach 4, the TN-DO response curves for the two cases of phosphorus that were tested show different levels of DO criterion violation. At a TP concentration of 0.05 mg/L, the DO criterion was violated approximately 0.7% of the hours of the year; whereas, at an OP concentration of 0.05 mg/L (almost twice the level of phosphorus), the DO criterion was violated approximately 1.2% of the hours of the year. This suggests that dissolved oxygen compliance in this region of the river is sensitive to increasing phosphorus concentrations under a low flow condition.

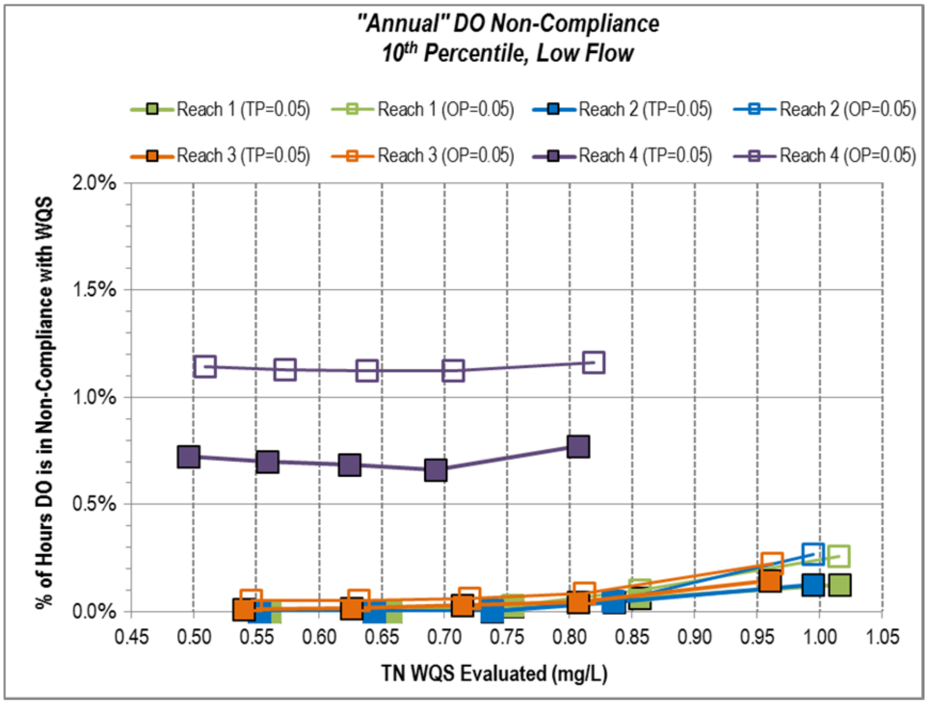

Figure D-1. Nutrient-DO response relationship for TN in the Truckee River under a low flow condition (calculated for aggregated reaches and percent of hours with DO criterion noncompliance)

Figure D-2 examines the response of noncompliance with Truckee River DO criteria to a range of TP concentrations in the river under a low flow condition. It shows the percent of hours that the DO criterion was violated for each aggregated reach across a range of annual average TP concentrations and an annual average TN concentration of 0.75 mg/L.

For Reaches 1, 2, and 3, DO criterion violation is less than 0.1% of hours at a TP concentration of 0.12 mg/L or less. The curve shows a very “flat” response indicating that dissolved oxygen compliance in this portion of the Truckee River is not sensitive to increasing phosphorus concentrations. The results for Reach 4 show that DO criterion violations range from approximately 0.6% to 1.25% of hours across the range of TP concentrations that were examined. This suggests that dissolved oxygen compliance in this region of the river is sensitive to increasing phosphorus concentrations under a low flow condition.

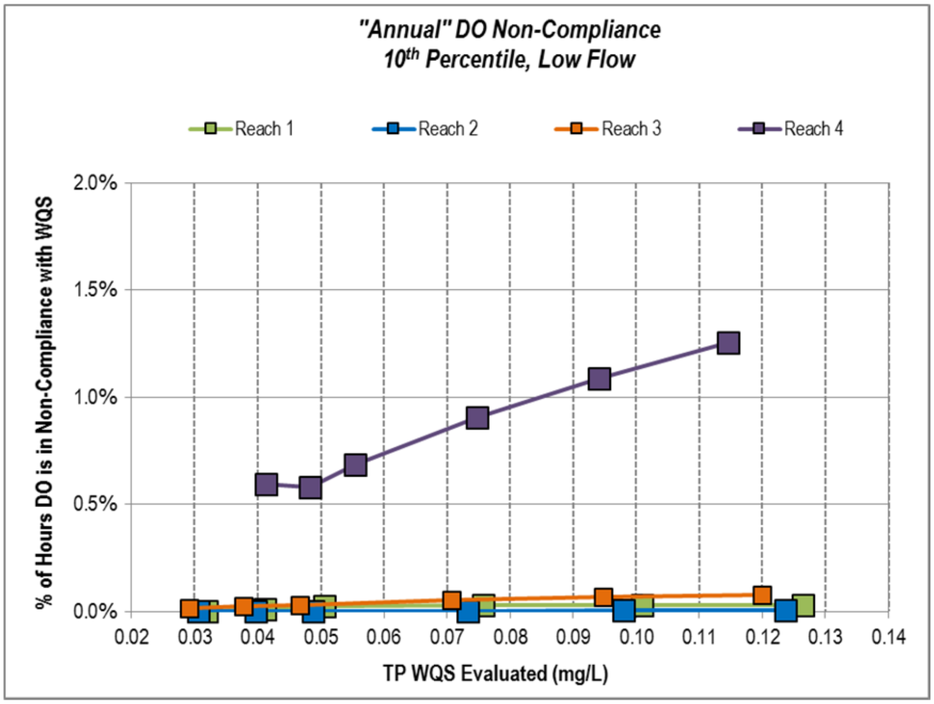

Figure D-2. Nutrient-DO response relationship for TP in the Truckee River under a low flow condition and an annual average TN concentration of 0.75 mg/L (calculated for aggregated reaches and percent of hours with DO criterion noncompliance)

Figure D-3 examines the response of noncompliance with Truckee River DO criteria to a range of ortho-phosphorus (OP) concentrations in the river under a low flow condition. It shows the percent of hours that the DO criterion was violated for each aggregated reach across a range of annual average OP concentrations and an annual average TN concentration of 0.75 mg/L.

For Reaches 1, 2, and 3, DO violation is less than approximately 0.1% of hours at a OP concentration of 0.1 mg/L or less. The curve shows a very “flat” response indicating that dissolved oxygen compliance in this portion of the Truckee River is not sensitive to increasing phosphorus concentrations. The results for Reach 4 show that DO criterion violations range from approximately 0.75% to 1.5% of hours across the range of OP concentrations that were examined. This suggests that dissolved oxygen compliance in this region of the river is sensitive to increasing phosphorus concentrations under a low flow condition.

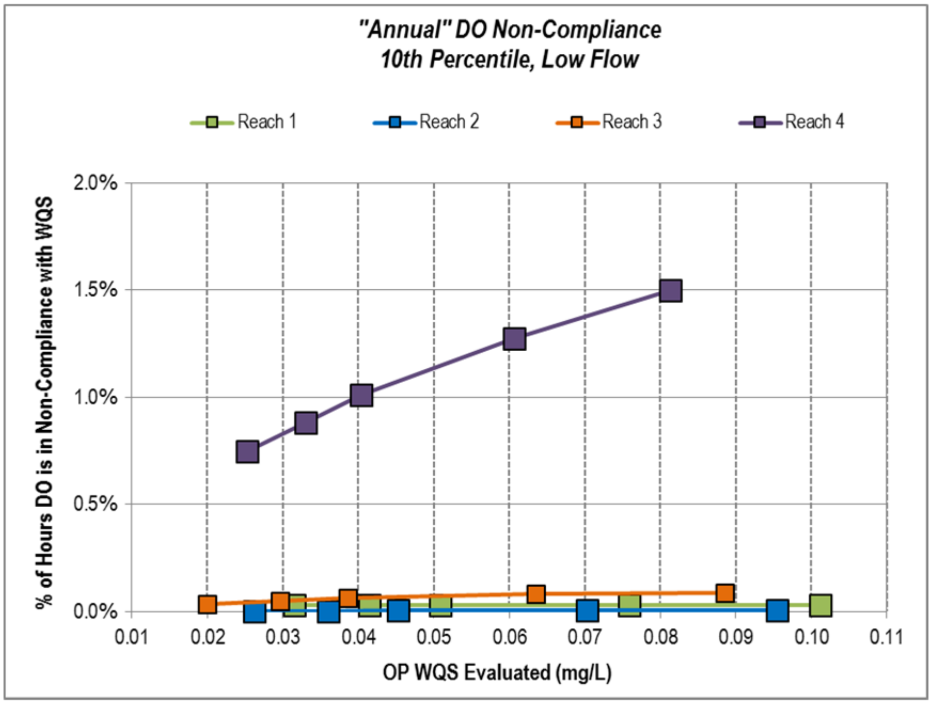

Figure D-3. Nutrient-DO response relationship for OP in the Truckee River under a low flow condition and an annual average TN concentration of 0.75 mg/L (calculated for aggregated reaches and percent of hours with DO criterion noncompliance)

D.2 Average Flow Condition

This section presents a similar set of results as were summarized in Section D.2; however, the scenarios presented below were run for a *50th percentile (average flow)* condition rather than the low flow condition. Results for each of the average flow condition iterative scenarios are presented as a curve showing the nutrient-DO response (criterion noncompliance) relationship for each aggregated reach and each nutrient that was examined (TN, OP, and TP). For all of the results presented in this section, the DO criterion noncompliance was calculated based on *percent of hours* that violated the criteria.

Figure D-4 examines the response of noncompliance with Truckee River DO criteria to a range of TN concentrations in the river under an average flow condition. It shows the percent of hours that the DO criterion was violated for each aggregated reach across a range of annual average TN concentrations. This figure shows results for two sets of runs: 1) a case where the annual average TP concentration was set at 0.05 mg/L (solid symbols), and 2) a case where the annual average OP concentration was set at 0.05 mg/L (open symbols). Note that when OP is 0.05 mg/L, the TP concentration is roughly 0.09 mg/L (approximately twice the amount of phosphorus as compared to the TP 0.05 mg/L case).

The DO response curves for Reaches 1 and 2 show that at increasing TN concentrations, there is a slight increase in DO criterion violation. For Reach 1 the DO criterion violations ranged from approximately 0.1% to 0.6% of hours across the range of TN concentrations examined. For Reach 2, the DO criterion violations ranged from approximately 0% of hours to 0.5% of hours across the range of TN concentrations examined.

The results for Reaches 3 and 4 show a very “flat” response of DO criterion violation regardless of the TN concentration examined. This suggests that dissolved oxygen compliance in this region of the river is not sensitive to increasing TN concentrations within the range tested.

For all reaches, the DO response curves for the TP at 0.05 mg/L case lines up very closely with the case when OP was set at 0.05 mg/L. This suggests that dissolved oxygen compliance in all portions of the Truckee River is not sensitive to increasing phosphorus concentrations under the average flow condition.

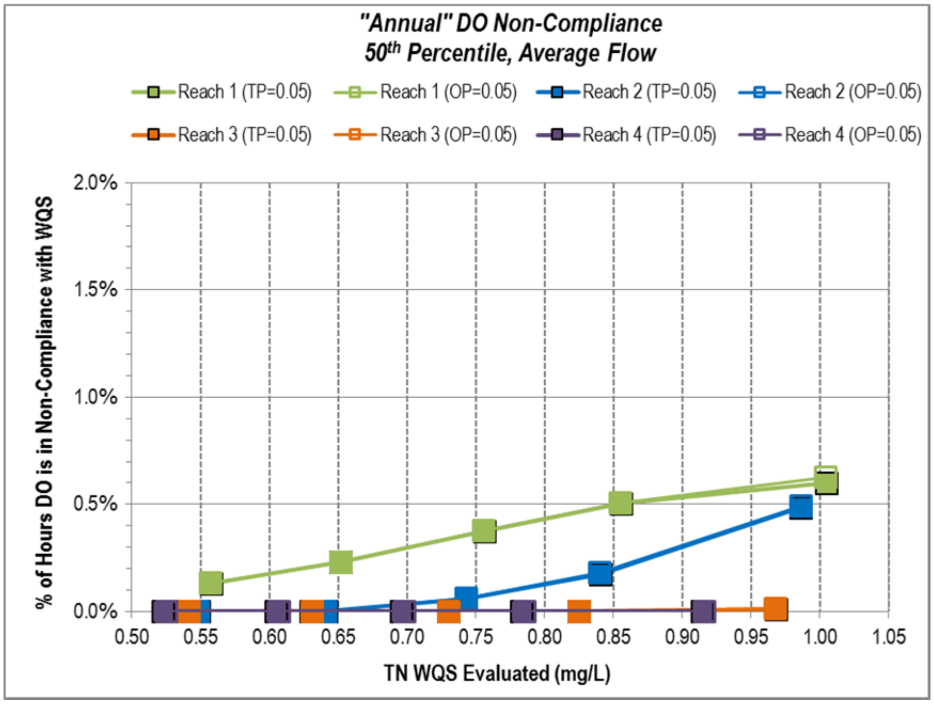

Figure D-4. Nutrient-DO response relationship for TN in the Truckee River under an average flow condition (calculated for aggregated reaches and percent of hours with DO criterion noncompliance)

Figure D-5 examines the response of noncompliance with Truckee River DO criteria to a range of TP concentrations in the river under an average flow condition. It shows the percent of hours that the DO criterion was violated for each aggregated reach across a range of annual average TP concentrations and an annual average TN concentration of 0.75 mg/L.

For all reaches, the DO response curves show a generally "flat" response indicating that dissolved oxygen compliance in all portions of the Truckee River are not sensitive to increasing phosphorus concentrations under an average flow condition. For Reach 1, the DO criterion violation was less than approximately 0.4% of hours at a TP concentration of 0.12 mg/L or less; whereas, for Reach 2 the DO criterion violation was less than 0.1% of hours. For Reaches 3 and 4, there were no hours with DO criterion violation under the average flow condition, regardless of the annual average TP concentration.

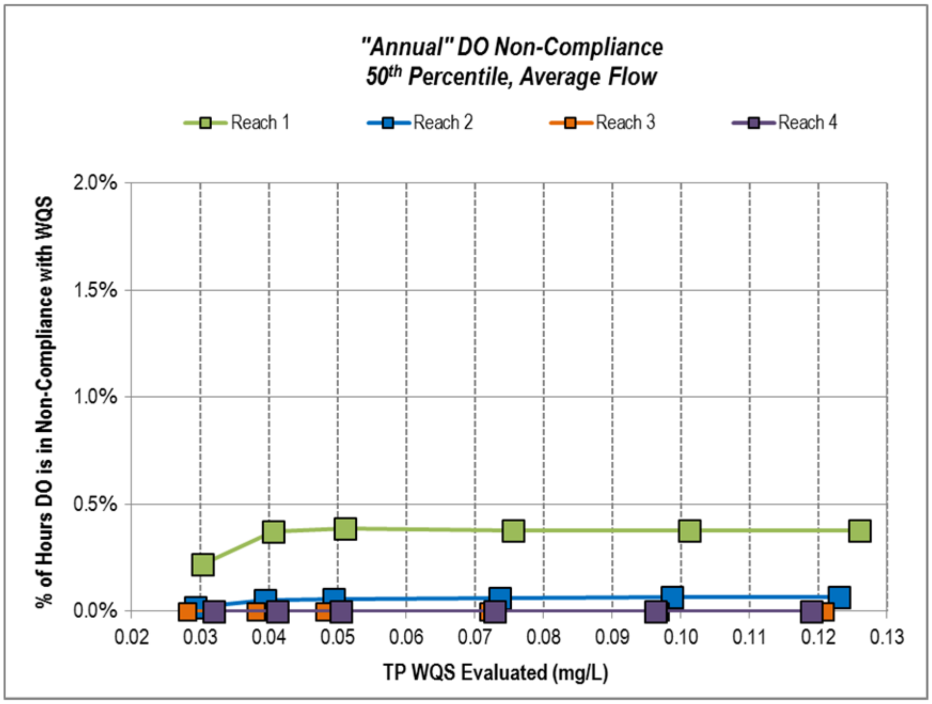

Figure D-5. Nutrient-DO response relationship for TP in the Truckee River under an average flow condition and an annual average TN concentration of 0.75 mg/L (calculated for aggregated reaches and percent of hours with DO criterion noncompliance)

Figure D-6 examines the response of noncompliance with Truckee River DO criteria to a range of ortho-phosphorus (OP) concentrations in the river under a low flow condition. It shows the percent of hours that the DO criterion was violated for each aggregated reach across a range of annual average OP concentrations and an annual average TN concentration of 0.75 mg/L.

For all reaches, the DO response curves show a generally "flat" response indicating that dissolved oxygen compliance in all portions of the Truckee River are not sensitive to increasing phosphorus concentrations under an average flow condition. For Reach 1, the DO criterion violation was less than approximately 0.4% of hours at a TP concentration of 0.12 mg/L or less; whereas for Reach 2 the DO criteria violation was less than approximately 0.1% of hours. For Reaches 3 and 4 there were no hours with DO criteria violation under the average flow condition, regardless of the annual average TP concentration.

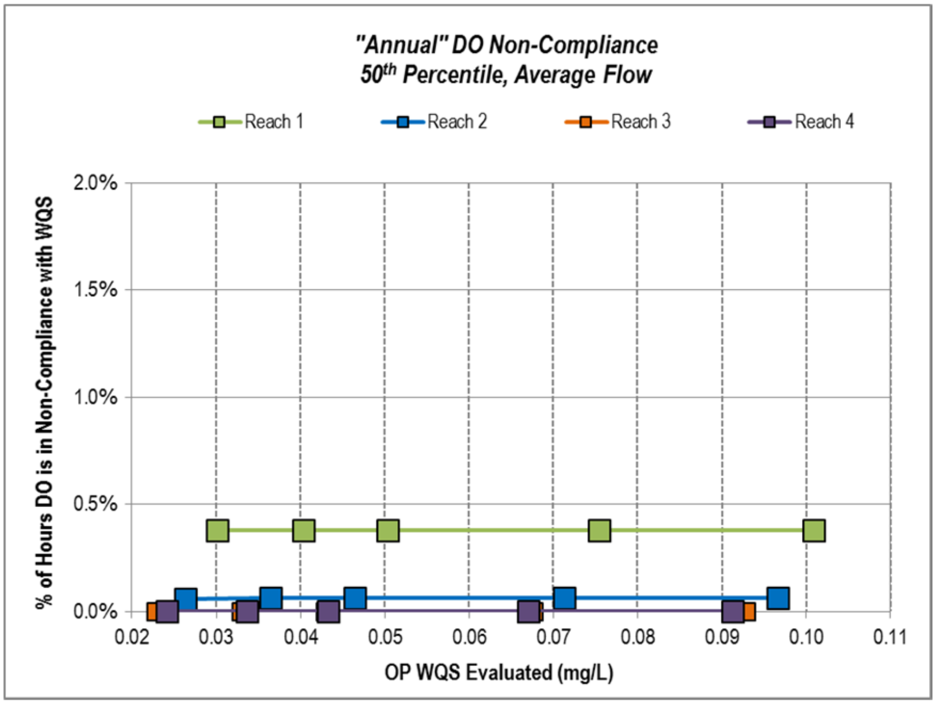

Figure D-6. Nutrient-DO response relationship for OP in the Truckee River under an average flow condition and an annual average TN concentration of 0.75 mg/L (calculated for aggregated reaches and percent of hours with DO criterion noncompliance)

Table D-1 summarizes the numerical results for the following three scenarios:

- **Scenario 1:** Current numeric nutrient criteria
- **Scenario 2:** Nitrogen levels at current numeric TN criteria; phosphorus levels at annual average TP = 0.05 mg/l; and
- **Scenario 3:** Nitrogen levels at current numeric TN criteria; phosphorus levels at annual average OP = 0.05 mg/l.

Table D-1. Summary of percent of hours of DO criterion violation for low flow and average flow regimes

	Location	Low Flow			Average Flow		
		Scenario 1: Existing Numeric Criteria	Scenario 2: TN=0.75 mg/L TP=0.05 mg/L	Scenario 3: TN=0.75 mg/L OP=0.05 mg/L	Scenario 1: Existing Numeric Criteria	Scenario 2: TN=0.75 mg/L TP=0.05 mg/L	Scenario 3: TN=0.75 mg/L OP=0.05 mg/L
Aggregated Reaches	Reach 1	0.03	0.03	0.03	0.39	0.39	0.38
	Reach 2	0.0	0.0	0.0	0.06	0.06	0.06
	Reach 3	0.03	0.03	0.07	0.0	0.0	0.0
	Reach 4	1.1	0.60	1.1	0.0	0.0	0.0
Most Critical Segments	Vista (within Reach 1)	0.17	0.17	0.18	1.4	1.4	1.4
	Tracy (within Reach 2)	0.16	0.16	0.17	0.70	0.70	0.71
	Below Derby (within Reach 3)	0.63	0.63	0.65	0.0	0.0	0.0
	Marble Bluff Dam (within Reach 4)	6.0	2.8	6.0	0.0	0.0	0.0

Appendix E: Comparison of Nutrient Seasonality for Low Flow and Average Flow Years

As shown in the results described in Section 6 and Appendix D and as described in Section 7, under the average flow regime, Reaches 1 and 2 show slightly greater DO criterion violations than were calculated for the low flow regime. The phenomenon is unexpected because one would think that under a "higher" flow condition, the river would have greater assimilative capacity for nutrients, cooler water temperatures, and a decreased tendency to grow periphyton, all of which would lead to higher dissolved oxygen concentrations.

LimnoTech conducted a more detailed inspection regarding why TRHSPF simulated higher than expected DO criterion violations in the upper river for the average flow condition. It was concluded that this phenomenon can be attributed to inadvertent effects resulting from the synthetic approach used to scale incoming loads to match instream annual average nutrient concentrations to the target value under examination. The following section provides additional information to explain this phenomenon.

First, a review of the "baseline" water quality simulations shows that even under baseline conditions, a small amount of DO criterion violations occur in Reach 1 in the vicinity of "Vista" for the average flow condition (Table E-1 and Figure E-1). However, no DO criterion violations were simulated in Reach 1 for the low flow baseline simulation (Table E-1 and Figure E-2)

Table E-1. Summary of DO criterion violation for the "baseline" simulations

Location		Baseline			
		% of Days in Violation		% of Hours in Violation	
		Low Flow (10th Percentile)	Average Flow (50th Percentile)	Low Flow (10th Percentile)	Average Flow (50th Percentile)
Aggregated	Reach 1	0.00	0.17	0.00	0.03
	Reach 2	0.00	0.00	0.00	0.00
	Reach 3	0.00	0.00	0.00	0.00
	Reach 4	4.36	0.00	0.83	0.00
Most Critical Reaches	Vista	0.00	1.08	0.00	0.16
	Tracy	0.27	0.00	0.01	0.00
	Below Derby	1.94	0.00	0.45	0.00
	Marble Bluff Dam	16.34	0.00	3.83	0.00

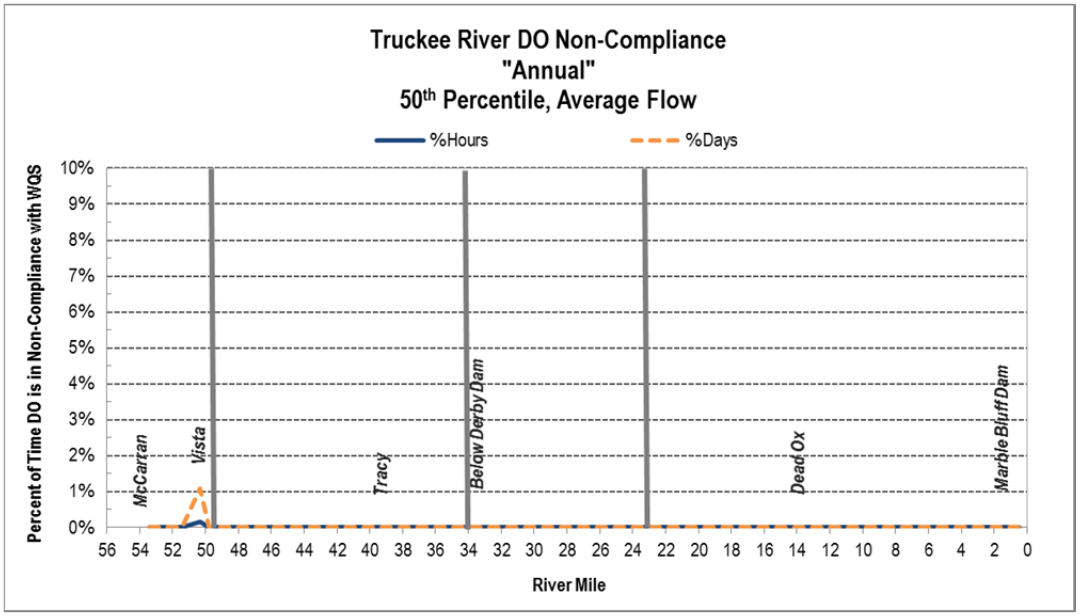

Figure E-1. Longitudinal plot of the percent of days with DO criterion noncompliance for the baseline simulation under an average flow condition

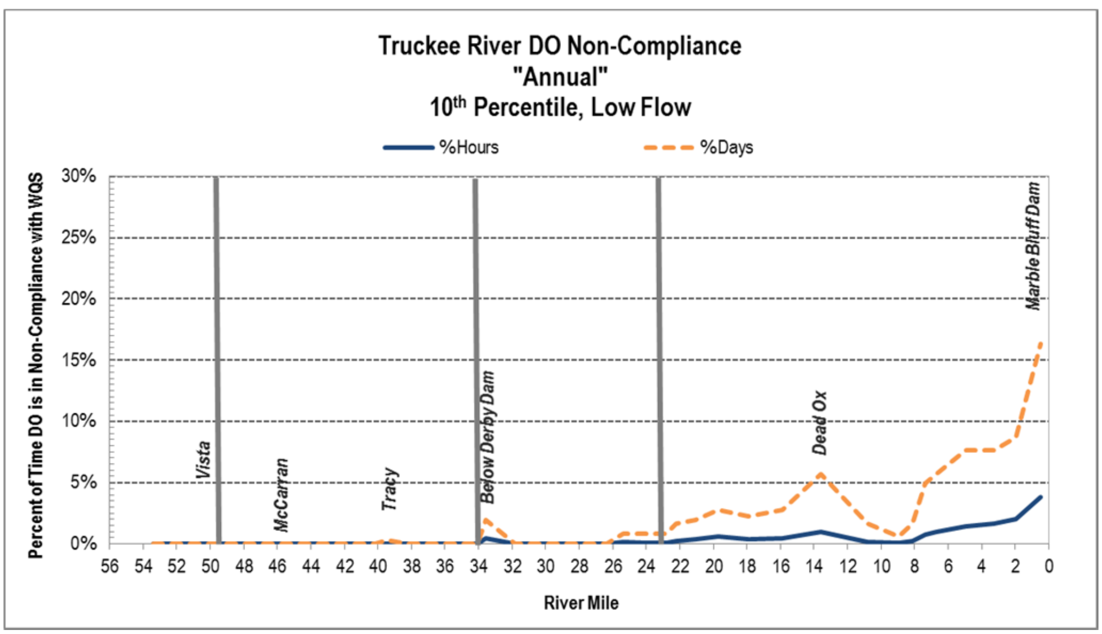

Figure E-2. Longitudinal plot of the percent of days with DO criterion noncompliance for the baseline simulation under a low flow condition

The most critical month with DO criterion violations for the average flow regime is July. The two primary factors to consider are the flow and the instream nutrient concentrations for the average and low flow regimes during this critical month. As shown in Figure 5-5, the flow at Vista for the average flow regime is slightly lower than the flow for the low flow regime during the second half of July. Although across the entire year and at other locations in the river the average flow regime is generally higher than the low flow regime, the opposite is true for the short, critical time period.

Inspection of instream concentrations of TN at Vista for the baseline run show that during the critical July period, the TN concentration is higher for the average flow regime (> 0.4 mg/L) than for the low flow regime (< 0.4 mg/L) (Figure E-3). Note that on an average annual basis, TN concentration at Vista is higher for the low flow regime (0.48 mg/L) than for the average flow regime (0.45 mg/L) under the baseline conditions.

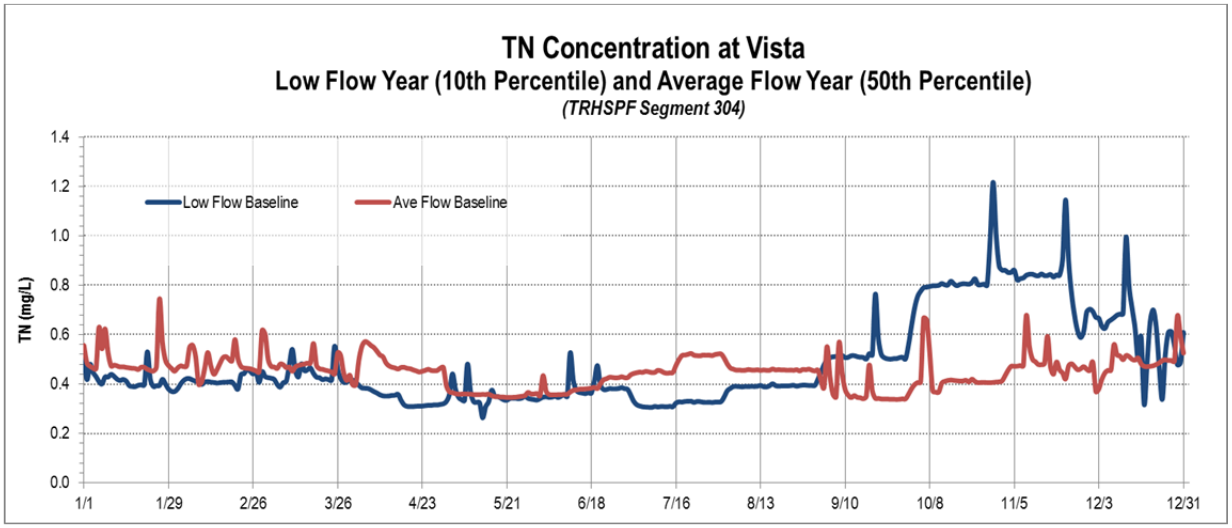

Figure E-3. Total nitrogen concentrations at Vista under the baseline conditions for the low flow and average flow regimes.

As described in Section 4, during each iterative simulation, the incoming nutrient loads were adjusted in the model to reach an annual average target concentration for the water quality standards evaluation. During this process, the nitrogen concentrations for the critical July period under the average flow regime were scaled to be much higher than July concentrations for the low flow regime. These higher concentrations resulted in a greater tendency for the river to grow periphyton and experience a DO deficit (Figure E-4). The direct scaling is reasonable, but it can produce artifacts as shown above.

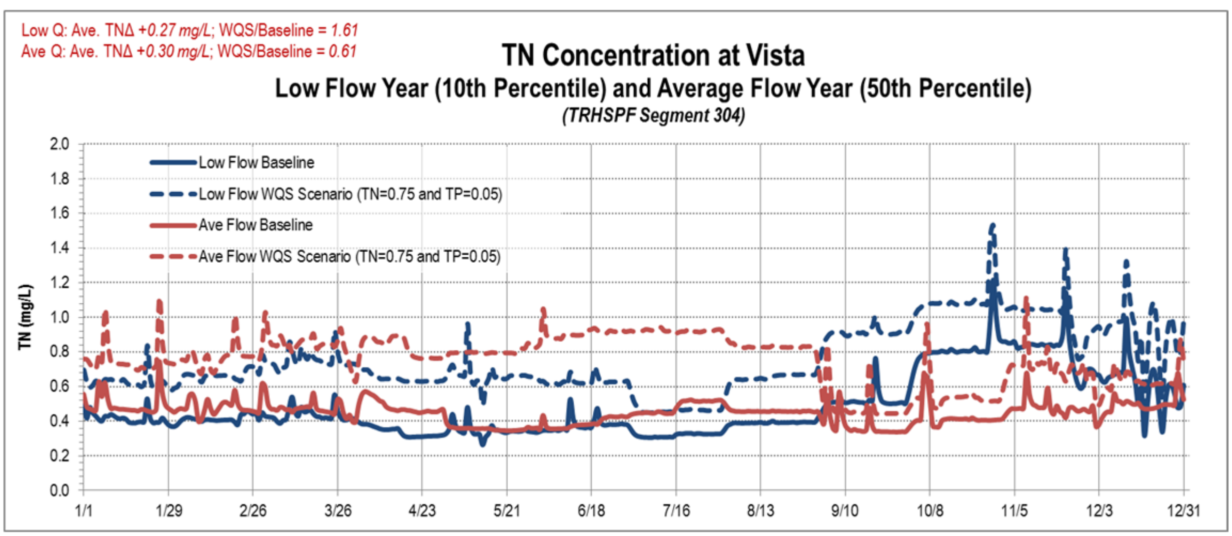

Figure E-4. Baseline and scaled total nitrogen concentrations at Vista for the low flow and average flow regimes

In summary, for all iterative simulations conducted, both the average and low flow regimes had annual average nutrient concentrations that matched the same target value. However, when looking at the critical period of July, the baseline concentration of TN for the average flow regime was initially higher than for the low flow regime. By nature of the approach to conduct the water quality standards evaluation, this July concentration was scaled up to a value much higher than the scaled value for the low flow regime in order to match the annual average target concentration. This in combination with the comparable (and slightly lower) July flows for the average flow regime as compared to the low flow regime resulted in greater than expected DO criterion violations in the vicinity of Vista for the average flow regime. It is important to note these effects do not influence the primary observations noted for upper reaches of the Truckee River (e.g., the flat DO response curve indicates a lack of sensitivity to phosphorus concentrations).