Adaptation of the WARMF Watershed Decision Support System to the Truckee River Basin of California and Nevada

2007 Calibration Report

Prepared for

City of Reno, NV
City of Sparks, NV

December 2007

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Executive Summary

The Watershed Analysis Risk Management Framework (WARMF) is a decision support system that allows stakeholders to explore various management alternatives to improve water quality. WARMF can be used to compare the relative merits of management alternatives and to support making management level decisions regarding non-structural measures in the watershed. WARMF was applied to the Truckee River Basin of California and Nevada, which extends from Lake Tahoe (CA) through the Truckee Meadows to Pyramid Lake (NV).

The WARMF delineation of the Truckee River watershed breaks the system down into a network of catchments, rivers, and reservoirs. Input data includes land use, meteorology, air quality, point sources, channel and lake bathymetry, and surface loading to pastures, golf courses and urban areas. Stream flow and water quality data were used to calibrate and verify the model. WARMF was adapted to the entire Truckee River basin; however, the focus of the calibration was the Truckee River downstream of Lake Tahoe. Simulations of hydrology and water quality were performed for the water years 1985 through 2004. WARMF accurately predicts flow and concentrations of key water quality parameters in the Truckee River and tributaries draining to the Truckee River including nitrogen, phosphorous, and total dissolved solids.

TR-HSPF is the in-stream water quality model for the middle Truckee River from Glendale Bridge in Reno to Pyramid Lake. WARMF was linked with TR-HSPF. Flow and loading output from WARMF provide boundary condition inputs for TR-HSPF. Local stakeholder information was included in WARMF. Examples of scenario evaluations have been included in this report. The scenarios considered include water rights purchases, livestock exclusion, river restoration, conversion of septic systems, and street sweeping. The stakeholders can follow the examples to develop specific non-structural alternative scenarios, and run the model to examine the effects of these identified alternatives on pollution loads and water quality.

Although WARMF is a simplified approximation of the real system, the model has captured the major processes that control river flow, nonpoint source loads, and water quality of the Truckee River and Pyramid Lake. For some locations, lack of available data precludes a perfect match between the simulated and observed values.

Further improvement of the model can be made by additional data collection, new research, and model modification. Sources of error may be reduced by obtaining additional data for precipitation, irrigation, diversions, land use specific loading, and total dissolved solids from hot springs sources. Stakeholders can import new data into WARMF for the continuous update of the model. As research is conducted for a better understanding of nutrient sinks in the lower Truckee River, this information can be incorporated into the model. In addition, WARMF can be modified to capture diurnal dissolved oxygen fluctuations.

Acknowledgments

The project was funded by the City of Reno, City of Sparks and Washoe County. These agencies, along with the Nevada Division of Environmental Protection (NDEP) and the Pyramid Lake Paiute Tribe (PLPT), participated in the project as members of the stakeholder group.

Since 1998, many stakeholders, agencies, and consultants have furnished data and insight to aid in the development of WARMF: Mahmood Azad and Greg Dennis (City of Reno), Mike Brisbin (TMWRF), Randy Pahl, Adele Basham, and Cathe Pool (NDEP), Seema Chavan, Elisa Garvey, Steve McDonald (Carollo Engineers), Paul Freedman, Dave Dilks, Troy Naperala, and Scott Rybarczyk (Limno-Tech), Christine Kirick and Karin Peternel (Kennedy-Jenks), Jay Parker, Craig Woods, and Richard Svetich (TTSA), Leonard Crowe, and Gail Prockish (Washoe County), James Brock (Rapid Creek Research), John Jackson and Dan Mosely (PLPT), Eric Oppenhiemer (Lahontan Regional Water Quality Control Board - LRWQCB), Dave Wathen (Federal Water Master's Office), Bill Carlos (UNR), Merlynn Bender, Jeff Rieker, and Gregg Reynolds (USBR), and Sandy Canning (SPPC).

In addition, WARMF was peer reviewed by a panel of experts from universities, research institutes, state and federal regulatory agencies and stakeholders (EPRI 2000). The peer review was performed according to the Environmental Protection Agency (EPA) Guidelines, under the auspices of EPA Headquarters, Regions 3, 4, and 9 and the Electric Power Research Institute (EPRI). Along with many other peer reviewers, Truckee River stakeholders who participated in the peer review included Ms. Adele Basham (NDEP), Dr. John Tracy (Desert Research Institute), and Mr. Robert K. Hall (EPA Region 9 – San Francisco).

1. Introduction

1.1 Background

The Truckee River is unique in that it is one of the few lake-to-lake rivers in the nation. It flows from the outlet of Lake Tahoe (California) in high alpine country through the arid desert region of northern Nevada. The Truckee River terminates in Pyramid Lake, a large lake with no outlet, located on Pyramid Lake Paiute Tribe (PLPT) reservation land. The Truckee River watershed, approximately 3,200 square miles, includes varied terrain such as mountainous forest, developed urban area, pastureland and arid scrubland. The most prominent city in the watershed is Reno, Nevada.

The river has been under increasing pressure to support competing uses of municipal and industrial water supply, agriculture, and recreation. Meanwhile, there is a need to protect the threatened salmonid species of Lahontan Cutthroat Trout (LCT) and endangered Cui-ui, which reside in the Truckee River and Pyramid Lake. Recently, regional stakeholders were organized to identify, evaluate and implement watershed management alternatives. The goal was to maximize beneficial uses while improving river water quality and accommodating for planned growth in the Truckee River watershed. This effort is consistent with EPA guidance for public involvement and should result in better supported, more cost effective and expeditiously implemented total maximum daily loads (TMDLs) including pollution trading.

To support the stakeholder process, the Watershed Analysis Risk Management Framework (WARMF) was applied to the Truckee River from Lake Tahoe to Pyramid Lake. WARMF is a decision support tool designed to be used by regional stakeholders including planners, regulatory agencies, the PLPT, water purveyors, and other interested parties. WARMF can be used to calculate nonpoint source loads, evaluate the impact of various loading scenarios on downstream water quality, evaluate compliance with water quality standards, evaluate the effectiveness of selected nonpoint source control measures (i.e. septic tank conversions, water augmentation, river restoration), develop land use policies consistent with the assimilative capacity of the river, and provide a basis for local governments to support policy changes.

WARMF was originally adapted to the Truckee River Basin in 1998-2001. The model adaptation included data compilation, model enhancements (see Appendix A), model setup, calibration and verification. WARMF makes use of existing regional data including landuse, water quality and quantity as well as data collected through the Coordinated Monitoring Program. The model accounts for municipal and agricultural diversions, irrigation, periphyton (algae on the riverbed), 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 project by providing input data and feedback through a series of workshops. The model was calibrated to the extent possible within time and budget constraints. The initial WARMF-Truckee model adaptation was completed and documented by Systech Engineering under a sub-contract with Carollo Engineers (Systech Engineering, 2002). In concert with this, a model comparison was conducted for Steamboat Creek watershed comparing WARMF (Systech Engineering) and HSPF (Aqua Terra). The model comparison showed comparable results between the two models (Carollo 2001). In 2003, WARMF was used to predict flow and loading boundary conditions for input to the DSAMMt model as part of the TROA EIS/EIR development. Truckee River watershed stakeholders participated in WARMF training workshops that were conducted by Systech Engineering and sponsored by the City of Reno and City of Sparks in 2004 and 2006. During 2005 to 2007 additional WARMF development has occurred in support of the Truckee River 3rd Party TMDL.

1.2 Scope and Objectives

As stated above, the objective of this project is to apply WARMF to the Truckee River Basin in support the 3rd Party TMDL being conducted by the Cities of Reno and Sparks. Output from WARMF will be linked with TR-HSPF, the river water quality model developed for the 3rd party TMDL analysis. WARMF will provide boundary conditions for upstream locations, predict the nonpoint loading into the Truckee River, and help evaluate how nonpoint loading could change with varying land use, meteorological conditions and/or water rights management. A discussion about the linkage of WARMF with TR-HSPF is provided in Section 5 of this report.

As focus has shifted toward WARMF / TR-HSPF model linkage and TMDL development, additional work has been conducted to refine the database and calibration of WARMF:

1. The WARMF database was updated to include data through 2004. Data that were updated include meteorology, air quality, flow, point source discharge, water diversions, water quality, and reservoir releases.

2. Model assumptions were revisited and adjusted as necessary based upon improved knowledge of the system. Estimated TDS loadings from Steamboat Springs and groundwater sources in the Fernley area were refined and yielded improved model results. A confined feeding operation in Steamboat Creek watershed was identified and incorporated into WARMF.

3. Sections of the Truckee River near Reno and Wadsworth were divided into smaller segments within the model. The revised segmentation increases the resolution of the model for calculating urban and groundwater flow and loading.

4. The biozone algorithm of WARMF was activated to better simulate the prediction of loadings from septic systems.

5. Model calibration was refined and an additional verification period (2000-2004) was added to the simulation set. Low-flow simulations in the Truckee River were improved using information from the Federal Water Master and by adjusting diversion records at Truckee Canal. Soil hydrology in the Steamboat Creek watershed was improved by adjusting model coefficients so that more flow is coming out of the shallow groundwater layers. The seasonal prediction of nitrogen species, phosphorus, organic carbon, and TDS were improved by adjusting litterfall and uptake rates, upper soil layer concentrations, and reaction rates in the soil layers, on the land surface and in rivers.

6. Potential scenario runs to support the TMDL revision were defined and tested in WARMF

This report provides a general overview of the adaptation of WARMF to the Truckee River. It also highlights the improvements in data input and model calibration that have been conducted from 2005 to 2007.

2. Description of WARMF

2.1 WARMF Background

Watershed Analysis Risk Management Framework (WARMF) is a decision support system for TMDL analysis and watershed management (http://www.systechengineering.com/warmf.htm). Systech Engineering developed WARMF under the sponsorship of the Electric Power Research Institute (EPRI). The tool is well documented and is compatible with USEPA BASINS. WARMF was released to the public domain and is now available from USEPA (http://www.epa.gov/athens/wwqtsc/). Figure 2.1 shows the components of the decision support system. WARMF has five modules (Data, Engineering, Knowledge, TMDL and Consensus) integrated by a Windows based graphical user interface (GUI). The modules work together and support each other.

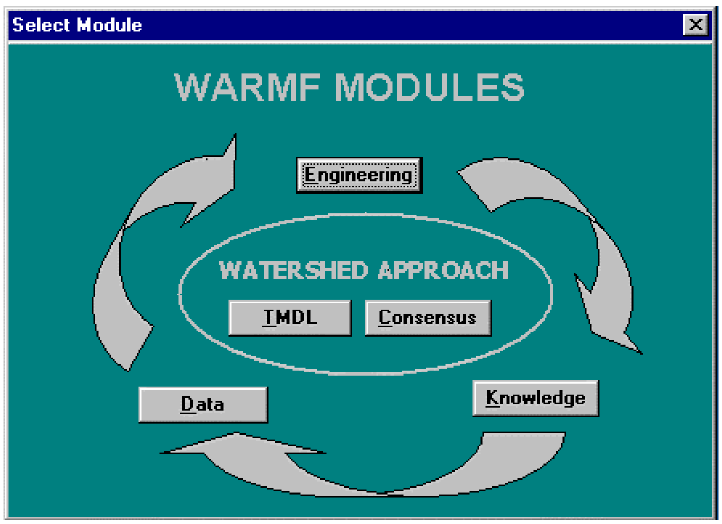


Figure 2.1 Components of WARMF

The Engineering module is the calculation engine which performs hydrologic and water quality simulations using data provided by the Data module. The Data module is a database of watershed specific data used as input to run the model simulations. The Data module can be easily updated by stakeholders as additional data is collected. WARMF has a TMDL module for step by step calculation of TMDLs to meet the water quality standards. WARMF also has a Consensus module for stakeholders to learn about the watershed, to formulate and evaluate alternatives to meet the water quality standards, and to negotiate a consensus implementation plan. The Knowledge module contains supporting documents and data files for the watershed.

2.2 Algorithms

Based on digital elevation model (DEM) data, WARMF delineates a river basin into a network of interconnected land catchments, river segments, and stratified lake segments. WARMF is a lumped-parameter model, and as such assumes uniform characteristics for each watershed compartment. The characteristics can vary from one compartment to the next. Each compartment is treated as a continuously stirred tank reactor (CSTR) in which various physical, chemical, and biological processes can occur.

Figure 2.2 shows a schematic representation of a catchment in WARMF containing land surface and soil layer compartments. The land surface is characterized by its land uses and cover, which may include forested areas, agriculture lands, urbanized cities, etc. The soil layers consist of solid, liquid, and gaseous fractions. Four soil layers were modeled for the Truckee River application of WARMF.

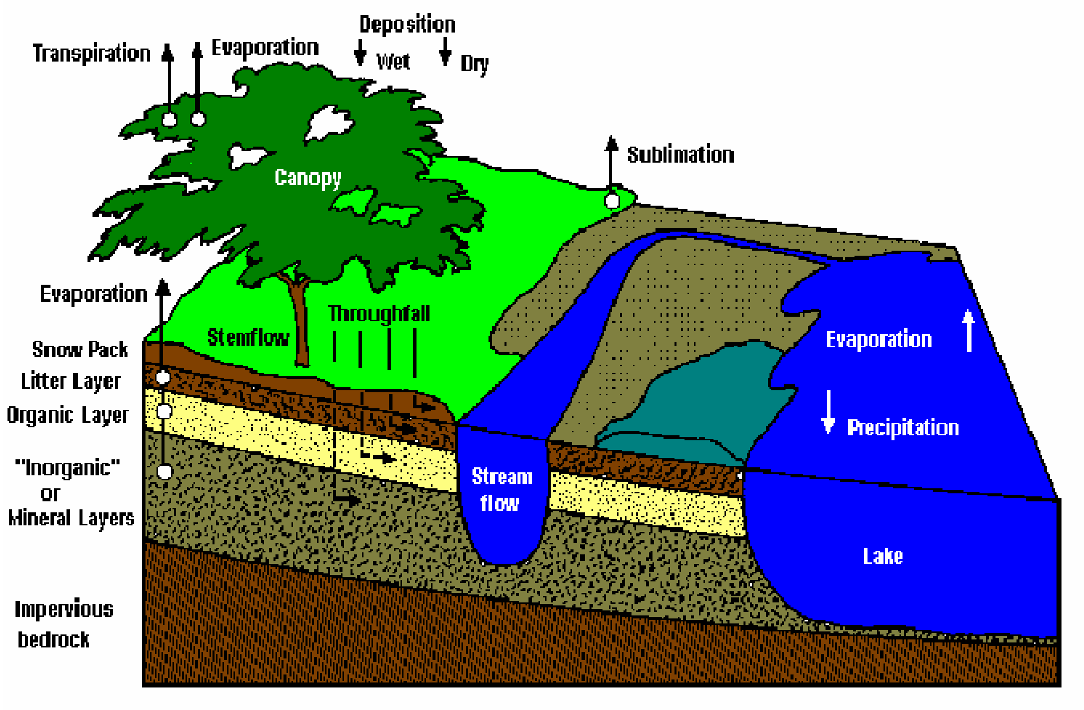


Figure 2.2. Components of a Catchment

The model accepts daily or hourly meteorological data as input and simulates snow pack accumulation, snowmelt, groundwater percolation, moisture content of soil layers, groundwater table elevation, and lateral flow to neighboring streams or lakes. When the groundwater table reaches the land surface, the model simulates surface runoff and soil erosion.

Nutrients and other pollutants are accumulated on the canopy and land surface via air deposition and land application (e.g. fertilizer, animal waste, or urban loading). During precipitation events, the pollutants accumulated on the canopy are washed down to the land surface as throughfall. As water reaches the land surface, the pollutants accumulated on the land surface are dissolved. The resulting pollutant concentrations are assigned to the infiltrating groundwater and to the surface runoff. As surface runoff flows to a nearby river segment it my also erode soil particles and carry adsorbed nutrients and minerals to the river. Thus, WARMF accounts for nonpoint source load associated with surface runoff. Stormwater is accounted for in WARMF as part of the surface runoff and associated dissolved pollutants from impervious urban areas.

In addition to overland flow, processes below the land surface contribute to the pollutant loadings. Solid phase minerals are weathered to release cations and anions. Litter is decomposed into humus to release its constituent cations and anions. Ammonia is nitrified to nitrate. Cations and anions are removed by tree and crop uptake. The percolating water dissolves the cations and anions into soil solution and subjects the cations to competitive exchange with the cation exchange sites of the soil particles. When the percolating water reaches the saturated zone, the flow becomes lateral. The lateral flow discharges groundwater and its chemical constituents to the river segment, which accounts for nonpoint source loads of groundwater accretion. Additional nonpoint loading can come from septic tank effluent.

WARMF accepts point source load as input data. The input file, one for each point source discharge, contains the time series of daily flow and pollutant loads for various chemical constituents. Point source data can vary on a daily basis and does not need to be specified at equal time intervals.

Heat budget and mass balance calculations are performed to calculate the temperature and concentrations of various chemical constituents in each river segment and lake layer. The mass balance and heat budget equations account for advection, sinks, and sources, and are similar to equations used in the well-known QUAL2E model. The main difference is that QUAL2E is a steady state model and WARMF is a dynamic model. With a steady state model, the flow is assumed to be constant for a given time period and the water volume of the river segment does not change with time. A dynamic model accounts for the changes in flow and water volume each day, similar to daily changes in an actual system.

The model maintains a complete volume balance of water and mass balance of chemical constituents at each time step. All model input coefficients can be viewed and changed by point-and-click on a watershed map. Time series simulation results can also be viewed anywhere in the watershed by point-and-click on the map.

The point and nonpoint loads of pollutants from various watershed regions are displayed on GIS maps with bar charts. The sources of the pollution loads are traced back to individual land use practices. WARMF can display loading for multiple scenarios including management plans for BMPs such as buffer strips, livestock exclusion, and reduction of land application rates for urban (e.g. street sweeping) or agricultural (e.g. fertilizer reduction) lands.

2.3 Sources of Algorithms

The algorithms of WARMF were derived from many well established codes. The main computational engine of WARMF was adapted from the Integrated Lake-Watershed Acidification Study (ILWAS) model (Chen et. al 1983; Gherini et. al 1985). Algorithms for snow hydrology, groundwater hydrology, river hydrology, lake hydrodynamics, and mass balance for acid base chemistry were based on the ILWAS model. Algorithms for erosion, deposition, re-suspension, and transport of sediment were adapted from ANSWERS (Beasley et al. 1980; Beasley and Huggins 1991). Pollutant accumulation on the land surface was adapted from the Storm Water Management Model (SWMM) (Chen and Shubinski 1971; Huber et. al 1988; USEPA 1992). In WARMF, instead of using export coefficients as in SWMM, an algorithm for mixing and washoff is used to simulate the processes that generate nonpoint source loading. The first order decay of coliform and BOD and its impact on dissolved oxygen follow traditional water quality models. The sediment sorption-desorption of pesticides and phosphorus and the kinetics of nutrients and algal dynamics were adapted from WASP5 (Ambrose et al. 1991). Periphyton algorithms were adapted from the Dynamic Stream Simulation Analysis Model – Temperature (DSSAMt) (Caupp et al, 1998). A complete description of the WARMF formulations can be found in the WARMF technical documentation report (Chen et al. 1998).

2.4 WARMF Peer Review

In addition to the Truckee River Basin, WARMF has been applied to many watersheds in USEPA Regions 1, 3, 4, 5, 6, 8, 9, and 10 including: the San Joaquin River Basin (CA), Mokelumne River Watershed (CA), San Juan Watershed (NM, CO), St. Louis River (MN), Santa Clara Watershed (CA), Catawba River Basin (NC, SC), the Cheat River Basin (WV), Chartiers Creek Basin (PA), City of Duluth Streams (MN), Blue River (CO), Oostanaula Creek (TN), Turtle Creek Reservoir and Watershed (IN), Mica Creek (ID), Santa Margarita River (CA), Hangman Creek (WA), Napa River (CA), Hockanum (CT), and Holston River (VA, TN).

In 1999, the USEPA and the Electric Power Research Institute (EPRI) jointly formed a peer review panel and evaluated the scientific efficacy and usability of WARMF (EPRI 2000). The review panel was derived from universities, research institutes, and regulatory agencies. The report summary stated that:

> *"The majority of reviewers felt that WARMF is suitable for developing TMDLs. Potential users need to be aware of key assumptions, issues with data needs and quality, and the performance evaluation. One of WARMF's key strengths is its very friendly Graphical User Interface, which combined with its TMDL and Consensus modules makes WARMF a powerful tool for supporting decision making. EPRI is currently supporting modifications to WARMF that incorporate recommendations of the review panel."*

Some of the enhancements added to WARMF based on recommendations from the peer review panel included: statistical analysis tools, septic system algorithms, periphyton algorithms, and a tool for comparing the differences between the input coefficients for two different model scenarios.

Subsequent to the initial peer review, WARMF was peer reviewed three additional times, focusing on the algorithms for acid mine drainage (July 2001), septic system effluents (May 2003), and mercury geochemistry and bioaccumulation (March 2004). All reviews were performed according to the EPA guidelines for the review of regulatory environmental models.

3. Model Adaptation

3.1 Truckee River Basin

The Truckee River watershed, located on border of California and Nevada, drains an area of approximately 3,200 miles^2 (Figure 3.1). The Truckee River starts at the outlet of Lake Tahoe and flows 116 miles through the Sierra Nevada range in California, into the Nevada desert and finally reaches its terminus at Pyramid Lake, Nevada. In addition to the Lake Tahoe outflow, the bulk of the Truckee River flow is derived from tributary streams between the Lake Tahoe outlet and the California-Nevada Stateline. In Nevada, the Truckee River flows through the Truckee Meadows, a valley bordered on the west by the Sierras and on the east by the Great Basin, which includes the cities of Reno and Sparks. A number of small tributaries join the river in Truckee Meadows, the largest of which is Steamboat Creek. Truckee River water is a heavily used resource in the region and supports listed species (threatened Lahontan Cutthroat Trout and endangered Cui-ui). Pyramid Lake, the terminus of the Truckee River, is located on Pyramid Lake Paiute Tribe (PLPT) reservation land.

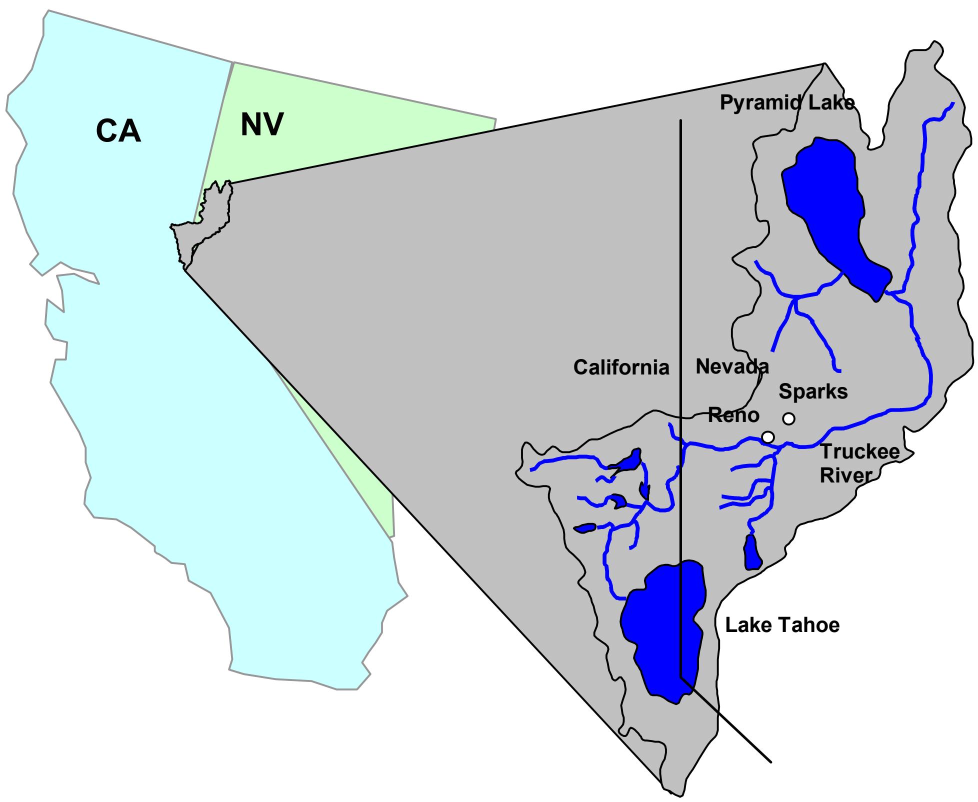


Figure 3.1 Truckee River Watershed.

The Truckee Meadows Water Reclamation Facility (TMWRF), owned and operated by the cities of Reno and Sparks, discharges treated effluent (permitted flow of 40 million gallons per day) to the Truckee River via Steamboat Creek. Data summarized in the 1994 Truckee River TMDL (NDEP) indicates that the Steamboat Creek watershed is a signficant non-point source of total nitrogen, total phosphorus and total dissolved solids to the Truckee River.

3.2 Input Data

A variety of input data are required to simulate watershed conditions in WARMF. Most of the data are available from national and local databases and were compiled for input to WARMF. This task was accomplished by first downloading information available from US Environmental Protection Agency (USEPA), United States Geological Survey (USGS), National Climatic Data Center (NCDC), and National Resource Conservation Service (NRCS) websites. These national databases were then augmented with state and local databases. The following sections discuss specific sources of data used for input to WARMF. Websites accessed for several sources of data are listed in Appendix B. Appendix C contains supporting data (e.g. stakeholder lists, designated uses, water quality criteria, photographs) that were gathered during the model adaptation process during stakeholder meetings and follow-up communications. Appendix D lists additional documents that were reviewed for qualitative information during the model application.

3.2.1 Basin Map Delineation

The first step in applying WARMF to a watershed is setting up a basin map which defines land catchment, river segment, and lake/reservoir boundaries. Basin map delineation for the Truckee River Watershed was performed using digital elevation model (DEM) data downloaded from the USGS website and imported into WARMF.

The Truckee River basin was delineated into 101 catchments, 87 river segments, 25 diversions, and 7 lakes and reservoirs. The map shows a higher resolution in areas with more complicated hydrology, such as Steamboat Creek. Coarser resolution was used in the arid regions around Pyramid Lake where streams are usually ephemeral. Rivers, lakes and reservoirs included in the map delineation are listed in Tables 3.1 and 3.2. Figure 3.2 shows the basin map created by WARMF. The basin map provides the coordinate reference for GIS data for catchments, river segments, and lakes.

Table 3.1 Rivers Included in Truckee River WARMF

Boynton Slough	Hungry Valley Creek	Sagehen Creek
Bronco Creek	Hunter Creek	Squaw Creek
Browns Creek	Independence Creek	Steamboat Creek
Bull Ranch Creek	Jumbo Creek	Taylor Creek
Cold Creek	Juniper Creek	Thomas Creek
Cottonwood Creek	Little Truckee River	Trout Creek
Davis Creek	Long Valley Creek	Truckee River
Dog Creek	Martis Creek	Upper Truckee River
Dry Creek	Mud Lake Slough	Whites Creek
Evans Creek	Musgrove Creek	Winnemucca Valley Creek
Franktown Creek	North Truckee Drain	Winters Creek
Galena Creek	Ophir Creek	
Gray Creek	Prosser Creek	

Table 3.2 Lakes and Reservoirs Included in Truckee River WARMF

Boca Reservoir	Pyramid Lake
Donner Lake	Stampede Reservoir
Lake Tahoe	Washoe Lake
Prosser Creek Reservoir	

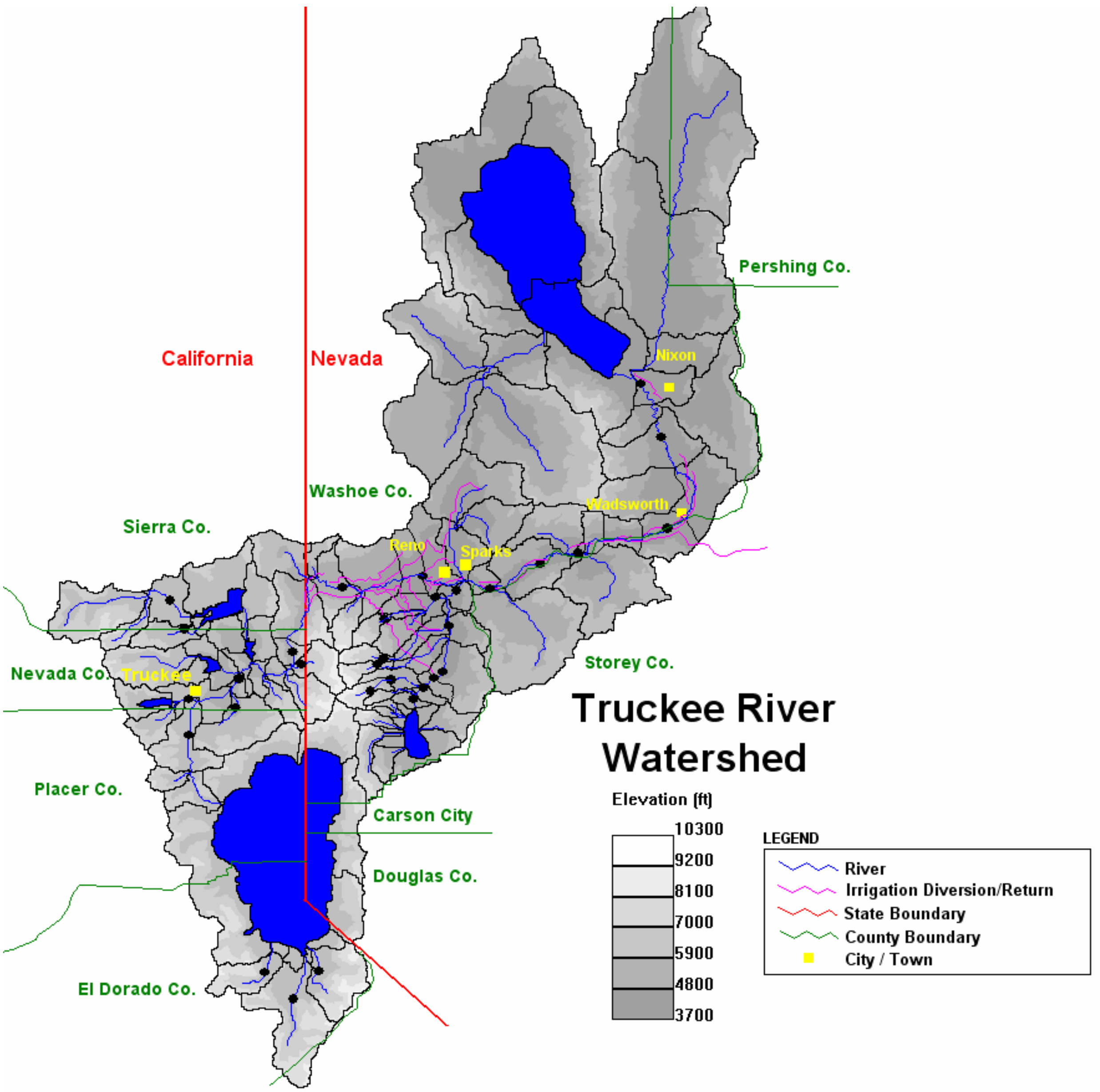


Figure 3.2 Truckee River Watershed Map Displayed in WARMF.

3.2.2 Land Use

Two different land use data sets are used for WARMF modeling of the Truckee River Basin. A "current" land use coverage was developed based on data from two different sources and used for model calibration/verification runs from 1985 to 2004. To develop this shape file, the Washoe County GIS department provided a 1999 land use coverage for the areas of the Truckee River basin contained within Washoe County. For the remaining areas of the watershed, land use data was compiled from EPA GIRAS LULC data available from the BASINS database (USEPA 1999). A few small adjustments were made to the "current" land use data set. The Mount Rose Ski area was originally classified as commercial/industrial land use in the GIS data layer. However the Mount Rose Ski area is primarily a forestland. Within WARMF, the land use of the ski area was changed to coniferous forest. Also, the location and size of a confined feeding operation in the Steamboat Creek watershed was estimated based on maps and aerial photos and incorporated into the dataset.

A second land use shape file was developed to represent projected 2020 "future" land use conditions. This data set is used for scenario runs which require the watershed to be characterized under future land development conditions and was compiled by Kennedy Jenks consultants in collaboration with Carollo Engineers, Washoe County, PLPT, Truckee Meadows and Tahoe Regional Planning Agency in 2005.

During model set up, the "current" land use shape file was imported into WARMF and overlayed with the WARMF catchment boundaries to define the percent of each land use type within each land catchment. Table 3.3 lists the twelve (12) land use categories in the Truckee River application of WARMF. Land use information for each catchment can be viewed under the input mode in the Engineering module. Figure 3.3 shows the input dialog for land use data. WARMF model parameters were set up to account for the various land use categories. For example, different leaf area index values were used to reflect different types of vegetation. Different impervious surface values were used along with cropping factors for different land use types. Table 3.4 presents a summary of the values used for key land use associated parameters in the model.

Table 3.3 Land Use and Cover Categories in Truckee River Basin

ID	Land Use/Cover Category Type
1	Coniferous Forest
2	Deciduous Forest
3	Shrub / Scrub
4	Grassland
5	Pasture
6	Golf Course / Farm
7	Marsh
8	Barren
9	Low Density Residential
10	High Density Residential
11	Commercial / Industrial
12	Confined Feeding

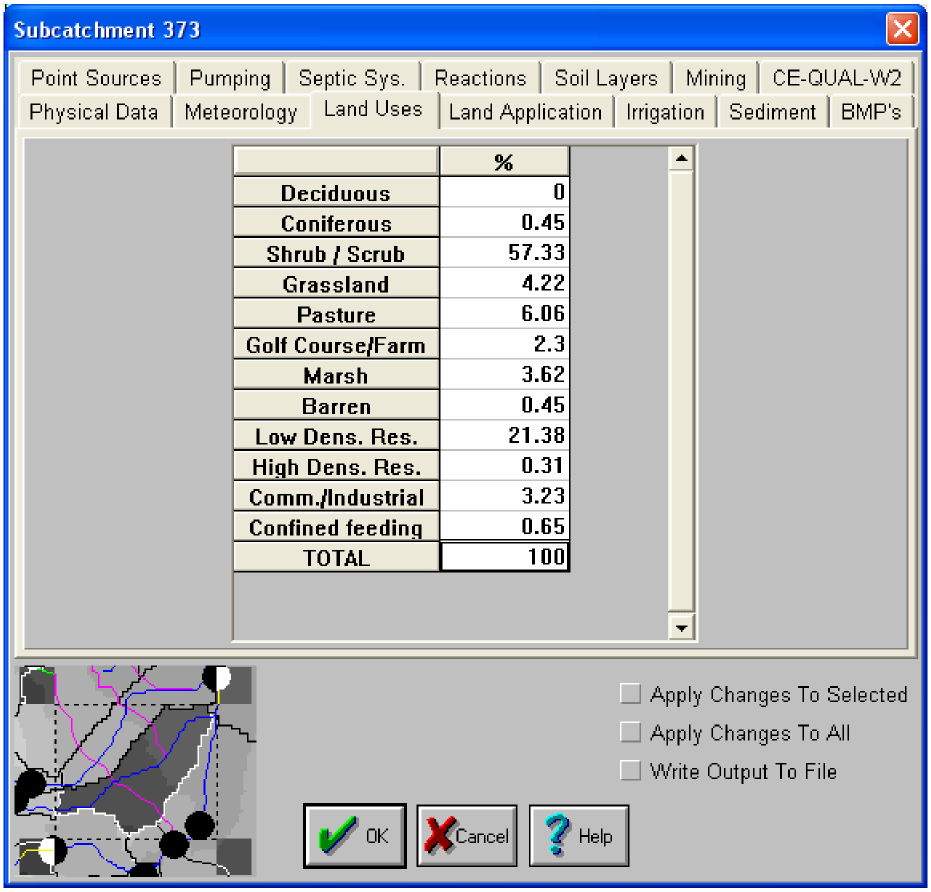


Figure 3.3 Land Use Input Dialog.

Table 3.4 Land Use Parameters in WARMF

Land Use	Open in winter	Rainfall Detach. Factor	Fraction Impervious	Interception Storage	Productivity (kg/m^2/yr)	Cropping Factor	Leaf Area Index-July
Deciduous	0.8	0	0	0.02	1.2	0.01	1.5
Coniferous	0	0	0	0.02	1.2	0.05	1
Shrub/Scrub	1	0	0	0.01	0.6	0.1	0.25
Grassland	1	0	0	0.01	0.5	0.1	0.25
Pasture	1	0.05	0	0.01	1.2	0.1	0.25
Golf Course/Farm	1	0.108	0	0.01	1.2	0.5	1.5
Marsh	1	0	0	0.01	0.9	0	0.25
Barren	1	0.108	0	0	0	1	0
Low Dens. Residential	0.8	0.03	0.25	0.01	0.8	0.2	1.8
High Dens. Residential	0.8	0.03	0.5	0.01	0.6	0.2	1.8
Commercial/Industrial	1	0	0.8	0	0.3	0.0	0
Confined Feeding	0.8	0.03	0.15	0.01	0.8	0.2	1.5

3.2.3 Meteorology and Evapotranspiration

Meteorology data drives the hydrology simulations of WARMF. Required meteorology data include daily minimum and maximum temperatures, precipitation, cloud cover, dew point temperature, air pressure, and wind speed. Daily precipitation and temperature data were available from eight locations (Table 3.5) in or near the Truckee River watershed. The remaining required data (air pressure, wind speed, dewpoint temperature, and cloud cover) were only available at one location, the Reno Airport, and were applied to the entire watershed. Cloud cover was only available through August 1995. After that, cloud cover was estimated based on an algorithm which uses minimum and maximum daily temperatures, dewpoint temperatures, and precipitation.

Table 3.5 Meteorology Stations in the Truckee River Basin

Station	Latitude	Longitude	Data	Source	Source ID	Period of Record
Reno	39.48	-119.77	Precip., Air Temp., Wind Speed, Air Press., Dewpoint Temp., Cloud Cover	NCDC	266779	1/1/1985 to 12/31/2004
Stateline	38.97	-119.95	Precipitation, Air Temperature	NCDC	267806	1/1/1985 to 12/31/1998
Tahoe City	39.17	-120.15	Precipitation, Air Temperature	NCDC	48758	1/1/1985 to 12/31/2004
Truckee	39.33	-120.18	Precipitation, Air Temperature	NCDC	49043	1/1/1985 to 12/31/2004
Virginia City	39.30	-119.63	Precipitation, Air Temperature	NCDC	268761	1/1/1985 to 12/31/2004
Wadsworth	39.68	-119.28	Precipitation, Air Temperature	NCDC	268838	1/1/1985 to 12/31/2004
Big Meadow	39.45	-119.95	Precipitation, Air Temperature	SNOTEL	19K08S	1/1/1985 to 12/31/2004
Mt. Rose Ski Area	39.32	-119.88	Precipitation, Air Temperature	SNOTEL	19K07S	1/1/1985 to 12/31/2004

Each catchment is assigned a nearby meteorological station. Precipitation weighting and temperature lapse factors are used to account for orographic affects between the catchment and its meteorology station. The estimate of adjustment factors was based on a review of precipitation isohyetal maps, ground elevation, and prevailing wind.

3.2.4 Air Quality

WARMF requires wet and dry deposition data of various parameters to simulate the loading and accumulation of pollutants on the tree canopy and ground surface. Precipitation concentration data (wet deposition) were obtained from the closest National Atmospheric Deposition Program (NADP) station, Smith Valley (NV03), which is located in Lyon County, southeast of the Truckee River watershed. Dry air concentration and deposition velocity data were obtained from the nearby CASNET station (YOS404).

Air deposition data is usually broken down into wet and dry fractions. Dry deposition will fall on any given day and accumulate on the ground surface. Wet deposition is based on the average concentration of constituents in precipitation. This concentration is multiplied by the daily precipitation to determine a wet deposition load.

3.2.5 Irrigation / Diversion

Diversion data was obtained from the Federal Water Master (FWM). The diversion data was not available on a daily basis for the period of record. A step function was used to estimate the diversions for the days without diversion data (i.e. a data value was used until the next data value was measured). Before water is diverted from a river segment, WARMF checks to see if river contains sufficient flow. If the river from which the diversion is taken contains adequate flow, the specified amount of diversion is removed. If not enough water is available in the river, only the amount available is diverted while still keeping the Minimum River Flow in the river. The Minimum River Flow is a parameter specified in user input and can range from 0 to 1 cms for various locations. When the requested amount of water cannot be diverted, the shortage is reported in the WARMF time series output.

Table 3.6 lists the diversions and the river segments from which the water was taken. The "Years Inactive" column indicates the year a diversion became inactive if applicable. Diversions with a single date are currently inactive. One diversion (Katz) was inactive for 16 years, but is currently active again. Another diversion (Idlewild) started diverting in 2004 to Reno High Ball Fields in Idlewild Park.

Table 3.6 Diversions in Truckee River Basin.

FWM ID	Diversion Name	WARMF ID	Segment Description	Year Inactive
G41	Big	532	Steamboat Creek at Rhodes Rd	active
--	Browns	693	Lower Galena Creek	active
--	Chalk Bluff	81	Truckee River at Reno/Arlington	active
G44	Chandler	504	Steamboat Creek at Steamboat	active
T8	Cochran	82	Truckee River at Reno/Glendale	2001 -
T2	Coldron	424	Truckee River at Farad	1995 -
G45	Crane-Clow	504	Steamboat Creek at Steamboat	active
G31	Crutchfield	151	Upper Galena Creek	active
G33	E. Callahan	693	Lower Galena Creek	1986 -
T10	Eastman	82	Truckee River at Reno/Glendale	1996 -
T25	Fellnagle	105	Truckee River at Wadsworth	active
T26	Gardella	105	Truckee River at Wadsworth	2003 -
T12	Glendale	395	Truckee River at Reno/Sparks	1997 -
T12	Glendale MI	82	Truckee River at Reno/Glendale	active
T21H	Gregory	105	Truckee River at Wadsworth	active
G43	Hansen	532	Steamboat Creek at Rhodes Rd	active
T22H	Herman	105	Truckee River at Wadsworth	active
T4	Highland	418	Truckee River at Mogul	active
T4	Highland M&I	418	Truckee River at Mogul	active
--	Hill	121	Truckee River at Tracy	1986 -
G42	Hughes Cameron	532	Steamboat Creek at Rhodes Rd	active
--	Idlewild M&I	81	Truckee River at Reno/Arlington	1994 -
	Idlewild	81	Truckee River at Reno/Arlington	started 2004
T27	Indian	93	Truckee River at Marble Bluff Dam	active -
--	Katz	424	Truckee River at Farad	1987-2003
T6	Lake	81	Truckee River at Arlington	active -
G38	Lower Sauer	693	Lower Galena Creek	1993 -

Table 3.6. Diversions in Truckee River Basin. (continued)

FWM ID	Diversion Name	WARMF ID	Segment Description	Years Inactive
T5	Last Chance	418	Truckee River at Mogul	active
T19	McCarran	121	Truckee River at Tracy	active
T17	Murphy	353	Truckee River at Vista	active
G34	N. Callahan	693	Lower Galena Creek	active
T16	Noce	353	Truckee River at Vista	1989 -
T9	North Truckee	82	Truckee River at Reno/Glendale	2002 -
TPOL1	Oling.Pump1	105	Truckee River at Wadsworth	active
TPOL3	Oling.Pump3	105	Truckee River at Wadsworth	active
T7	Orr	81	Truckee River at Reno/Arlington	active
T23	Pierson	105	Truckee River at Wadsworth	2000 -
T11	Pioneer	395	Truckee River at Reno/Sparks	Active
T24	Proctor	105	Truckee River at Wadsworth	Active
G35	S. Callahan	693	Lower Galena Creek	Active
--	Sessions	82	Truckee River at Reno/Glendale	1989 -
G36	Smith	693	Lower Galena Creek	Active
T1	Steamboat	424	Truckee River at Farad	Active
T1	Stmboat M&I	424	Truckee River at Farad	1996
T14	Truckee Canal	105	Truckee River at Wadsworth	Active
G37	Upper Sauer	693	Lower Galena Creek	Active
T20	Washburn	105	Truckee River at Wadsworth	Active
--	WashoePower	418	Truckee River at Mogul	Active

3.2.6 Point Sources

For the WARMF application, major point source dischargers to surface waters were included in the model development. A number of smaller point source dischargers, with insignificant contributions in comparison to the listed point sources, were not included. Table 3.7 presents the point source loading data included in the WARMF application. The data was obtained from municipal dischargers and from NDEP. The quality of data varied greatly from excellent daily records to very sparse records.

Table 3.7 Point Source Data for the Truckee River Watershed

Name	NPDES ID	Lat/Long	Dates of Operation	Data Source	Data Quality	Permitted Flow (MGD)
TMWRF	NV0020150	39.52, -119.71	current	TMWRF	excellent, daily	44.0
Reno Masonic Temple	NV0020338	39.53, -119.82	current	NDEP	sparse, none post-1997	0.01
Vista Canyon Group	NV0020893	39.53, -119.73	current	NDEP	sparse	7.0
Ranch 102 Sand & Gravel	NV002155	39.57, -119.49	10/1988 - 4/1995	NDEP	quarterly	1.5
Sparks Marina	NV0022918	39.53, -119.73	1997 - current	NDEP	sparse	5.5
Harrah's Hotel and Casino	NV0021598	39.53, -119.8	current	NDEP	sparse, none post- 1995	0.007
Western Energenix	NV0022390	39.52, -119.76	current	NDEP	sparse, monthly 1995-1996	0.005

WARMF inputs actual discharge quantity and quality data instead of the permitted discharge characteristics as the actual discharge is more representative of what is added to the river. Of the listed point source dischargers, only the Truckee Meadows Water Reclamation Facility (TMWRF) had daily discharge data. For the smaller dischargers with more sparse data, WARMF uses a step function to fill in the data gaps. A data value is used for the day of measurement and every day after that until the next measurement becomes available. Before entering the data into WARMF, concentration data were converted to loading rates in units of kilograms per day (kg/day).

Point source input parameters include individual constituents such as temperature ammonia, calcium, magnesium, potassium, sodium, sulfate, nitrate, chloride, phosphate, inorganic carbon, fecal coliform and BOD. Internally, WARMF computes the resulting pH, alkalinity, total nitrogen, total phosphorus, and total dissolved solids (TDS) concentrations. If a particular constituent was not measured and it is not considered to be a significant component of the discharge, it is excluded from the data file and therefore assumed to equal zero. In cases where the measured data includes TDS and not the individual components, the TDS load was distributed among the various components in the input file so that the resulting pH, alkalinity, and TDS matched the monitoring data.

3.2.6.1 TWMRF

To accommodate the discharge of TMWRF effluent and the diversion of reuse water from the TMWRF discharge (NV0020150), a separate river segment was created that contains only the TMWRF point source (ID 67). Water is diverted from this segment and applied to specific UNR farms, golf courses and parks in the region. The time series output of river segment 67 shows the flow and concentration of TMWRF discharge as compared to monitoring data. TMWRF effluent is discharged into the most downstream section Steamboat Creek and drains to the Truckee River.

Since the mid-1990's, treated effluent from TMWRF has been used for the irrigation of UNR farms, several parks and golf courses the Reno area. The application of re-use water has declined since 2003, but has started to increase in late 2006 due to the addition of other reuse sites. Table 3.8 lists the sites using reuse water as of 2004 and the approximate area of irrigation.

Table 3.8 Water Reuse Sites in Operation in Reno Area.

Service Area	Reuse Site	Estimated Irrigated Acres
Truckee Meadows	UNR Farms	405
	Don Mellow Sports Complex	15
	Sparks Blvd. Van Meter Park	5
	Shadow Mtn. Sports Complex	20
	Wildcreek Golf Course	210
South Truckee Meadows	S. Meadows Bus. Pkwy Space, Parks, Sports Fields	150
	South Valley Regional Park	30
	Arrowcreek Golf Course	230
	Wolfrun Golf Course	100

TWMRF records provided the quantity of treated effluent used for irrigation each day. This data is stored in the managed flow file TMWRFir.flo. The TMWRF point source file (NC0020150.pts) contains flow and constituent loads of the total treated effluent, including the reuse fraction. After WARMF computes the quality of the TMWRF discharge from the point source file, a fraction of the water is diverted and distributed to several catchments based on the location of reuse sites and in proportion to the estimated irrigation area. For golf courses, the TMWRF effluent was applied to the golf course land use. For parks, the water was applied to the grassland land use. The percent of TMWRF irrigation water applied to various WARMF catchments is shown in Appendix E. Several additional golf courses and parks have been identified as potential reuse sites. In the future, WARMF can be modified to account for irrigation to these additional locations if needed.

3.2.6.2 Tahoe-Truckee Sanitation Agency (T-TSA)

Tahoe-Truckee Sanitation Agency (T-TSA) discharges treated municipal wastewater to an underground disposal field roughly 2,000 feet southwest of the confluence of Martis Creek and the Truckee River in California. In a recent environmental impact report (CH2M Hill 1999), it was determined that the majority of the T-TSA effluent entering the groundwater seeps into Truckee River within approximately 40 days (personal communication with Richard Svetich). Approximately six (6) percent of the effluent enters the lower 2,000 feet of Martis Creek.

To account for the loading contribution of T-TSA to the Truckee River and Martis Creek, two point source files were generated (TTSAMartis.pts and TTSATruckee.pts). Flow effluent data and water quality data collected at Well 31 (close to confluence of Martis Creek with Truckee River) were obtained from T-TSA and used to generate the point sources files. To account for the lag in reaching the Truckee River, the flow data was shifted back 40 days. The files were set up so that 94% of the flow and load went to the Truckee River, while the remaining 6% of the flow and load went to Martis Creek.

Water quality data for Well 31 provided by T-TSA included temperature, total dissolved solids (TDS), chloride (Cl), total phosphorus (TP), phosphate (PO_4-P), ammonia (NH_4-N), nitrate (NO_3-N), total nitrogen (TN), total organic carbon (TOC), and fecal coliform. In WARMF, TDS is the sum of individual constituents, which include NH_4, aluminum (Al), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), sulfate (SO_4), nitrate (NO_3), chloride (Cl), phosphate (PO_4), and total inorganic carbon (TIC). Since the T-TSA data did not include measurements for all of the individual TDS components, it was necessary to make some approximations. First, it was assumed that the Al concentration was negligible. Then, since the loads for N, P, and Cl ions were available, they were subtracted from the measured TDS. The remaining TDS load was then distributed between the cations (Ca, Mg, K, Na) and anions (SO4, TIC) that were not measured. The distribution of the remaining TDS to specific ion species was made according to the proportion found in the receiving water. Flow effluent and Well 31 water quality measurements were collected at roughly monthly intervals.

3.2.6.3 Estimated Point Sources

Several loading contributions to the Truckee River and Steamboat Creek were estimated on limited data and local knowledge.

3.2.6.3.1 Steamboat Hot Springs

The Steamboat Hot Springs, while not contributing significant flows, does contribute significant TDS, and heat load. Though the springs are considered a nonpoint source, its load is not generated by local runoff. For modeling purposes, the heat and TDS loads of the springs were treated as a point source. No direct measurements of TDS and heat loads were available for Steamboat Springs. Therefore, a constant loading estimate was calculated based on the difference between water quality data collected at the Rhodes Road gage (above the hot springs) and the Geiger Grade gage (below the hot springs). There was not enough data at the two locations to accurately come up with a seasonally varying load.

3.2.6.3.2 Fernley Total Dissolved Solids

The Truckee River gains discharge from ground water sources in the reach below Derby Dam extending to Nixon, a distance of 50 km. The accretion is on the order of 15-20 cfs. The magnitude of the gain appears to be consistent when comparing data from roughly five attempts to quantify the gain which were made during the period from 1973 to 2001 (Katzer et. al 1998). It has also been determined that a significant load of TDS enters the Lower Truckee River via ground water in the Fernley area.

Previously, rough estimates for groundwater accrual and TDS loadings were used in WARMF. WARMF assumptions were not consistent with other modeling efforts (DSAMMt and TRHSPF). Also, WARMF often had issues with model instabilities when large amounts of TDS were added to the river without sufficient flow. In an effort to gain consistency between modeling efforts, WARMF input data files were modified to better represent what is currently used in DSSAMt and TRHSPF. Groundwater accrual and concentration data were obtained from Jim Brock. This data summarized incoming flow and nutrient, BOD, DO, and TDS concentrations at several locations along the Lower Truckee River. Based on the data, the groundwater seepage to the Truckee River does not appear to be spatially uniform, with a flow increase amounting to ~10 cfs in the reach from the Wadsworth highway bridge to S-S Ranch, a distance of ~12 km. The ground water seepage constitutes a significant portion of the Truckee River flow (50% or more) during periods of low stream flow below Derby Dam. The water quality of the GW seepage has not yet been measured directly, but has been inferred from monitoring of wells near the Truckee River channel as well as by changes in surface water quality that are especially pronounced during low flow periods. The provided flow and water quality data were distributed into four (4) separate point source files which were then applied to the corresponding river reaches in WARMF (Table 3.9). The flow and loading were assumed to be constant throughout the year.

Table 3.9 Lower Truckee River Ground Water Accrual and Loading Point Source Files.

Parameter	orchardgw.pts	wadsworthgw.pts	SBARSgw.pts	nixongw.pts
Flow (cms)	0.1574	0.1574	0.0624	0.0765
Temperature (C)	15	15	15	15
Calcium (kg/d)	679	1495	1207	898
Magnesium (kg/d)	272	598	604	337
Potassium (kg/d)	136	299	181	135
Sodium (kg/d)	883	1944	2762	1684
Sulfate (kg/d)	363	799	907	480
Nitrate (kg/d)	6.8	6.8	2.696	3.303
Chloride (kg/d)	1155	2542	5131	3368
Phosphate (kg/d)	0.544	0.544	0.216	0.264
Inorg. Carbon (kg/d)	508	1119	490	663
Dissolved Oxygen (kg/d)	66.43	66.43	26.33	32.27
BOD (kg/d)	13.60	13.60	5.39	6.61

3.2.6.3.3 Tile Drains

Personal communication with Dan Mosely (PLPT) provided information to estimate the loading of tile drains located on the Lower Truckee River near Wadsworth. These tile drains were installed to lower the water table in the land on the east side of the Truckee River so the land could be put into (alfalfa) production. During irrigation season, the tiles drain the water from the soil, which flows into a collection ditch, then to the river. The ditch is lined with riparian plants (e.g. willows, rushes, sedges), which helps uptake nutrients. Water quality samples were collected by PLPT and used to estimate the loading input.

3.2.7 Channel Characteristics

WARMF requires stage-width data to define the channel cross sections. For the main channel of the Truckee River, this data was developed from cross section data collected by USGS (Brock 1999). The geometry of the main channel of Steamboat Creek was estimated from cross-section data contained in Phase I and II of Fluvial Geomorphology Studies (WESTEC 1994). For smaller tributaries to Steamboat Creek and the Truckee River where measured cross-section data was not available, the typical cross section was estimated.

3.2.8 Reservoirs – Bathymetry and Releases

For the modeling of reservoirs, WARMF requires bathymetry and flow release data. Table 3.10 lists the data sources for bathymetry and releases/spills.

Table 3.10 Sources of Bathymetric and Flow Release Data

Lake / Reservoir	Bathymetry Data[1,2,3]	Release / Spill Data[4]
Lake Tahoe	USGS	USGS
Donner Lake	CDEC	USGS
Prosser Creek Reservoir	USBR	USGS
Stampede Reservoir	CDEC	USGS
Boca Reservoir	USBR	USGS
Washoe Lake	USGS	FWM
Pyramid Lake	USGS	na

[1]USGS – US Geological Survey
[2]CDEC – California Data Exchange Center,
[3]USBR – US Bureau of Reclamation
[4]FWM – Federal Water Master

USGS gaging station data collected just downstream of a dam were used as the daily flow releases. For Washoe Lake, the flow release data were obtained from the Federal Water Master. Stage-storage data for Lake Tahoe, Prosser Creek, and Boca were obtained from the USGS and the US Bureau of Reclamation (USBR). For the remaining reservoirs, daily storage and elevation data were processed to establish bathymetric relationships. This data came from the California Data Exchange Center (CDEC) and the USGS.

3.2.9 Surface Loading Rates

In WARMF, each land use category can accept a specific constituent surface loading rate such as a fertilizer application rate, animal loading rate, or urban loading rate in units of kilogram per hectare per month (kg/ha/month). Table 3.11 lists the loading rates specified in the model translated to English units for each land use type. Because no direct data are available to characterize these loadings, estimates were made based on knowledge of the system. Section 3.3 discusses these model assumptions in greater detail.

Table 3.11 Nutrient Application Rates by Land Use.

		Nutrient Loading (lb./acre/month)				
Land Use	**Time Period**	NH4-N	K	PO4-P	Organic C	Fecal Coliform (#/acre/month)
Pasture	Jan to Dec	1.84	3.89	0.89	12.69	4,000
Golf Course	Apr to Oct	31.09	15.55	7.77	0.000	2,000
Low Density Residential	Jan to Dec	0.02	0	0.009	0.17	2,000
High Density Residential	Jan to Dec	0.04	0	0.013	0.45	2,000
Commercial / Industrial	Jan to Dec	0.03	0	0.013	0.27	2,000
Confined Feeding	Jan to Dec	36.8	77.8	17.84	253.7	81,000

3.2.10 Septic Systems

Several sources of data were used to estimate the load contribution of septic systems in the watershed. GIS data from Washoe County was used to calculate the number of septic systems in each catchment. The calculation showed roughly 10,000 septic systems in the Spanish Springs, South Truckee Meadows, Reno, and Verdi areas. Approximately 5,000 septic systems are located elsewhere in the Truckee River watershed. This number was consistent with that projected by a recent study (AGRA 2000). For the areas outside of Washoe County, 2000 US Census data was translated into a GIS shapefile and used to calculate the number of septic systems in each WARMF catchment. WARMF also requires input data for the number of people per household (per septic system), the per capita flow and the average concentration of septic effluent. Table 3.12 shows the septic effluent data used in WARMF. These data are based on information from the Reno/Sparks/Washoe County Design Phases I and II (developed by Carollo Engineers) as well as literature values compiled as part of an EPA study of the watershed-scale cumulative impacts of onsite wastewater systems (Siegrist et. al 2005).

Table 3.12 Septic System Data for WARMF-Truckee

Number of Residents per Household	2.4
Ave Flow from Septic Systems (L/cap/day)	200
Total Nitrogen Concentration (mg/L)	32
Total Phosphorus Concentration (mg/L)	6
BOD Concentration (mg/L)	170
Fecal Coliform Concentration (#/100mL)	$1.0e^6$

As part of the EPA study (Siegrist et. al 2005), a biozone algorithm was developed in WARMF to simulate the treatment processes of onsite wastewater (septic) systems and calculates the "edge-of-drainfield" pollution loads rather than requiring them as input. The biozone algorithm is used for the Truckee River application on WARMF and provides a more robust calculation of septic system loads because the nitrification, BOD decay, fecal coliform decay and phosphorus adsorption that occurs in septic system leach fields, is explicitly modeled as a separate control volume for each land catchment rather than being lumped together with background soil reactions. Appendix A provides a more thorough explanation of the algorithm.

3.2.11 Observed Hydrology

For hydrology model calibration, observed flow, velocity and reservoir elevation data were compiled to check against the simulation results.

3.2.11.1 Stream Flow

USGS stream flow data was the primary source of calibration data for hydrology. The USGS stream flow data were also used to specify reservoir releases. Table 3.13 lists the available USGS stream gage stations and their period of record.

Table 3.13 Observed Stream Flow and Reservoir Release Data.

WARMF File Name	Station Name (using USGS notation)	Station ID	Period of Record
Bronco.orh	Bronco Creek at Floriston, CA	10345700	4/93-10/98
Dog.orh	Dog Creek at Verdi, NV	10347310	11/92-11/04
Donner.orh	Donner Cr at Highway 89 nr Truckee	10338700	3/93-1/05
Farad.orh	Truckee River at Farad, CA	10346000	10/84-1/05
Frank1.orh	Franktown C Nr Carson City, Nv	10348460	10/84-9/03
Galena2.orh	Galena C At Galena C State Park	10348850	10/84-1/05
Hunter.orh	Hunter Cr above Last Chance Ditch	10347620	9/93-10/95
Independ.orh	Independence C Nr Truckee Ca	10343000	10/84-1/05

Littruck.orh	Little Truckee River at Highway 89	10343200	4/93-7/95
Littruck2.orh	Little Truckee R Bl Div Dam Nr Sierraville Ca	10341950	6/93-10/98
Martis.orh	Martis Creek near Truckee, CA	10339400	10/84-1/05
Nixon.orh	Truckee River near Nixon, NV	10351700	10/84-1/05
NTDrain.orh	N Truckee Drain at Kleppe Ln	10348300	10/92-9/03
Sagehen.orh	Sagehen Cr Nr Truckee Ca	10343500	10/84-2/05
Sparks.orh	Truckee River near Sparks, NV	10348200	10/84-1/05
Squaw.orh	Squaw Creek	LRWQCB	12/95-5/97
Stmboat2.orh	Steamboat Cr at Steamboat, NV	10349300	10/84-9/03
Stmboat4.orh	Steamboat Cr at Cleanwater Way	10349980	10/84-9/03
Taylor.orh	Taylor Cr near Camp Richardson, CA	10336626	10/84-12/92
Tracy.orh	Truckee River below Tracy, NV	10350400	10/84-10/98
TRbelDerby.orh	Truckee R below Derby Dam near Wadsworth, NV	10351600	10/84-2/05
Trout.orh	Trout C Nr Tahoe Valley Ca	10336780	10/84-10/99
Truckcan.orh	Truckee Ca Nr Wadsworth, Nv	10351300	10/84-1/05
Truckee1.orh	Truckee River above Prosser Creek	10339419	10/93-10/98
Truckee3.orh	Truckee River near Truckee, CA	10338000	10/92-1/05
Truckee4.orh	Truckee River near Mogul, NV	10347460	2/93-1/05
Truckee5.orh	Truckee River at Reno, NV	10348000	10/84-9/02
Truckee7.orh	Truckee River below Little Truckee River	LRWQCB	1/96-6-97
UpTruck.orh	Upper Truckee R at S. Lake Tahoe	10336610	10/84-2/05
Vista.orh	Truckee River at Vista, NV	10350000	10/84-2/05
Wadswrth.orh	Truckee R At Wadsworth, Nv	10351650	10/84-1/05
Boca.flo	Boca Reservoir Release	10344500	10/84-2/05
Donner.flo	Donner C A Donner Lk Nr Truckee Ca	10338500	10/84-2/05
Prosser.flo	Prosser Creek Reservoir Release	10340500	10/84-1/05
Stampede.flo	Stampede Reservoir	10344400	10/84-1/05
Tahoe.flo	Lake Tahoe Outlet	10337500	10/84-2/05

3.2.11.2 Stream Velocity

Two travel time dye studies were conducted on the Truckee River (Bohman, 1999; Crompton and Bohman, 2000) as part of the Coordinated Monitoring Program (CMP). Using the time to peak concentration data and the distance from injection point, approximate river velocities were calculated for November 1993, May 1999, and August 1999 at eight (8) locations along the Truckee River. The data was entered into WARMF for comparison to the simulated velocity.

3.2.11.3 Reservoir Elevation

Daily storage data obtained from the USGS was converted to daily elevation values using reservoir bathymetry data and used for model calibration.

3.2.12 Observed Water Quality

During water quality calibration, in-stream water quality measurements are compared with simulated concentrations to assess the accuracy of the model predictions. Observed water quality data for number of locations in the watershed were obtained and entered into the WARMF database. Table 3.14 lists the observed river chemistry (ORC) files in WARMF, including period of record, station ID and data source.

Table 3.14 Observed Water Quality Data in WARMF.

WARMF ORC File	Period of Record	Station ID (using notation of source)	Data Source
Marble Bluff	10/84 - 6/98	21-NEV-1 310514, 21-NEV-4 310519, 112WRD 10351750, 112WRD 10351775	STORET
		mbd	TMWRF
Nixon	11/84 – 9/04	21-NEV-1 310517, 21-NEV-4 310514, 112WRD 10351690, 112WRD 10351700	STORET
		nixon	TMWRF
Wadsworth	10/84 - 7/00	21-NEV-1 310005, 21-NEV-4 310005, 21-NEV-4 310512, 21-NEV-4 310515, 112WRD 10351650, 112WRD 10351648, 112WRD 10351600, 112WRD 10351684, 112WRD 10351619, 06-TRU-01-09	STORET
		Painted, sbars, wadsworth	TMWRF
Derby	10/84 – 9/04	21NEV-1 310004, 21NEV-4 310004, 21NEV-1 310510, 112WRD 10350500	STORET
		clark, derby	TMWRF
Tracy	11/88 – 7/03	21NEV-1 310509, 21NEV-1 310508, 21NEV-1 310500, 112WRD 10350400, 112WRD 10350200, 06-TRU-01-08	STORET
		Tracy	TMWRF
Vista	10/84 – 8/03	21NEV-1 310006, 21NEV-1 310003, 112WRD 10350000, 112WRD 10350050, 06-TRU-01-07	STORET
		Lockwood	TMWRF
North Truckee Drain	10/84 – 9/04	21NEV-1 310513, 112WRD 10348300, 112WRD 10348245, 06-TRU-01-T02-A	STORET
		Ntd	TMWRF
Sparks	10/84 – 9/04	21NEV-1 310002, 06-TRU-01-06, 112WRD 10348000, 112WRD 10348200	STORET
		Mccarran	TMWRF
Arlington	10/84-11/03	21NEV-1 310001, 112WRD 10347705, 06_Tru-01-05	STORET
Truckee6 (at Circle C)	10/84 – 4/03	21NEV-1 310092, 112WRD 10347640, 112WRD 10347690, 06-TRU-01-04	STORET

Table 3.14. Observed Water Quality Data in WARMF (continued).

WARMF ORC File	Period of Record	Station ID (using notation of source)	Data Source
Truckee Below Farad	8/81 – 12/04	TTSA (T3)	TTSA
Farad	10/84 – 12/03	21NEV-1 310000, 112WRD 10345909, 06-TRU-01-03	STORET
		TR at Farad	LRWQCB
Truckee8 (bel Juniper)	10/91	112WRD 392156120041400	STORET
Truckee7 (bel Lit Truckee)	10/91 - 6/97	112WRD 392304120053400	STORET
		TR blw LTR	LRWQCB
Truckee5 (abv Bronco Ck)	10/91	112WRD 392257120011100	STORET
Truckee4 (bel Prosser)	10/91	112WRD 392215120065600	STORET
Truckee3 (bel Martis)	1/85 – 12/04	21NEV-1 310217, 06-TRU-01-02	STORET
		TR abv Prosser	LRWQCB
		TTSA T-2	T-TSA
Truckee2 (bel Donner)	11/90 - 10/91	112WRD 10339010, 112WRD 391950120100200, 112WRD 392018120080300, 112WRD 10339498	STORET
Truckee1 (abv Donner)	1/88 – 12/04	21NEV-1 310216, 112WRD 10338000	STORET
		112WRD 10338010, 06-TRU-01-01	STORET
		TTSA T-1	TTSA
		TR abv Donner	LRWQCB
Truckee9 (abv Squaw)	4/85 - 10/91	21CAL-1 G7166500, 112WRD 10337500, 112WRD 391108120113900, 112WRD 391146120115000, 112WRD 391240120115000	STORET
squaw	11/90 – 6/97	112WRD 10337855	STORET
		Squaw Creek	LRWQCB
donner	11/90 - 6/97	112WRD 10339003	STORET
		Donner Creek	LRWQCB
martis	10/84 – 12/04	112WRD 10339250, 112WRD 10339380, 112WRD 10339400, 112WRD 10339405	STORET
		M2	T-TSA
		Martis Creek	LRWQCB
prosser	11/90 - 6/97	112WRD 392213120065800	STORET
		Prosser Creek	LRWQCB
sagehen	10/84 - 8/96	112WRD 10343500	STORET

Table 3.14. Observed Water Quality Data in WARMF (continued).

WARMF ORC File	Period of Record	Station ID (using notation of source)	Data Source
gray	10/91 - 6/97	112WRD 392224120014600	STORET
		Gray Creek	LRWQCB
bronco	10/91	112WRD 392303120011000	STORET
trout	10/84 - 11/96	112WRD 10336780, 1115FSCH 43-10, 112WRD 10336790, 112WRD 10336775, 112WRD 10336770	STORET
uptruck	4/85 - 11/96	112WRD 10336610, 1115FSCH 44-10, 1115FSCH 44-5, 112WRD 103366092, 112WRD 10336580, 112WRD 103366098	STORET
		USGS Data Report	
stmditch	10/87 – 8/00	21NEV-1 310204, 112WRD 392537119474701, 112WRD 392729119485901, 06-STE-01-T02-A	STORET

Table 3.14. Observed Water Quality Data in WARMF (continued).

WARMF ORC File	Period of Record	Station ID (using notation of source)	Data Source
washout	4/89 – 2/01	21NEV-1 310200, 06-STE-01-01	STORET
pleasant	12/87 - 6/02	21NEV-1 310201, 06-STE-01-02	STORET
rhodes	10/87 – 6/02	21NEV-1 310203, 06-STE-01-03	STORET
galena	10/87 – 8/01	21NEV-1 310202, 06-STE-01-T01-A	STORET
geiger	10/87 – 4/02	21NEV-1 310205, 06-STE-01-04	STORET
stmboat3	10/87 – 10/01	21NEV-1 310208, 06-STE-01-05	STORET
whites	10/87 – 2/02	21NEV-1 310206, 06-STE-01-T03-A	STORET
thomas	10/87 – 2/02	21NEV-1 310207, 06-STE-01-T04-A	STORET
stmboat4	10/87 – 9/04	21NEV-1 310502, 21NEV-1 310212, 21NEV-1 310214, 06-STE-01-07, 112WRD 10349980	STORET
		Steamboat	TMWRF
boynton	10/87 – 4/02	21NEV-1 310211 / 06-STE-01-T07-A	STORET

EPA STORET was the primary source for water quality data. The Lahontan Regional Water Quality Control Board (LRWQCB), Nevada Division of Environmental Protection (NDEP), Sierra Pacific Power Company (SPPC), TMWRF, T-TSA, and PLPT also contributed data. Water quality data was also obtained for the following reservoirs and lakes: Tahoe (STORET), Prosser Creek (STORET), Washoe Lake (STORET), and Pyramid Lake (PLPT).

3.3 Model Assumptions

As with any modeling effort, model assumptions are required to help characterize watershed processes in situations where detailed, local data are not available. The following sections describe several key model assumptions that were made during the application of WARMF to the Truckee River watershed.

3.3.1 Livestock Loading Rates

Significant nonpoint source loading comes from animal waste deposited on pastureland. The animal waste is generally deposited on the land surface, however, if there is no fence to limit animal access to the river, it can be deposited directly into river.

Mr. M. Levitt (Farm Service Agency), Mr. B. Bruce (University of Nevada-Reno Farms), Mr. G. Bowers (Nevada Cooperative Program) and Mr. S. Walker (Washoe County) provided several estimates of animal density on pastureland. The average estimate used in WARMF for the Steamboat Creek and Reno areas was 0.5 animals per acre. For the Lower Truckee River, a smaller density of 0.25 animals per acre was assumed in WARMF.

According to local stakeholders, the primary livestock in the region is beef cattle and horses. Animals are present throughout the year. Based on Brenner et. al (1995), and Vitko (1999), the approximate livestock loading rate is 120 pounds per day of manure per animal. The reports also provided average manure composition data. This information was used to determine the surface loading rates shown in Table 3.11. In the Steamboat Creek and Lower Truckee River regions, there is minimal animal fencing. It was assumed that the animals deposited approximately 5% of their waste directly into the river.

A confined feeding operation in Steamboat Creek watershed was identified based on local knowledge and maps from the City of Reno. The area of this site was estimated to be 45.9 acres (18.6 ha) with approximately 500 animals on the site. A density of 10 animals / acre was assumed and used to calculate the surface loading rate in Table 3.11.

3.3.2 Golf Course Fertilization

Golf courses in the region apply synthetic fertilizer, which can vary greatly in nitrogen and phosphorous content. Based discussions with Mr. B. Carlos (UNR Farms), Mr. R. Martin (Washoe County Golf Course), and Mr. T. Jannings (Rosewood Lakes Golf Course), the average Nitrogen:Phosphorus:Potassium ratio was 4:1:2. Mr. B. Carlos also stated that the typical fertilizer application rate was one (1) pound of nitrogen per 1,000 square feet, four (4) to six (6) times a year. Fertilizer is generally applied only during the growing months of March through October. The same assumption was made within WARMF. This information was used to calculate the monthly loading rates of fertilizer shown in Table 3.11.

3.3.3 Periphyton

WARMF has adapted the periphyton algorithms of DSAMMt (Caupp et. al 1998) and TR-HSPF. To the extent possible, periphyton coefficients in WARMF were set to be equal to the values used for the TR-HSPF Truckee River modeling (Table 3.15). A more detailed description of the periphyton algorithms in WARMF is provided in Appendix A.

Table 3.15 Periphyton Coefficients in WARMF.

Coefficient	Value	Units
Maximum Growth Rate	2.88	day^{-1}
Endogenous Respiration Coefficient	0.0267	none
Endogenous Resp. Exponential Coefficient	0.0776	none
Photorespiration Fraction	0.075	none
Nitrogen Half Saturation	0.025	mg/L
Phosphorus Half Saturation	0.005	mg/L
Velocity Half Saturation	0.25	m/s
Light Half Saturation	194	W/m^2
Spatial Limitation Half Saturation	16	g/m^2
Spatial Limitation Intercept	10	none
Mortality Rate	0.2	day^{-1}
Fraction Recycled of Grazed and Scoured	0	none
Ammonia Preference Factor	20	none
Scour Regression Coefficient	0.0024	day^{-1}
Scour Regression Exponent	4.5	1/m
Chl a / Carbon Ratio	0.07	None

3.3.4 Irrigation

WARMF applies diverted water as irrigation to various land uses within individual land catchments. Maps showing the path of diversion ditches were used to determine the irrigated catchments. A spreadsheet was developed to calculate the average application rate of irrigation water to each catchment in units of foot per year (ft/yr) (IrrigationSpreadsheet.xls). The formula is based on the area of irrigated lands (pasture, golf courses, and parks), average diversion flow for each ditch and percent of diversion applied to catchments. According to the Orr Ditch Decree, the irrigation application rate is approximately 4 to 4.5 ft/yr for the Steamboat Creek area. The spreadsheet provides a trial and error method of determining the percent of diversion water applied to each catchment, while maintaining the average application rate below 5 ft/yr.

Several sources of information were used to populate the spreadsheet with estimates of irrigation for each catchment and land use. In addition to intentional irrigation, it was assumed that approximately 30% of diversion water is lost from ditches during transport (personal communication with L. Crowe, Washoe Co.). This "loss" fraction of each diversion was applied to the scrub/shrub land in nearby catchments. Typically, 70% of each diversion was applied as irrigation to pasture land, golf courses or grasslands (parks) within the watershed. One exception was Steamboat Ditch where 21% of the diverted water remained in the ditch and was returned to Steamboat Creek. This number was estimated by calculating the ratio of terminal flow to diverted flow during dry times, when there is minimal infiltration to the ditch. Also, based on communication with Dave Wathen (Federal Water Master), Indian ditch was set to allow approximately 10% pass through. Also, a recent report on Lower Truckee River irrigation ditches (Wood Rodgers 2005) provided efficiency data for several ditches. This information was used to refine the 30% loss and 0% pass through assumptions. Appendix E shows the percent of each diversion applied to each WARMF catchment. A copy of IrrigationSpreadsheet.xls is stored in the Knowledge Module of WARMF.

3.3.5 Sediment

Based on GIS data, soil reports and field observations, it was assumed that the soil surface consists of 70% sand, 20% silt, and 10% clay. The soil permeability is a calibration parameter that was set to represent watershed characteristics. In the upper portions of the watershed, typical values ranged from $6.0e^{-6}$ to $6.0e^{-4}$ m/s. In the lower portions of the watershed (i.e. Steamboat Creek) typical values were higher ranging from $1.0e^{-4}$ to $1.5e^{-3}$ m/s. Rainfall detachment and flow detachment factors were set to represent various soil types and land uses (Table 3.4). Based on the input data, WARMF simulated surface erosion in the upper sections of the Truckee River (mainly California) during high flow periods. However, in the Lower Truckee and Steamboat Creek region, the model showed very little surface erosion due to lack of significant surface runoff from pervious areas.

WARMF also simulates scour, re-suspension and deposition from the riverbed as well as bank erosion due to steep, unstable banks without good vegetative cover. Based on data collected in steamboat creek (WESTEC 1994), the streambed was assumed to be 55% sand, 25% silt, and 20% clay. For regions known to have incised, un-vegetated streambanks (e.g. Steamboat Creek, Lower Truckee River), empirical coefficients for bank stability and vegetation were set to range from 0.0002 to 0.008. For regions with good bank stability, these coefficients remained at a default of zero. Table 3.16 lists the properties of each soil fraction.

Table 3.16 Soil Properties

Sediment Type	Size (mm)	Specific Gravity	Settling Velocity (mm/s)
Clay	0.002	2.65	0.003
Silt	0.01	2.65	0.08
Sand	0.2	2.65	0.349

3.3.6 Adjustment of Truckee Canal Flows

Return flows from the Truckee Canal via the Gilpin Spill and the Pyramid Spill, dump waters diverted at Derby Dam back into the Truckee River between the gaging station located just below Derby Dam and Wadsworth. Therefore, by using the USGS gage for Truckee Canal near Wadsworth (USGS 10351300) to specify the Truckee Canal diversion, the amount of water diverted is too high because it includes what would eventually be spilled back into the Truckee River. To address the uncertainty related to the Truckee Canal diversion and the flow remaining in the river, DSSAMt and TRHSPF modelers adopted an approach where the flow balance is "reset" at Derby to actual measured values and the "error" in the flow balance is "sent down the canal". In this approach, the flow measured at the Truckee River below Derby Dam near Wadsworth (USGS 10351650) was subtracted from the simulated flow in the river above Derby Dam. The difference was then sent down the canal which leaves a flow in the river equal to what was measured at the gage below Derby Dam.

WARMF follows a similar approach to specify Truckee Canal diversions. Figure 3.4 provides a map showing gaging station locations. First, an "interim" canal diversion ($Diversion^1$) was calculated as:

$$Diversion^1 = \text{Simulated flow above Derby Dam} - 1035600\ \text{gage} \qquad (1)$$

This diversion flow is a bit high since it doesn't account for Gilpin spill back into the river which occurs between Derby Dam and the Wadsworth gage. So, $Diversion^1$ was adjusted by first simulating stream flow above Wadsworth using $Diversion^1$ as the Truckee Canal diversion. Then, a comparison was made between the simulated river flow at Wadsworth to the gage at that location (10351650). In this first simulation, the model underpredicted flow at Wadsworth and the difference between the simulated and gaged data was used to represent Gilpin Spill.

$$\text{Gilpin Spill} = 10351650 – \text{simulated flow at Wadwsoth using } Diversion^1 \qquad (2)$$

Then, $Diversion^1$ was reduced by the estimated Gilpin Spill, and the "final" Canal diversion (Diversion) was used for a revised simulation.

$$Diversion = Diversion^1 – \text{Gilpin Spill} \qquad (3)$$

This method is basically equivalent to:

$$\text{Canal Diversion} = \text{Simulated flow above Derby Dam} - 10351650\ \text{gage} \qquad (4)$$

The only difference is some minor local flows that WARMF can account for by doing it in two steps. When Wadsworth gaged flow was available (10351650), it was used to perform the above calculations. However, there is a large gap in records from 1986 to 1993. For this time period, the missing flows at Wadsworth gage were estimated based on gaged flows at Nixon (10351700), diversion flows between the two gaging stations, and WARMF simulated outflow from local catchments. The following formula was used:

Estimated Wads = Nixon Obs – local catch. flow – local point src flow + div. flows (5)

where local catchments = C102, C105, C99
local point sources = wadsworthgw.pts, SBARSgw.pts, tiledrains.pts
local diversions = Proctor, Fellnagle, Gardella, Oling1, Oling3

Simulations run using the revised Truckee Canal diversion showed much fewer instances of the river running dry below Derby Dam.

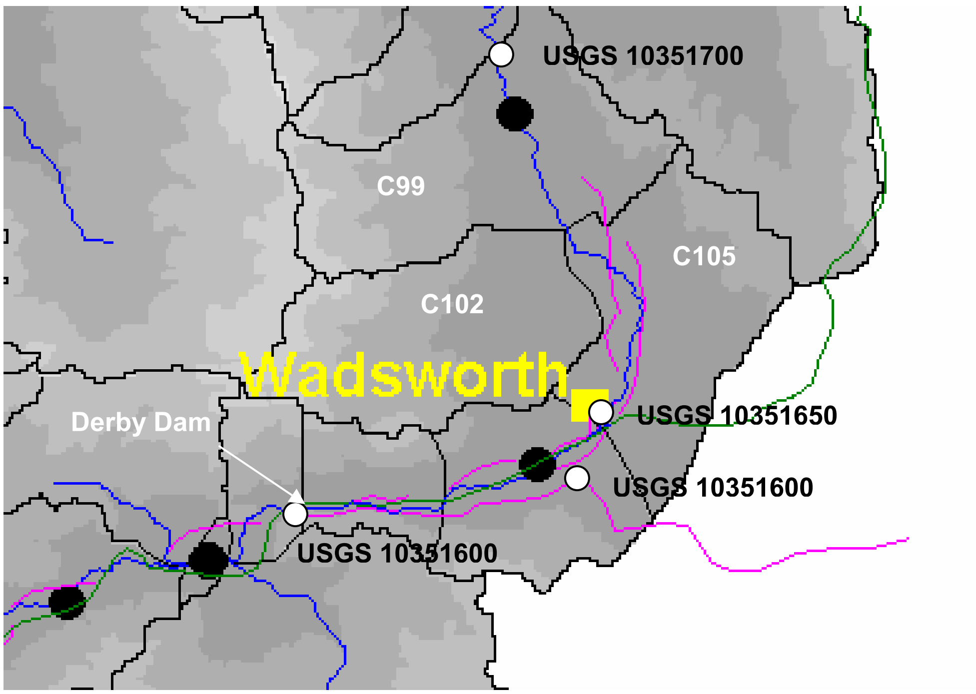


Figure 3.4 Map showing Truckee River gaging stations in the Wadsworth area.

4. Model Calibration/Verification

4.1 Introduction

After populating WARMF with available input data to characterize the watershed, the next step was to run simulations and compare output with measured streamflow and water quality. Model calibration is performed by adjusting model parameters and reaction rates until simulated flow and concentrations are as close as possible to the observed data, while maintaining calibration parameters within a reasonable range. Calibration begins with independent parameters and progresses to dependent parameters. For example, a typical progression would be as follows:

Flow → temperature → sediment → conservative substances → pH → nutrients → algae →DO

Flow is the only independent parameter and must be calibrated first. In order to model the transport of a constituent well, the transport of the water must be modeled well first. Temperature, sediment and conservative substances (e.g. cations, anions, TDS) can then be calibrated next. These are typically non-reactive constituents (though sediment can settle and re-scour). Next, dependent constituents can be calibrated in a hierarchical order. For example, pH depends on the balance of cations and anions, and phosphorus adsorbs to sediment therefore must be calibrated after sediment. Dissolved oxygen depends on several other parameters such as temperature, nutrients (e.g. nitrification consumes oxygen), and algae growth and decay. Therefore, dissolved oxygen usually calibrated last.

There is no single objective to measure calibration. Possible ways to measure calibration include calculating error statistics (simulated vs. observed) and visual inspection of trends, timing of peaks, and match during important time periods. Typically with WARMF, the goal is to have a relative error less than 10 percent and r-square value of 0.7 or greater for hydrology calibration. For water quality calibration, seasonal trends and range of values are important to match. In typical WARMF applications, a relative error less than 20 percent is can be achieved.

In 2006, a WARMF model recalibration was performed by revisiting and checking model input data and model assumptions that we assigned during the original calibration effort (Systech Engineering, 2002). Additional knowledge regarding watershed characteristics was tracked down. Model parameters were adjusted during simulations to yield an improved prediction of stream water quality as compared with measured data. Model calibration/verification was performed for 3 time periods: 1990-1997 (calibration), 1985-1990 (verification), 1998-2004 (verification). Simulations for all three time periods used the same set of input model coefficients, with the exception of the initial conditions for soil moisture, initial concentrations and initial reservoir elevations, which varied for each simulation time period. This approach demonstrated the model's ability to predict flow and concentration for different time periods and hydrologic conditions using the same model assumptions.

In the following sections, simulated output and observed data are compared for several parameters at the following locations:

1. Truckee River at Reno/Sparks
2. Streamboat Creek at Cleanwater Way
3. North Truckee Drain at confluence with the Truckee River
4. Truckee River at Vista

The first 3 locations represent boundary conditions connections with the river model, TRHSPF. At location four, the Truckee River flow and water quality represents the loadings from the two major tributaries (Steamboat Creek and North Truckee Drain) as well as from the watershed upstream of Reno, and TMWRF. Output is provided for all three calibration/verification periods.

4.2 Hydrology

4.2.1 Calibration Parameters

During hydrology calibration, predicted streamflow and reservoir elevations are compared with observed data. The goal is to improve all aspects of the water budget including the global water balance for the entire time period, the seasonal water balance, as well as matching specific events. Key hydrology calibration parameters include the following:

- *Precipitation Weighting Factors*. Precipitation weighting factors account for the difference in precipitation at weather stations and the specified catchment due to elevation or lateral differences.
- *Evaporation Coefficients*. Scaling factor and degree of variation of evaporation between the seasons.
- *Snow Melt Coefficients*. Temperature at which snow forms and melts, melting rates open or forested land uses.
- *Soil Field Capacity*. Volume fraction of water in each soil layer which does not flow out of the soil.
- *Saturation Moisture Content*. Maximum volume fraction of water in each soil layer.
- *Hydraulic Conductivity*. The ease with which water can move through pore spaces or fractures of the soil.

Snowmelt coefficients and soil parameters control the timing of the rising limb and the shape of the hydrograph, respectively.

In the following sections, the simulated and observed stream flows are compared for four locations and three time periods. During all three time periods WARMF provides four graphical comparisons: time series plot, scatter plot, frequency distribution curves, and cumulative curves. These four comparisons constitute the necessary and sufficient conditions for the validity of the model.

4.2.2 Truckee River at Reno/Sparks

The first location for comparison is the Truckee River at Reno/Sparks Figure ? (USGS gage USGS 10348200). Flow at this location includes drainage from the California portion of the watershed, including outflow from Lake Tahoe and reservoir releases from Donner Lake, Prosser Creek Reservoir, Stampede Reservoir, and Boca Reservoir. Streamflow at this location is also influenced by local inflows along the Truckee River from Farad to Reno and diversions and return flows in this region. Average flows of Truckee River at Reno/Sparks make up about 85% of the flow that is measured downstream at Vista. Figure 4.1 compares the model simulated flow of Truckee River at Reno/Sparks with observed values for 10/1/1985 to 12/31/1990 and shows good agreement. The model captures the peaks during high flow (1986) and simulates the base flow very well. The correlation between simulated and observed values is high, suggesting good agreement between the two (Figure 4.2). The relative error is 1.218 cms (43.01 cfs) with a relative percent error of 8.25 percent. Model simulated frequency of flow distribution agreed well with observed data (Figure 4.3). Comparison of cumulative hydrograph (Figure 4.4) shows a slight over prediction in the overall water balance.

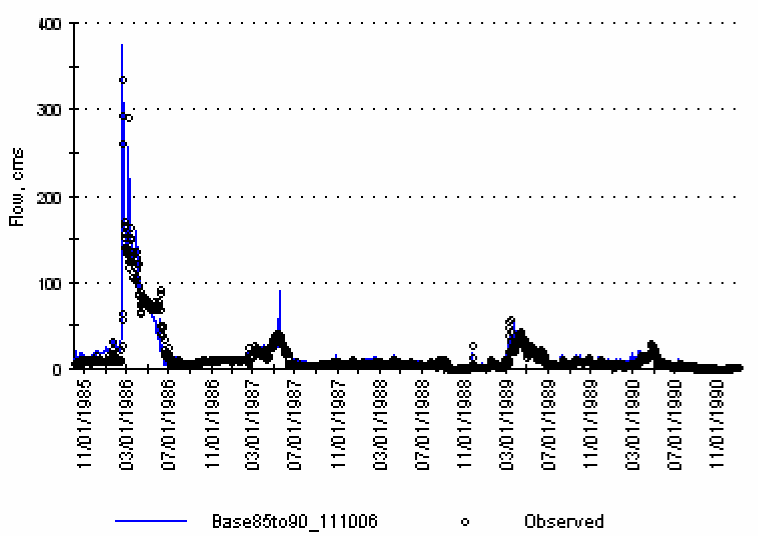
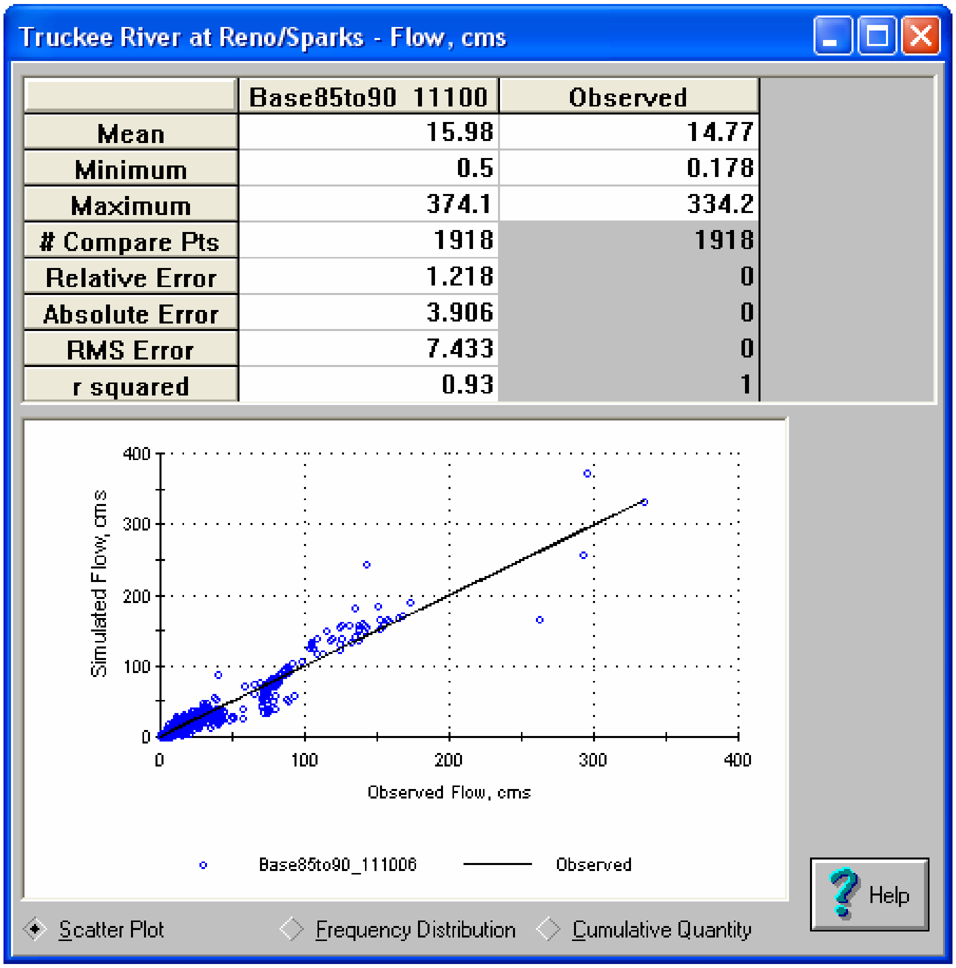


Figure 4.1 Simulated and Observed Streamflow of Truckee River at Reno/Sparks 1985-1990



	Base85to90 11100	Observed
Mean	15.98	14.77
Minimum	0.5	0.178
Maximum	374.1	334.2
# Compare Pts	1918	1918
Relative Error	1.218	0
Absolute Error	3.906	0
RMS Error	7.433	0
r squared	0.93	1

Figure 4.2 Correlation Statistics of Simulated and Observed Flows of Truckee River at Reno/Sparks 1985-1990

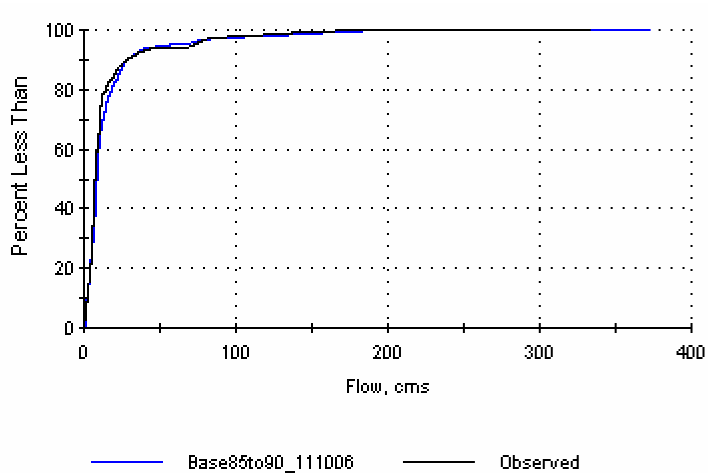


Figure 4.3 Frequency Distribution of Simulated and Observed Flow of Truckee River at Reno/Sparks, 1985-1990

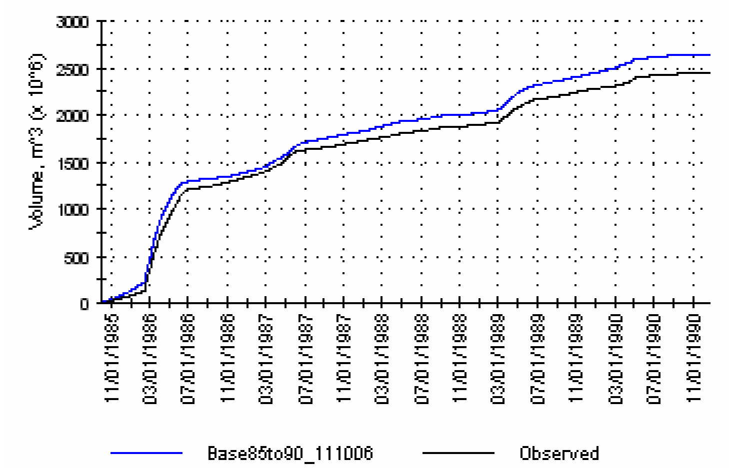


Figure 4.4 Cumulative Hydrograph for Simulated and Observed Flows of Truckee River at Reno/Sparks, 1985-1990

Figure 4.5 through 4.8 show similar results for simulated versus observed stream flow of Truckee River at Reno/Sparks for 10/1/1990 to 12/31/1997. Figure 4.5 shows a good match of streamflow including high peaks during the wet years of 1995 and 1996 and the very wet year of 1997. The model also predicts the peaks during the drier years as well as the hydrograph baseflow. The correlation between the simulated and observed flow suggested good agreement with a relative error of 1.123 cms (39.66 cfs) or 6.19% (Figure 4.6). The frequency distribution (Figure 4.7) shows a good match and the cumulative hydrograph (Figure 4.8) shows a slight over prediction in the cumulative flows over the seven year simulation period.

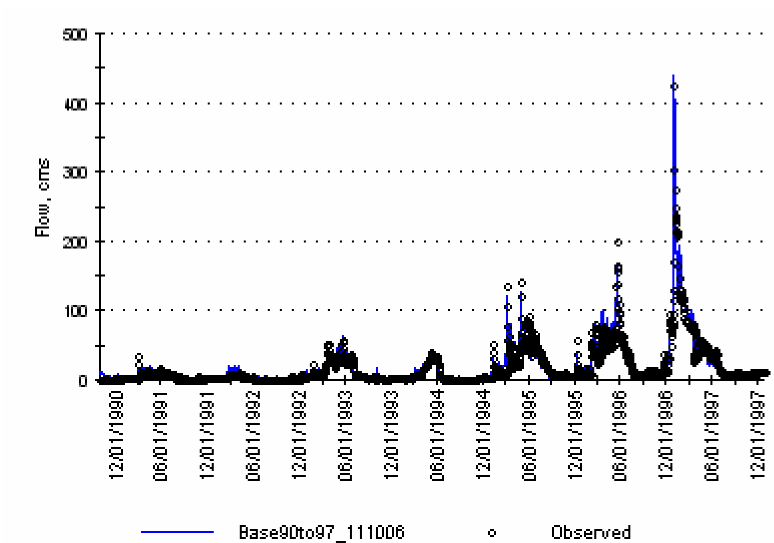
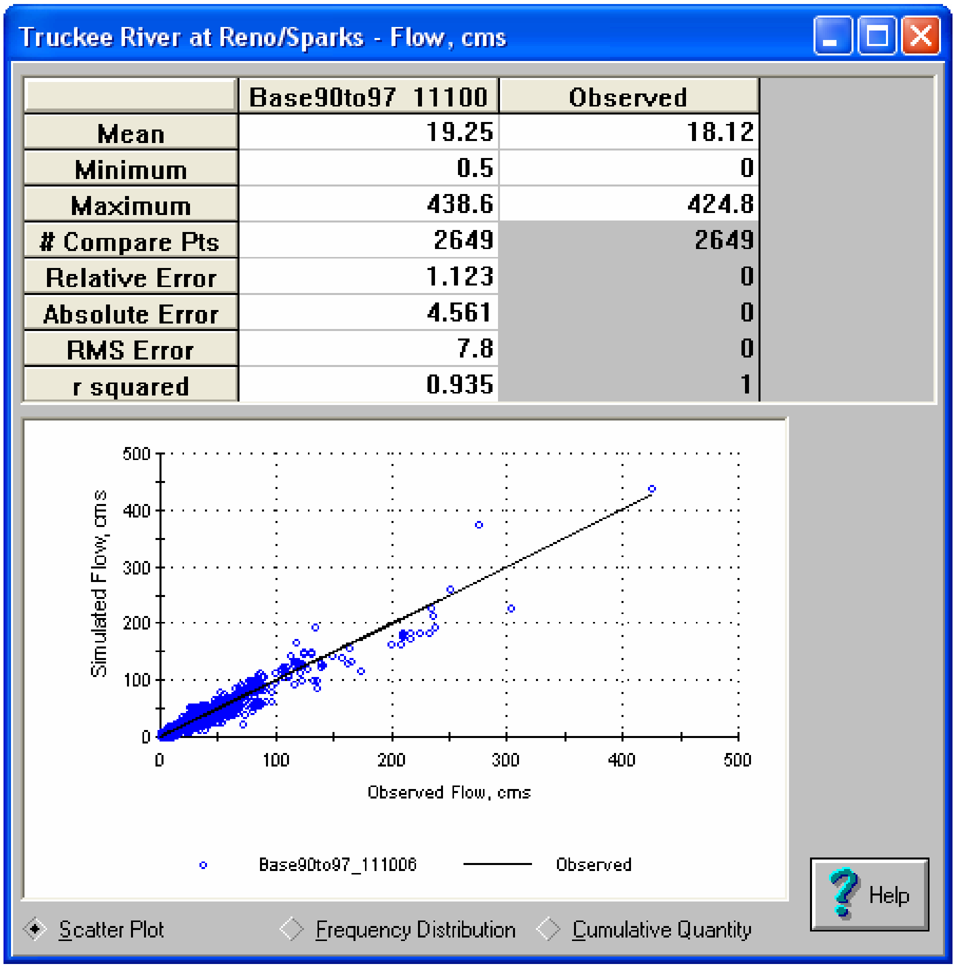


Figure 4.5 Simulated and Observed Streamflow of Truckee River at Reno/Sparks 1990-1997



	Base90to97 11100	Observed
Mean	19.25	18.12
Minimum	0.5	0
Maximum	438.6	424.8
# Compare Pts	2649	2649
Relative Error	1.123	0
Absolute Error	4.561	0
RMS Error	7.8	0
r squared	0.935	1

Figure 4.6 Correlation Statistics of Simulated and Observed Flows of Truckee River at Reno/Sparks 1990-1997

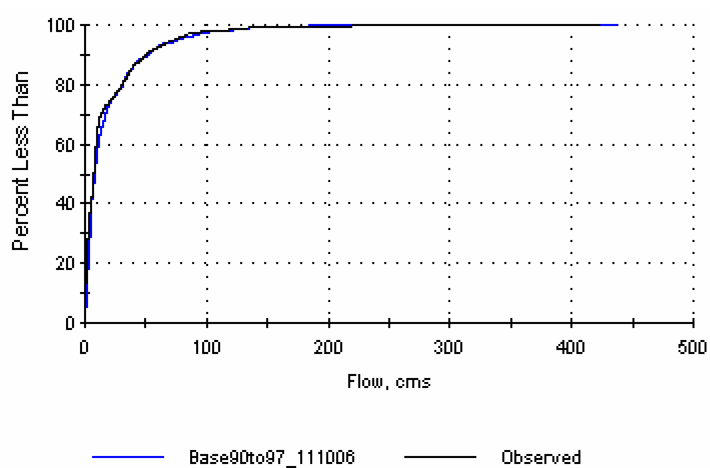


Figure 4.7 Frequency Distribution of Simulated and Observed Flow of Truckee River at Reno/Sparks, 1990-1997

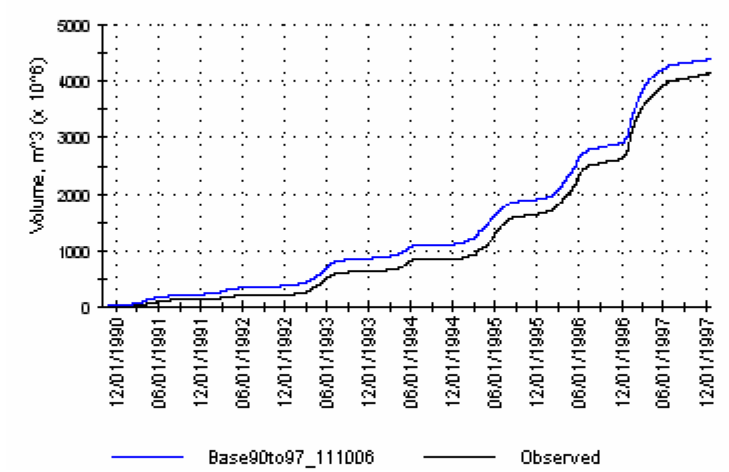


Figure 4.8 Cumulative Hydrograph for Simulated and Observed Flows of Truckee River at Reno/Sparks, 1990-1997

As with the other time periods, WARMF predicts streamflow well for Truckee River at Reno/Sparks for the time period of 10/1/197 to 12/31/2004. For the two wettest years (1998 and 1999), WARMF slightly under predicts the maximum flows (Figure 4.9). For the remaining, drier, years both peak and base flows are captured well. The correlation statistics presented in Figure 4.10 indicate a good match with a calculated relative error of 0.0789 cms (2.78 cfs) or 0.46%. The frequency distribution and cumulative hydrographs suggest the model performs well in reproducing frequency of high and low flow and simulating the cumulative water budget over the simulation period of seven years (Figures 4.11 and 4.12).

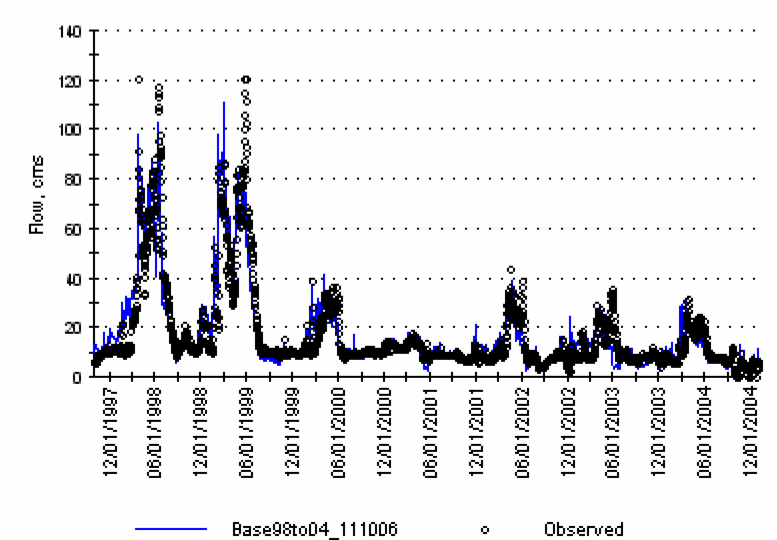
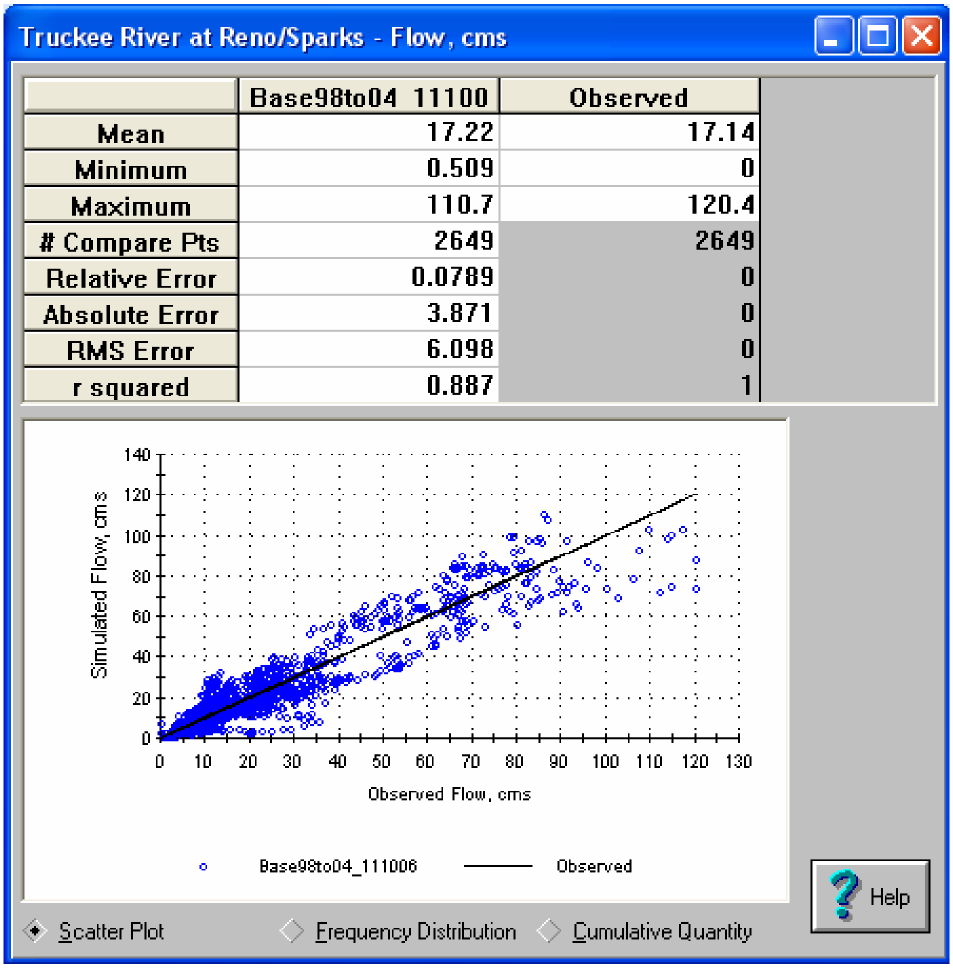


Figure 4.9 Simulated and Observed Streamflow of Truckee River at Reno/Sparks 1997-2004



	Base98to04_11100	Observed
Mean	17.22	17.14
Minimum	0.509	0
Maximum	110.7	120.4
# Compare Pts	2649	2649
Relative Error	0.0789	0
Absolute Error	3.871	0
RMS Error	6.098	0
r squared	0.887	1

Figure 4.10 Correlation Statistics of Simulated and Observed Flows of Truckee River at Reno/Sparks 1997-2004

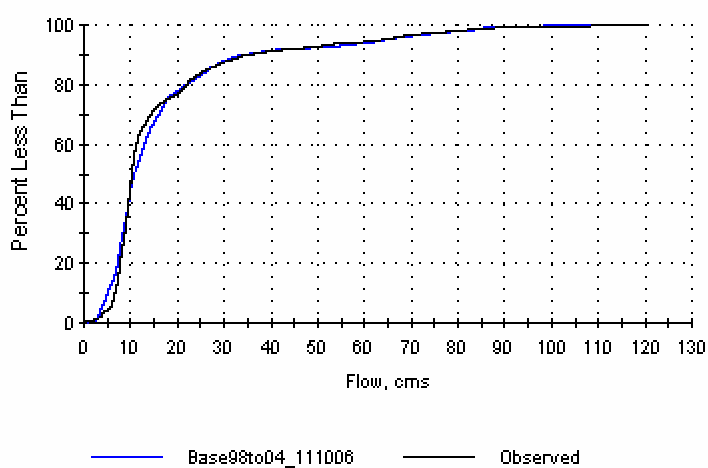


Figure 4.11 Frequency Distribution of Simulated and Observed Flow of Truckee River at Reno/Sparks, 1997-2004

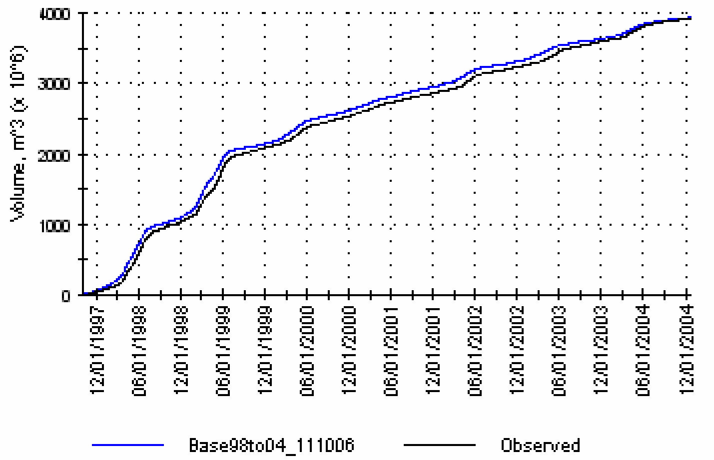


Figure 4.12 Cumulative Hydrograph for Simulated and Observed Flows of Truckee River at Reno/Sparks, 1997-2004

4.2.3 Steamboat Creek at Cleanwater Way

The next location for comparison is the most downstream location of Steamboat Creek at Cleanwater Way (USGS gage USGS 10349980). Steamboat Creek is a major tributary of the Truckee River which includes drainage from Washoe Lake and the Steamboat Creek watershed. It has a complex terrain extending from high mountain regions that accumulate snow to arid valleys. Steamboat Creek drains agricultural return flows for irrigation water diverted from the Truckee River. The average flow for Steamboat Creek makes up approximately 7.5% of the Truckee River flow that is measured at Vista. Figure 4.13 shows a comparison of simulated and observed flows of Steamboat Creek for 10/1/1985 to 12/31/1990. WARMF simulates the higher flows of 1986 and the lower flows of 1988. For most years, the general pattern of the hydrograph is good though storm peaks are slightly over predicted. Figure 4.14 shows correlation statistics and the calculated relative error of 0.202 cms (7.13 cfs) or 15.68%. Figure 4.15 shows a good match for the frequency distribution of flow. Figure 4.16 indicates that the cumulative flow volume simulated over time in Steamboat Creek is slightly larger than observed. Differences between simulated and observed data are likely due to uncertainties in the input data for precipitation and irrigation water. Limited data were available to characterize the irrigation practices of the Steamboat Creek region in WARMF and therefore it was difficult to replicate the complex and highly managed flow in Steamboat Creek.

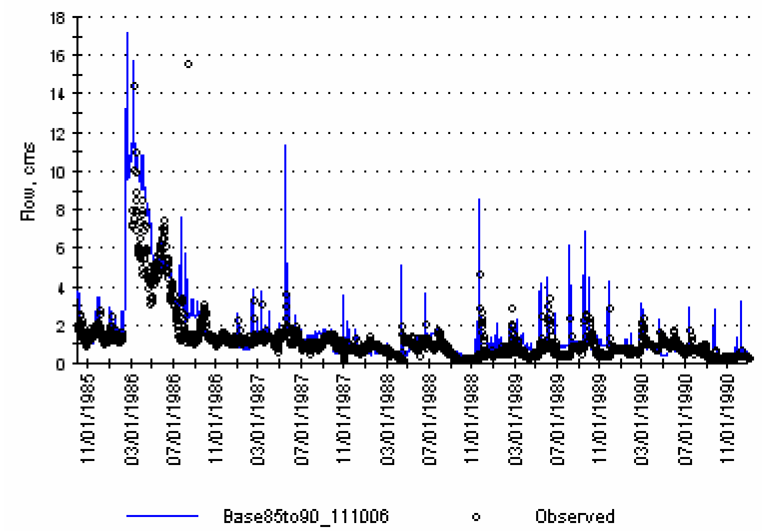
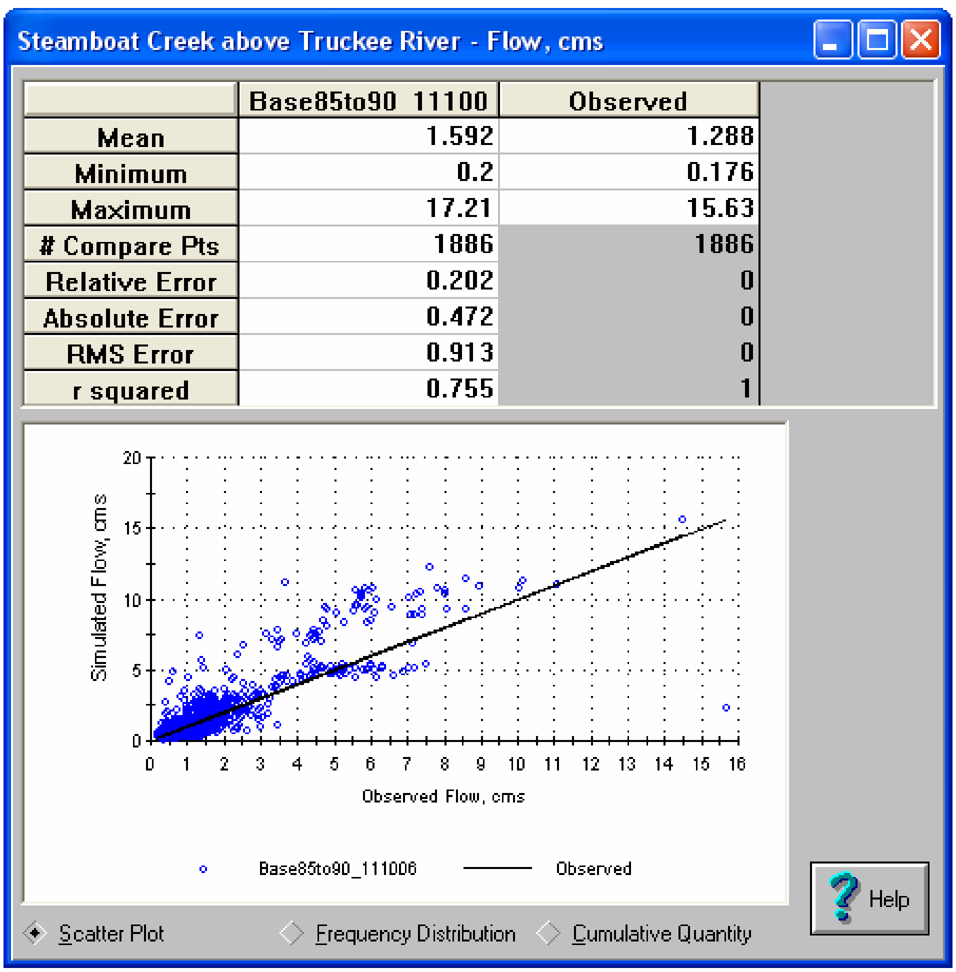


Figure 4.13 Simulated and Observed Streamflow of Steamboat Creek at Cleanwater Way 1985-1990



	Base85to90_11100	Observed
Mean	1.592	1.288
Minimum	0.2	0.176
Maximum	17.21	15.63
# Compare Pts	1886	1886
Relative Error	0.202	0
Absolute Error	0.472	0
RMS Error	0.913	0
r squared	0.755	1

Figure 4.14 Correlation Statistics of Simulated and Observed Flows of Steamboat Creek at Cleanwater Way 1985-1990

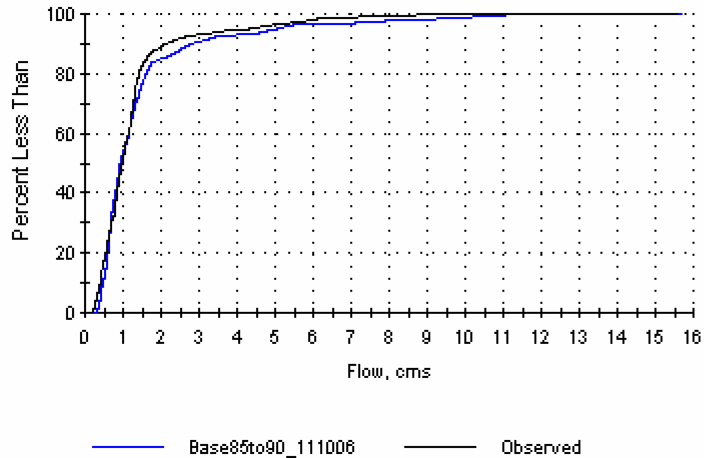


Figure 4.15 Frequency Distribution of Simulated and Observed Flow of Steamboat Creek at Cleanwater Way 1985-1990

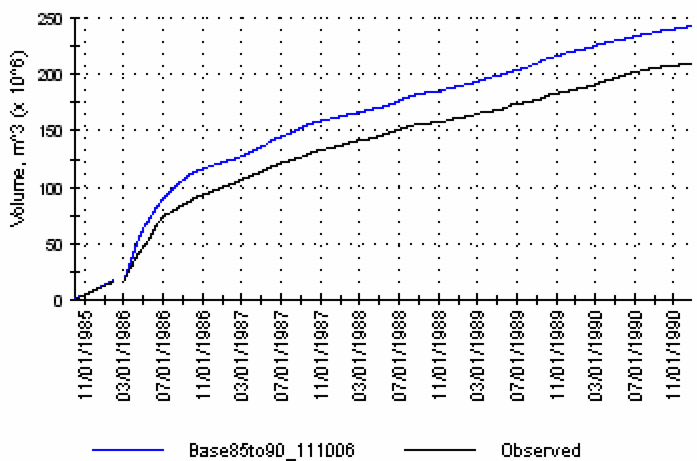


Figure 4.16 Cumulative Hydrograph for Simulated and Observed Flows of Steamboat Creek at Cleanwater Way 1985-1990

Figure 4.17 shows a comparison of simulated and observed streamflow of Steamboat Creek for 10/1/1990 to 12/31/1997. During this time period, WARMF does a good job of predicting the hydrograph pattern, however, several peak flows were under predicted, particularly in 1995 and 1996. The statistical output in shown in Figure 4.18 indicates a good correlation and a relative error of 0.13 cms (4.6 cfs) or 10.7%. The frequency distribution plot (Figure 4.19) shows a good prediction of high and low flows, with the exception of the mismatch at the highest measured flows. As with the 1985-1990 time period, WARMF slightly predicted the overall water balance for 1990-1997 (Figure 4.20).

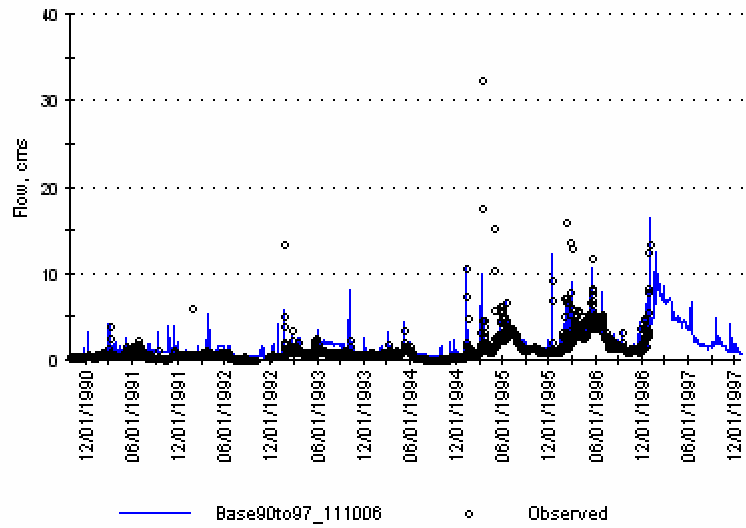
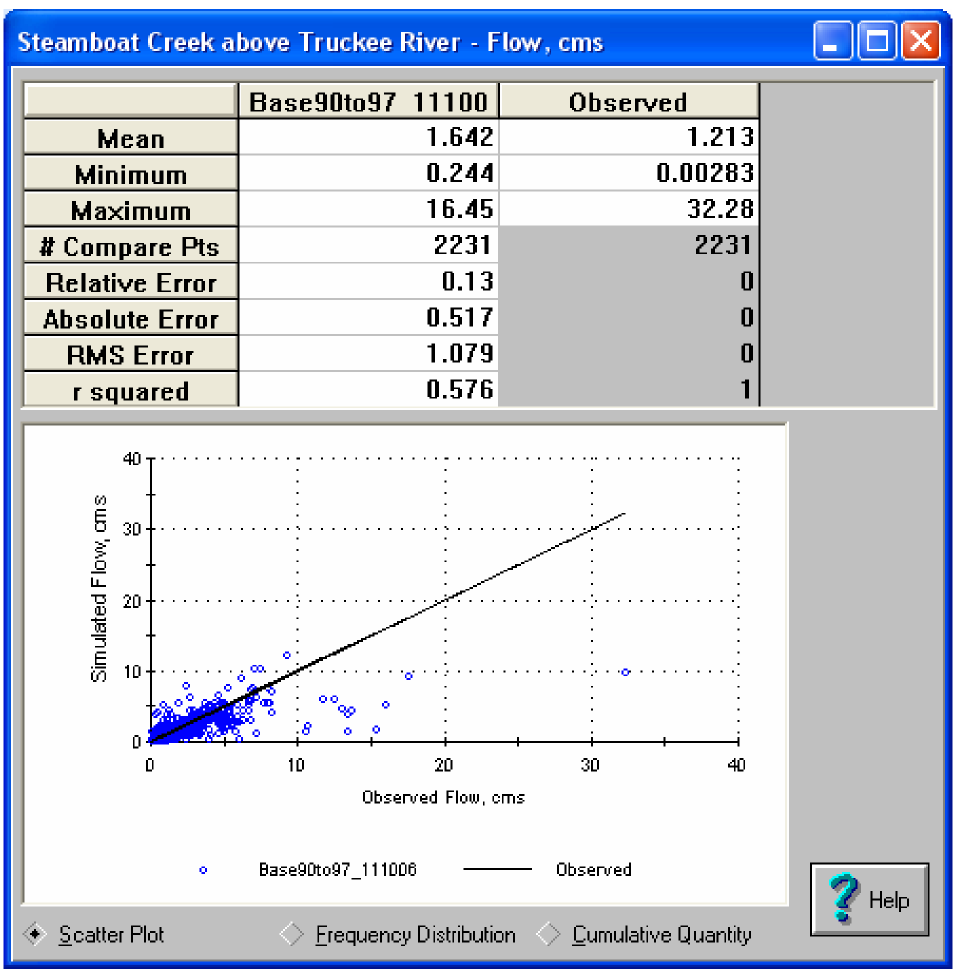


Figure 4.17 Simulated and Observed Streamflow of Steamboat Creek at Cleanwater Way 1990-1997



Steamboat Creek above Truckee River - Flow, cms

	Base90to97 11100	Observed
Mean	1.642	1.213
Minimum	0.244	0.00283
Maximum	16.45	32.28
# Compare Pts	2231	2231
Relative Error	0.13	0
Absolute Error	0.517	0
RMS Error	1.079	0
r squared	0.576	1

Figure 4.18 Correlation Statistics of Simulated and Observed Flows of Steamboat Creek at Cleanwater Way 1990-1997

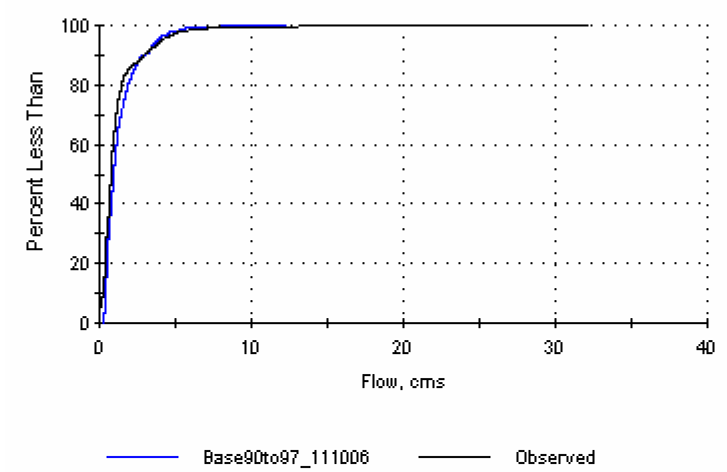


Figure 4.19 Frequency Distribution of Simulated and Observed Flow of Steamboat Creek at Cleanwater Way 1990-1997

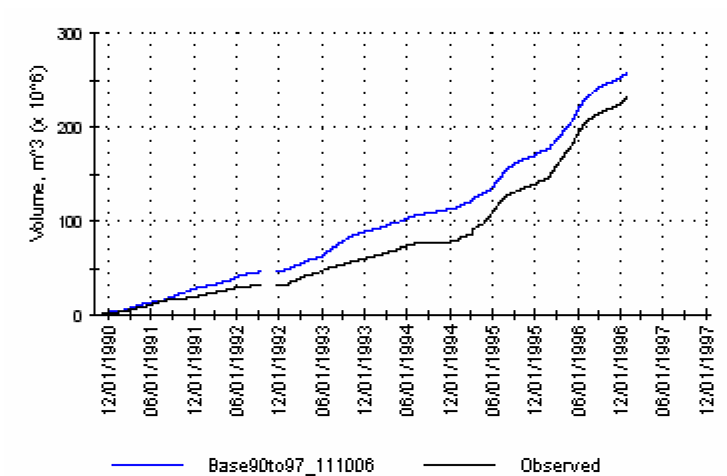


Figure 4.20 Cumulative Hydrograph for Simulated and Observed Flows of Steamboat Creek at Cleanwater Way 1990-1997

Simulated and observed flows were also compared for Steamboat Creek at Cleanwater Way for 10/1/1997 to 12/31/2004 (Figure 4.21). During this time period, WARMF simulated the pattern and magnitude of the hydrograph well. Peak and baseflow predictions were within good agreement with observed values. The correlation statistics (Figure 4.22) also show a good match with a relative error of -0.00684 cms (-0.24 cms) or -0.04%. Likewise, the frequency distribution (Figure 4.23) and cumulative flow (Figure 4.24) plots indicated a good match of simulated with observed data.

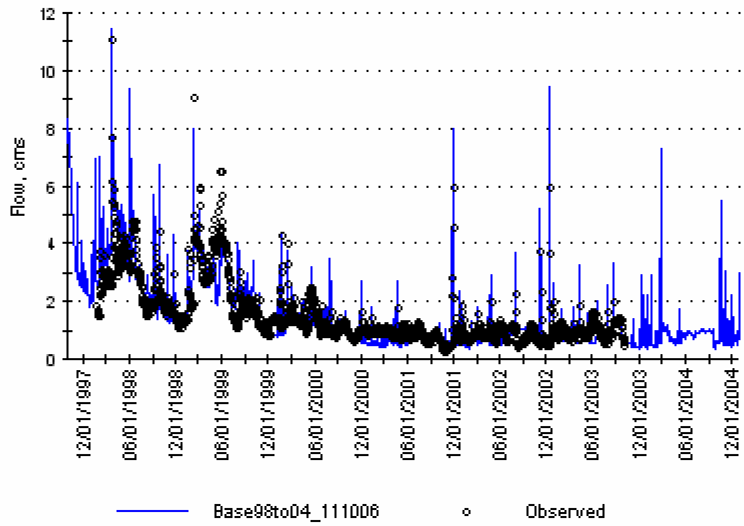
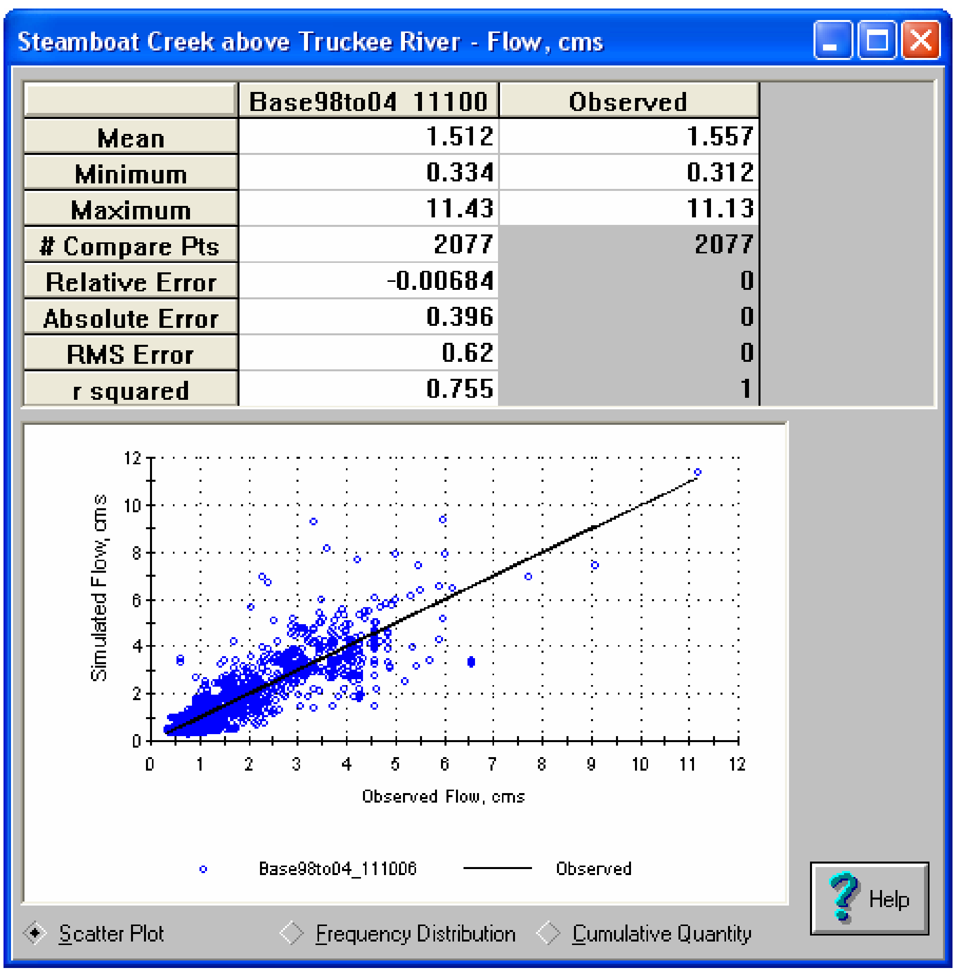


Figure 4.21 Simulated and Observed Streamflow of Steamboat Creek at Cleanwater Way 1997-2004



	Base98to04_11100	Observed
Mean	1.512	1.557
Minimum	0.334	0.312
Maximum	11.43	11.13
# Compare Pts	2077	2077
Relative Error	-0.00684	0
Absolute Error	0.396	0
RMS Error	0.62	0
r squared	0.755	1

Figure 4.22 Correlation Statistics of Simulated and Observed Flows of Steamboat Creek at Cleanwater Way 1997-2004

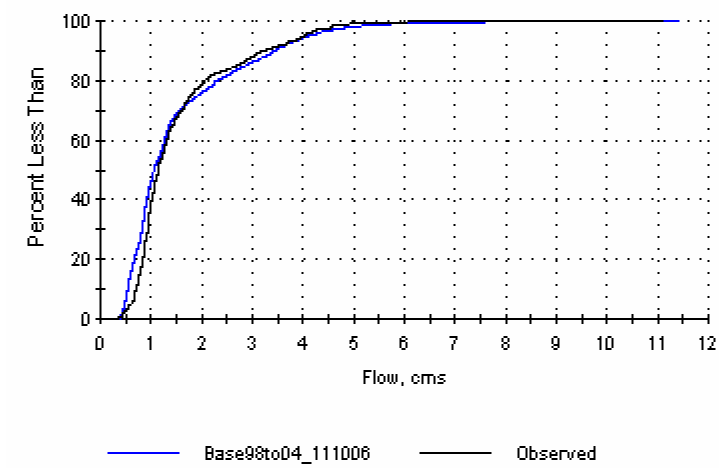


Figure 4.23 Frequency Distribution of Simulated and Observed Flow of Steamboat Creek at Cleanwater Way 1997-2004

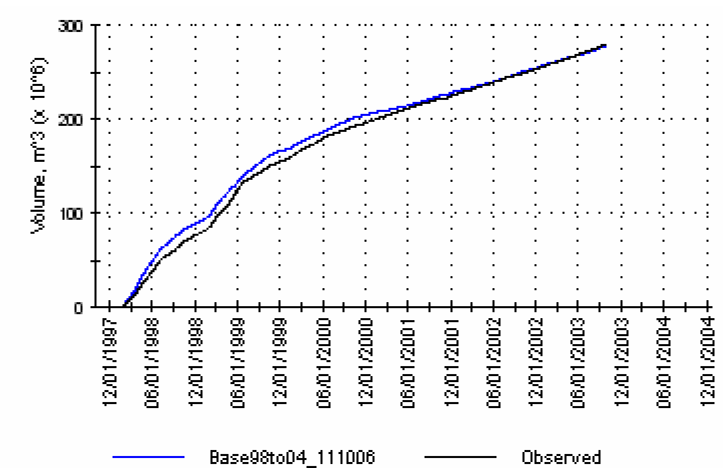


Figure 4.24 Cumulative Hydrograph for Simulated and Observed Flows of Steamboat Creek at Cleanwater Way 1997-2004

4.2.4 North Truckee Drain

A second major tributary which joins the Truckee River just downstream of Reno is North Truckee Drain (USGS gage USGS 10348300). This waterway drains a watershed influenced by agricultural diversions (e.g. North Truckee Ditch and Orr Ditch) as well as residential development (e.g. Spanish Springs). In addition, two moderately sized point sources 1) Vista Canyon Group (NV0020893) and 2) Sparks Lake Marina (NV0022918) contribute flow to North Truckee Drain. Up until 1997, Vista Canyon Group discharged an approximate average flow of 0.27 cms (9.5 cfs), which accounted for approximately one third of the flow in North Truckee Drain. Unfortunately, limited monitoring data exists to characterize the impact of these point sources on North Truckee Drain. North Truckee Drain contributes about 2.5% of the Truckee River flow measured at Vista. For the 10/1/1985 to 12/31/1990 time period, no observed data was available for comparison. Simulated flow for this time period is shown in Figure 4.25.

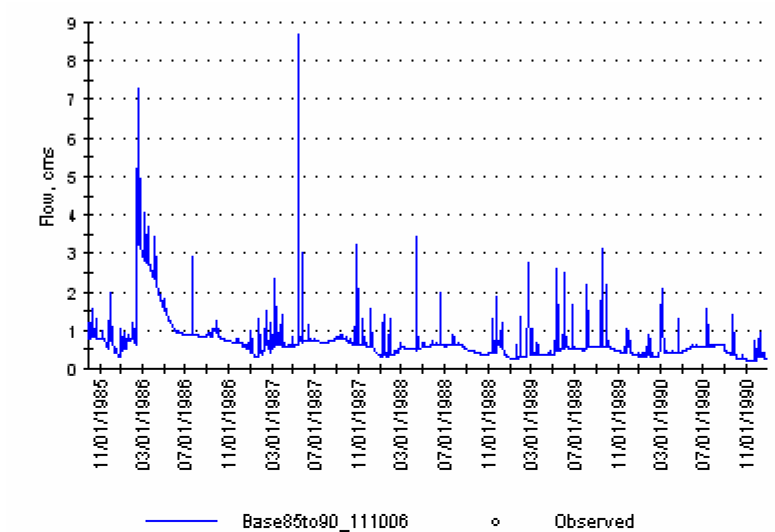


Figure 4.25 Simulated Streamflow of North Truckee Drain 1985-1990

Figure 4.25 shows simulated and observed flow of North Truckee Drain for 10/1/1990 to 12/31/1997. WARMF predicts the baseflow during this time period reasonably well, though several peak flows were under or over predicted. The calculated relative error is -0.0635 cms (-2.2 cfs) or -10.5% (Figure 4.27). Figures 4.28 and 4.29 show a good match with respect to frequency distribution and cumulative flows respectively.

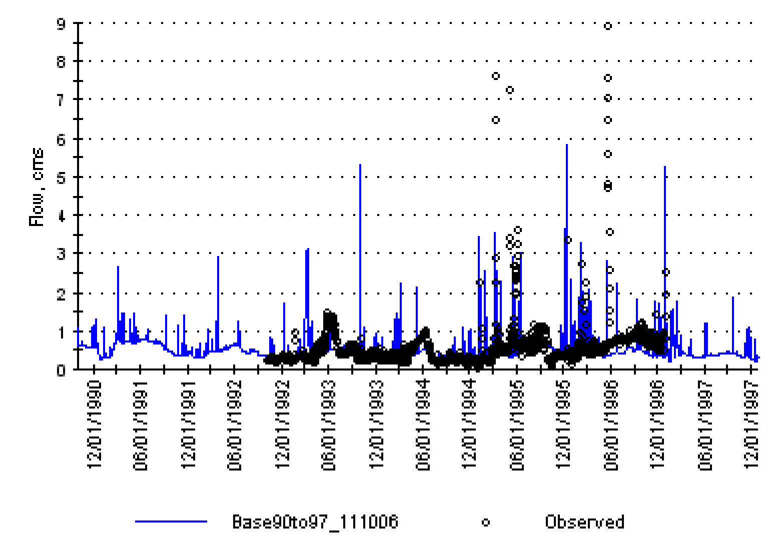
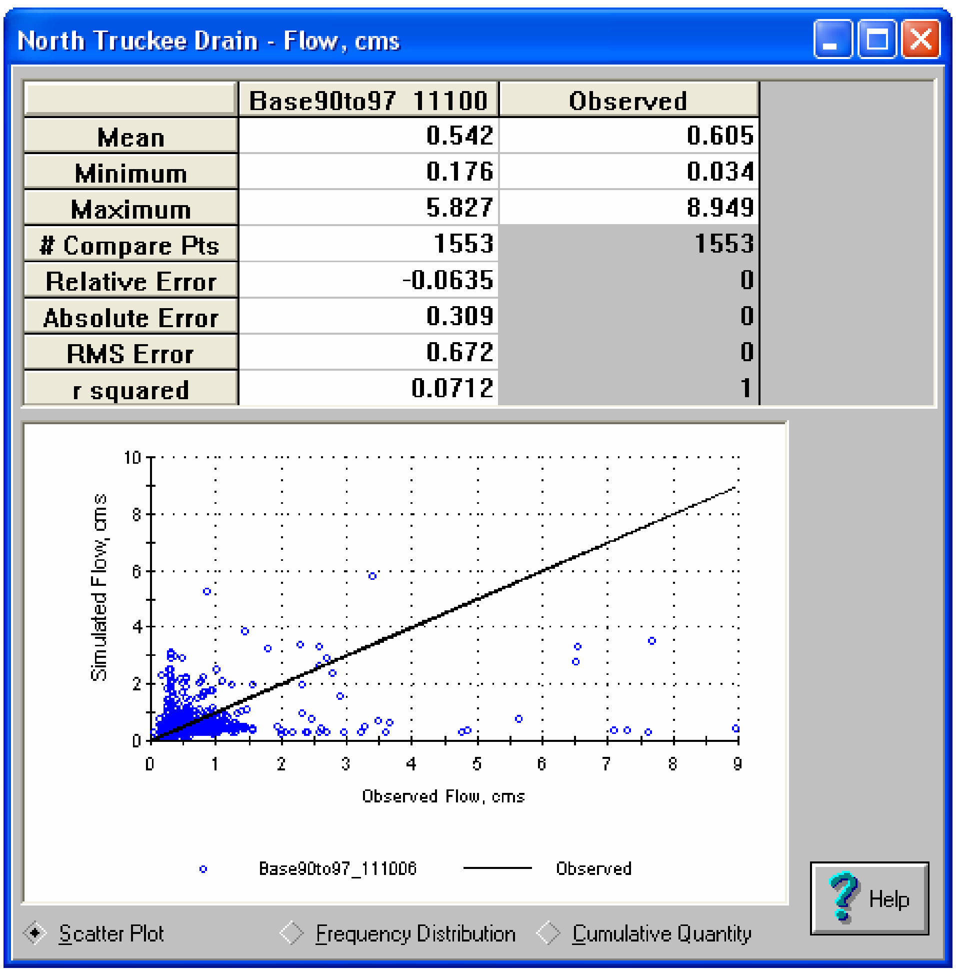


Figure 4.26 Simulated and Observed Streamflow of North Truckee Drain 1990-1997



	Base90to97 11100	Observed
Mean	0.542	0.605
Minimum	0.176	0.034
Maximum	5.827	8.949
# Compare Pts	1553	1553
Relative Error	-0.0635	0
Absolute Error	0.309	0
RMS Error	0.672	0
r squared	0.0712	1

Figure 4.27 Correlation Statistics of Simulated and Observed Flows of North Truckee Drain 1990-1997

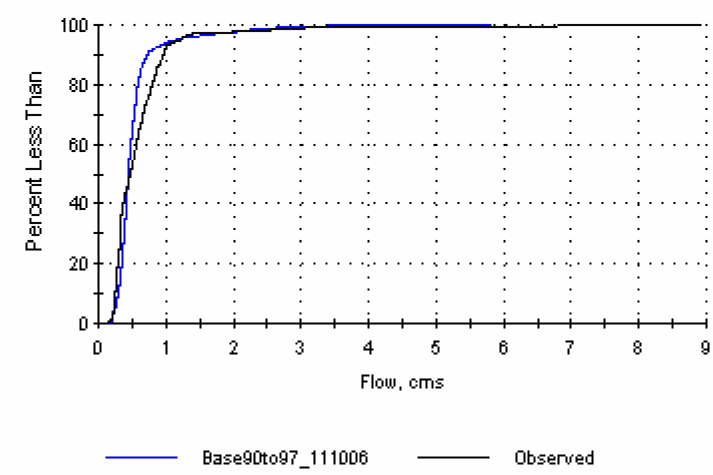


Figure 4.28 Frequency Distribution of Simulated and Observed Flow of North Truckee Drain 1990-1997

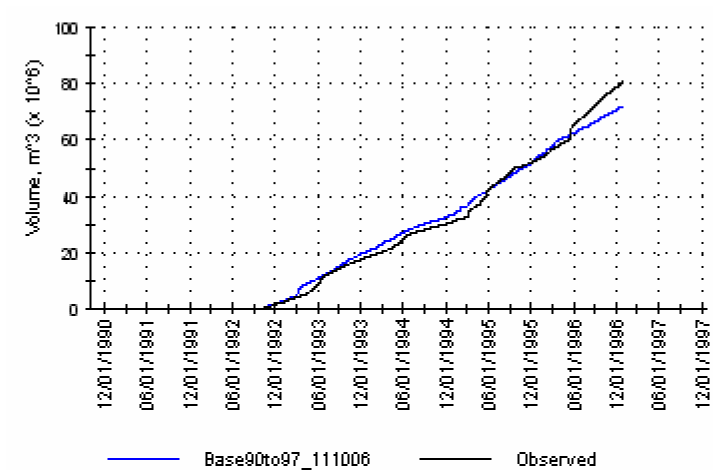


Figure 4.29 Cumulative Hydrograph for Simulated and Observed Flows of North Truckee Drain 1990-1997

Simulated and observed flow of North Truckee Drain for 10/1/1997 to 12/31/2004 is shown in Figure 4.30. Most of the time period is simulated quite well, however, WARMF slightly over predicts flow during the spring of 1998 and under predicts flow during the fall of 2002. Figure 4.31 shows the correlation statistics and a calculated relative error of -0.026 cms (-0.92 cfs) or -6.3%. Figure 4.32 shows a reasonable comparison of frequency distribution of flows and figure 4.33 shows a slight deviation with respect to the overall cumulative flow.

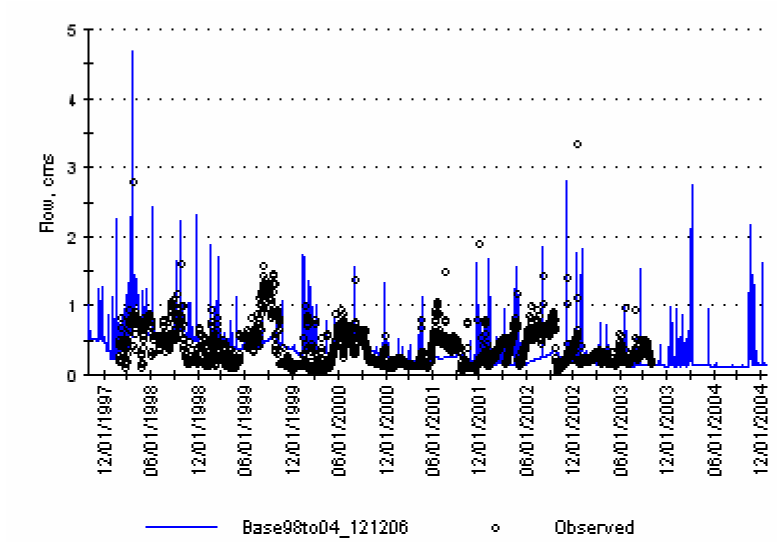


Figure 4.30 Simulated and Observed Streamflow of North Truckee Drain 1997-2004

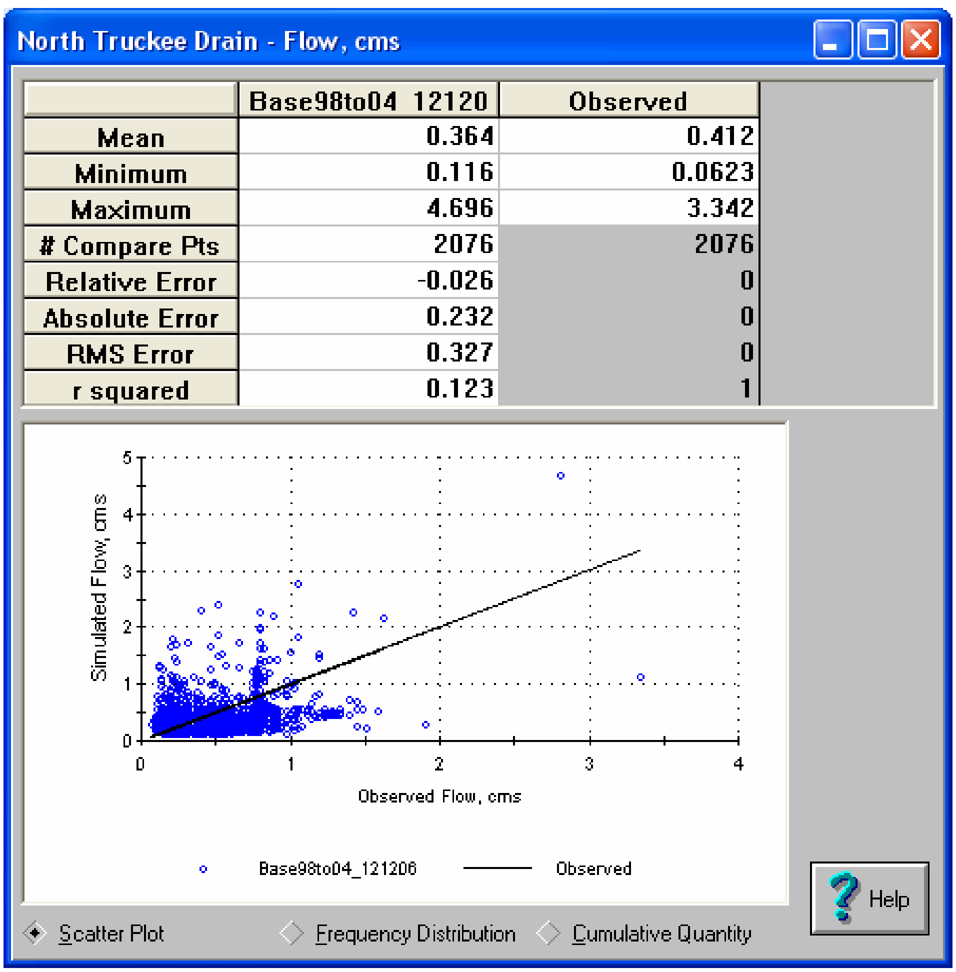


Figure 4.31 Correlation Statistics of Simulated and Observed Flows of North Truckee Drain 1990-1997

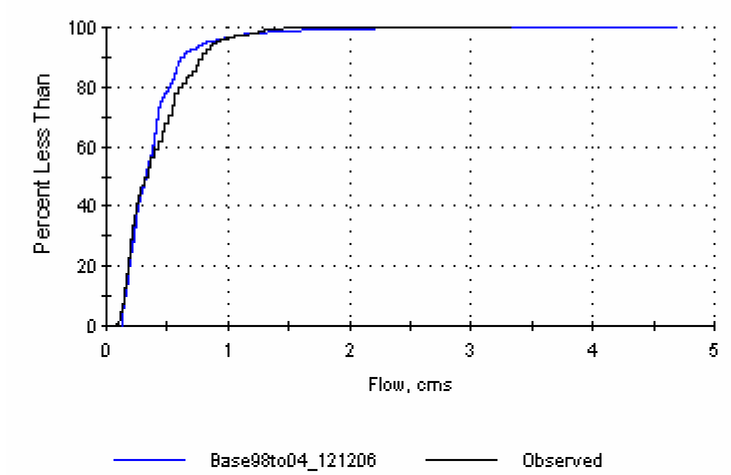


Figure 4.32 Frequency Distribution of Simulated and Observed Flow of North Truckee Drain 1997-2004

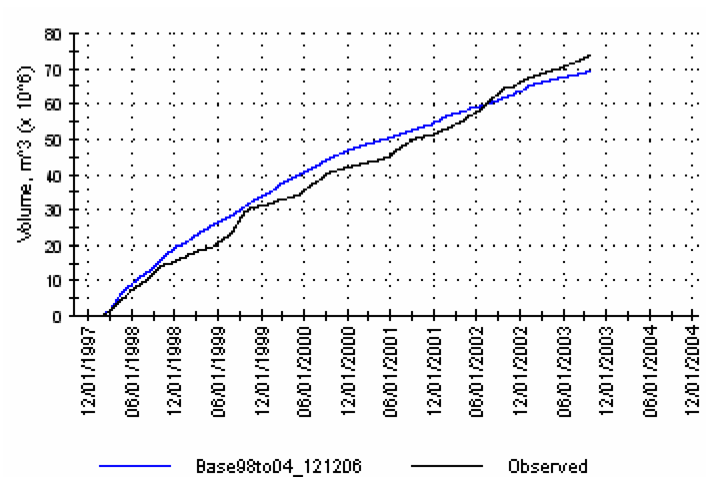


Figure 4.33 Cumulative Hydrograph for Simulated and Observed Flows of North Truckee Drain 1997-2004

4.2.5 Truckee River at Vista

The fourth location for comparison is the Truckee River at Vista (USGS gage USGS 10350000), which includes drainage from Reno and the watershed upstream of Reno (~84%), North Truckee Drain including drainage from Sparks (~7.5%), Steamboat Creek (~2.5%) and TMWRF point source discharge (~6%). Figure 4.34 shows the time series of simulated and observed flows of Truckee River at Vista for 10/1/1985 to 12/31/1990. The simulated and observed flows matched very well with the exception of a slight under prediction of peak flows in the spring of 1986 and a slight over prediction of the peak in spring 1987. The correlation statistics shown in Figure 4.35 show an excellent match with a relative error of 1.037 cms (32.5 cfs) or 5.65%. The frequency distribution (Figure 4.36) and cumulative hydrographs (Figure 4.37) show a good match with respect to simulating the frequency of high and low flows and calculating the cumulative water budget.

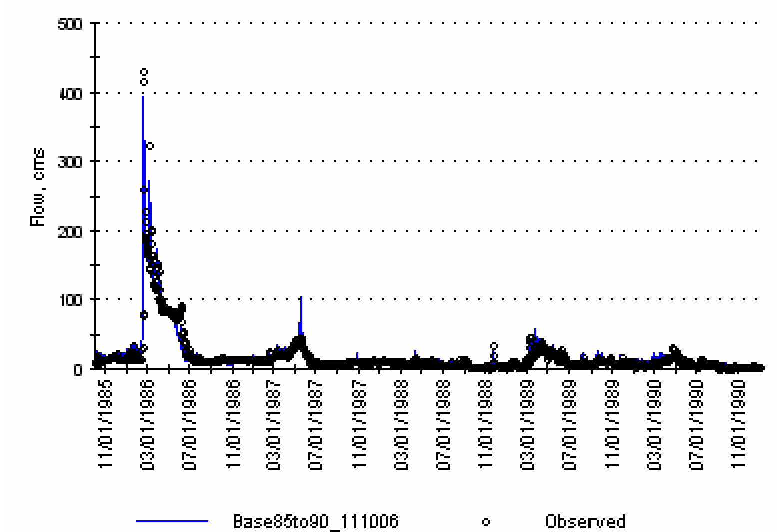
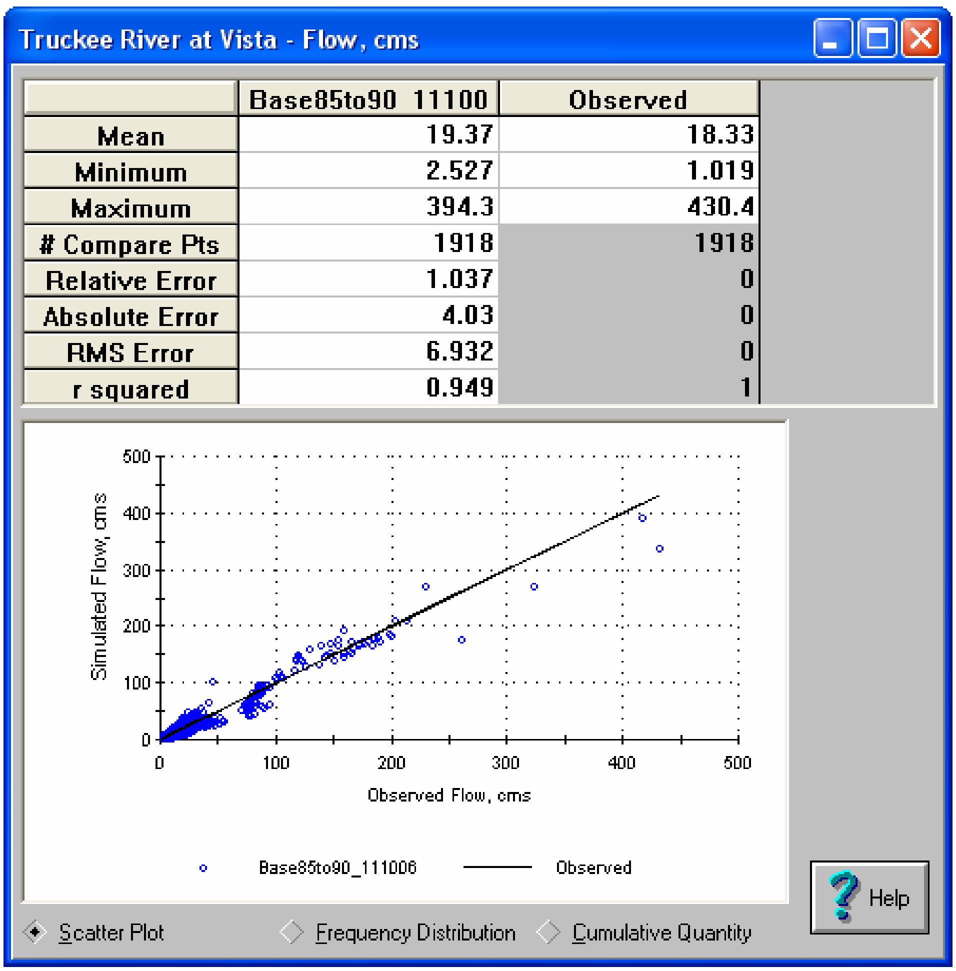


Figure 4.34 Simulated and Observed Streamflow of Truckee River at Vista 1985-1990



	Base85to90 11100	Observed
Mean	19.37	18.33
Minimum	2.527	1.019
Maximum	394.3	430.4
# Compare Pts	1918	1918
Relative Error	1.037	0
Absolute Error	4.03	0
RMS Error	6.932	0
r squared	0.949	1

Figure 4.35 Correlation Statistics of Simulated and Observed Flows of Truckee River at Vista 1985-1990

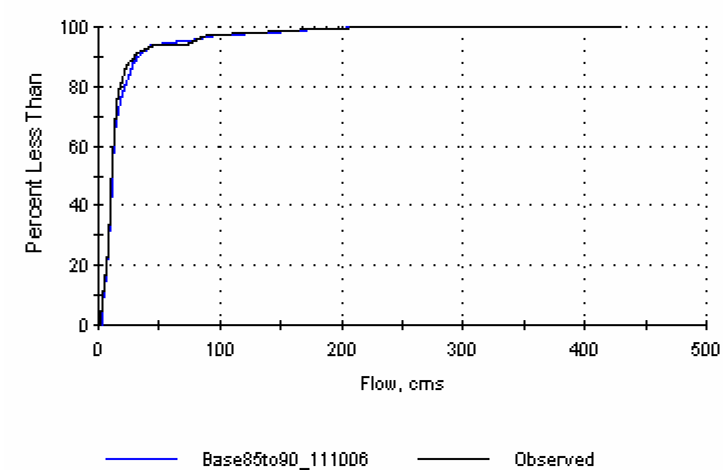


Figure 4.36 Frequency Distribution of Simulated and Observed Flow of Truckee River at Vista 1985-1990

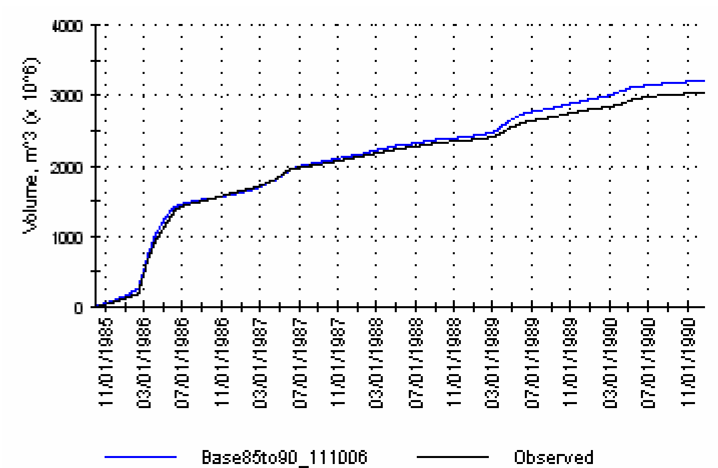


Figure 4.37 Cumulative Hydrograph for Simulated and Observed Flows of Truckee River at Vista 1985-1990

Figure 4.38 shows simulated versus observed stream flow for Truckee River at Vista for the time period of 10/1/1990 to 12/31/1997. As with other time periods, WARMF predicts the seasonal pattern of streamflow well. All major storm peaks are simulated very closed to observed levels. Figure 4.39 shows the good correlation between simulated and observed with a calculated relative error of 0.893 cms (31.5 cfs) or 4.1%. A good comparison of the prediction of high and low flows is presented in the frequency distribution plot (Figure 4.40). The cumulative water balance for Truckee River at Vista (Figure 4.41) was also predicted well, with just a slight over prediction over the entire the seven year simulation.

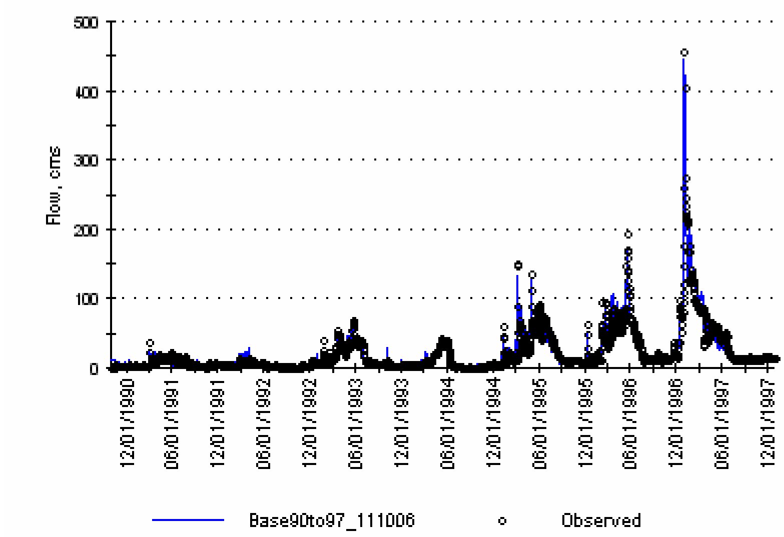
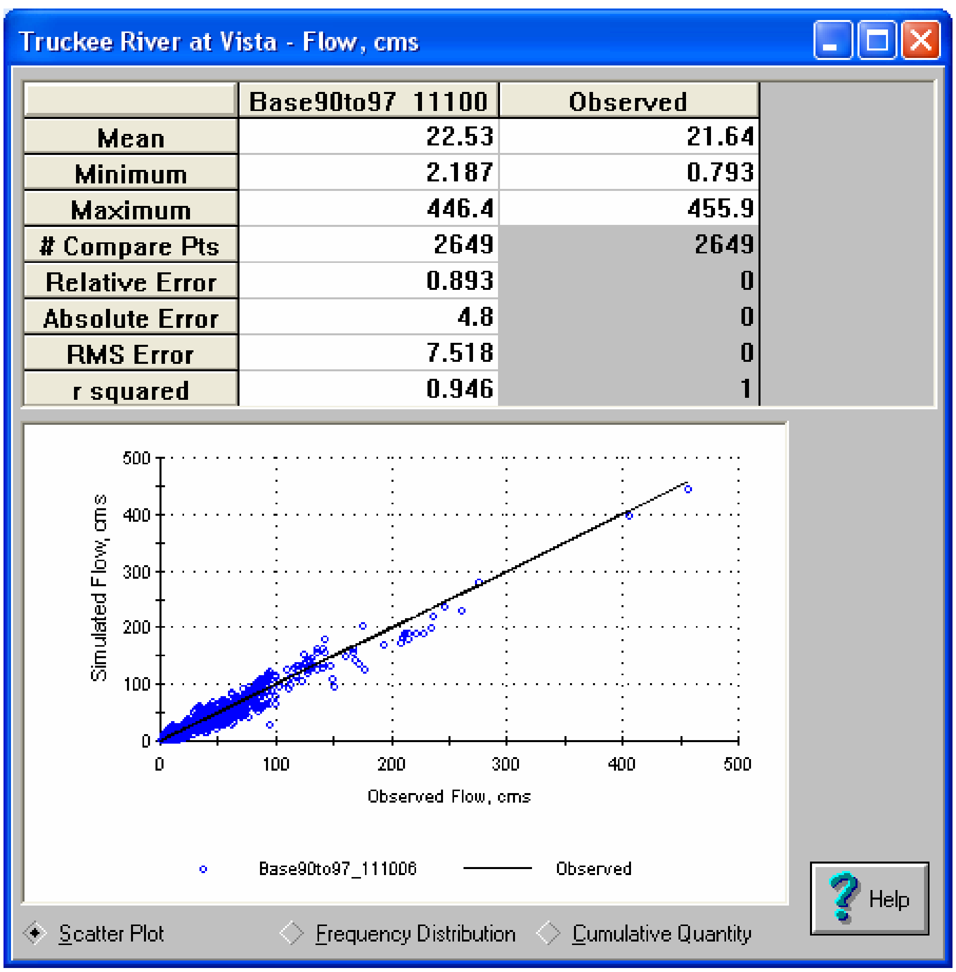


Figure 4.38 Simulated and Observed Streamflow of Truckee River at Vista 1990-1997



	Base90to97_11100	Observed
Mean	22.53	21.64
Minimum	2.187	0.793
Maximum	446.4	455.9
# Compare Pts	2649	2649
Relative Error	0.893	0
Absolute Error	4.8	0
RMS Error	7.518	0
r squared	0.946	1

Figure 4.39 Correlation Statistics of Simulated and Observed Flows of Truckee River at Vista 1990-1997

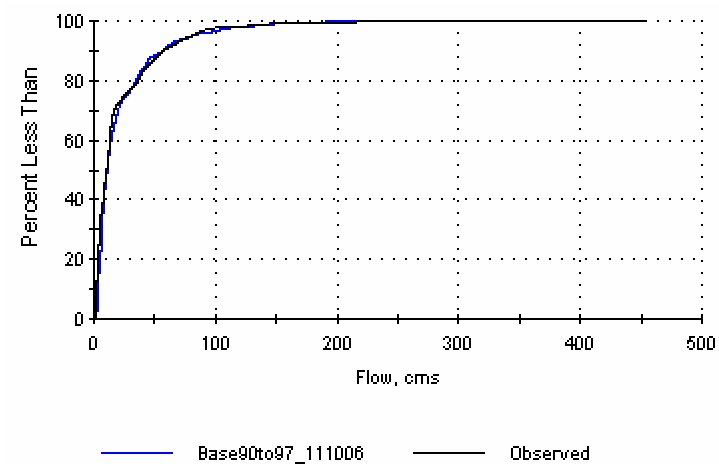


Figure 4.40 Frequency Distribution of Simulated and Observed Flow of Truckee River at Vista 1990-1997

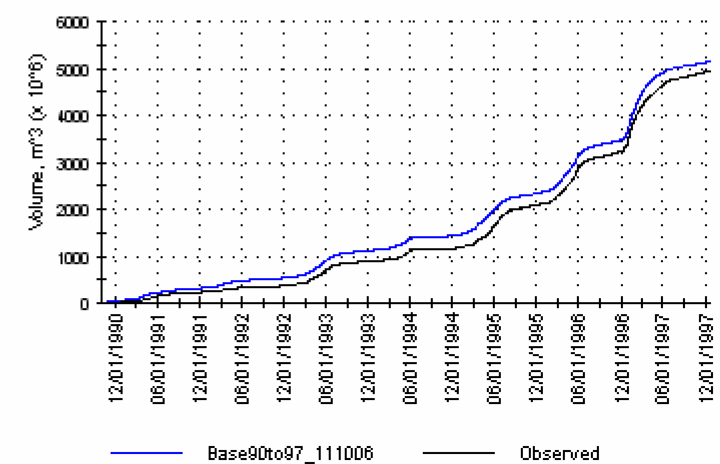


Figure 4.41 Cumulative Hydrograph for Simulated and Observed Flows of Truckee River at Vista 1990-1997

Figure 4.42 shows the simulated versus observed flows for Truckee River at Vista for 10/1/1997 to 12/31/2004. As with the simulation at Reno/Sparks for this time period, WARMF slightly under predicts the highest flow peaks for 1998 and 1999 but captures the rest of the hydrograph quite well. The correlation statistics (Figure 4.43) indicate a good match with a relative error of -0.28 cms (-9.9 cfs) or -1.4%. Both the frequency distribution plot (Figure 4.44) and the cumulative flow plot (4.45) indicate an excellent match of simulated with observed data for this time period.

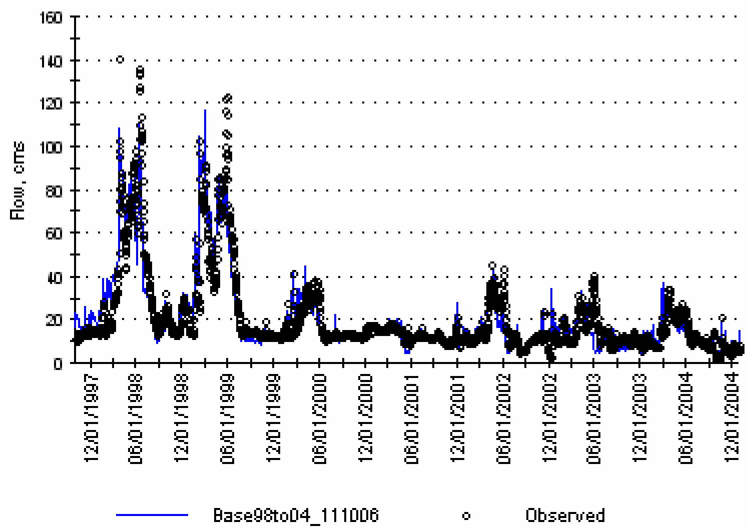
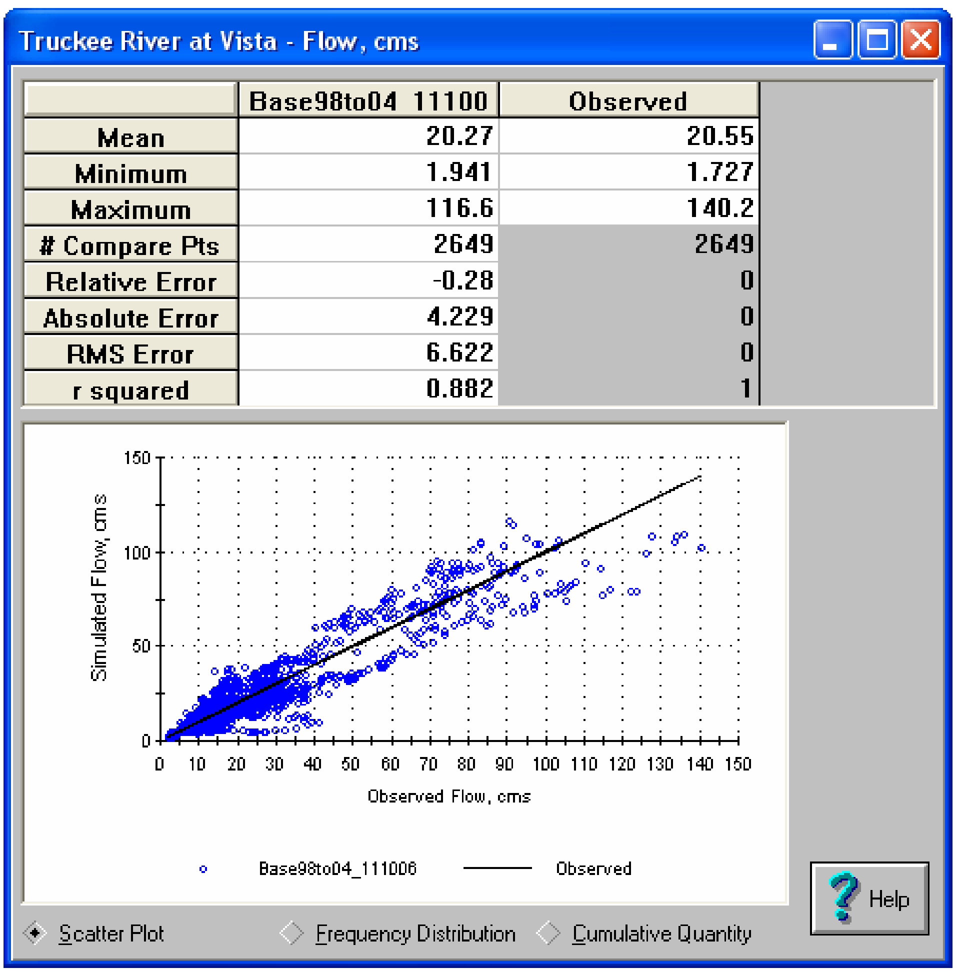


Figure 4.42 Simulated and Observed Streamflow of Truckee River at Vista 1997-2004



	Base98to04 11100	Observed
Mean	20.27	20.55
Minimum	1.941	1.727
Maximum	116.6	140.2
# Compare Pts	2649	2649
Relative Error	-0.28	0
Absolute Error	4.229	0
RMS Error	6.622	0
r squared	0.882	1

Figure 4.43 Correlation Statistics of Simulated and Observed Flows of Truckee River at Vista 1997-2004

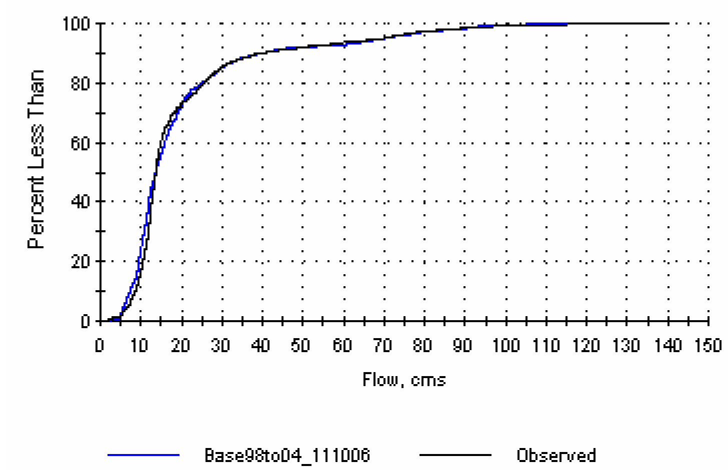


Figure 4.44 Frequency Distribution of Simulated and Observed Flow of Truckee River at Vista 1997-2004

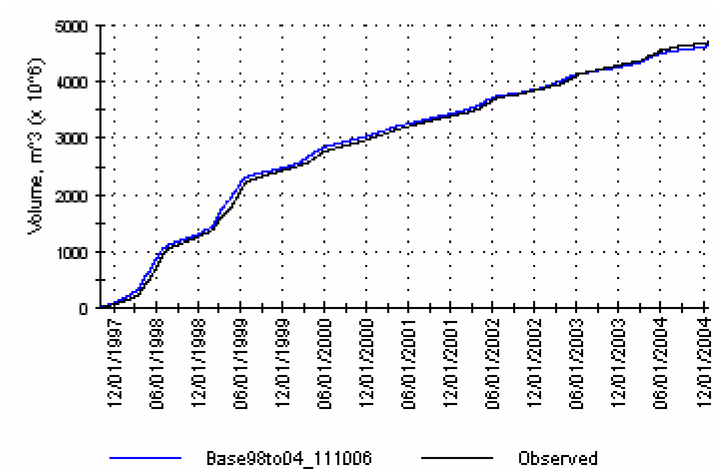


Figure 4.45 Cumulative Hydrograph for Simulated and Observed Flows of Truckee River at Vista 1997-2004

4.2.6 Hydrology Discussion

Results presented in the Hydrology Calibration/Verification section show that WARMF was able to predict flow for four relevant river and tributary locations during three separate time periods. Plotted output indicated a reasonable match of simulated flows with observed flows. For most locations and time periods, the calculated relative error was less than the desired +/- 10%. In general, cumulative flow predictions were very good for the 1997 to 2004 time period. For the 1985 to 1990 and 1990 to 1997 time periods, the cumulative flow tended to run a little high. An additional limitation with respect to North Truckee Drain is the limited data available for the two moderately sized point sources which discharge to North Truckee Drain. Because discharge records are very sparse, it is difficult to quantify the actually flow added from these point sources during much of the modeled time periods.

4.3 Water Quality Calibration

4.3.1 Calibration Parameters

The calibration of water quality is performed one constituent at a time. The calibration sequence of water quality constituents must follow a logical hierarchy. For example, biological oxygen demand (BOD), ammonia, and temperature can affect the dissolved oxygen concentration and are calibrated before dissolved oxygen.

Calibration parameters for water quality vary by constituent. For suspended sediment, they are the erosivity of soil on the ground and settling velocity of soil particles. For coliform bacteria, BOD, ammonia, nitrate, phosphorus and others, it is a matter of checking the input data for their point or nonpoint source loadings. After the accuracy of input loading is assured, the default values for rate coefficients are often used. The default values have been used in many model applications elsewhere. Minor adjustments may be made in fine-tuning of the model or as site specific values become available. All rate coefficients are accessible through WARMF's graphical user interface.

WARMF provides plots for time series, correlation statistics, frequency distribution, and cumulative curve of water quality constituents similar to those for stream flow. Since the water quality data is not as plentiful as flow data, often only the time series plots are used to compare observed and simulated water quality for river segments.

In the following sections, the simulated and observed water quality is compared for four river segments: Truckee River at Reno/Sparks, Steamboat Creek at Cleanwater Way, North Truckee Drain, and Truckee River at Vista. For each location, output is provided for the following constituents:

- Ammonia (NH_4-N)
- Nitrate (NO_3-N)
- Total Organic Nitrogen
- Total Kedjal Nitrogen
- Total Nitrogen
- Phosphate (PO_4-P)
- Total Phosphorus
- Disssolved Organic Carbon
- Total Organic Carbon
- Total Dissolved Solids

4.3.2 Truckee River at Reno / Sparks

4.3.2.1 Ammonia (NH_4-N)

Figures 4.46 through 4.48 show the simulated versus observed ammonia for Truckee River at Reno/Sparks for the three calibration/verification time periods. Nearly all of the observed ammonia data show low concentrations of less than 0.1 mg/L. WARMF successfully modeled ammonia concentrations near observed levels. One exception is the spring of 1986 (Figure 4.46) where measured ammonia concentrations were recorded near 0.3 mg/L, however, upstream (Truckee River at Mogul), ammonia concentrations were measured to be much lower (~0.005 mg/L) during this time period. It is suspected that a local extreme event, either due to urban runoff or a point source discharge caused this spike in ammonia. Due to lack of detailed data, to characterize the source, WARMF was unable to predict this ammonia peak. Note, for several time periods the ammonia concentration was measured at the detection limit (indicated by a straight line of data points). For this situation, it is acceptable that WARMF simulated a concentration less than the detection limit.

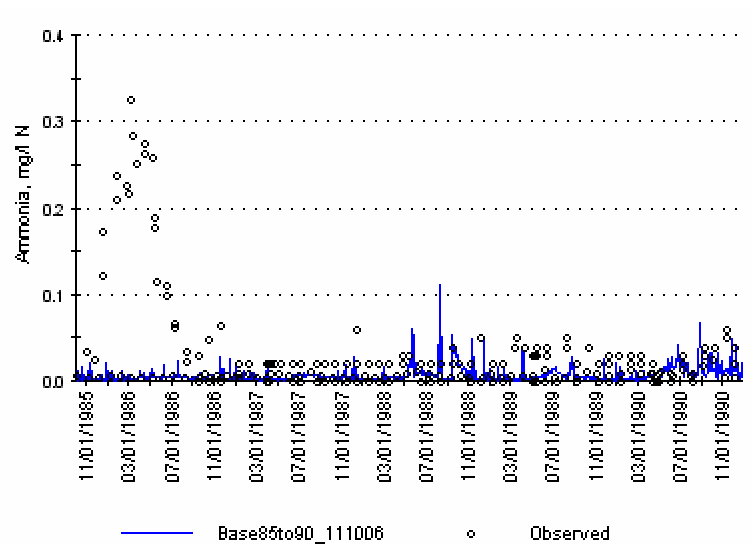


Figure 4.46 Simulated and Observed Ammonia Concentration in Truckee River at Reno/Sparks 1985-1990

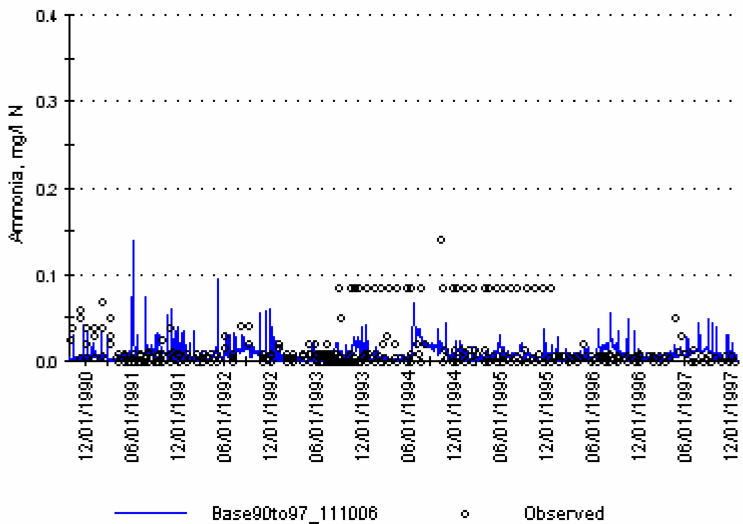


Figure 4.47 Simulated and Observed Ammonia Concentration in Truckee River at Reno/Sparks 1990-1997

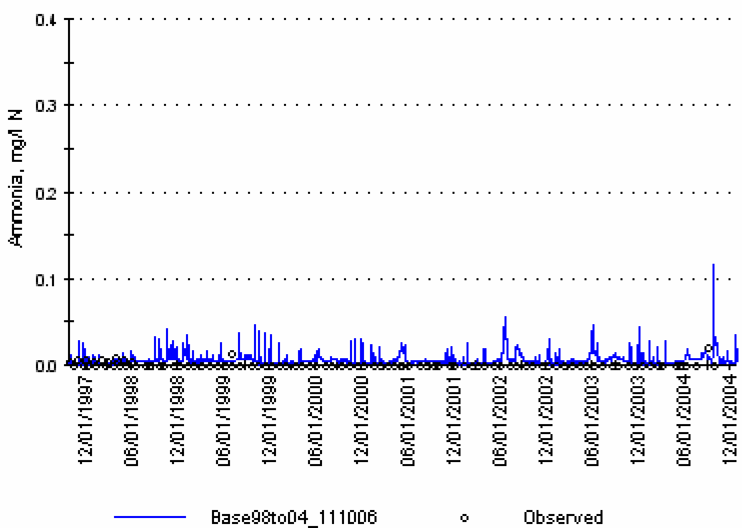


Figure 4.48 Simulated and Observed Ammonia Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.2 Nitrate (NO_3-N)

Figures 4.49 through 4.51 show the simulated versus observed nitrate for Truckee River at Reno/Sparks for the three calibration/verification time periods. Observed nitrate concentrations for this location were recorded to be between 0 and 0.2 mg/L for most time periods. Several higher peaks, up to approximately 0.5 mg/L were also recorded. WARMF predicted nitrate concentrations within the measured range. WARMF also typically predicted a seasonal peak in the spring during the runoff period. This matched well with observed peaks for several years (e.g. spring 1995, 1996, and 1997 in Figure 4.50, and spring 2000 and 2003 in Figure 4.51). Some of the localized peaks that were not matched may have been due to local runoff events from the Reno area or point source discharges. As with ammonia, a lack of detailed data to characterize these sources limited WARMF's ability to predict the measured concentrations exactly.

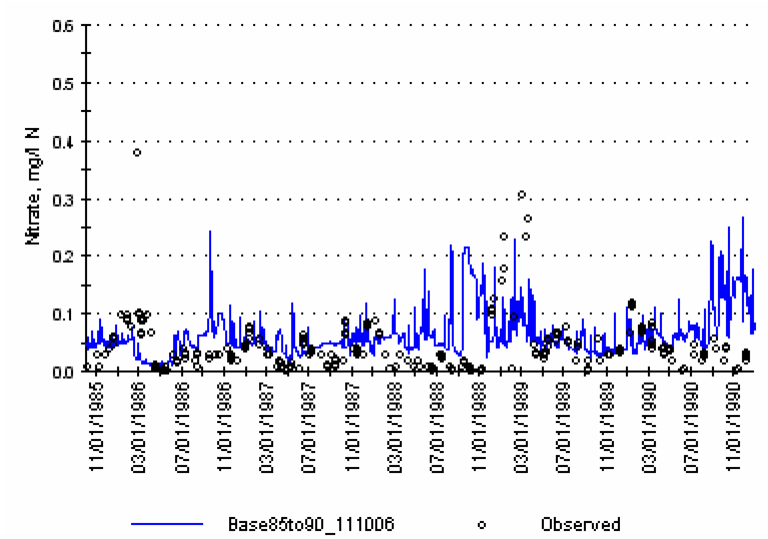


Figure 4.49 Simulated and Observed Nitrate Concentration in Truckee River at Reno/Sparks 1985-1990

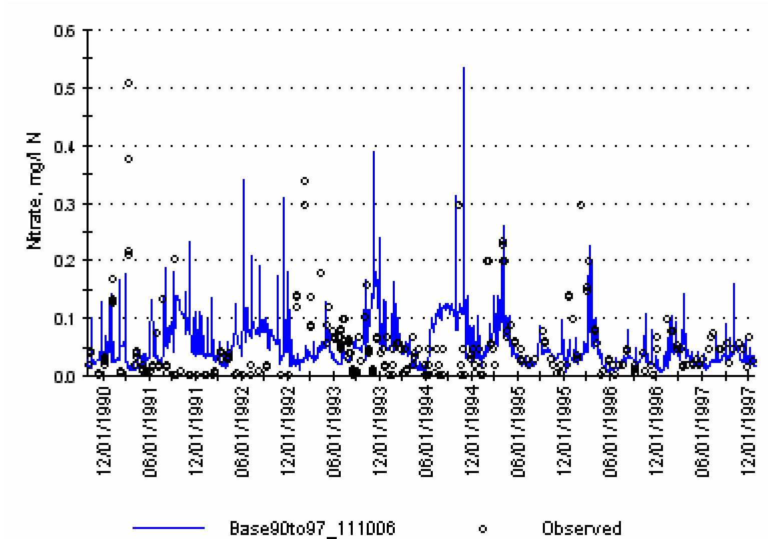


Figure 4.50 Simulated and Observed Nitrate Concentration in Truckee River at Reno/Sparks 1990-1997

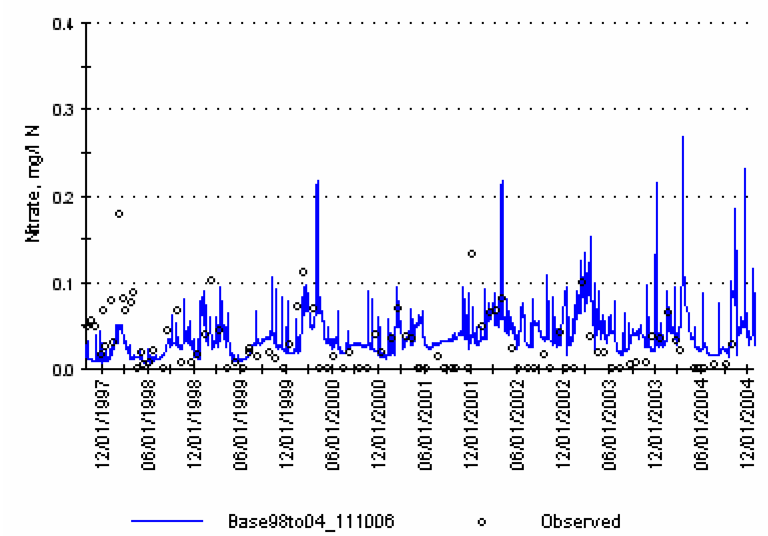


Figure 4.51 Simulated and Observed Nitrate Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.3 Total Organic Nitrogen (TON)

Simulated and observed concentrations of total organic nitrogen are shown in Figures 4.52 to 5.54 for Truckee River at Reno/Sparks for all 3 time periods. Total organic nitrogen includes all organic components of total nitrogen including nitrogen tied up in algae and nitrogen tied up in dissolved and adsorbed organic carbon. It excludes inorganic ammonia, nitrite and nitrate nitrogen. Measured TON concentrations at Reno/Sparks typically range from 0 to 0.4 mg/L with measured peaks as high as 1 to 1.3 mg/L. WARMF generally predicts TON within the measured range. The best prediction of TON peaks is shown during the 1990 to 1997 time period. Due to the high degree of scatter with observed data, it is not possible for WARMF to match every observed data point.

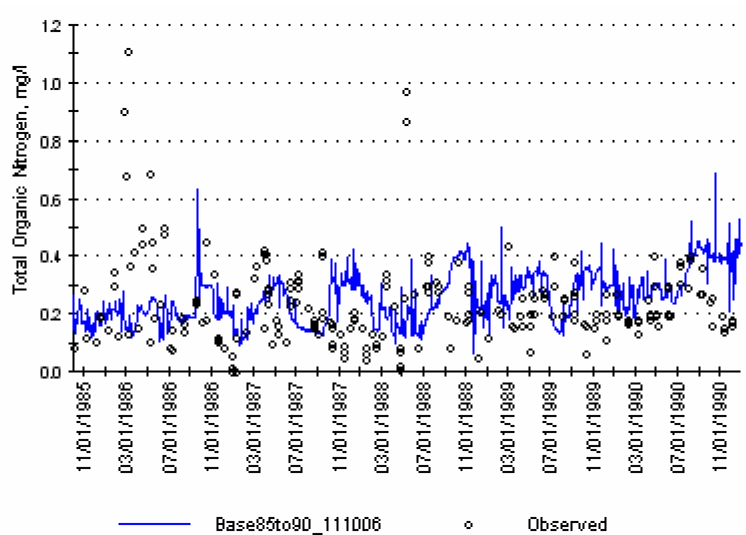


Figure 4.52 Simulated and Observed Total Organic Nitrogen Concentration in Truckee River at Reno/Sparks 1985-1990

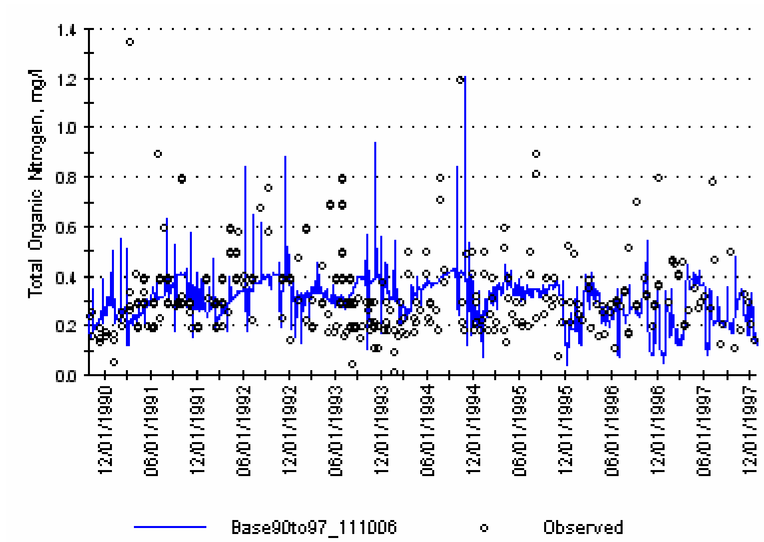


Figure 4.53 Simulated and Observed Total Organic Nitrogen Concentration in Truckee River at Reno/Sparks 1990-1997

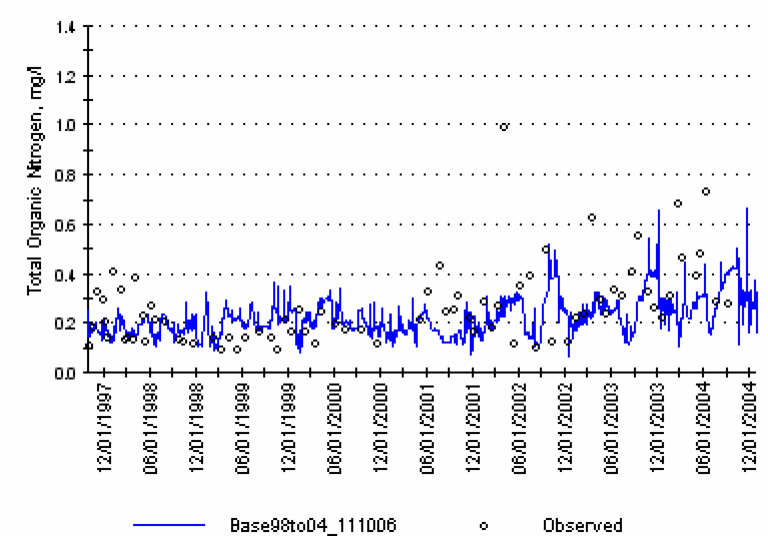


Figure 4.54 Simulated and Observed Total Organic Nitrogen Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.4 Total Kjeldahl Nitrogen (TKN)

Simulated and observed total kjeldahl nitrogen (TKN) concentrations for Truckee River at Reno/Sparks are shown in Figures 4.55 to 4.57. TKN includes ammonia, adsorbed ammonia, and organic nitrogen, but TKN does not include nitrite and nitrate nitrogen. Measured TKN values for this location typically range from 0 to 0.6 mg/L. A few peaks as high as 1.4 mg/L were also recorded. WARMF predicted the pattern and range of TKN quite well for all time periods. One exception was the peak of TKN that was recorded for spring of 1986 (Figure 4.55) which WARMF did not capture. This corresponds to the localized peak of observed ammonia in Figure 4.46.

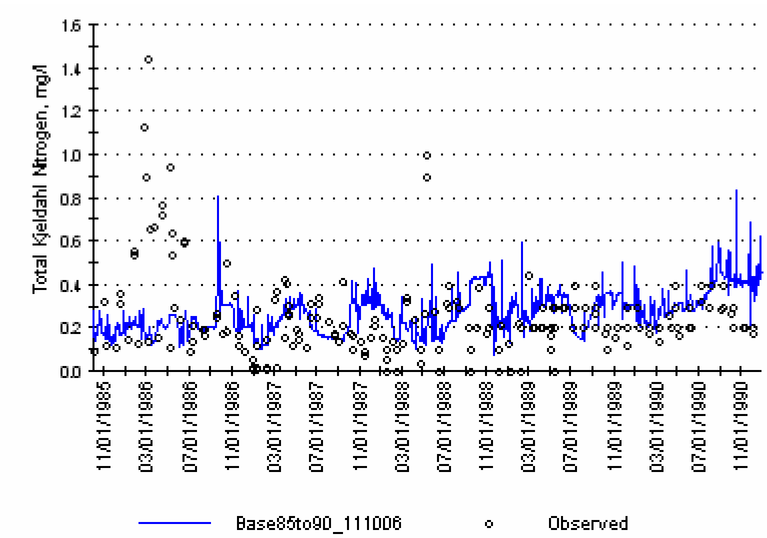


Figure 4.55 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Truckee River at Reno/Sparks 1985-1990

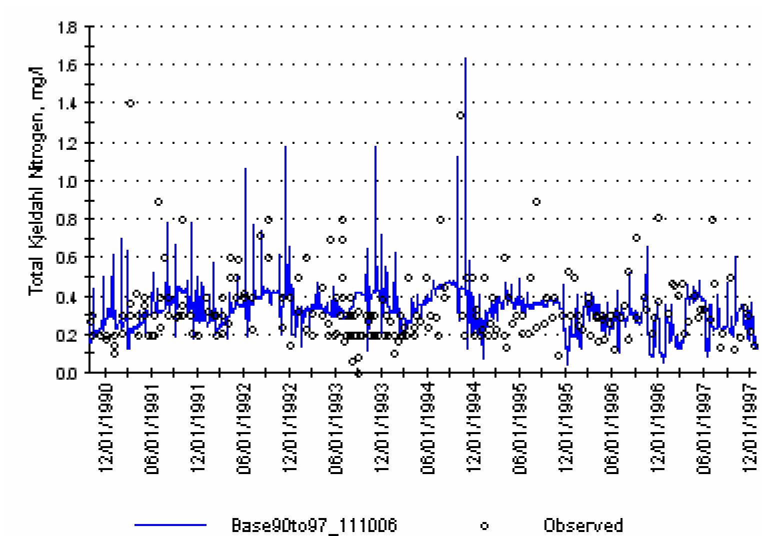


Figure 4.56 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Truckee River at Reno/Sparks 1990-1997

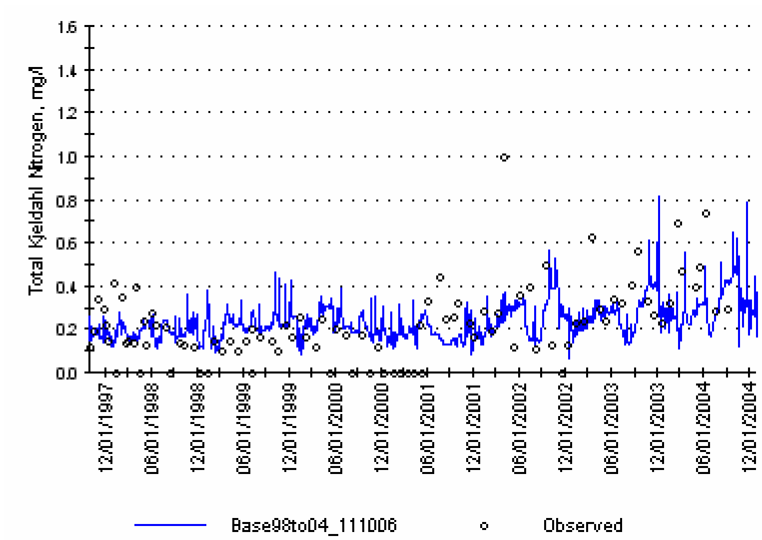


Figure 4.57 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.5 Total Nitrogen (TN)

Total nitrogen includes all species of nitrogen (inorganic and organic, dissolved and particulate). Figure 4.58 to 4.60 show simulated and observed TN for Truckee River at Reno/Sparks for the three calibration/verification time periods. WARMF predicted well TN concentrations within the measured range of approximately 0 to 1.0 mg/L. During the 1990 to 1997 time period, WARMF predictions of peak and dip TN concentrations were matched quite well. Due to the high scatter of measured TN data, WARMF is unable to match every peak or dip that was measured. As with ammonia and TKN, the localized peak during the spring of 1986 was not captured by WARMF.

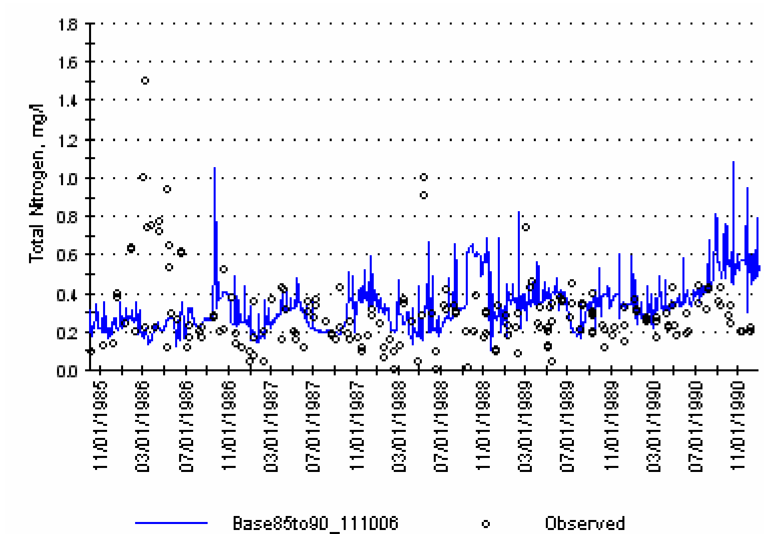


Figure 4.58 Simulated and Observed Total Nitrogen Concentration in Truckee River at Reno/Sparks 1985-1990

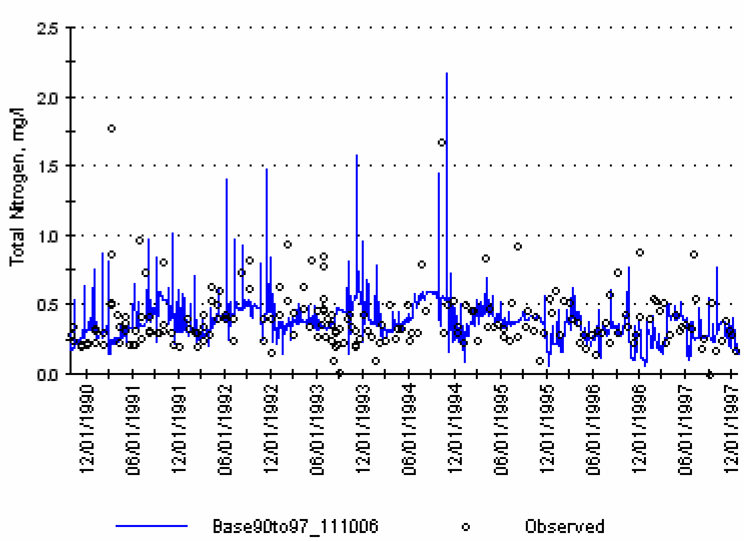


Figure 4.59 Simulated and Observed Total Nitrogen Concentration in Truckee River at Reno/Sparks 1990-1997

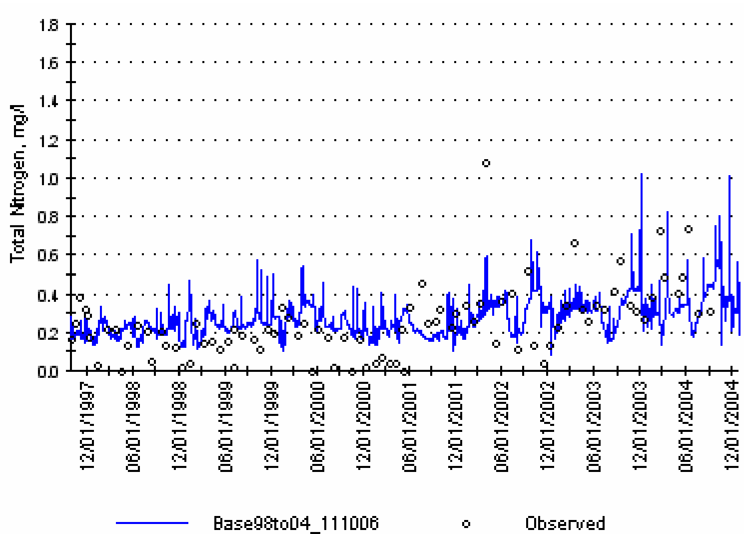


Figure 4.60 Simulated and Observed Total Nitrogen Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.6 Phosphate (PO_4-P)

Figure 4.61 through 4.63 show simulated and observed phosphate concentrations for Truckee River at Reno/Sparks for all three simulation periods. Phosphate is the dissolved form of inorganic phosphorus. Most measured phosphate values range between 0 and 0.04 mg/L at this location. WARMF predicts the baseflow concentration of phosphate to be close to observed levels. Several observed peaks were measured to be as high as 0.2 mg/L. WARMF as well predicted peaks of phosphate in this range though the peaks did not always correspond directly with observed values. Peaks of phosphate are likely due to adsorbed phosphorus becoming desorbed when it reaches the stream with a lower phosphate concentration. During the spring of 1986, a peak of phosphate was observed but not simulated. This likely corresponds to the unquantified peak of ammonia that was also measured during this time period.

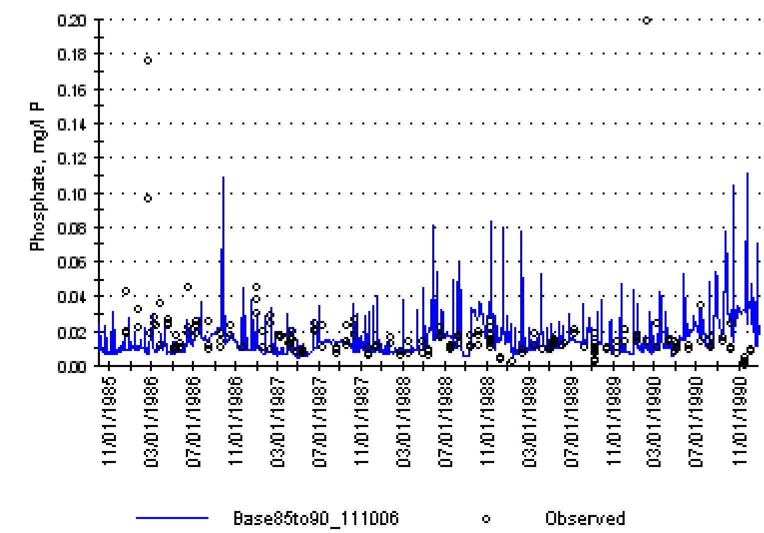


Figure 4.61 Simulated and Observed Phosphate Concentration in Truckee River at Reno/Sparks 1985-1990

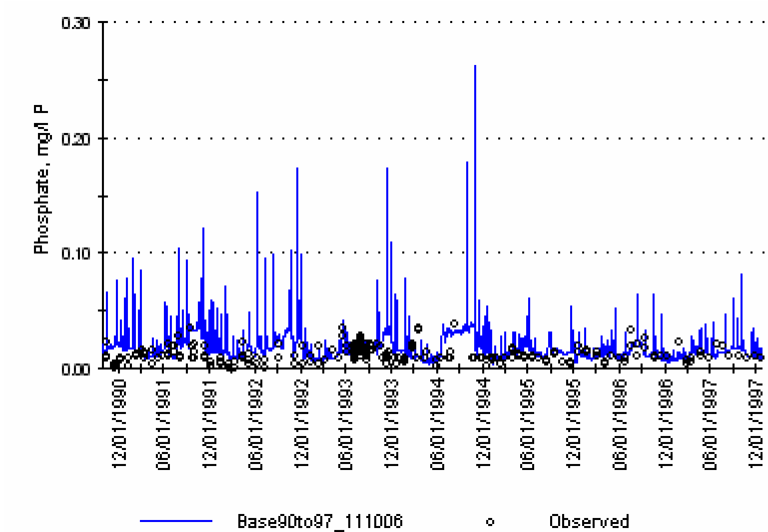


Figure 4.62 Simulated and Observed Phosphate Concentration in Truckee River at Reno/Sparks 1990-1997

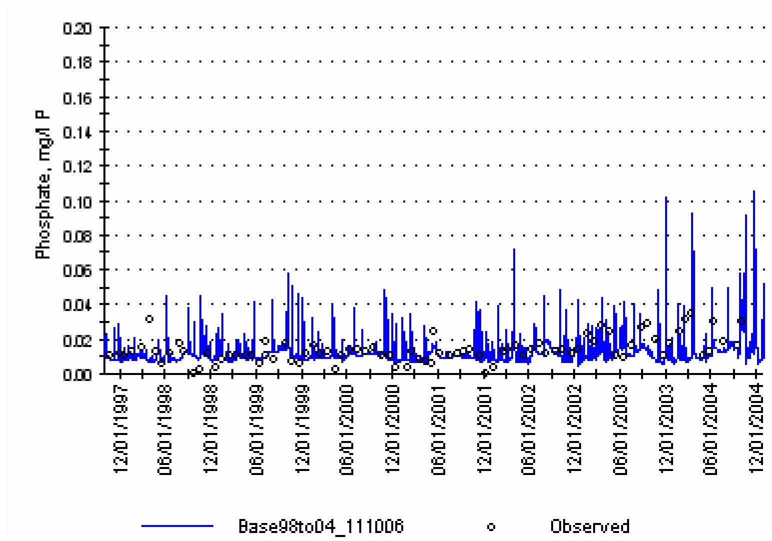


Figure 4.63 Simulated and Observed Phosphate Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.7 Total Phosphorus (TP)

Figures 4.64 to 4.66 show simulated and observed total phosphorus for Truckee River at Reno / Sparks. Total phosphorus includes inorganic dissolved phosphate as well as the other organic and adsorbed forms of phosphorus. For all three simulation periods, WARMF simulated TP well within the observed baseflow range of approximately 0 to 0.05 mg/L. During runoff periods, higher peaks of TP are seen due to sediment carrying adsorbed phosphorus. WARMF simulated TP peaks within the range of observed values.

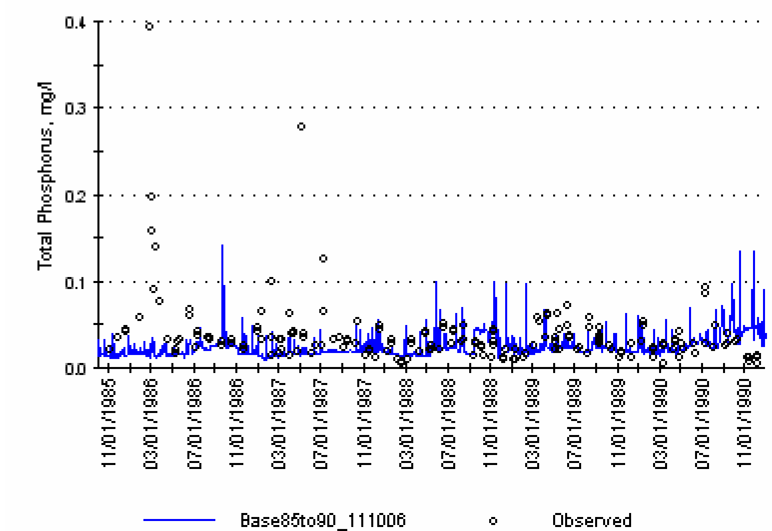


Figure 4.64 Simulated and Observed Total Phosphorus Concentration in Truckee River at Reno/Sparks 1985-1990

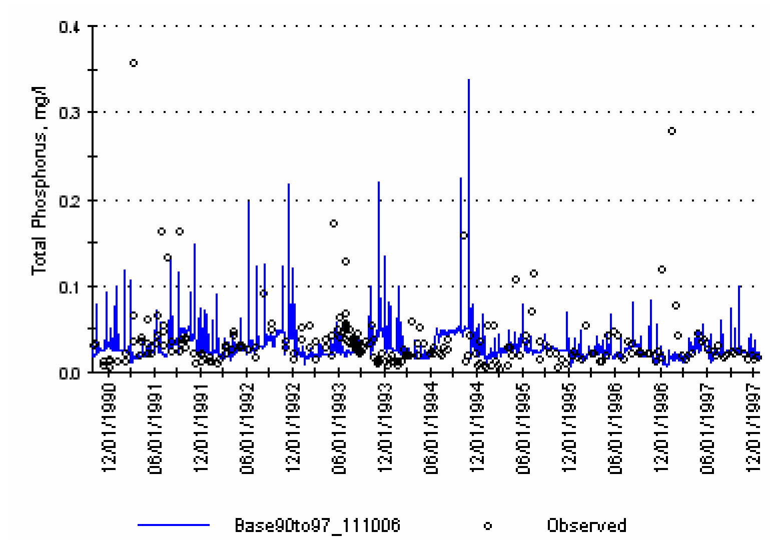


Figure 4.65 Simulated and Observed Total Phosphorus Concentration in Truckee River at Reno/Sparks 1990-1997

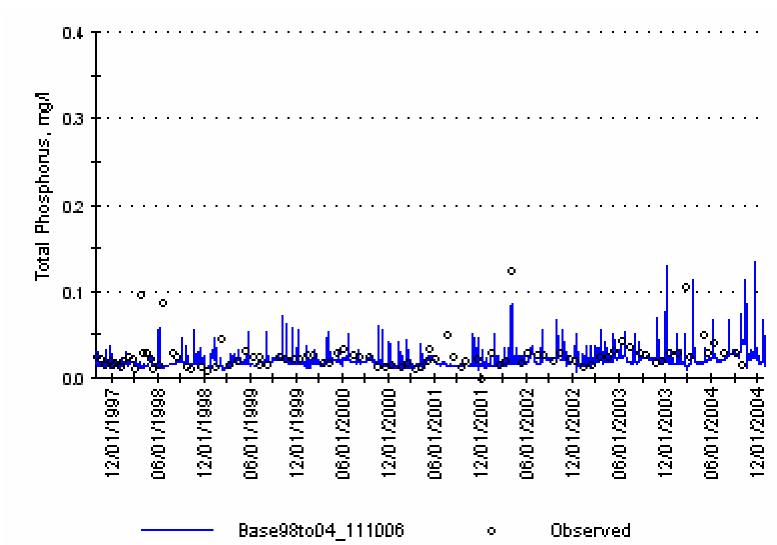


Figure 4.66 Simulated and Observed Total Phosphorus Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.8 Dissolved Organic Carbon (DOC)

Simulated and observed dissolved organic carbon for Truckee River at Reno/Sparks are shown in Figures 4.67 to 4.69. For all three time periods, WARMF simulates well the range and pattern of observed DOC between roughly 0 and 3 mg/L. During the 1990 to 1997 time period, several higher peaks of DOC between 5 and 11 mg/L were measured. WARMF predicted some higher peaks during this period though the timing and magnitude did not perfectly match observed.

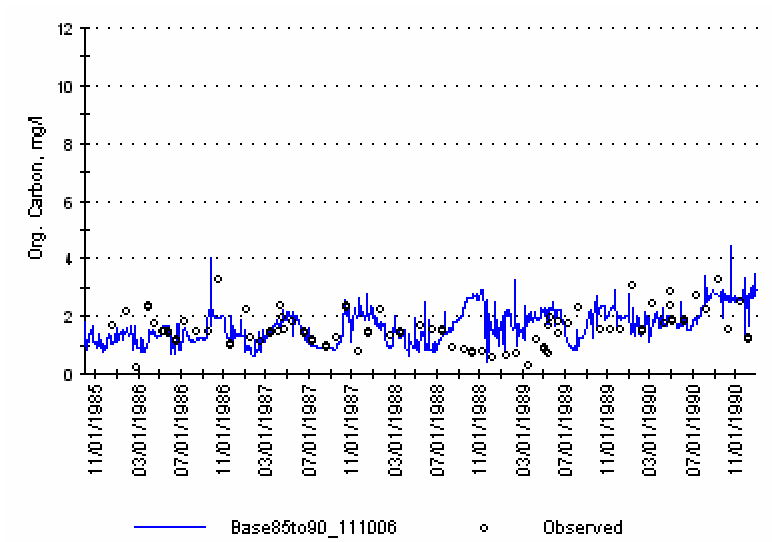


Figure 4.67 Simulated and Observed Dissolved Organic Carbon Concentration in Truckee River at Reno/Sparks 1985-1990

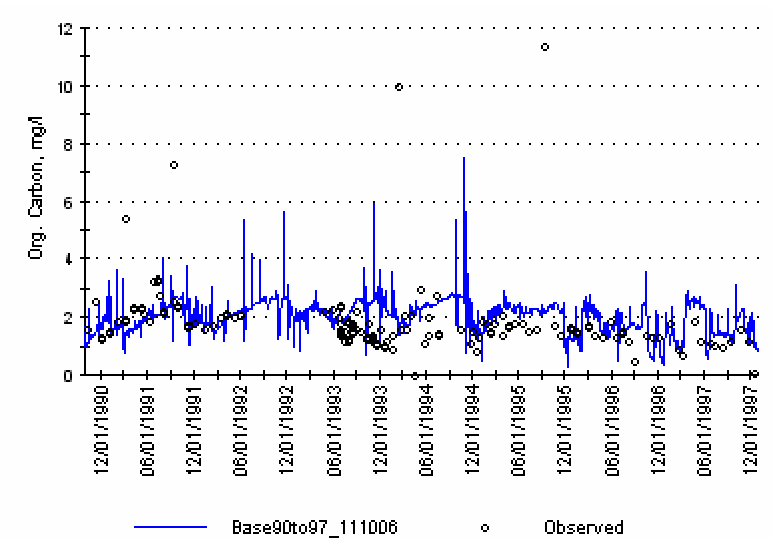


Figure 4.68 Simulated and Observed Dissolved Organic Carbon Concentration in Truckee River at Reno/Sparks 1990-1997

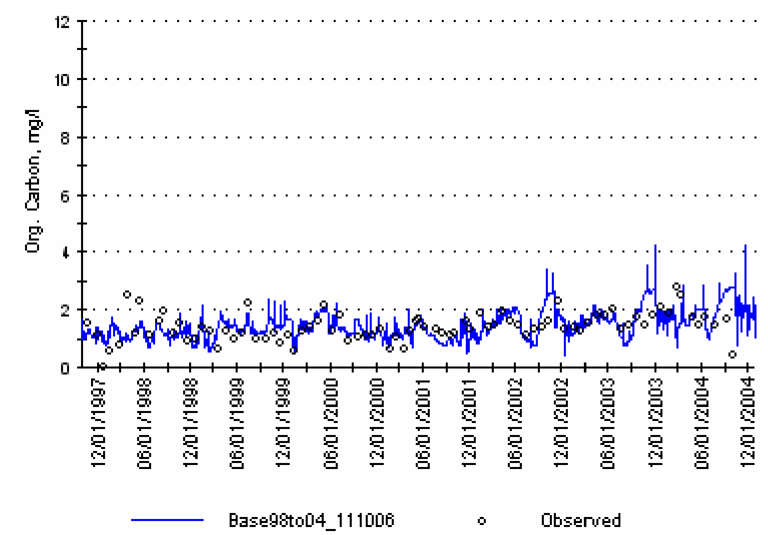


Figure 4.69 Simulated and Observed Dissolved Organic Carbon Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.9 Total Organic Carbon (TOC)

Figures 4.70 to 4.72 show simulated and observed Total Organic Carbon concentrations for Truckee River at Reno/Sparks. TOC concentrations tend to be higher than DOC concentrations because TOC includes the particulate organic carbon as well as dissolved. Observed TOC data are more sparse than DOC for this location. WARMF simulated DOC compares well with observed concentrations. Several large peaks measured in 1987 (Figure 4.70) were not simulated by the model and are likely due to a local runoff or point source event that was not characterized due to lack of data. Note also, that no TOC data was measured for this location during 1997 to 2004, therefore Figure 4.72 shows only simulated results.

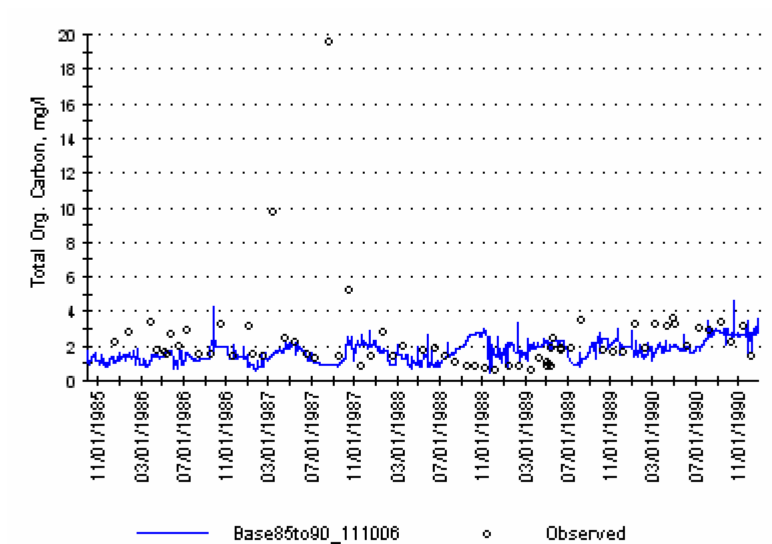


Figure 4.70 Simulated and Observed Total Organic Carbon Concentration in Truckee River at Reno/Sparks 1985-1990

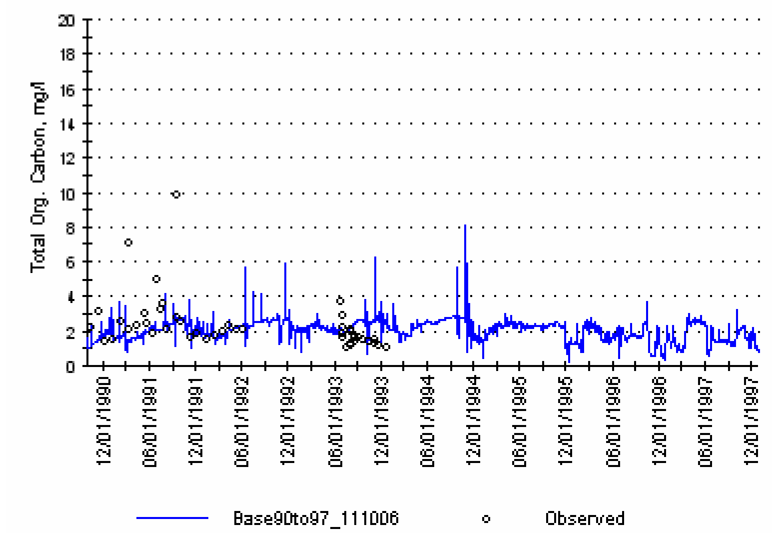


Figure 4.71 Simulated and Observed Total Organic Carbon Concentration in Truckee River at Reno/Sparks 1990-1997

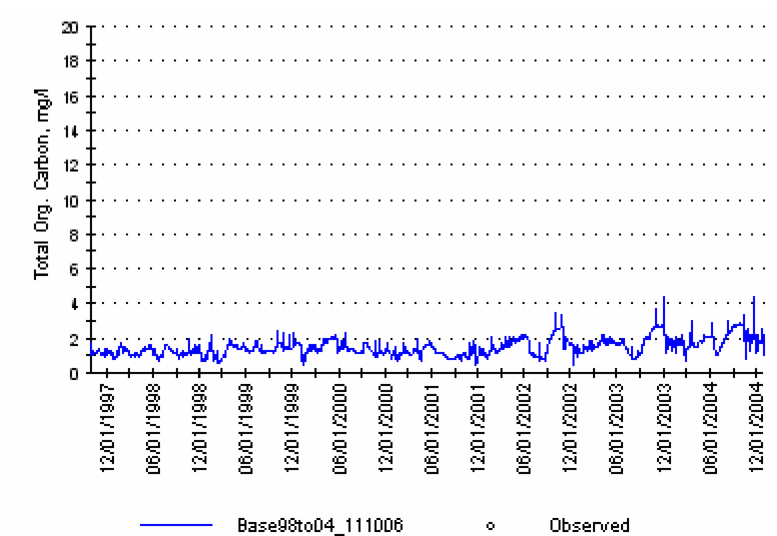


Figure 4.72 Simulated Total Organic Carbon Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.2.10 Total Dissolved Solids (TDS)

Figures 4.73 to 4.75 shows simulated and observed total dissolved solids for Truckee River at Reno/Sparks. In WARMF, cations and anions are modeled as individual species and TDS is calculated as a sum of all cations and anions. Most cations and anions are picked up by water as it passes through the soil layers. For all three time periods, WARMF simulates the range of observed TDS well. For many years, an increase in TDS is observed during the winter months when subsurface flow is higher and a decrease in TDS is observed during the summer months when baseflow is at a minimum. This seasonal pattern is simulated well by WARMF is most evident during the 1990 to 1997 time period (Figure 4.74). Also to note in this figure is that during the wetter years (e.g. 1995 through 1997), simulated and observed TDS is much lower than during drier years (e.g. 1991 through 1994). This is because during the wetter years, there is a greater amount of overland flow which does not pass through the soil and have the opportunity to pick up cations and anions.

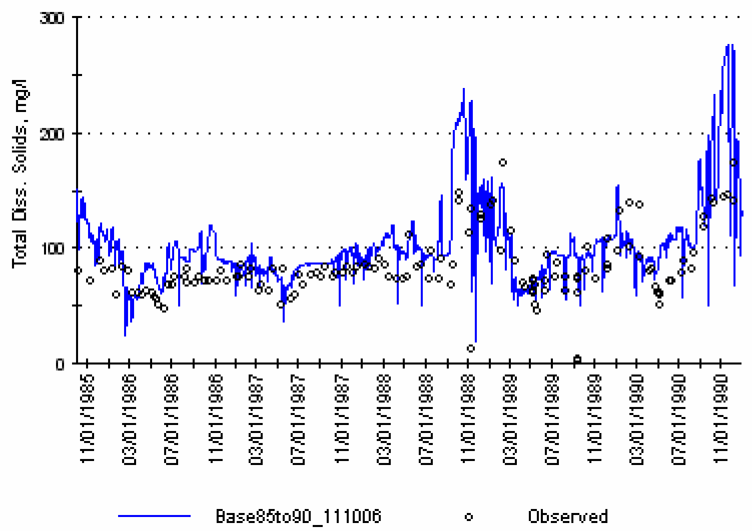


Figure 4.73 Simulated and Observed Total Dissolved Solids Concentration in Truckee River at Reno/Sparks 1985-1990

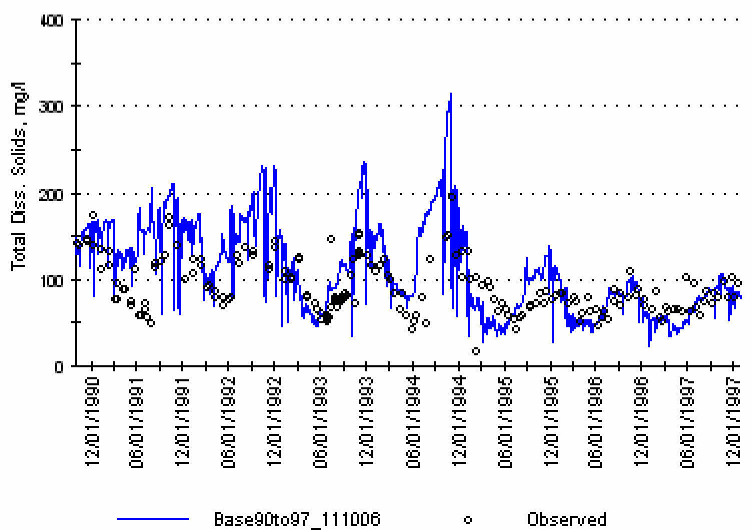


Figure 4.74 Simulated and Observed Total Dissolved Solids Concentration in Truckee River at Reno/Sparks 1990-1997

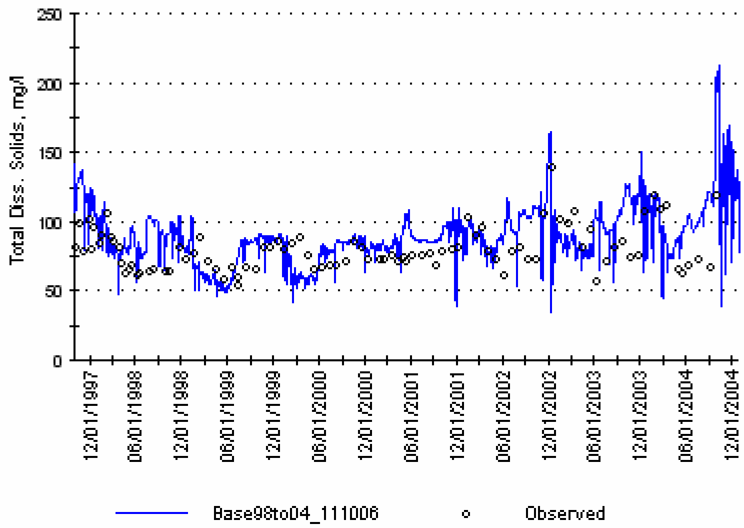


Figure 4.75 Simulated and Observed Total Dissolved Solids Concentration in Truckee River at Reno/Sparks 1997-2004

4.3.3 Steamboat Creek at Cleanwater Way

4.3.3.1 Ammonia (NH_4-N)

Figures 4.76 to 4.78 show simulated and observed results for ammonia concentration in Steamboat Creek at Cleanwater Way for all three simulation time periods. Measured ammonia concentrations generally range between 0 and 0.2 mg/L with occasional peaks up to 0.5 mg/L. WARMF simulates a seasonal pattern of increased ammonia during the spring runoff period (peaking in roughly March). For most years, observed data showed this same pattern though sometimes the measured ammonia concentration data were too scattered to discern a pattern. During the 1990-1997 time period detection limit ammonia concentrations were reported (indicated by a straight line of points). During these time periods, it is acceptable that WARMF simulates an ammonia concentration less than detection limit.

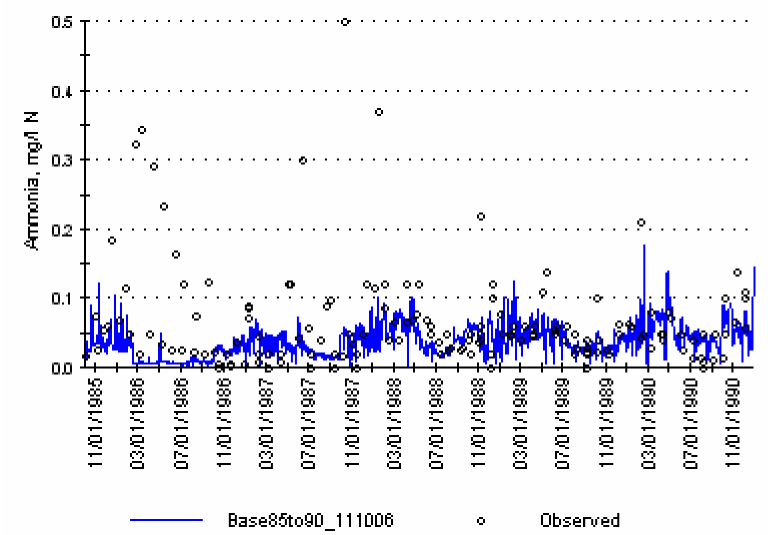


Figure 4.76 Simulated and Observed Ammonia Concentration in Steamboat Creek at Cleanwater Way 1985-1990

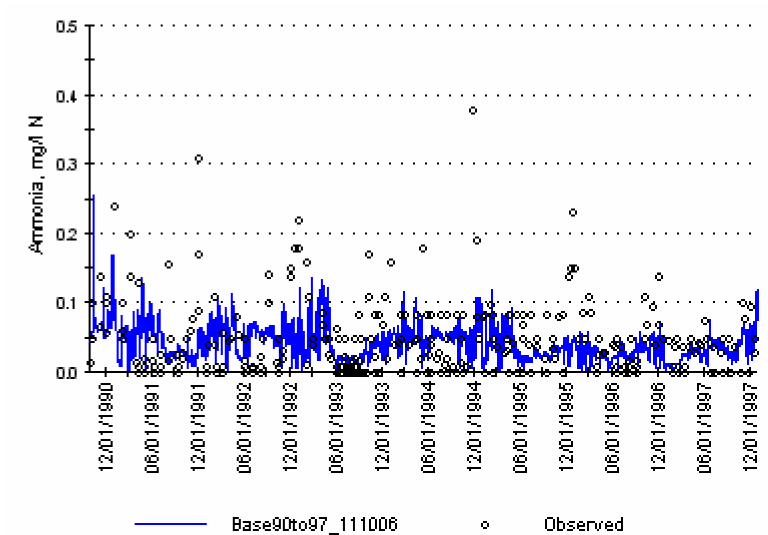


Figure 4.77 Simulated and Observed Ammonia Concentration in Steamboat Creek at Cleanwater Way 1990-1997

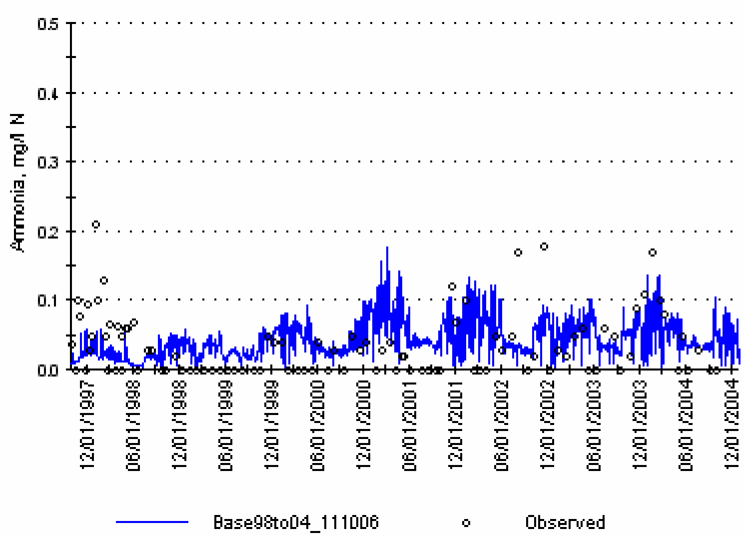


Figure 4.78 Simulated and Observed Ammonia Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.2 Nitrate (NO_3-N)

Simulated and observed nitrate concentrations for Steamboat Creek at Cleanwater Way are shown in Figures 4.79 to 4.81. Observed nitrate concentrations typically range between 0 and 1 mg/L and follow a distinct seasonal pattern of higher nitrate during the spring runoff and lower nitrate during the drier fall periods. Simulated nitrate follows this pattern as well, though not always at the exact magnitude for maximum and minimum values. The match with observed data seems to be most accurate during drier simulations years (e.g. 1989-1990, 1992-1994, 2001-2004) with not as good of a match seen during the wetter water years.

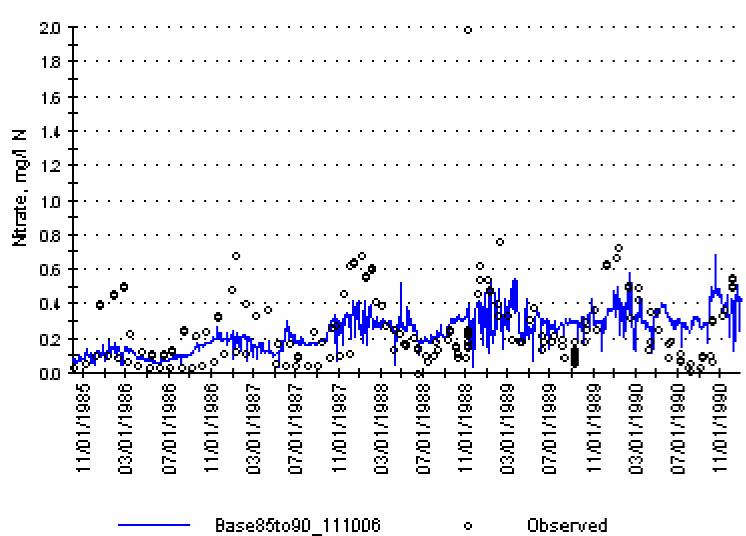


Figure 4.79 Simulated and Observed Nitrate Concentration in Steamboat Creek at Cleanwater Way 1985-1990

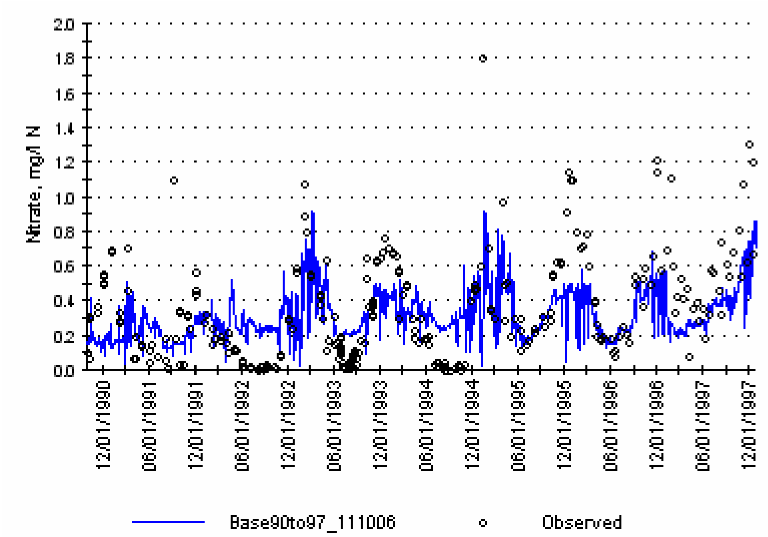


Figure 4.80 Simulated and Observed Nitrate Concentration in Steamboat Creek at Cleanwater Way 1990-1997

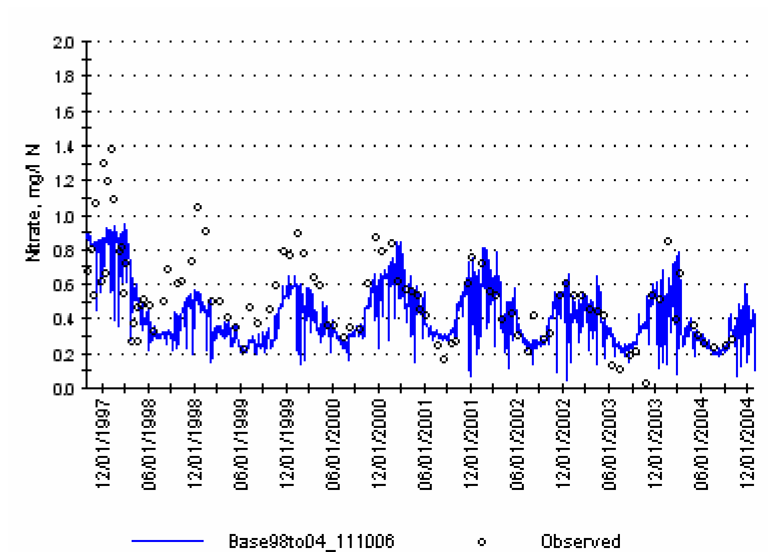


Figure 4.81 Simulated and Observed Nitrate Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.3 Total Organic Nitrogen (TON)

Figures 4.82 to 4.84 show simulated and observed total organic carbon for Steamboat Creek at Cleanwater Way. Observed data tends to have a high degree of scatter and indicates typical TON concentrations to range from 0.25 to 1.5 mg/L at this location. WARMF predicts TON concentrations within the range of observed values for all three time periods. One exception is during the spring of 1995 (a wet year) where WARMF under predicted an observed peak of TON between 2 and 2.5 mg/L (Figure 4.83).

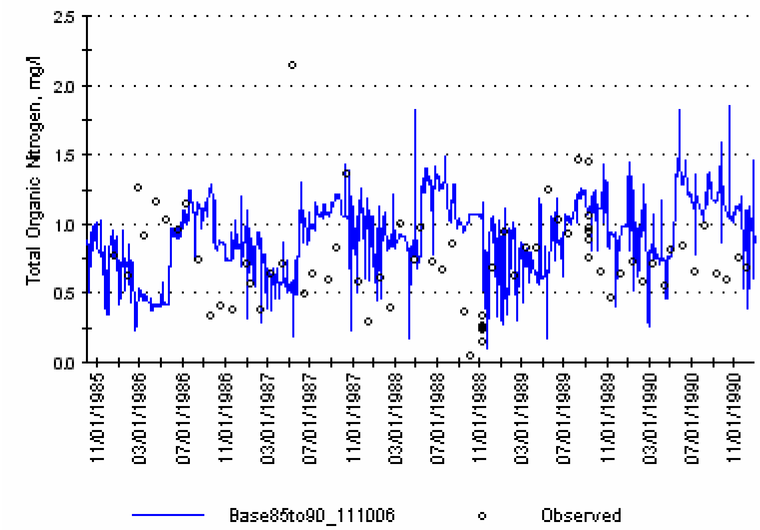


Figure 4.82 Simulated and Observed Total Organic Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1985-1990

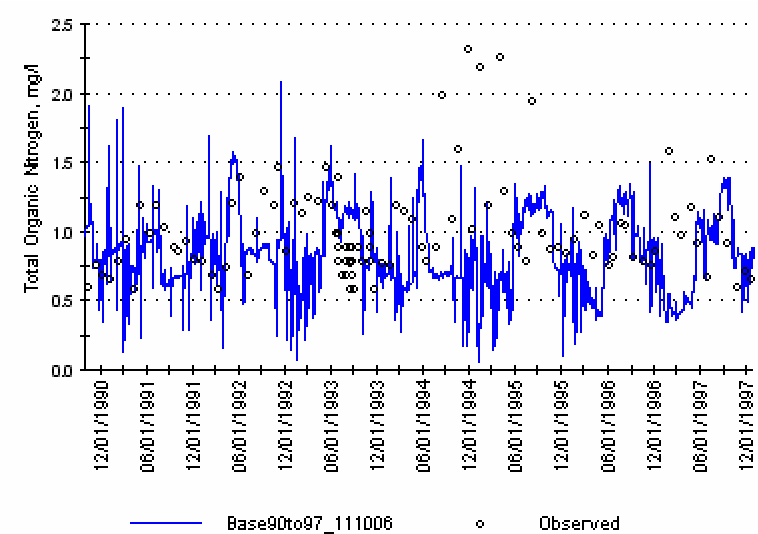


Figure 4.83 Simulated and Observed Total Organic Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1990-1997

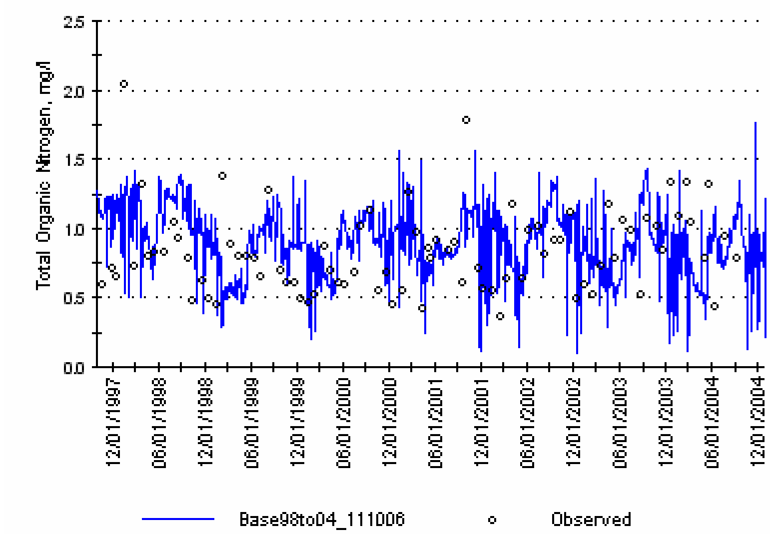


Figure 4.84 Simulated and Observed Total Organic Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.4 Total Kjeldahl Nitrogen (TKN)

Simulated and observed total kjeldahl nitrogen for Steamboat Creek at Cleanwater Way is shown in figures 4.85 to 4.87. Observed TKN values typically range from 0 to 1.5 mg/L with occasional peaks as great as 2.5 mg/L. WARMF predicts TKN within the range of observed for all three time periods. The closest match is seen for the 1997 to 2004 time period (Figure 4.87). As with TON, WARMF under predicted an observed TKN peak during the wet spring of 1995 (Figure 4.86).

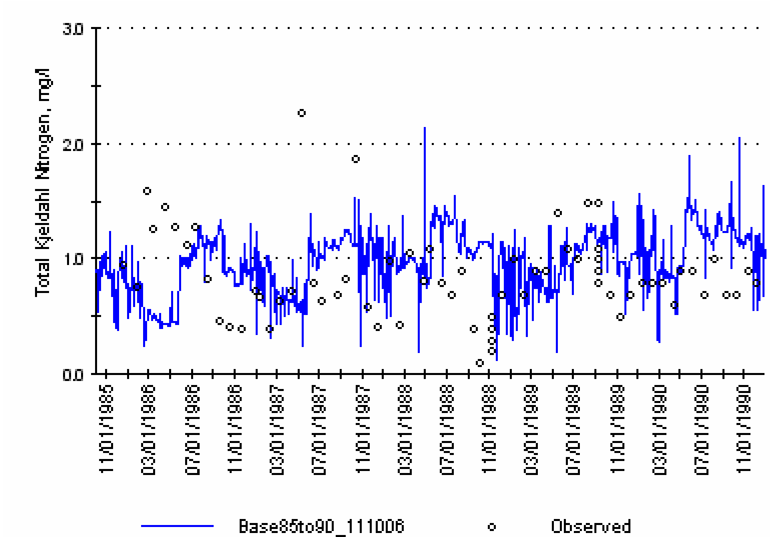


Figure 4.85 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1985-1990

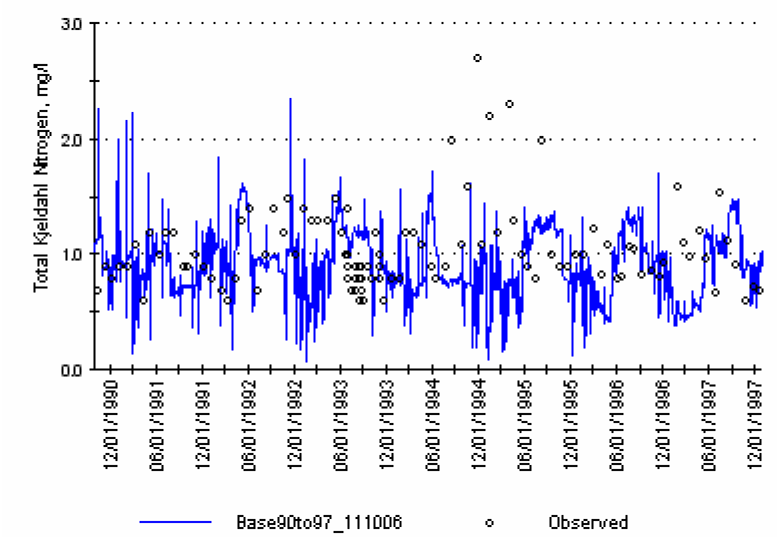


Figure 4.86 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1990-1997

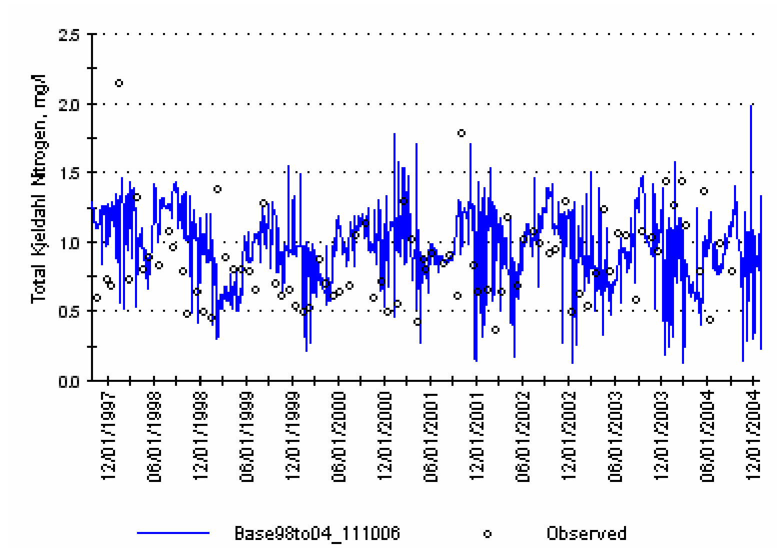


Figure 4.87 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.5 Total Nitrogen (TN)

Figures 4.88 to 4.90 show simulated and observed total nitrogen concentrations for Steamboat Creek at Cleanwater Way. Most observed concentrations fall between 0.5 and 2.5 mg/L. Occasional peaks as greater than 3 mg/L were also recorded. The closest match of simulated to observed is seen for 1997 to 2004 (Figure 4.90). During this time period, a seasonal pattern of total nitrogen (higher in the winter and lower in the summer) is also noted.

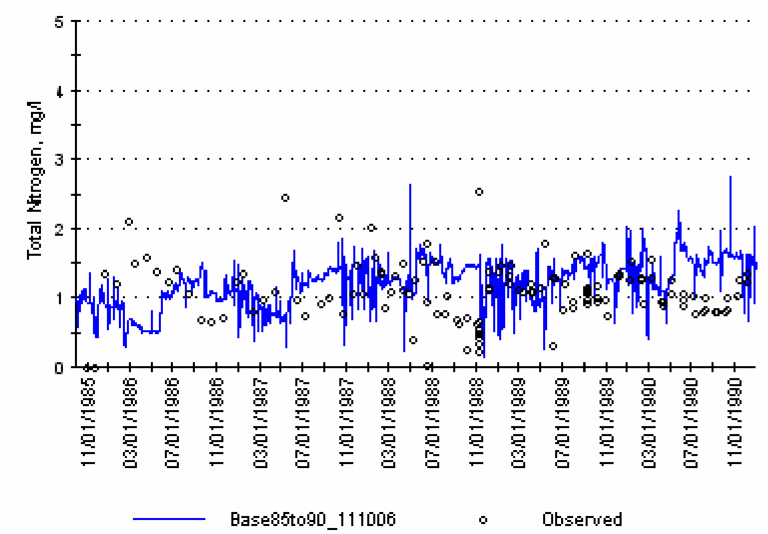


Figure 4.88 Simulated and Observed Total Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1985-1990

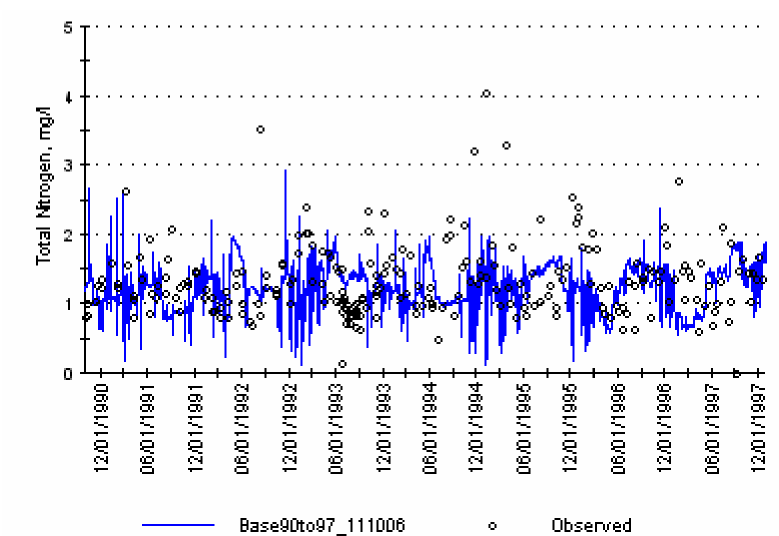


Figure 4.89 Simulated and Observed Total Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1990-1997

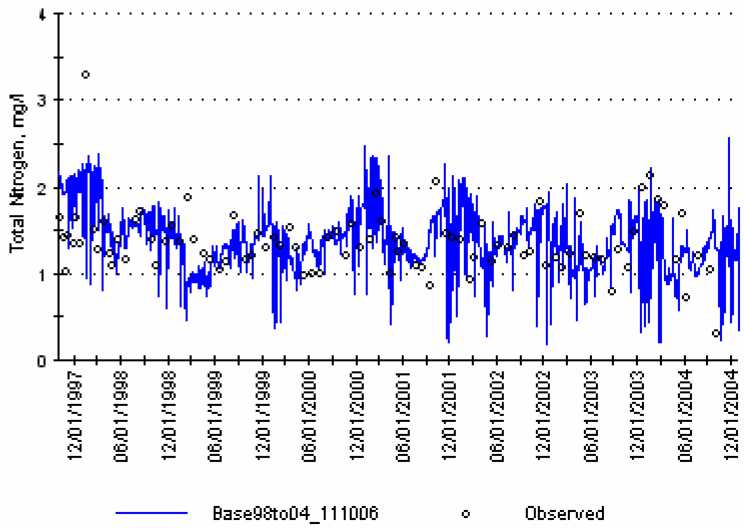


Figure 4.90 Simulated and Observed Total Nitrogen Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.6 Phosphate (PO_4-P)

Simulated and observed phosphate concentrations in Steamboat Creek at Cleanwater Way are shown in figures 4.91 to 4.93. Observed phosphate concentrations range from 0.05 mg/L to 0.3 mg/L. WARMF predictions fall within this range. The wetter years (e.g. 1986, 1996, 1997, 1999) appear to show the best match of simulated with observed data.

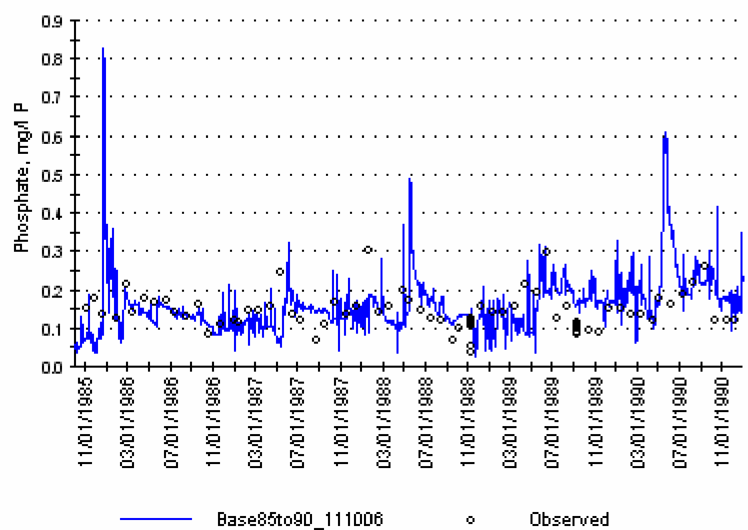


Figure 4.91 Simulated and Observed Phosphate Concentration in Steamboat Creek at Cleanwater Way 1985-1990

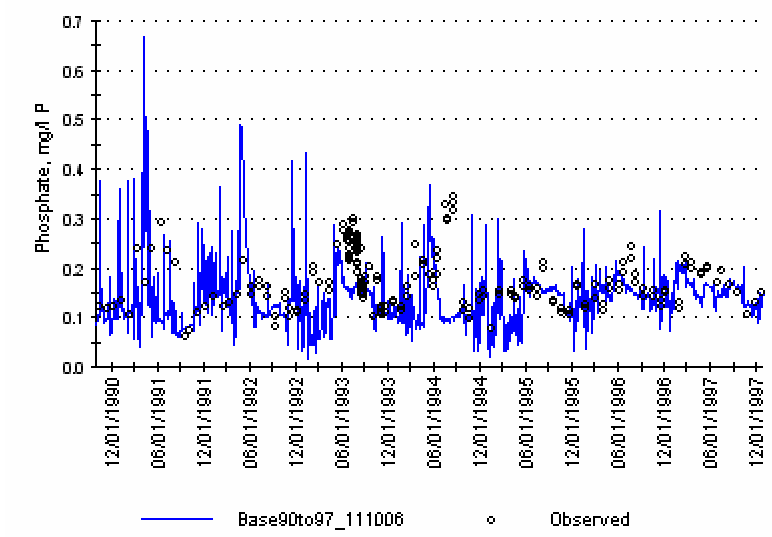


Figure 4.92 Simulated and Observed Phosphate Concentration in Steamboat Creek at Cleanwater Way 1990-1997

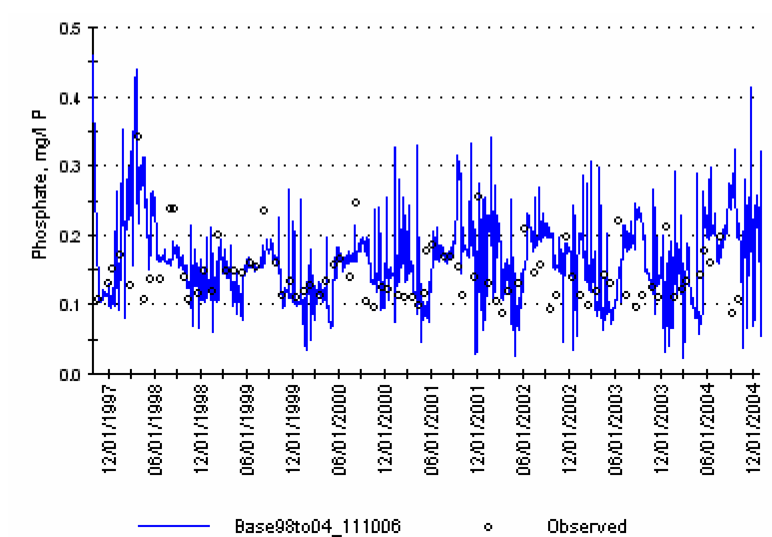


Figure 4.93 Simulated and Observed Phosphate Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.7 Total Phosphorus (TP)

Figures 4.94 to 4.96 show simulated and observed total phosphorus concentrations for Steamboat Creek at Cleanwater Way. Measured TP concentrations typically range from 0.15 mg/L to 0.5 mg/L. One higher peak of 0.8 mg/L was recorded during the spring of 1998. Though WARMF did not capture this particular peak, simulated predictions of TP correspond well with observed concentrations.

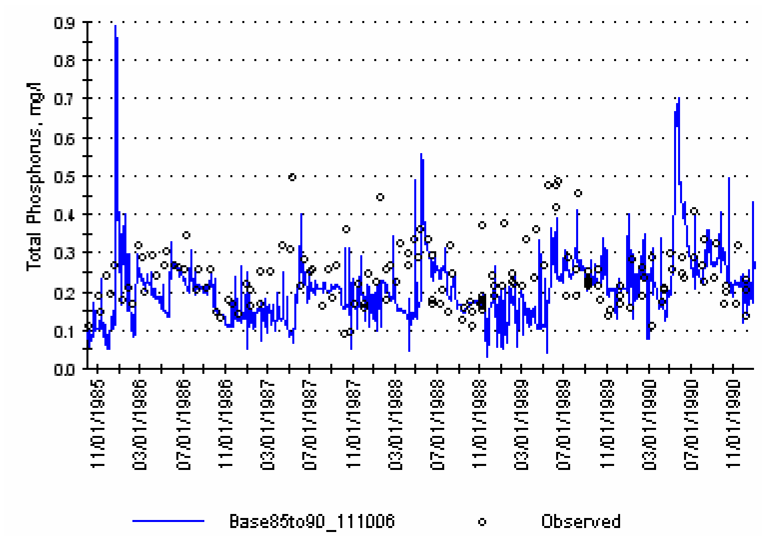


Figure 4.94 Simulated and Observed Total Phosphorus Concentration in Steamboat Creek at Cleanwater Way 1985-1990

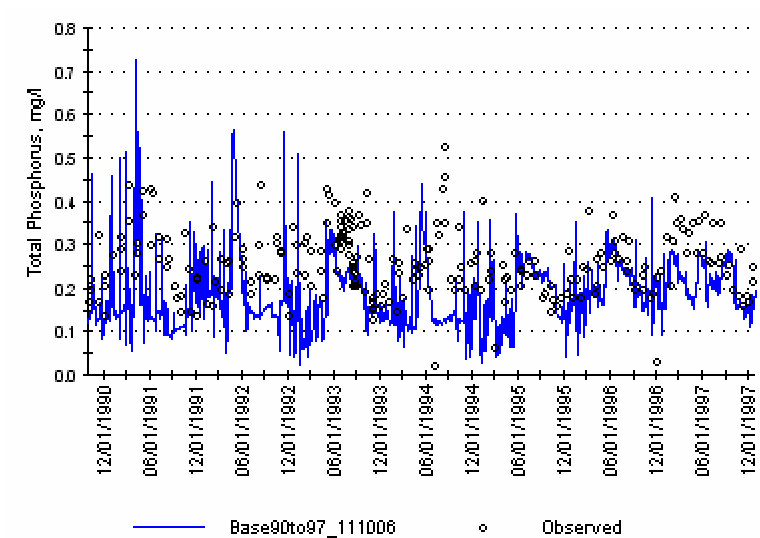


Figure 4.95 Simulated and Observed Total Phosphorus Concentration in Steamboat Creek at Cleanwater Way 1990-1997

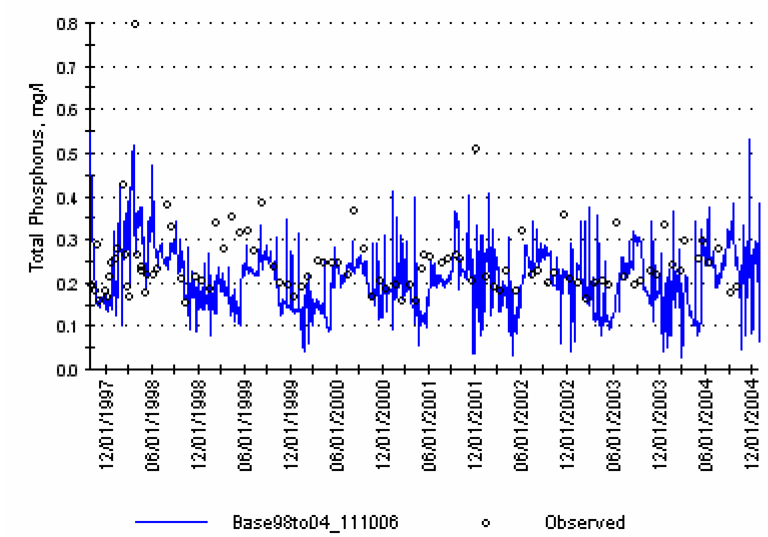


Figure 4.96 Simulated and Observed Total Phosphorus Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.8 Dissolved Organic Carbon (DOC)

Figures 4.97 to 4.99 show simulated DOC for Steamboat Creek at Cleanwater Way. Observed data was unavailable for 1985 to 1990 (Figure 4.97). The observed TOC concentrations available from 1993 to 2004 show a range of 2 mg/L to 8 mg/L with several peaks near 12 mg/L. WARMF simulated DOC within the range of observed data though an exact match to the pattern was not obtained. WARMF tends to simulate lower DOC concentrations in the wet spring periods and higher concentrations in the dry fall periods. With a high scatter to observed data, it is difficult to see a similar pattern was observed in the field.

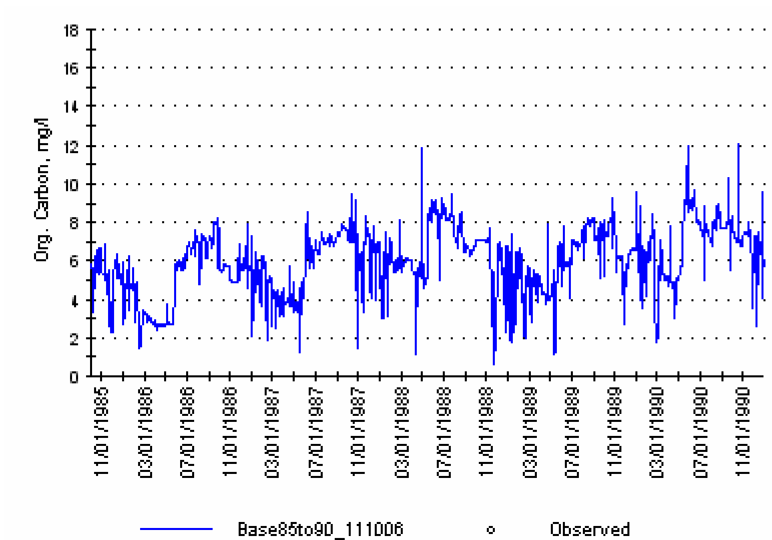


Figure 4.97 Simulated Dissolved Organic Carbon Concentration in Steamboat Creek at Cleanwater Way 1985-1990

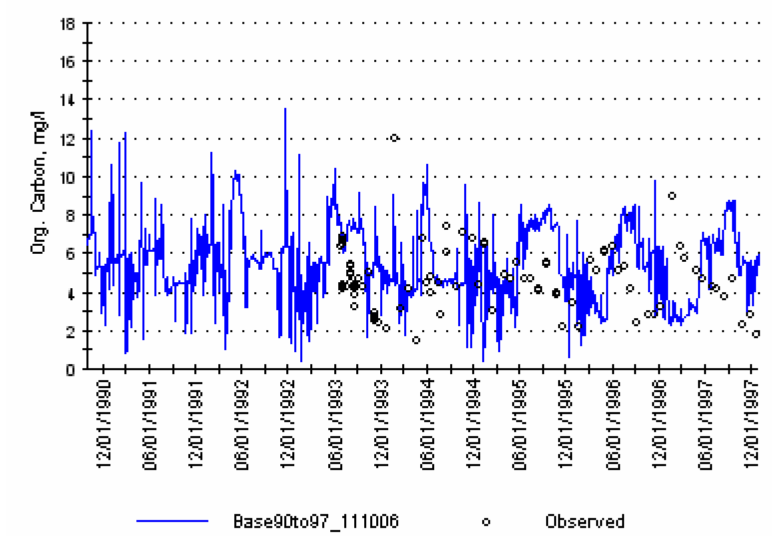


Figure 4.98 Simulated and Observed Dissolved Organic Carbon Concentration in Steamboat Creek at Cleanwater Way 1990-1997

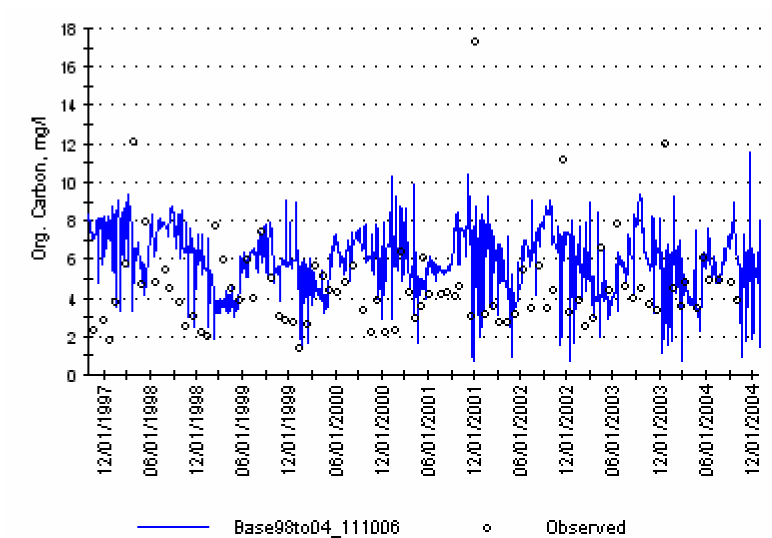


Figure 4.99 Simulated and Observed Dissolved Organic Carbon Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.9 Total Organic Carbon (TOC)

Figures 4.100 to 4.102 show simulated TOC for Steamboat Creek at Cleanwater Way. Only a small cluster of observed data was available for this parameter and location during the fall of 1993 (Figure 4.101). For this time period, WARMF simulated DOC concentrations within the range of observed data.

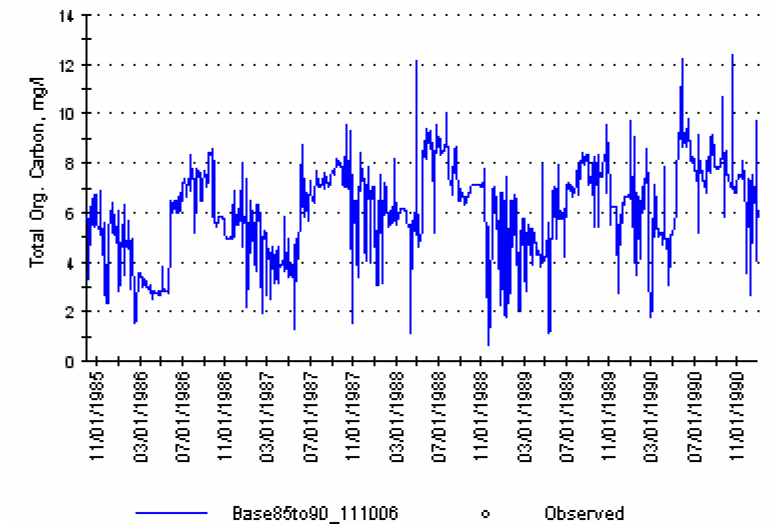


Figure 4.100 Simulated Total Organic Carbon Concentration in Steamboat Creek at Cleanwater Way 1985-1990

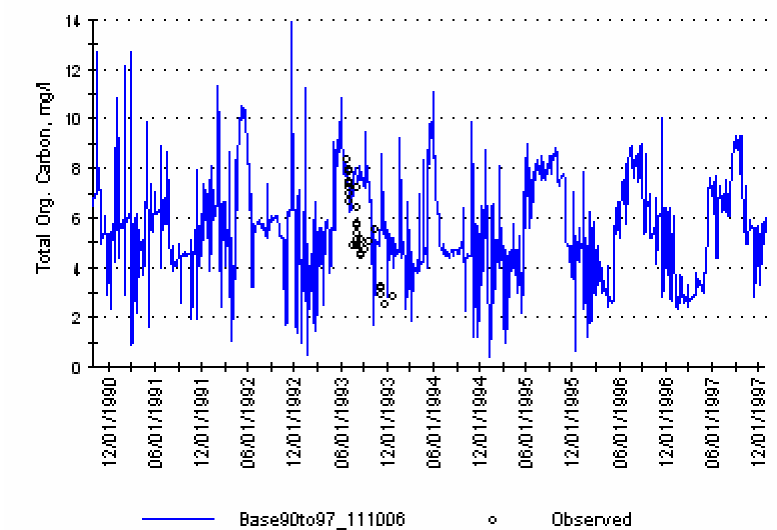


Figure 4.101 Simulated and Observed Total Organic Carbon Concentration in Steamboat Creek at Cleanwater Way 1990-1997

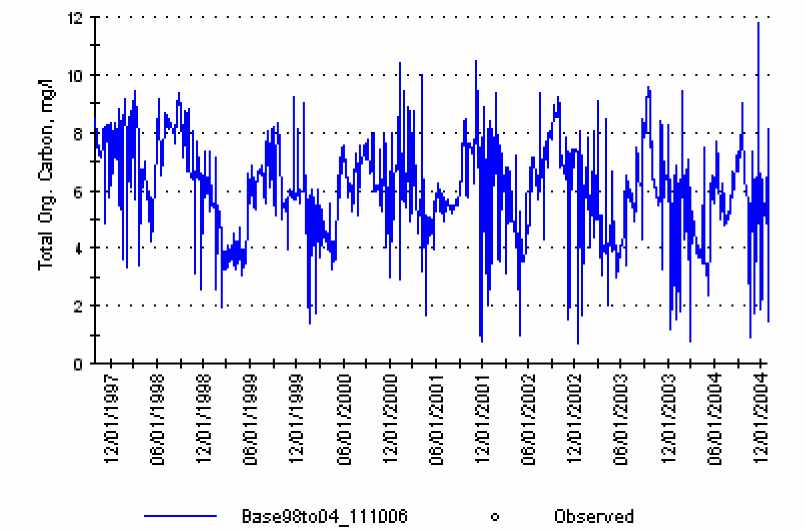


Figure 4.102 Simulated Total Organic Carbon Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.3.10 Total Dissolved Solids (TDS)

Simulated and observed TDS concentrations for Steamboat Creek at Cleanwater Way are shown in Figures 4.103 to 4.105. TDS concentrations in Steamboat Creek are observed to be much higher (3 to 4 times higher) than was observed in Truckee River at Reno/Sparks. A major contributor of TDS in Steamboat Creek is the Steamboat Hot Springs. Observed TDS ranges from approximately 200 mg/L to 600 mg/L with a distinct seasonal pattern of higher TDS during the wet spring months and lower TDS during the dry summer and fall months. For all time periods, WARMF simulated the range and pattern of TDS well for this location.

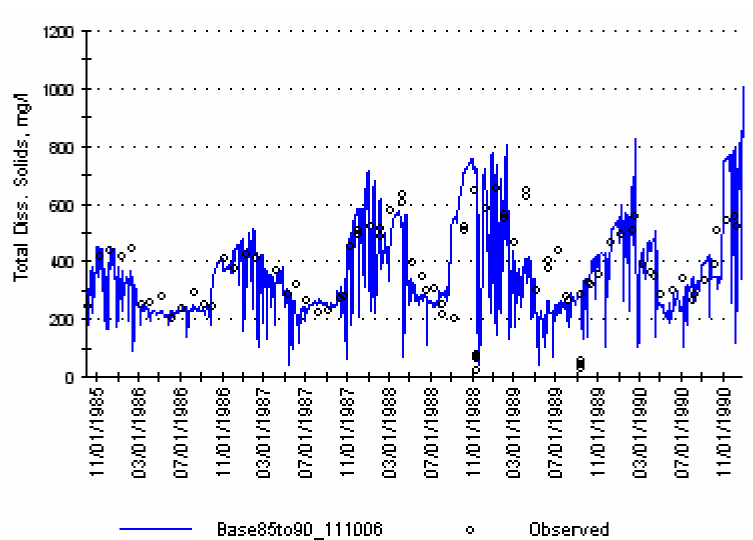


Figure 4.103 Simulated and Observed Total Dissolved Solids Concentration in Steamboat Creek at Cleanwater Way 1985-1990

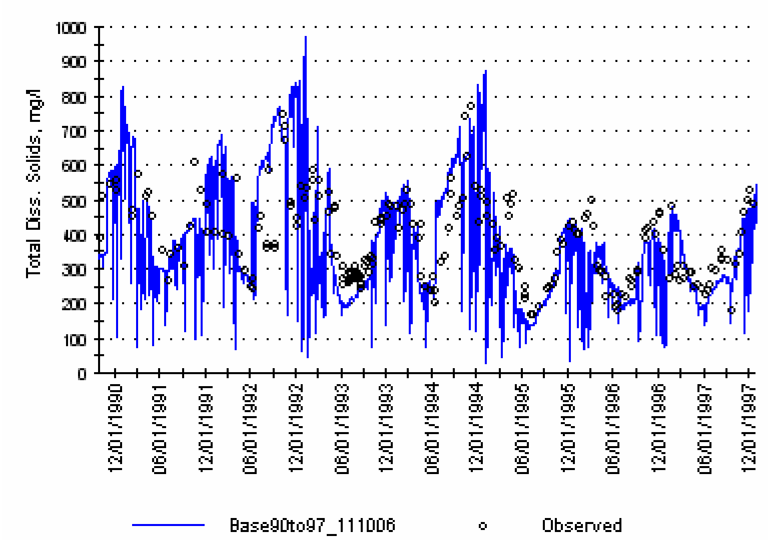


Figure 4.104 Simulated and Observed Total Dissolved Solids Concentration in Steamboat Creek at Cleanwater Way 1990-1997

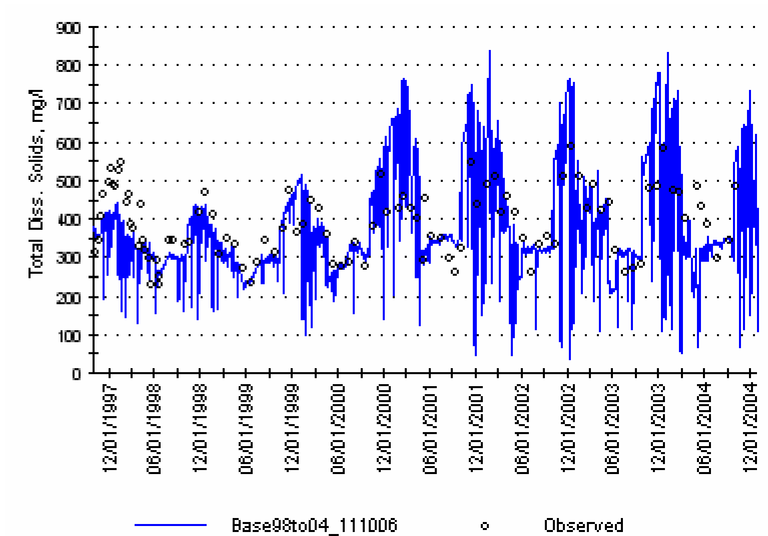


Figure 4.105 Simulated and Observed Total Dissolved Solids Concentration in Steamboat Creek at Cleanwater Way 1997-2004

4.3.4 North Truckee Drain

A second major tributary which joins the Truckee River just downstream of Reno is North Truckee Drain (USGS gage USGS 10348300). This waterway drains a watershed influenced by agricultural diversions (e.g. North Truckee Ditch and Orr Ditch) as well as residential development (e.g. Spanish Springs). In addition, two moderately sized point sources 1) Vista Canyon Group (NV0020893) and 2) Sparks Lake Marina (NV0022918) contribute flow to North Truckee Drain. Up until 1997, Vista Canyon Group discharged an approximate average flow of 0.27 cms (9.5 cfs), which accounted for approximately one third of the flow in North Truckee Drain. Unfortunately, limited monitoring data exists to characterize the impact of these point sources on North Truckee

Drain. North Truckee Drain contributes about 2.5% of the Truckee River flow measured at Vista. For the 10/1/1985 to 12/31/1990 time period, no observed data was available for comparison. Simulated flow for this time period is shown in Figure 4.25.

4.3.4.1 Ammonia (NH_4-N)

Simulated and observed ammonia concentrations for North Truckee Drain are shown in Figures 4.106 to 4.108. Observed ammonia concentrations typically range from 0.01 mg/L to 0.1 mg/L. A few time periods have ammonia peaks as high as 0.2 to 0.8 mg/L. Also to note is that measurements recorded from fall 1993 to December 1995 indicate measurements at a detection limit of 0.08 mg/L. WARMF predicts ammonia concentrations in the range of most observed data with two notable exceptions. During 1985-1987 (Figure 4.106), WARMF under predicts ammonia concentrations. Also, during the spring of 2004 (Figure 4.107) WARMF overpredicts ammonia concentration. Both of these discrepancies are likely due to limited point source data for two moderate point sources (Vista Canyon Group -- NV0020893 and Sparks Lake Marina -- NV0022918), which both discharge to North Truckee Drain.

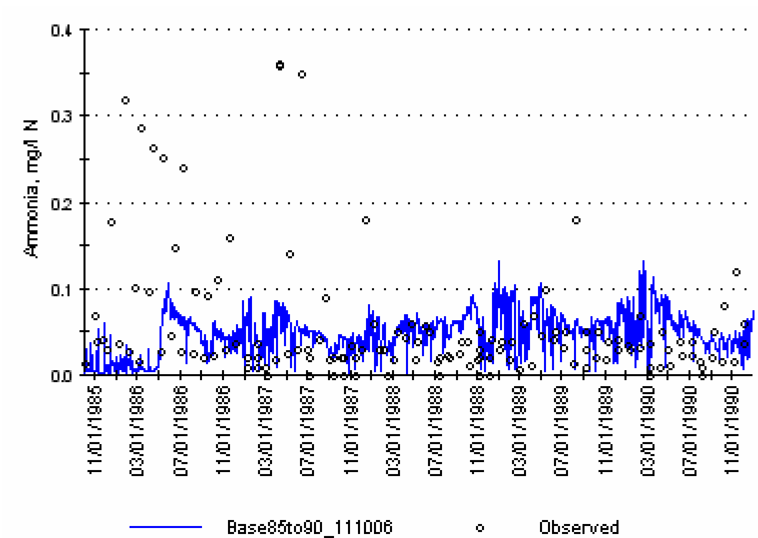


Figure 4.106 Simulated and Observed Ammonia Concentration in North Truckee Drain 1985-1990

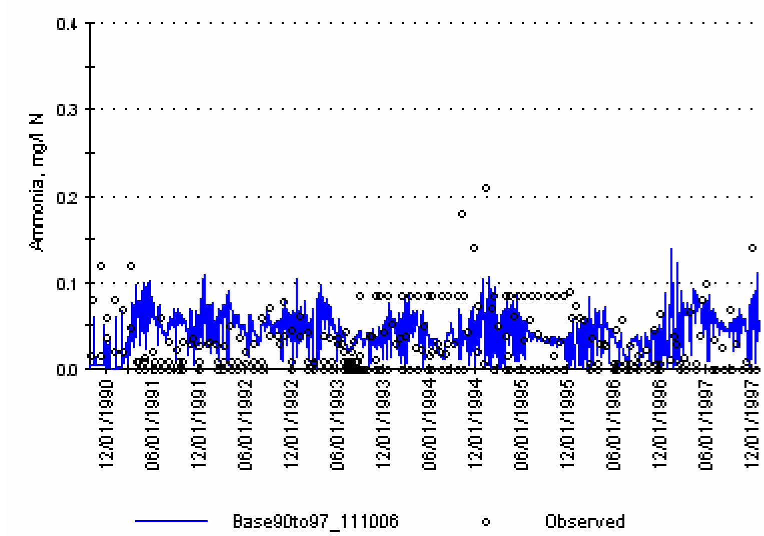


Figure 4.107 Simulated and Observed Ammonia Concentration in North Truckee Drain 1990-1997

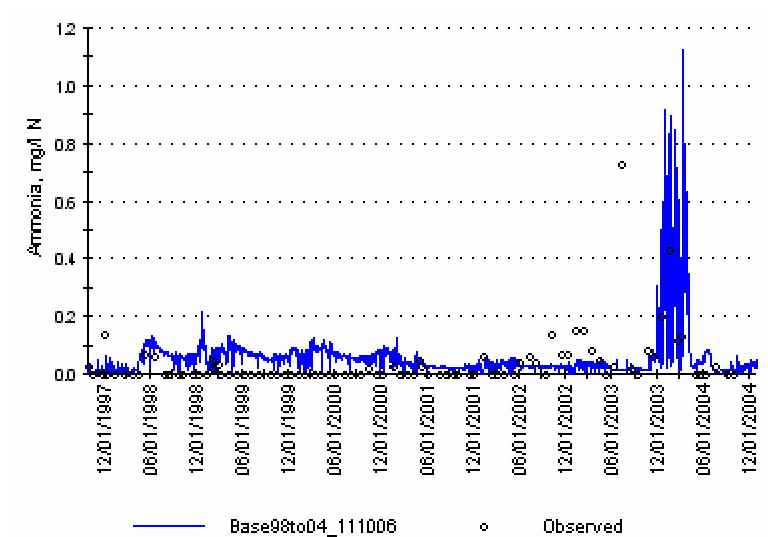


Figure 4.108 Simulated and Observed Ammonia Concentration in North Truckee Drain 1997-2004

4.3.4.2 Nitrate (NO_3-N)

Figures 4.109 to 4.111 show simulated and observed nitrate concentrations for North Truckee Drain. Observed concentrations range from 0 mg/L to 2.5 mg/L and follow a seasonal pattern of higher nitrate during the wet winter/spring months and lower nitrate during the summer/fall months. After 2001, measured nitrate in North Truckee Drain was considerable lower (less than 1 mg/L). This reduction is likely due to the change in point source discharge from Vista Canyon Group (N0020893). For all time periods, WARMF simulates nitrate in the range of observed concentrations. The closest match to observed data is found for 1989-1990 (Figure 4.109) and 2003-2004 (Figure 4.111). During other years, WARMF was not able to produce as close as a match an on average tended to under predict nitrate concentration. It is suspected that a lack of more detailed point source data for North Truckee Drain prevents WARMF from providing a better prediction of nitrate concentrations.

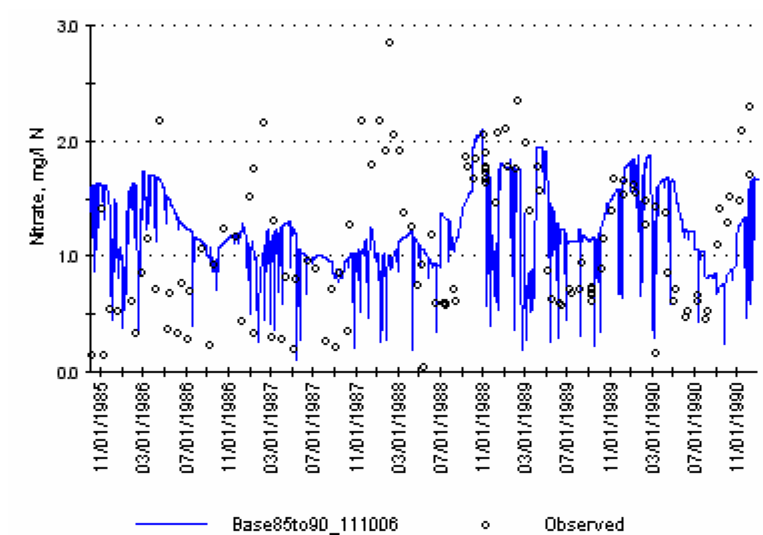


Figure 4.109 Simulated and Observed Nitrate Concentration in North Truckee Drain 1985-1990

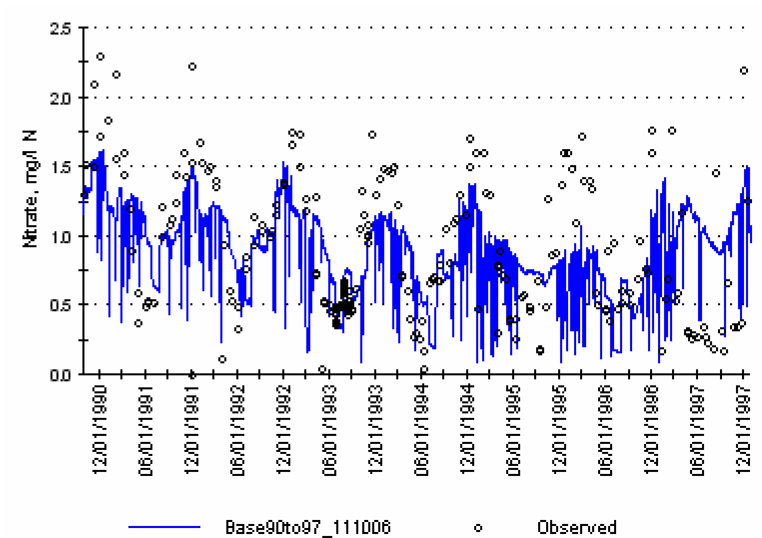


Figure 4.110 Simulated and Observed Nitrate Concentration in North Truckee Drain 1990-1997

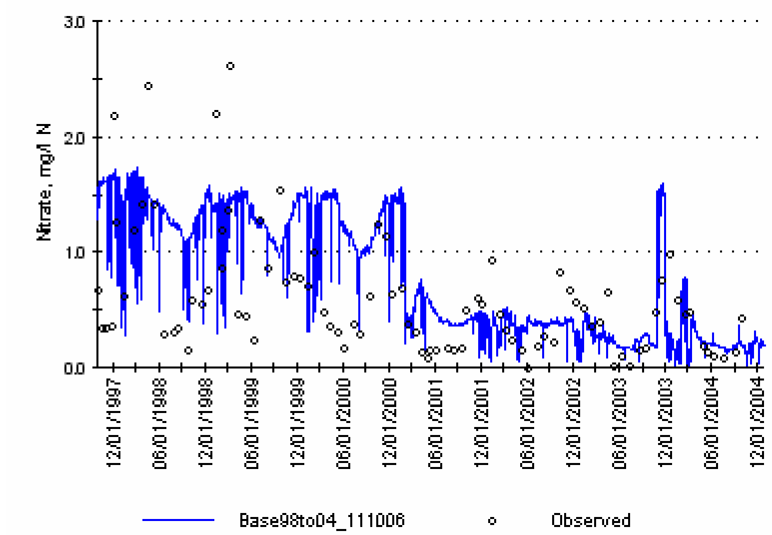


Figure 4.111 Simulated and Observed Nitrate Concentration in North Truckee Drain 1997-2004

4.3.4.3 Total Organic Nitrogen (TON)

Figures 4.112 to 4.114 show simulated and observed total organic nitrogen for North Truckee Drain. Observed TON concentrations range from roughly 0.2 mg/L to 1.6 mg/L and follow a general pattern of higher TON during the dry months and lower TON during the wet months. WARMF simulated this range and pattern of TON well for most years.

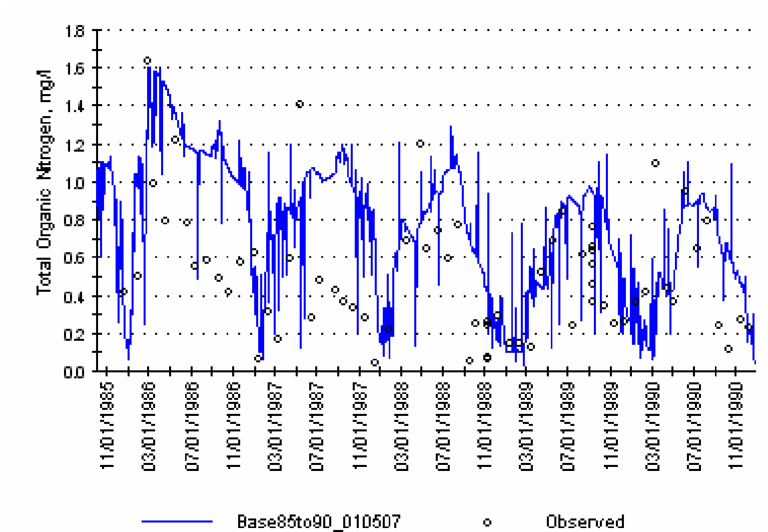


Figure 4.112 Simulated and Observed Total Organic Nitrogen Concentration in North Truckee Drain 1985-1990

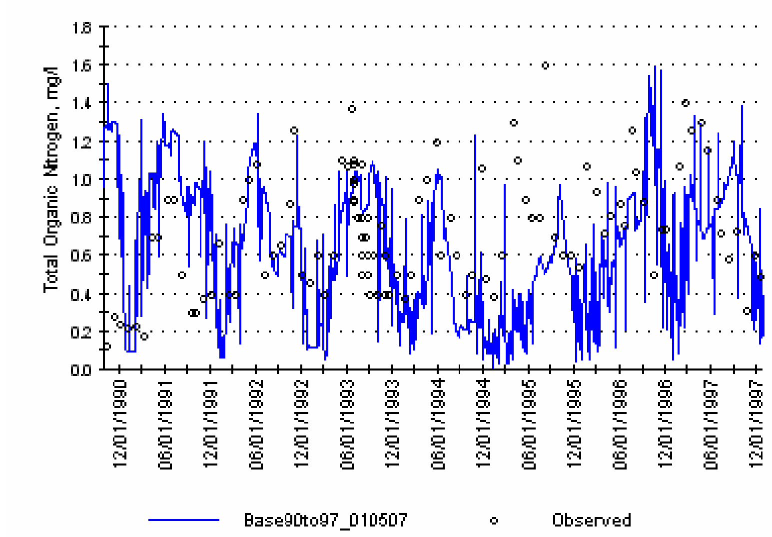


Figure 4.113 Simulated and Observed Total Organic Nitrogen Concentration in North Truckee Drain 1990-1997

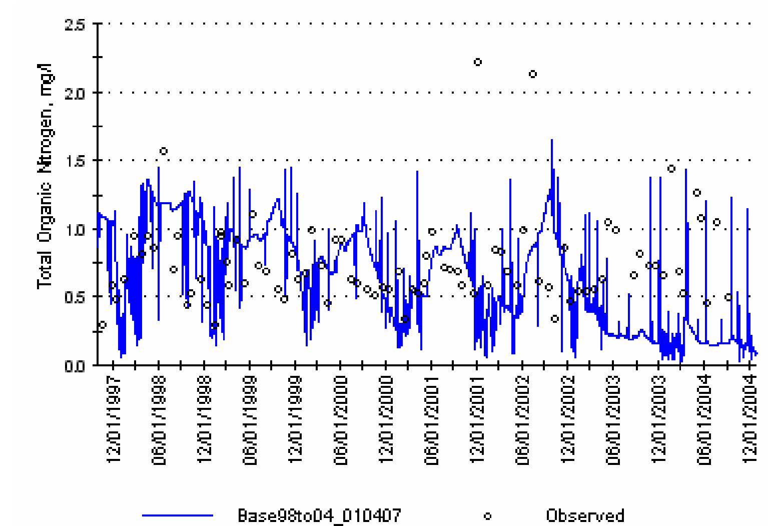


Figure 4.114 Simulated and Observed Total Organic Nitrogen Concentration in North Truckee Drain 1997-2004

4.3.4.4 Total Kjeldahl Nitrogen (TKN)

Simulated and observed concentrations for Total Kjeldahl Nitrogen in North Truckee Drain are shown in Figures 4.115 to 4.117. Observed TKN ranges from approximately 0.2 mg/L to 1.4 mg/L with a few peaks as high as 2 mg/L. WARMF simulations yielded a good match of TKN for most simulations years. A slight under prediction of TKN is noted for 1995 and 2003.

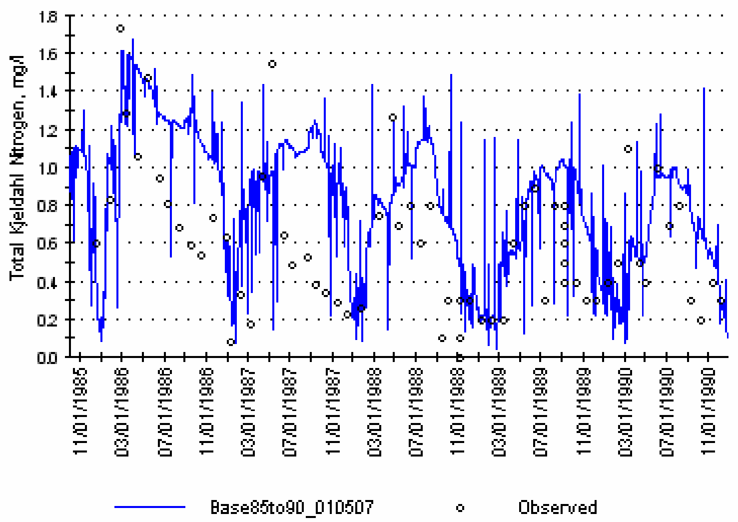


Figure 4.115 Simulated and Observed Total Kjeldahl Nitrogen Concentration in North Truckee Drain 1985-1990

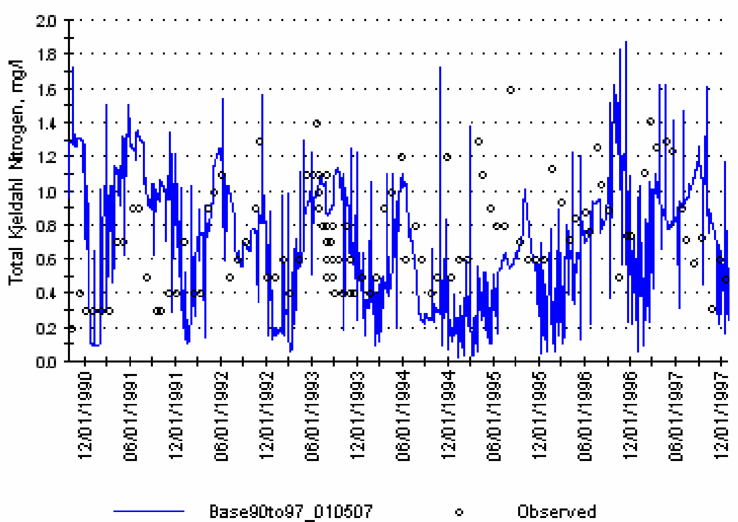


Figure 4.116 Simulated and Observed Total Kjeldahl Nitrogen Concentration in North Truckee Drain 1990-1997

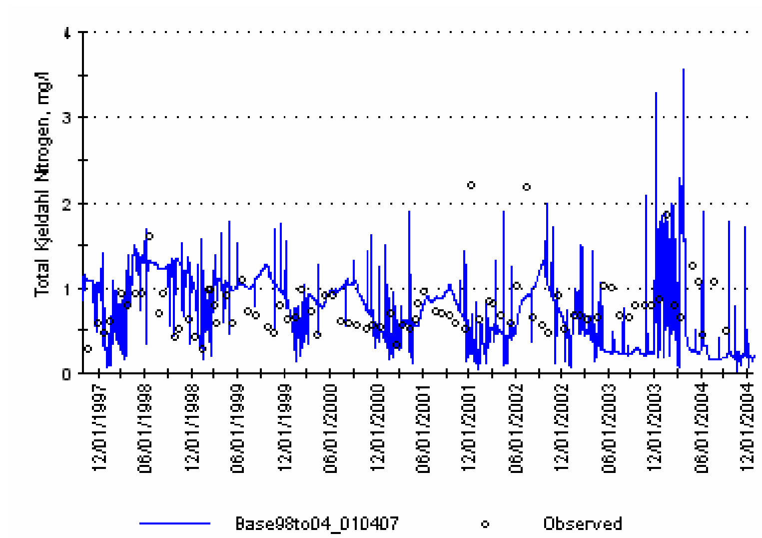


Figure 4.117 Simulated and Observed Total Kjeldahl Nitrogen Concentration in North Truckee Drain 1997-2004

4.3.4.5 Total Nitrogen (TN)

Figures 4.118 to 4.120 show simulated and observed total nitrogen concentrations in North Truckee Drain. Measured TN concentrations range from 0.5 mg/L to 3.5 mg/L. A slight pattern of higher TN in wet months and lower TN in dry months is also observed though data does show a high degree of scatter. WARMF simulates TN well within the range of observed data. For several years, the match is quite close (e.g. 1989-1993 and 1997-1999). For a few periods (e.g. 1994-1995), WARMF underpredicts TN concentrations as we seen above with individual nitrogen species. It is suspected that limitations on point source data for this tributary are contributed to the discrepancies between simulated and observed nitrogen.

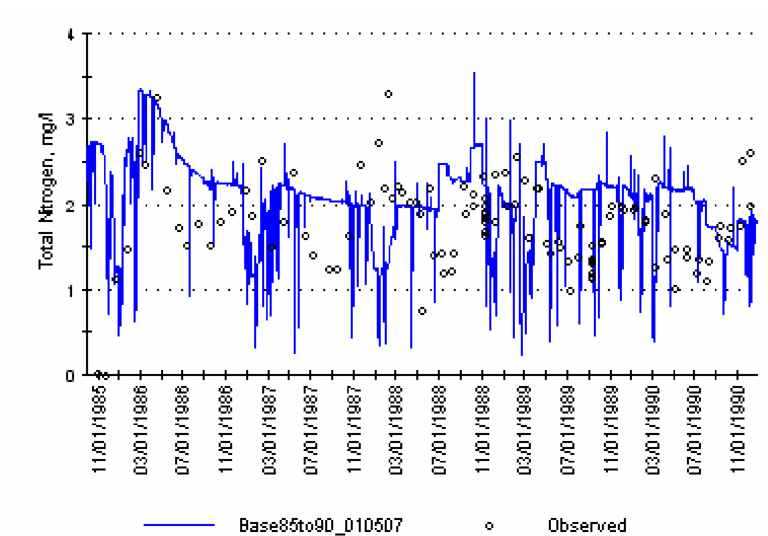


Figure 4.118 Simulated and Observed Total Nitrogen Concentration in North Truckee Drain 1985-1990

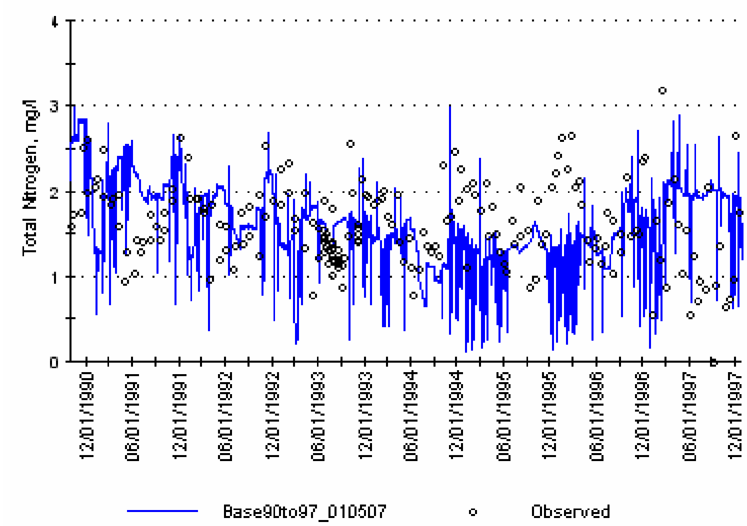


Figure 4.119 Simulated and Observed Total Nitrogen Concentration in North Truckee Drain 1990-1997

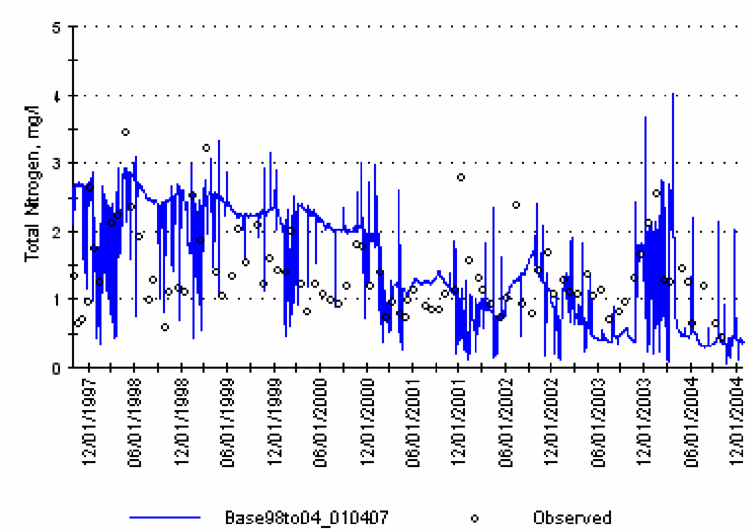


Figure 4.120 Simulated and Observed Total Nitrogen Concentration in North Truckee Drain 1997-2004

4.3.4.6 Phosphate (PO_4-P)

Simulated and observed phosphate concentrations in North Truckee Drain are shown in Figures 4.121 to 4.123. Measured phosphate levels range from roughly 0.02 mg/L to 0.3 mg/L. The highest concentrations were observed during the wet years of 1996 and 1997 (Figure 4.122) and during 2003 and 2004 when elevated phosphate loadings were discharged from Sparks Lake Marina (NV0022918). For all time periods, WARMF-predicted phosphate concentrations match well with observed data with respect to range and pattern.

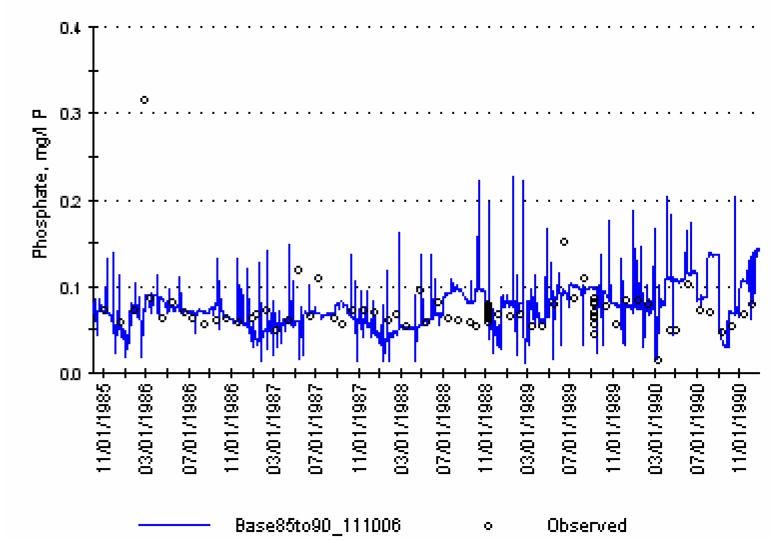


Figure 4.121 Simulated and Observed Phosphate Concentration in North Truckee Drain 1985-1990

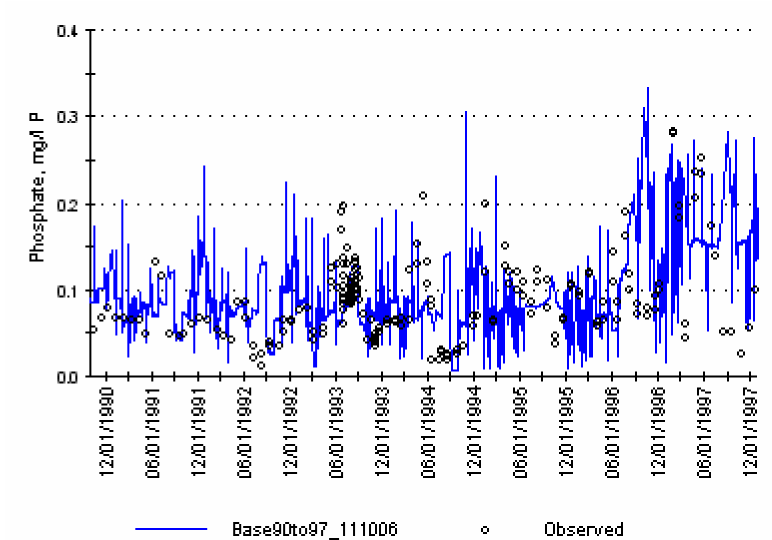


Figure 4.122 Simulated and Observed Phosphate Concentration in North Truckee Drain 1990-1997

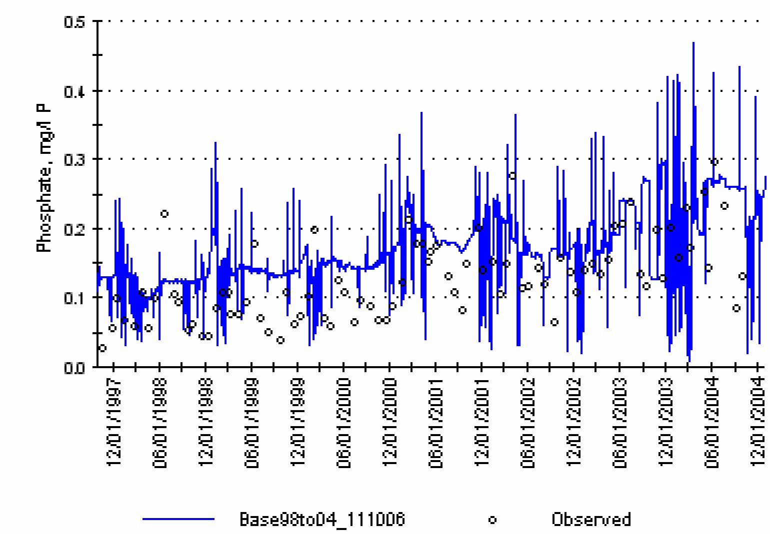


Figure 4.123 Simulated and Observed Phosphate Concentration in North Truckee Drain 1997-2004

4.3.4.7 Total Phosphorus (TP)

Figures 4.124 to 4.126 show simulated and observed total phosphorus concentrations for North Truckee Drain. Observed TP concentrations for this location range from roughly 0.05 mg/L to 0.4 mg/L. During the late 1980's, it appears that a detection limit of 0.1 mg/L was recorded (Figure 1.124). WARMF simulated the concentration of TP well for all time periods. Most predicted TP peaks were within range of observed values, though the timing of peaks was not always matched. During winter 1986, WARMF did not capture a pulse of elevated TP that is notable in measured data. It is unclear whether this peak could be attributed to nonpoint or point source contributions of phosphorus.

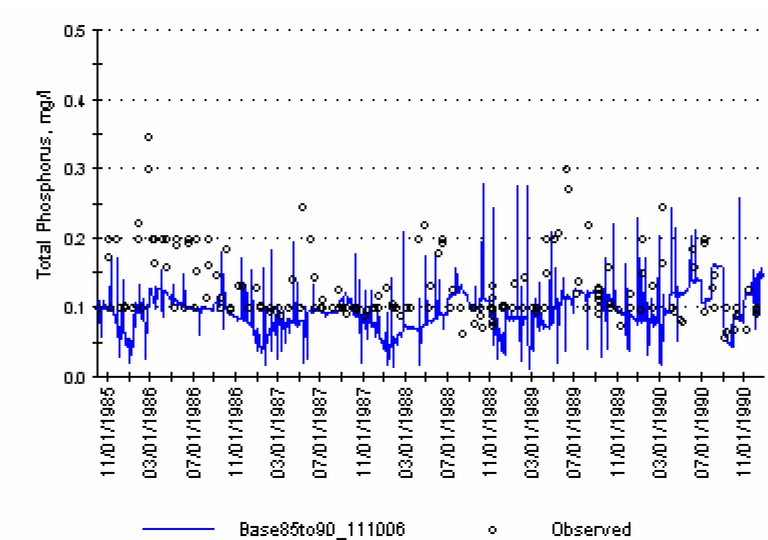


Figure 4.124 Simulated and Observed Total Phosphorus Concentration in North Truckee Drain 1985-1990

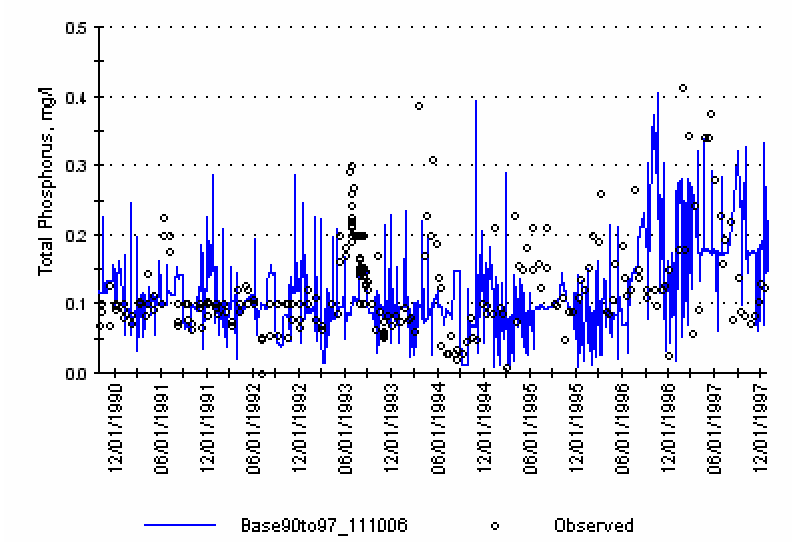


Figure 4.125 Simulated and Observed Total Phosphorus Concentration in North Truckee Drain 1990-1997

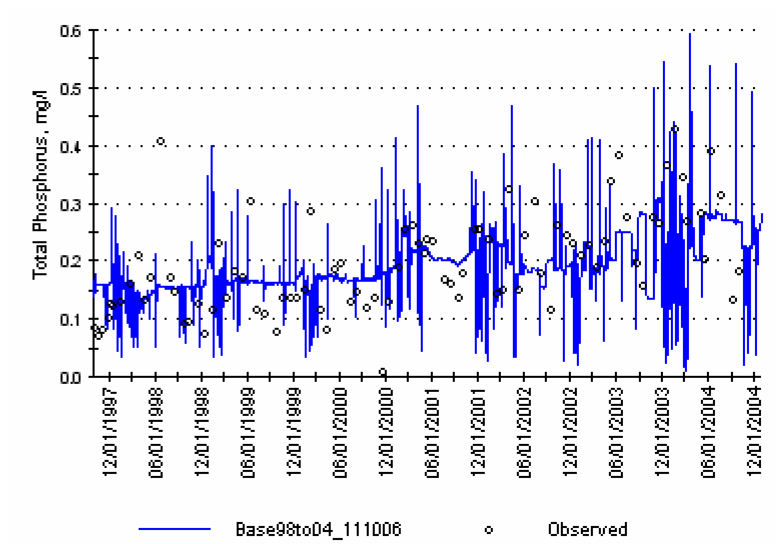


Figure 4.126 Simulated and Observed Total Phosphorus Concentration in North Truckee Drain 1997-2004

4.3.4.8 Dissolved Organic Carbon (DOC)

Simulated dissolved organic carbon concentrations in North Truckee Drain are shown in Figures 4.127 to 4.129. Observed data was measured after 1993 (Figures 4.128 and 4.129). Available data shows a high degree of scatter and ranges from 1 mg/L to 12 mg/L. WARMF simulates DOC within this range however concentrations from 2002 to 2004 are notably under predicted. Point source discharge data for organic carbon are not available for the mid-sized point sources contributing to North Truckee Drain.

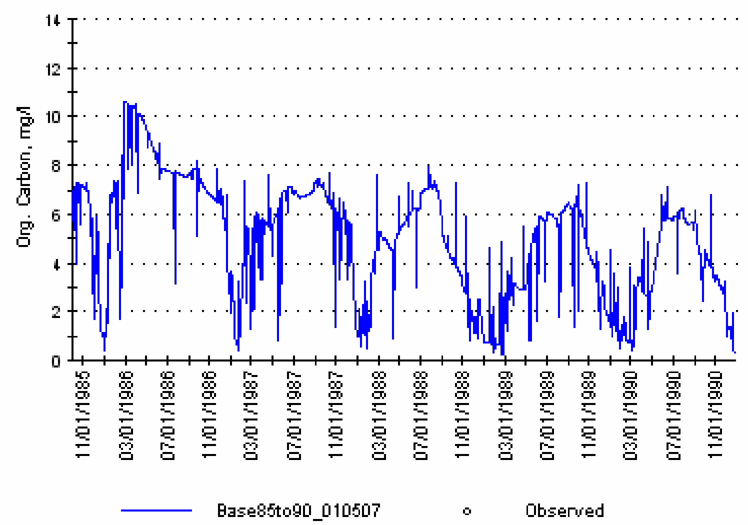


Figure 4.127 Simulated and Observed Dissolved Organic Carbon Concentration in North Truckee Drain 1985-1990

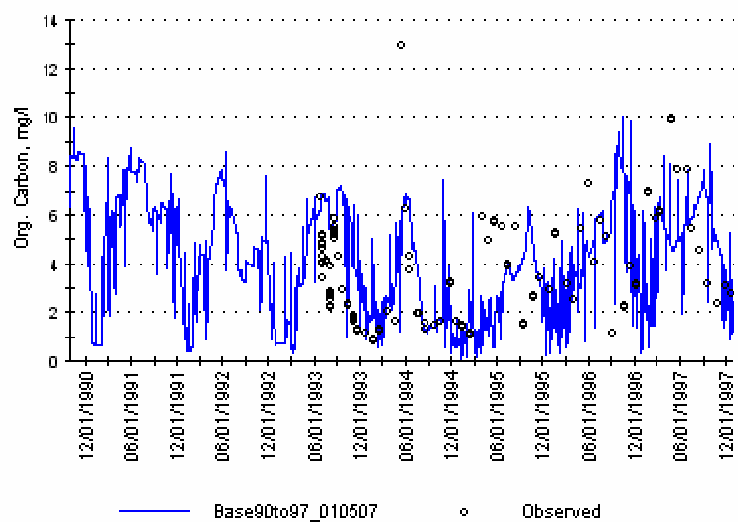


Figure 4.128 Simulated and Observed Dissolved Organic Carbon Concentration in North Truckee Drain 1990-1997

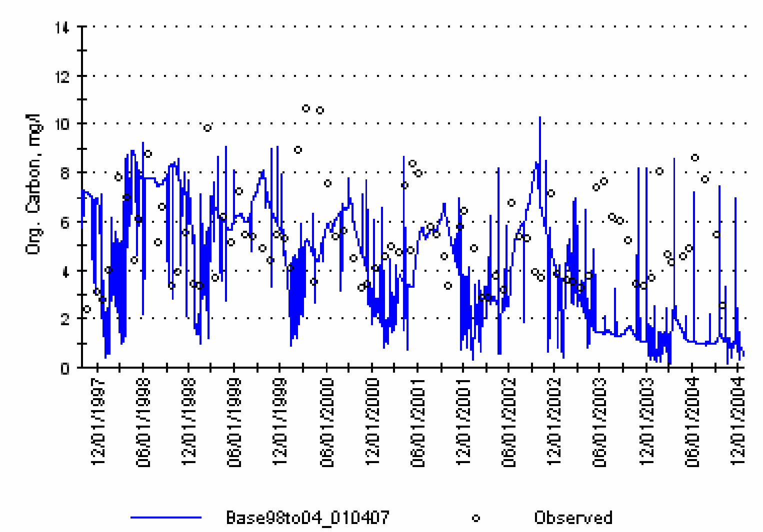


Figure 4.129 Simulated and Observed Dissolved Organic Carbon Concentration in North Truckee Drain 1997-2004

4.3.4.9 Total Organic Carbon (TOC)

Simulated total organic carbon concentrations in North Truckee Drain are shown in Figures 4.130 to 4.132. A small cluster of observed TOC data are available for 1993. WARMF-simulated TOC concentrations are within the range of this limited data set.

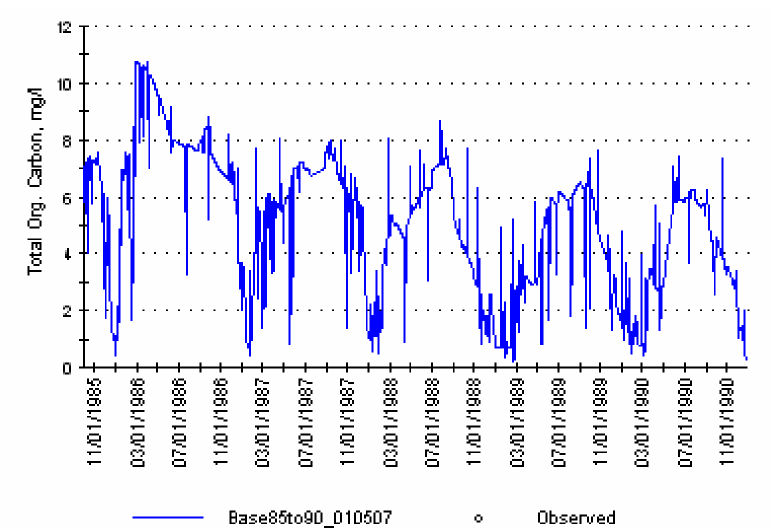


Figure 4.130 Simulated Total Organic Carbon Concentration in North Truckee Drain 1985-1990

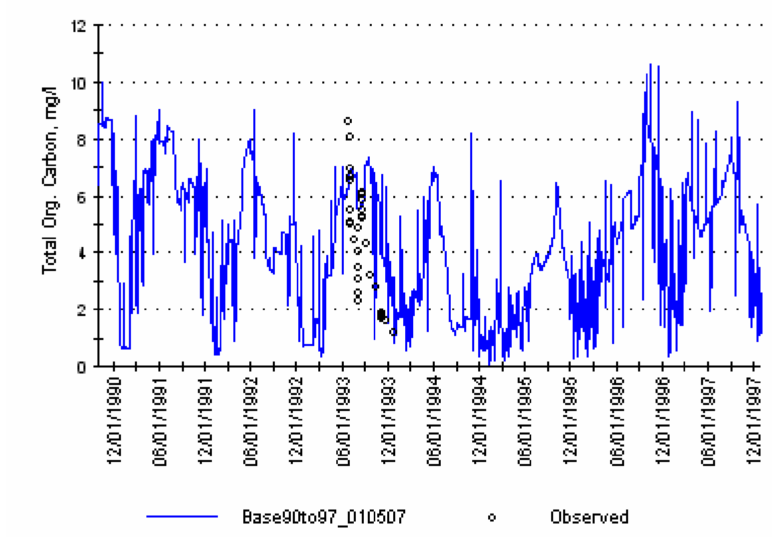


Figure 4.131 Simulated and Observed Total Organic Carbon Concentration in North Truckee Drain 1990-1997

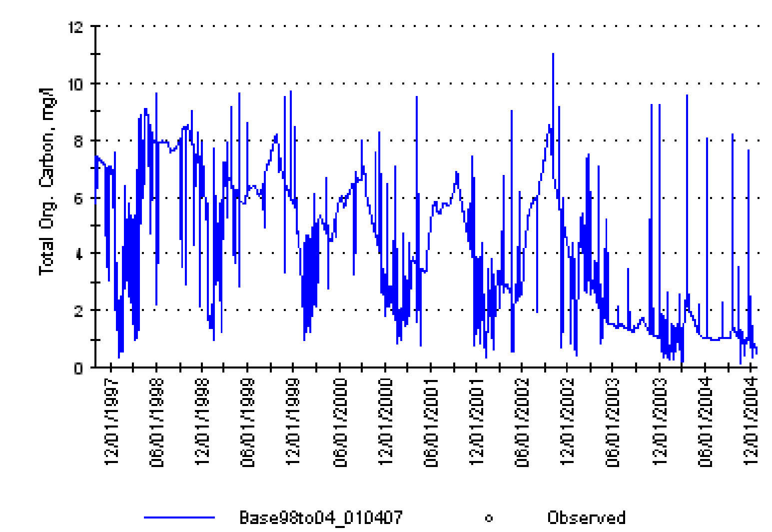


Figure 4.132 Simulated Total Organic Carbon Concentration in North Truckee Drain 1997-2004

4.3.4.10 Total Dissolved Solids (TDS)

Figures 4.133 to 4.135 show simulated and observed total dissolved solids concentrations for North Truckee Drain. Measured concentrations range from approximately 200 mg/L to 800 mg/L with occasional spikes as high as 900 mg/L. WARMF simulates TDS within the range of observed data though a match of exact pattern is not met for all simulation periods.

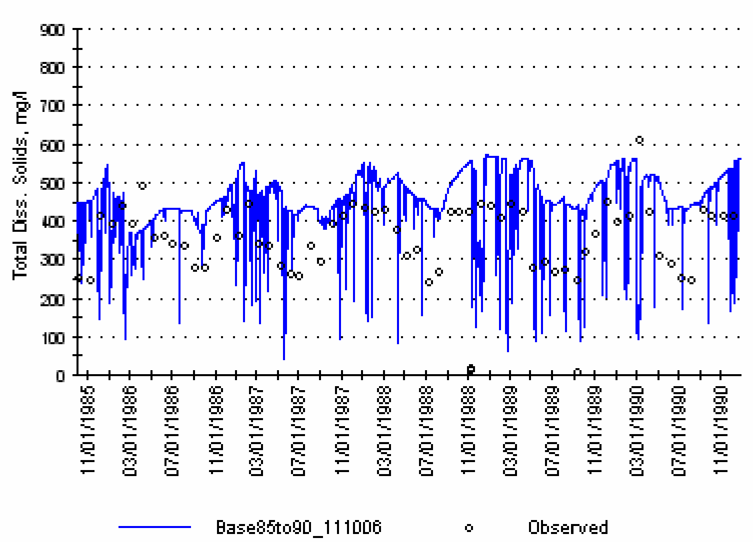


Figure 4.133 Simulated and Observed Total Dissolved Solids Concentration in North Truckee Drain 1985-1990

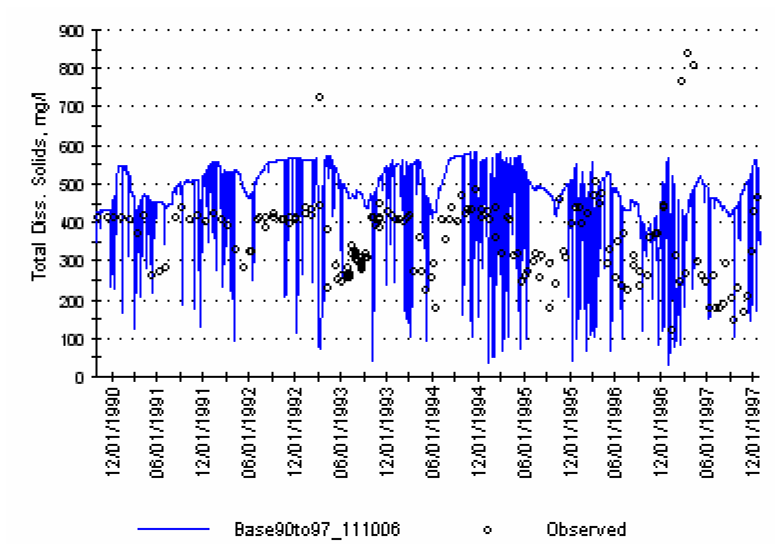


Figure 4.134 Simulated and Observed Total Dissolved Solids Concentration in North Truckee Drain 1990-1997

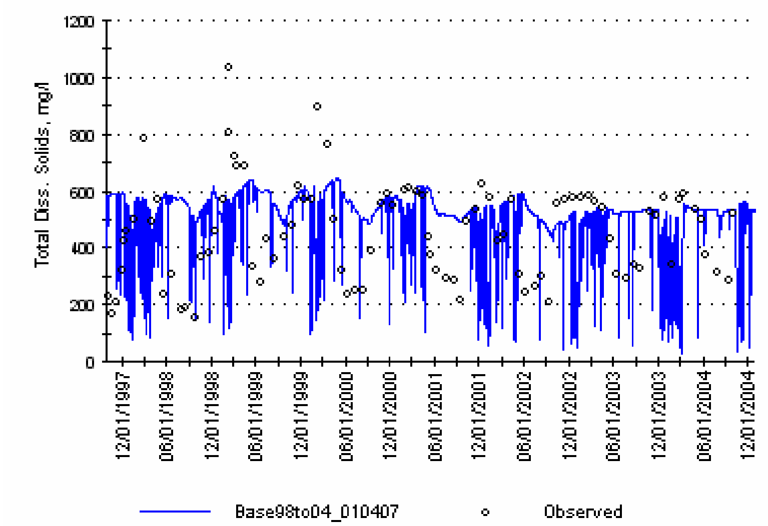


Figure 4.135 Simulated and Observed Total Dissolved Solids Concentration in North Truckee Drain 1997-2004

4.3.5 Truckee River at Vista

4.3.5.1 Ammonia (NH_4-N)

Figures 4.136 to 4.138 show simulated and observed ammonia concentration for Truckee River at Vista. Observed ammonia concentrations are typically less than 0.5 mg/L. A few time periods have a trend of higher measurements up to 2 mg/L (10/1985 to 10/1988) or brief peaks as high as 3 to 4 mg/L (2/1994, 7/1994, and 5/2001). WARMF simulates the lower concentrations of ammonia well for all time periods. WARMF matched the 2001 ammonia peak, however the elevated ammonia concentrations for other time periods were under predicted by WARMF. The pattern of elevated ammonia corresponds with elevated ammonia discharges from TMWRF during these time periods.

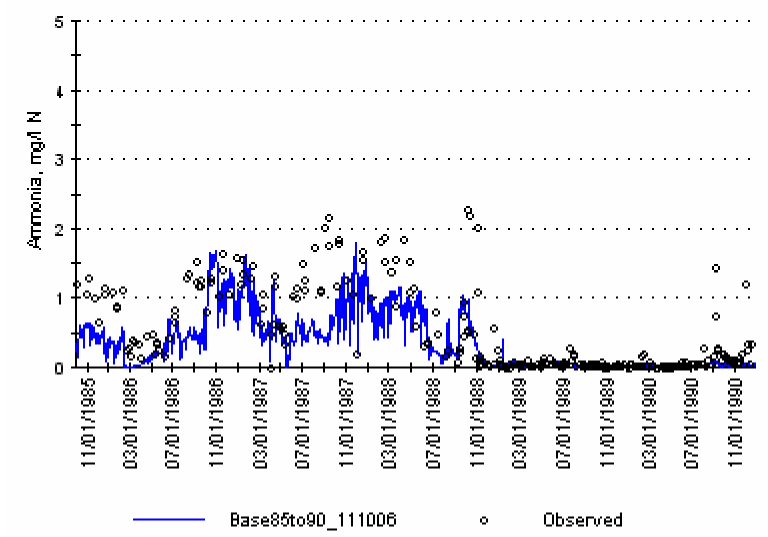


Figure 4.136 Simulated and Observed Ammonia Concentration in Truckee River at Vista 1985-1990

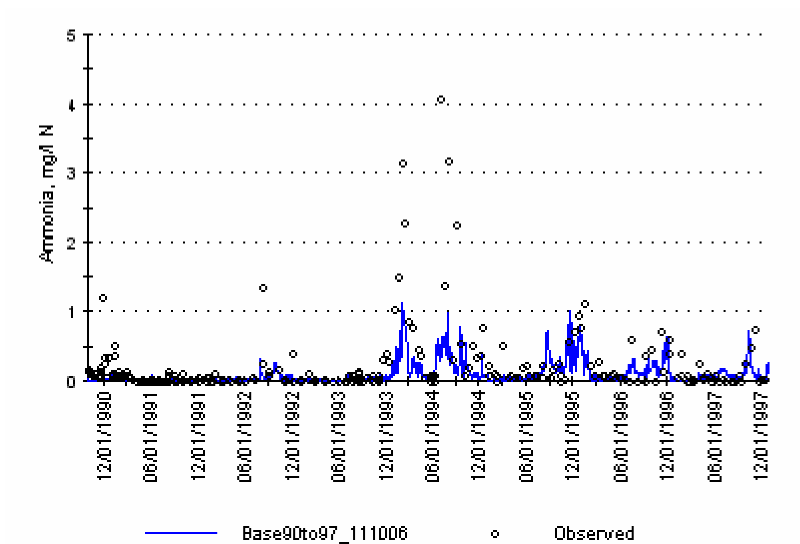


Figure 4.137 Simulated and Observed Ammonia Concentration in Truckee River at Vista 1990-1997

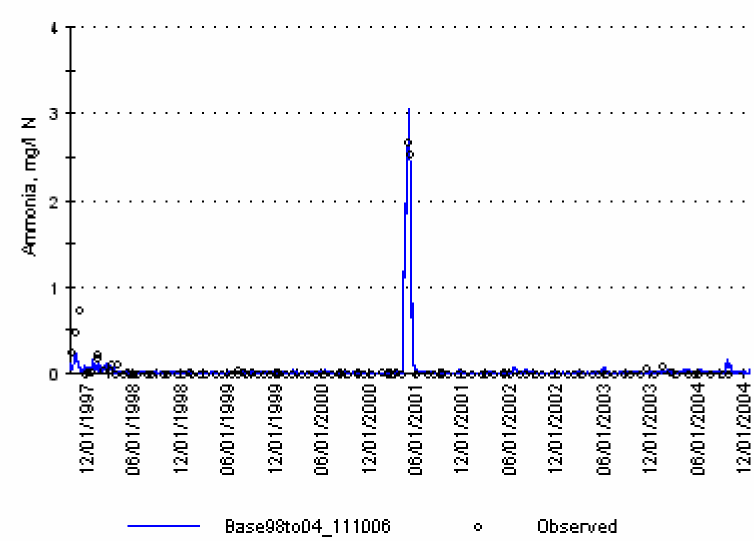


Figure 4.138 Simulated and Observed Ammonia Concentration in Truckee River at Vista 1997-2004

4.3.5.2 Nitrate (NO_3-N)

Simulated and observed nitrate concentration in the Truckee River at Vista are shown in Figures 4.139 to 4.141. Measured nitrate concentrations are typically less than 0.5 mg/L. A period of higher nitrate during the fall of 1988 (approximately 9 mg/L) was recorded at this location and attributed to equipment issues TMWRF. WARMF simulated the range and pattern of nitrate at this location within a reasonable range and pattern for most time periods. WARMF underpredicted the nitrate peak in the fall of 1998 and over predicted a peak in June of 2001.

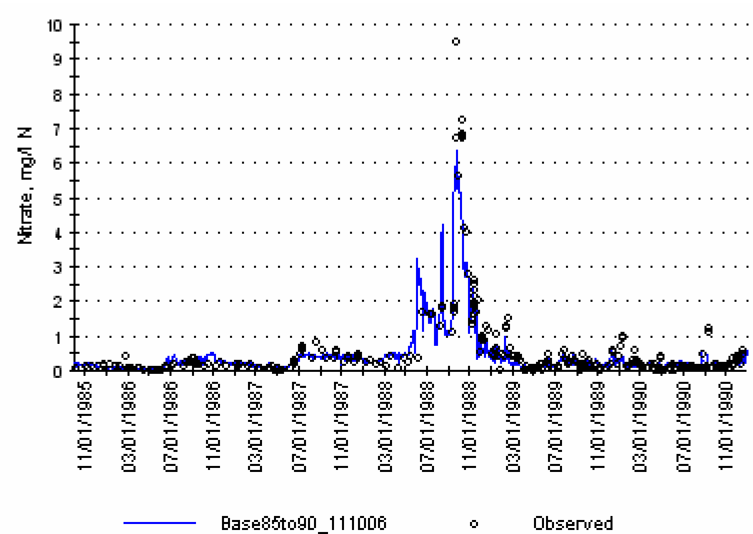


Figure 4.139 Simulated and Observed Nitrate Concentration in Truckee River at Vista 1985-1990

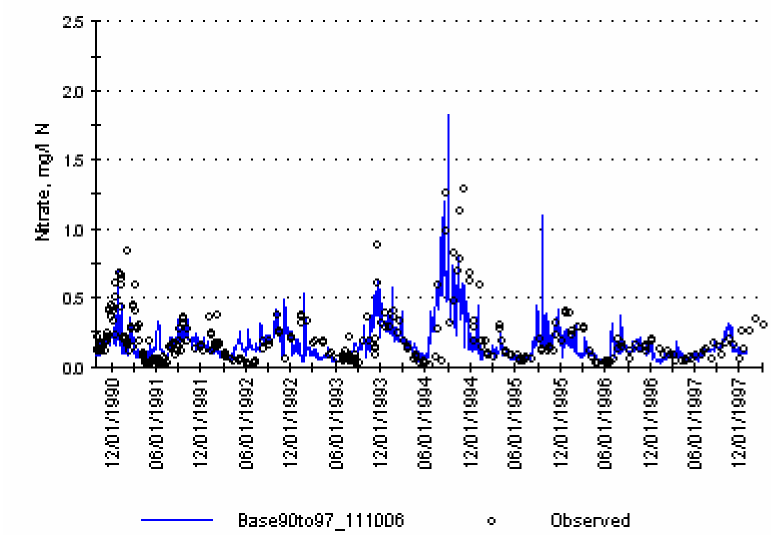


Figure 4.140 Simulated and Observed Nitrate Concentration in Truckee River at Vista 1990-1997

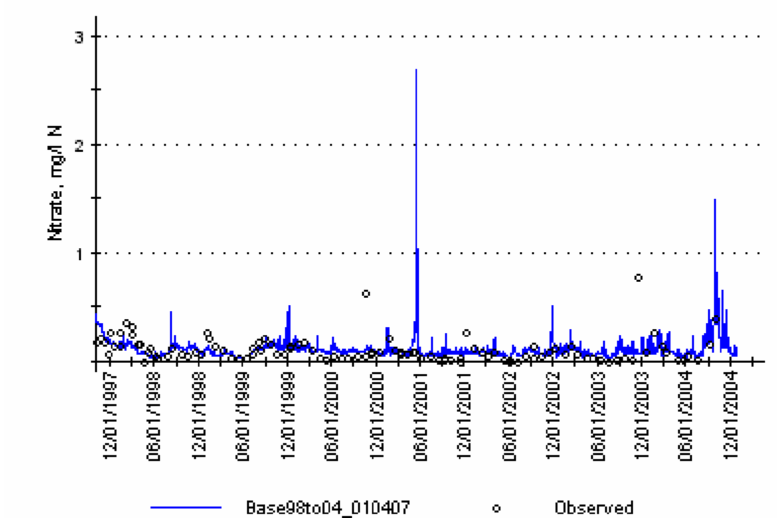


Figure 4.141 Simulated and Observed Nitrate Concentration in Truckee River at Vista 1997-2004

4.3.5.3 Total Organic Nitrogen (TON)

Figures 4.142 to 4.144 show simulated and observed total organic nitrogen concentrations for Truckee River at Vista. Measured TON at this location was recorded in a range of 0.1 mg/L to 1.5 mg/L and included a seasonal trend of higher TON during the dry fall periods and less TON during the wet spring periods. Measured TON from 1985 to 1990 showed much more scatter than later time periods. WARMF simulated TON well with respect to pattern and magnitude. Time periods with a less favorable match tended to have a higher scatter with observed data (Figure 4.142).

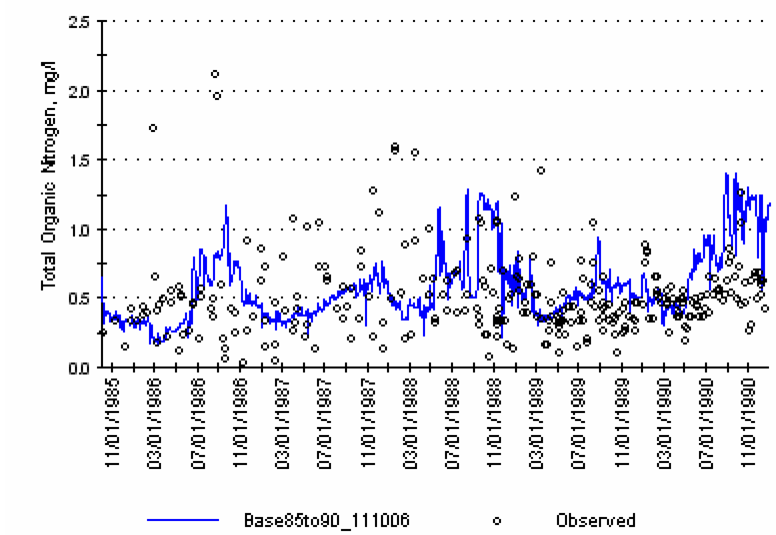


Figure 4.142 Simulated and Observed Total Organic Nitrogen Concentration in Truckee River at Vista 1985-1990

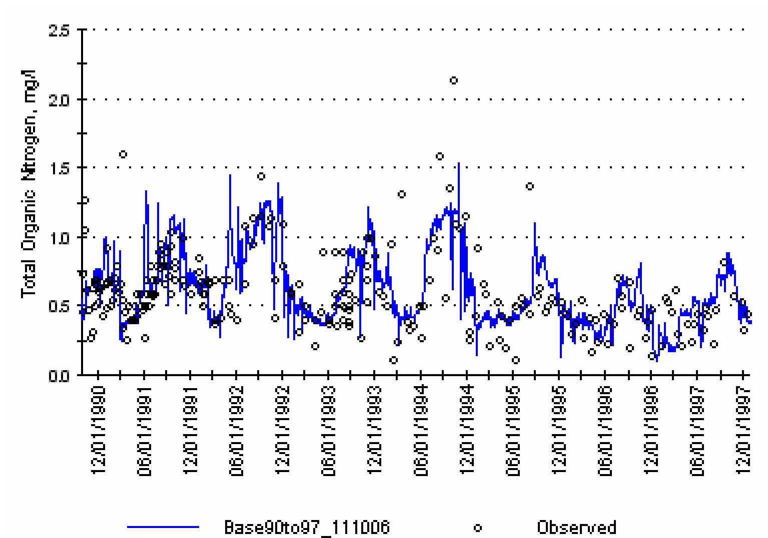


Figure 4.143 Simulated and Observed Total Organic Nitrogen Concentration in Truckee River at Vista 1990-1997

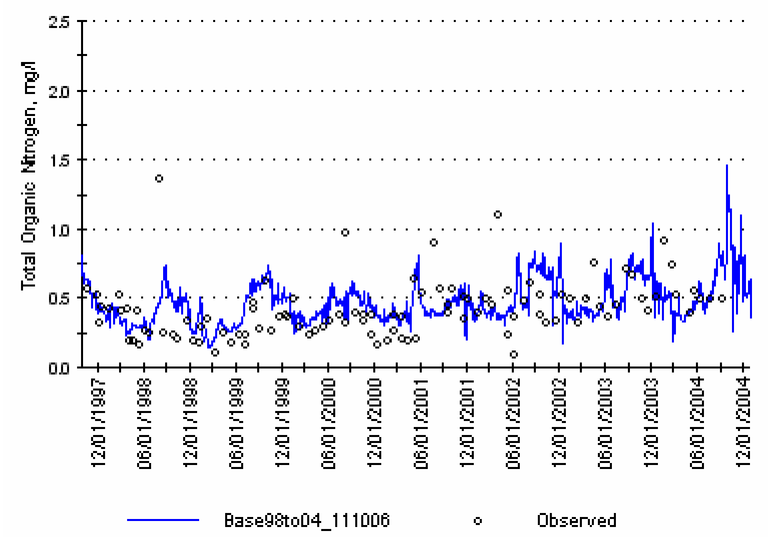


Figure 4.144 Simulated and Observed Total Organic Nitrogen Concentration in Truckee River at Vista 1997-2004

4.3.5.4 Total Kjeldahl Nitrogen (TKN)

Simulated and observed TKN concentrations for Truckee River at Vista are shown in Figures 4.145 to 4.147. Measured TKN concentrations range from approximately 0.5 mg/L to 4 mg/L. WARMF simulates TKN well within the range of observed data. TKN is slightly under predicted during the spring and fall of 1994 and slightly overpredicted during the summer of 2001. These discrepancies correspond with elevated ammonia discharges from TMWRF.

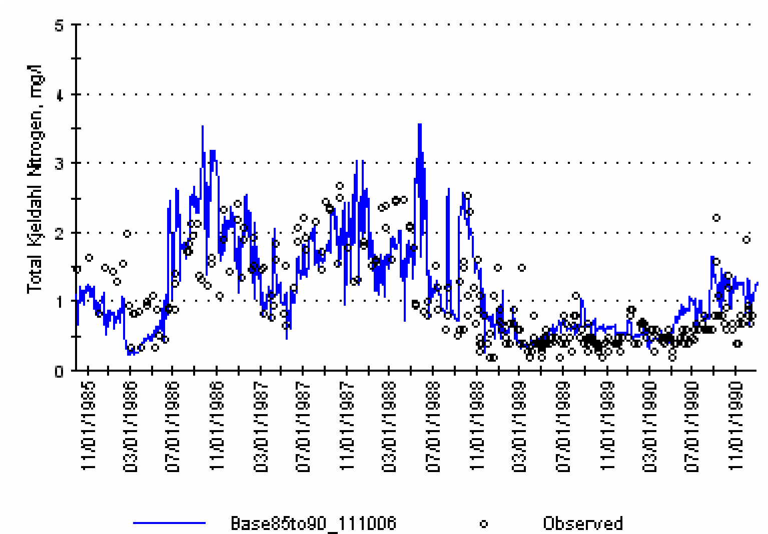


Figure 4.145 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Truckee River at Vista 1985-1990

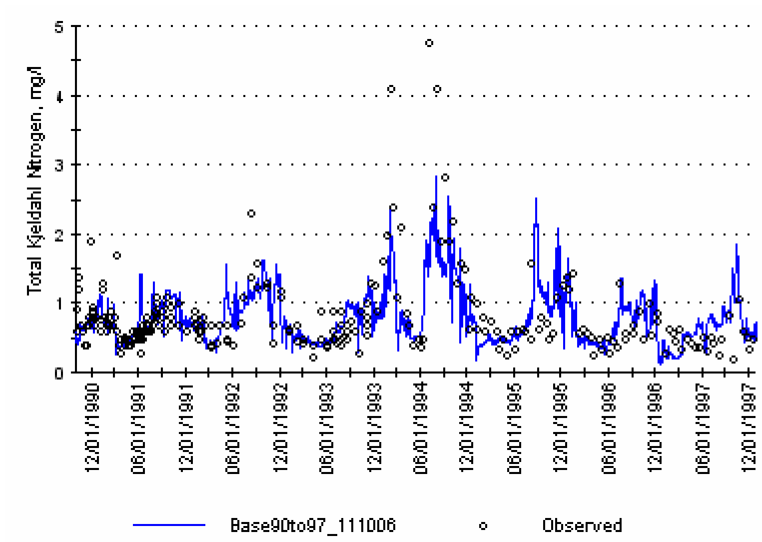


Figure 4.146 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Truckee River at Vista 1990-1997

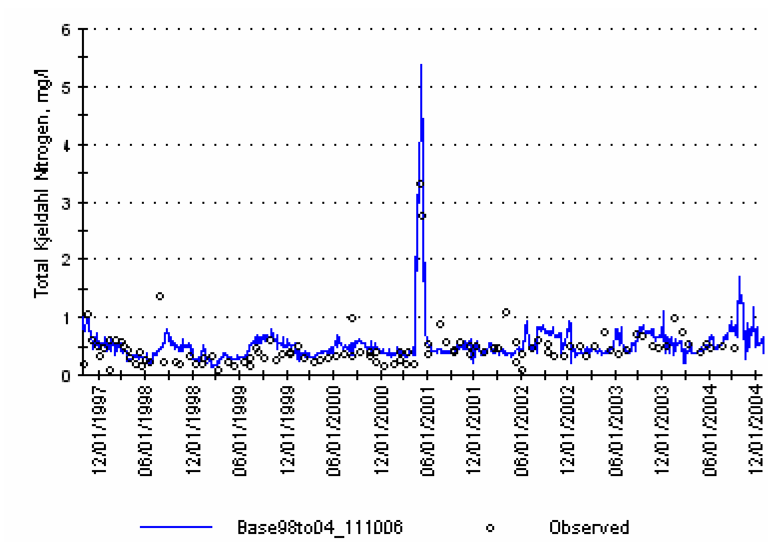


Figure 4.147 Simulated and Observed Total Kjeldahl Nitrogen Concentration in Truckee River at Vista 1997-2004

4.3.5.5 Total Nitrogen (TN)

Figures 4.148 to 4.150 show simulated and observed total nitrogen concentration for Truckee River at Vista. Measured TN ranges from roughly 0.5 mg/L to 3 mg/L with one distinct larger peak of 10 mg/L during 1988 which corresponds with TMWRF equipment problems. As with other nitrogen species, WARMF simulates TN concentrations well with the exception of an underprediction of peaks during 1988, 1993 and 1994, and an over prediction of a peak during 2001.

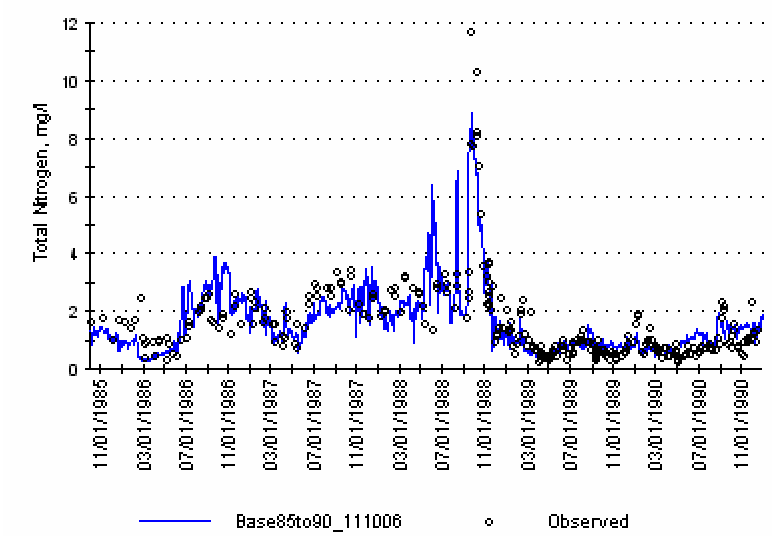


Figure 4.148 Simulated and Observed Total Nitrogen Concentration in Truckee River at Vista 1985-1990

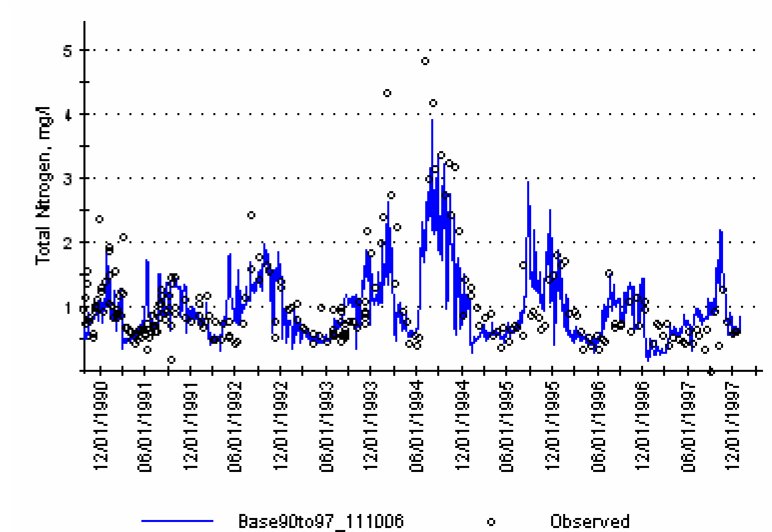


Figure 4.149 Simulated and Observed Total Nitrogen Concentration in Truckee River at Vista 1990-1997

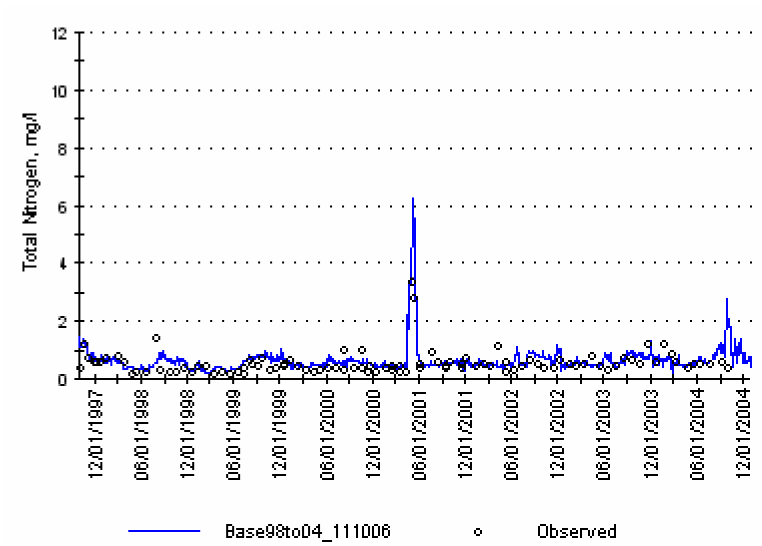


Figure 4.150 Simulated and Observed Total Nitrogen Concentration in Truckee River at Vista 1997-2004

4.3.5.6 Phosphate (PO_4-P)

Figures 4.151 to 4.153 show simulated and observed phosphate concentrations for Truckee River at Vista. Measured phosphate typically ranges from 0 to 0.2 mg/L with occasional peaks as great as 0.4 mg/L. For all time periods, WARMF simulates phosphate well with respect to range and pattern of observed values. For some time period, WARMF does under predict peak phosphate concentrations (e.g. 1986, 1988) as well as over predicts other peaks (e.g. 1990, 1995). WARMF predicted phosphate runs a bit high for the latest simulation time period (Figure 4.153).

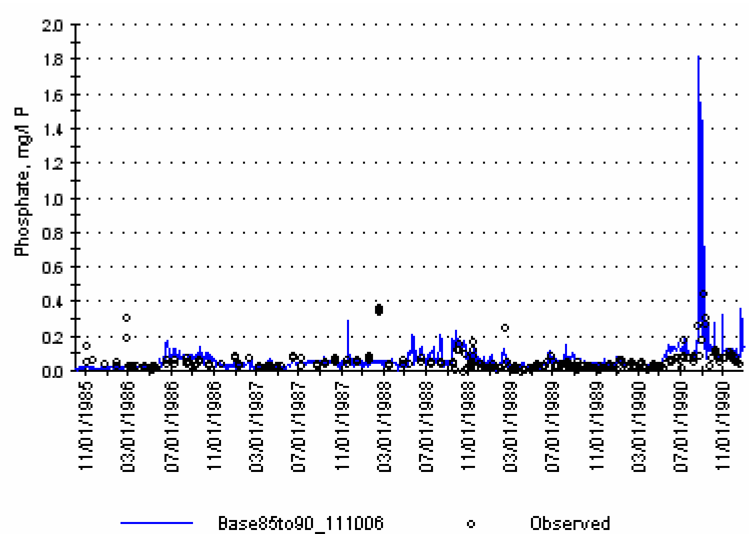


Figure 4.151 Simulated and Observed Phosphate Concentration in Truckee River at Vista 1985-1990

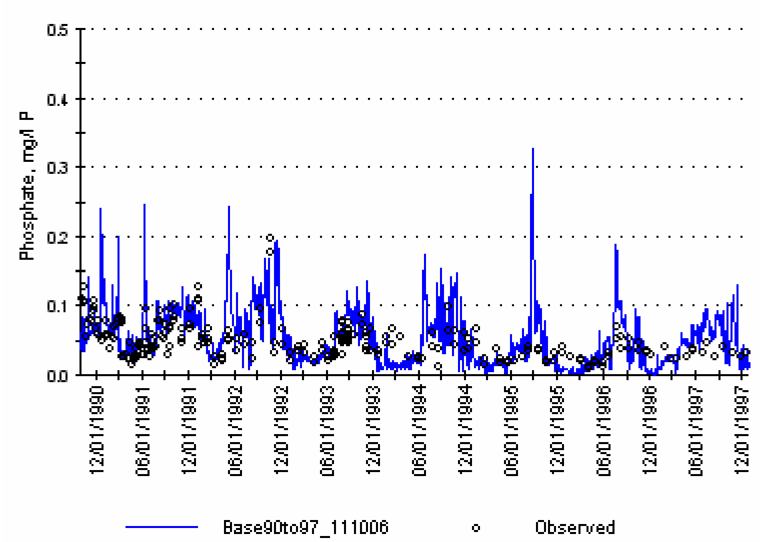


Figure 4.152 Simulated and Observed Phosphate Concentration in Truckee River at Vista 1990-1997

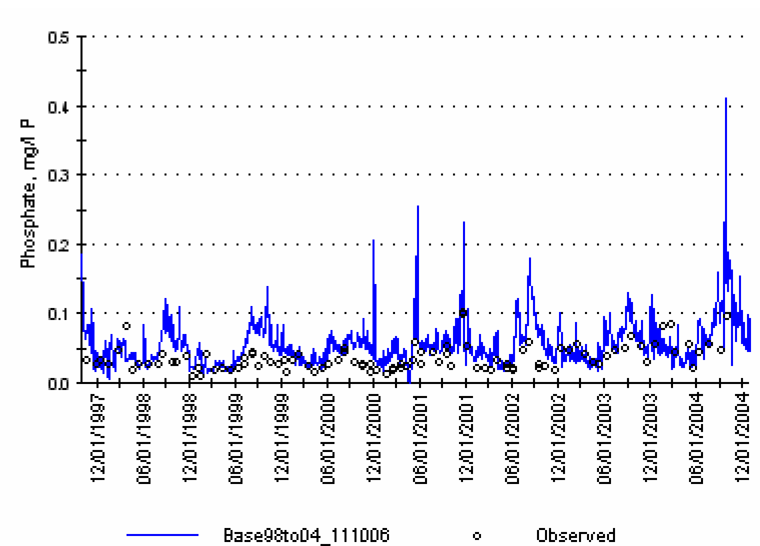


Figure 4.153 Simulated and Observed Phosphate Concentration in Truckee River at Vista 1997-2004

4.3.5.7 Total Phosphorus (TP)

Simulated and observed total phosphorus concentrations in Truckee River at Vista are shown in Figures 4.154 to 4.156. Measured total phosphorus concentrations are only slightly higher than measured phosphate with concentrations ranging from 0 to 0.2 mg/L with maximum peaks near 0.6 mg/L. Though WARMF does miss a few peaks, particularly during the 1985 to 1990 time period (Figure 4.154), WARMF generally provides a good prediction of total phosphorus when compared to observed data.

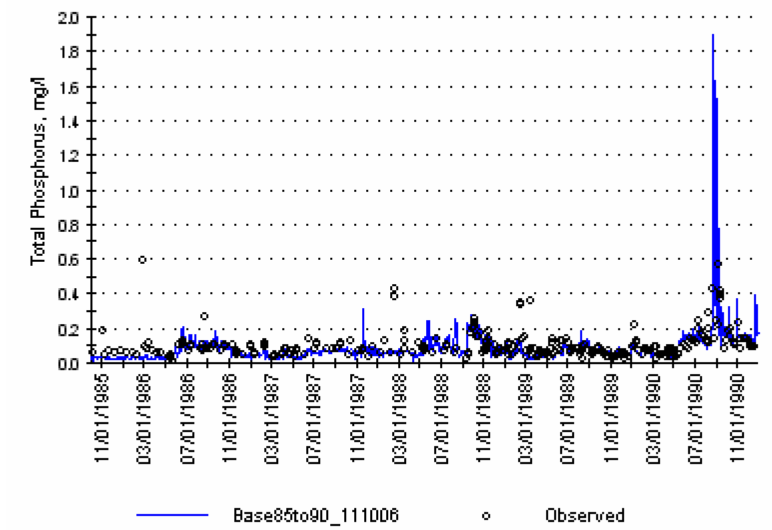


Figure 4.154 Simulated and Observed Total Phosphorus Concentration in Truckee River at Vista 1985-1990

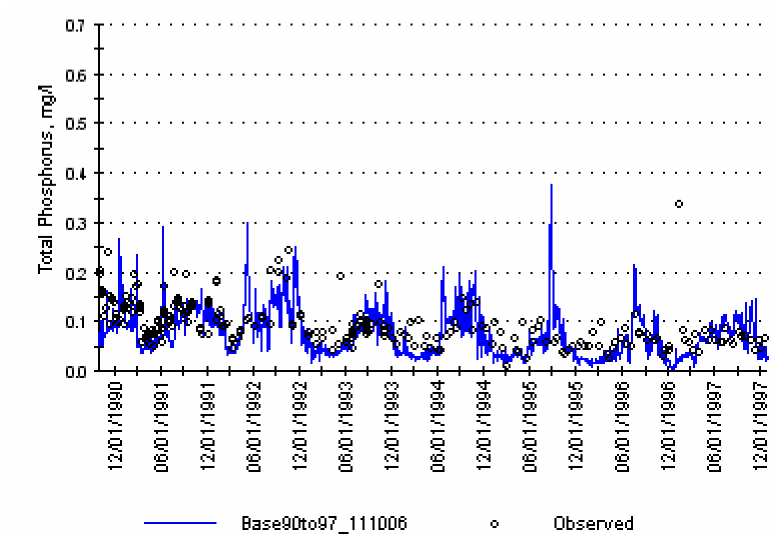


Figure 4.155 Simulated and Observed Total Phosphorus Concentration in Truckee River at Vista 1990-1997

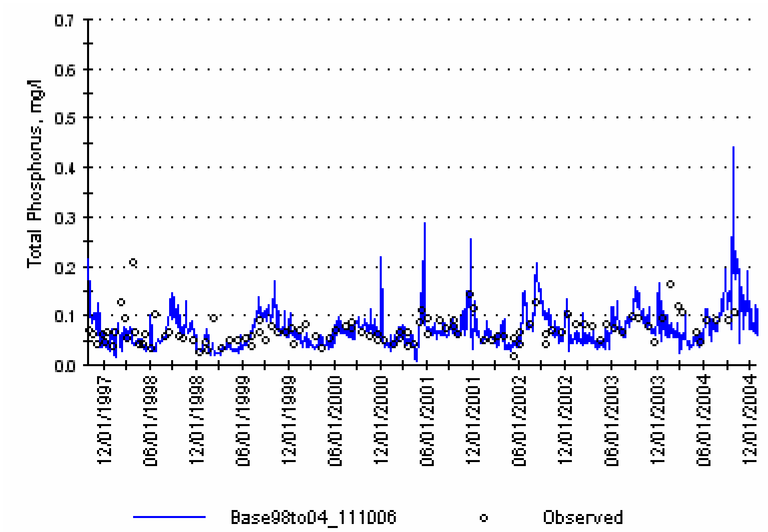


Figure 4.156 Simulated and Observed Total Phosphorus Concentration in Truckee River at Vista 1997-2004

4.3.5.8 Dissolved Organic Carbon (DOC)

Simulated and observed dissolved organic carbon concentrations for Truckee River at Vista are shown in Figures 4.157 to 4.158. Observed DOC concentrations for this location range from 1 mg/L to 8 mg/L and show a high degree of scatter and a slight pattern of lower DOC during the dry fall months and higher DOC during the wet spring months. WARMF simulated DOC generally following this pattern and are within the range of observed concentrations though WARMF over predicted DOC concentrations for several years.

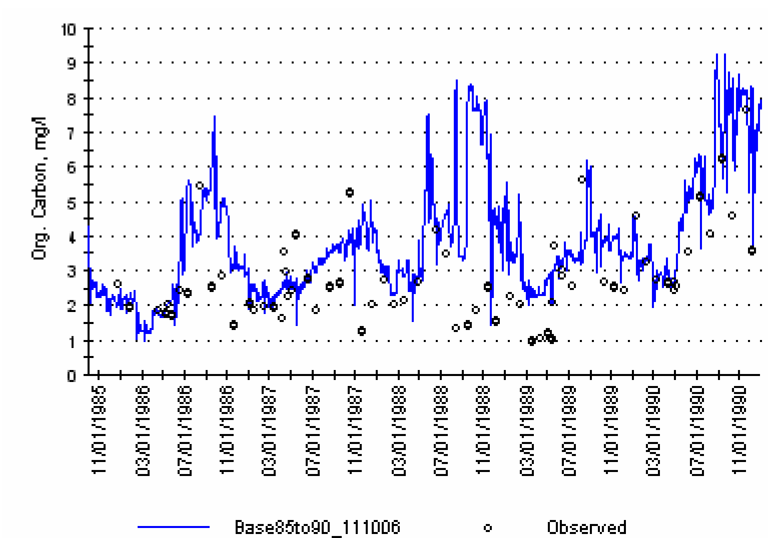


Figure 4.157 Simulated and Observed Dissolved Organic Carbon Concentration in Truckee River at Vista 1985-1990

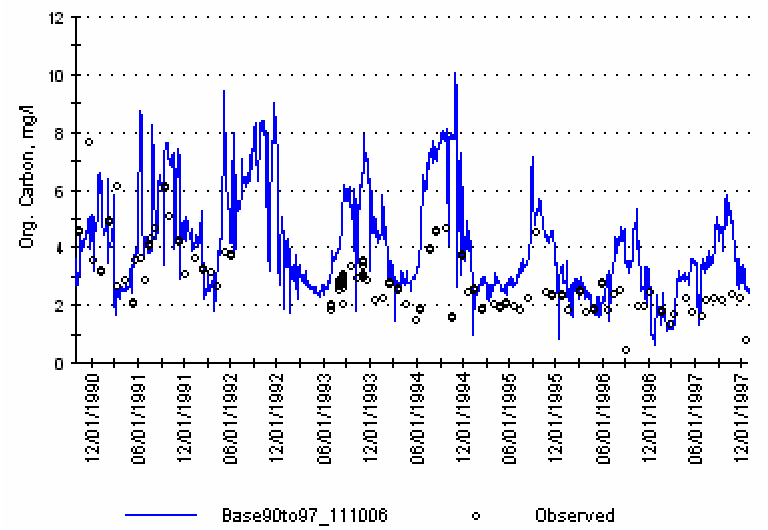


Figure 4.158 Simulated and Observed Dissolved Organic Carbon Concentration in Truckee River at Vista 1990-1997

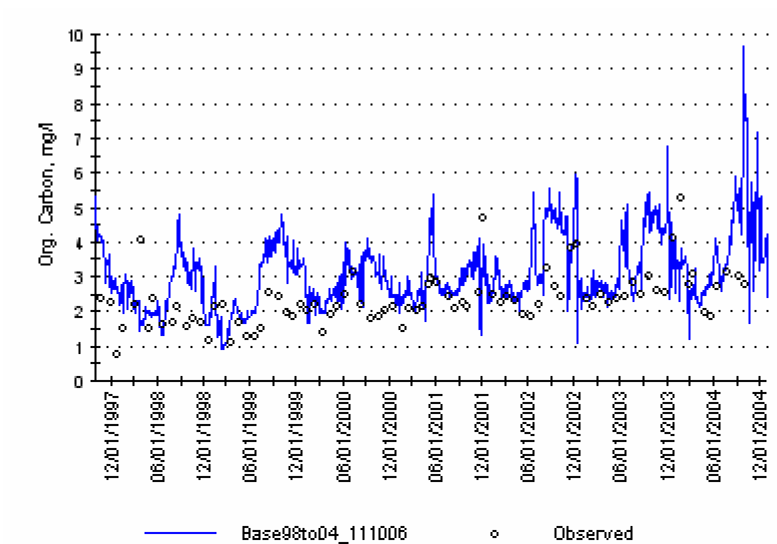


Figure 4.159 Simulated and Observed Dissolved Organic Carbon Concentration in Truckee River at Vista 1997-2004

4.3.5.9 Total Organic Carbon (TOC)

Figures 4.160 to 4.162 show simulated total organic carbon concentrations for Truckee River at Vista. Observed data was also available for comparison from 1985 to 1993 (Figures 4.160 and 4.161). For time periods with observed data, WARMF simulated the seasonal pattern and level of measured TOC within range.

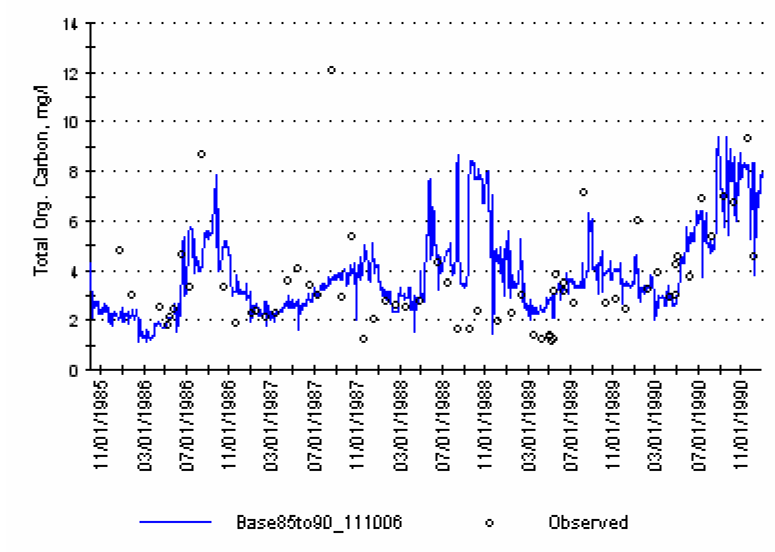


Figure 4.160 Simulated and Observed Total Organic Carbon Concentration in Truckee River at Vista 1985-1990

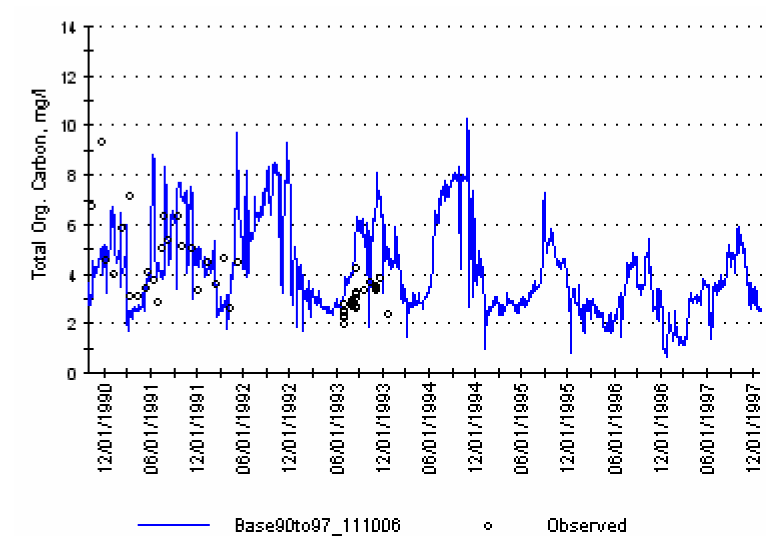


Figure 4.161 Simulated and Observed Total Organic Carbon Concentration in Truckee River at Vista 1990-1997

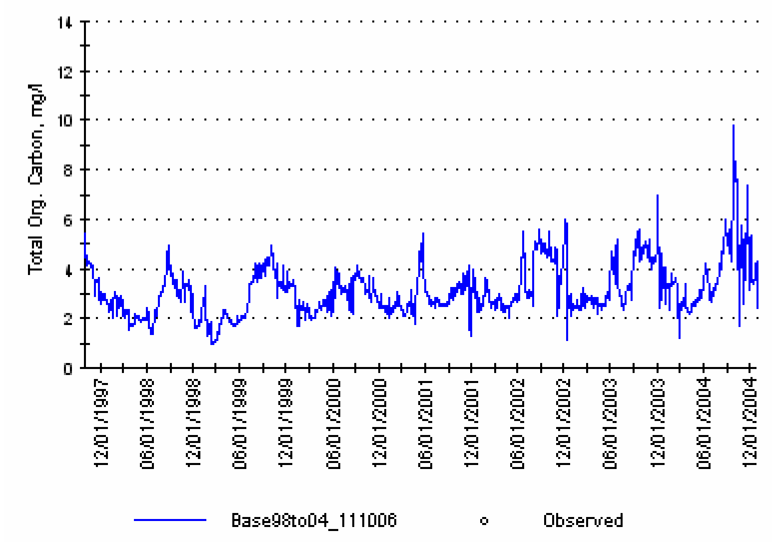


Figure 4.162 Simulated and Observed Total Organic Carbon Concentration in Truckee River at Vista 1997-2004

4.3.5.10 Total Dissolved Solids (TDS)

Simulated and observed TDS concentrations for Truckee River at Vista are shown in Figures 4.163 to 4.165. Measured TDS for this location typically ranges from 50 mg/L to 400 mg/L. For most years, a seasonal trend of high TDS during the dry fall months and low TDS during the wet spring months was also observed. WARMF captured this trend and simulated TDS concentrations very close to observed levels for all time periods.

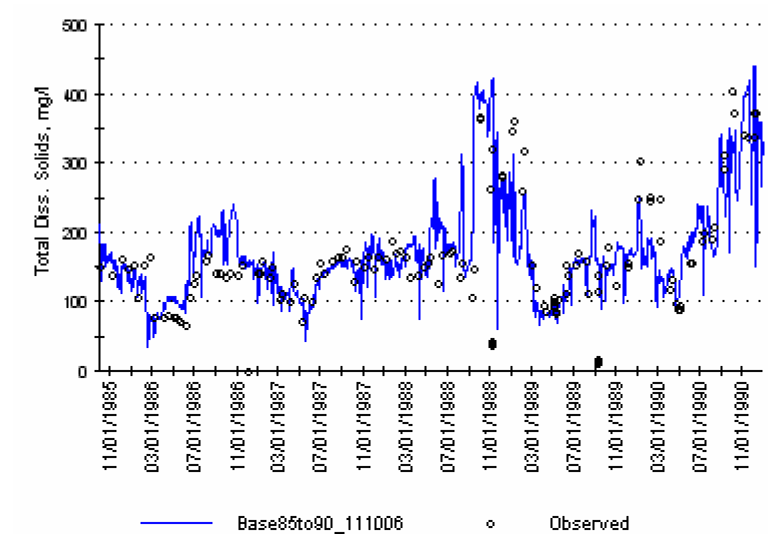


Figure 4.163 Simulated and Observed Total Dissolved Solids Concentration in Truckee River at Vista 1985-1990

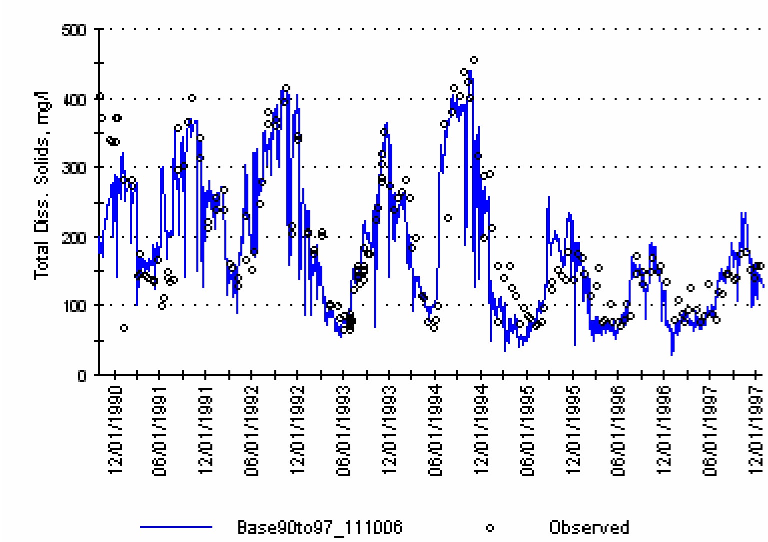


Figure 4.164 Simulated and Observed Total Dissolved Solids Concentration in Truckee River at Vista 1990-1997

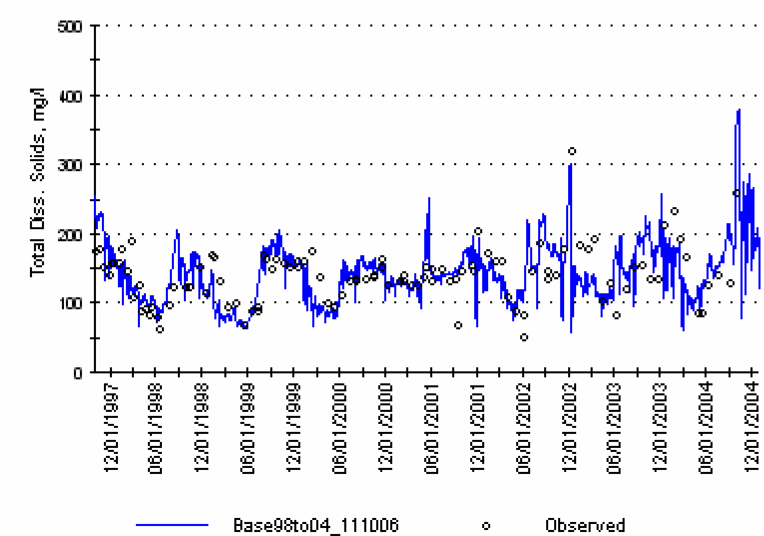


Figure 4.165 Simulated and Observed Total Dissolved Solids Concentration in Truckee River at Vista 1997-2004

4.3.6 Water Quality Discussion

Results presented in the Water Quality Calibration / Verification section above show that WARMF was able to predict concentrations during three different time periods cover a total of 20 years. Across the various time periods, model coefficients (e.g. reaction rates, soil conductivity) were held constant. This indicates that the calibrated WARMF model could be used to simulate flow and water quality during other time periods as well.

In addition to flow and in stream concentrations, WARMF is also able to predict average loading from a selected watershed region. As an example, Figure 4.166 shows the Total Nitrogen loading displayed for the Reno/Sparks/Steamboat Creek region (shaded pink) for the time period of 1990 to 1997 in units of kg/day. The fraction of total nitrogen loading that is from nonpoint sources is shown as the green bar and the point source fraction is shown as the magenta bar. The spreadsheet in the lower right corner of the figure shows the loading broken down by land use and/or source (e.g. forest land, residential, septic systems). Loading data can be extracted from WARMF for any selected watershed region and for any water quality parameter. Also, multiple scenarios can be compared side by side to view the increase or decrease in loading due to watershed management changes.

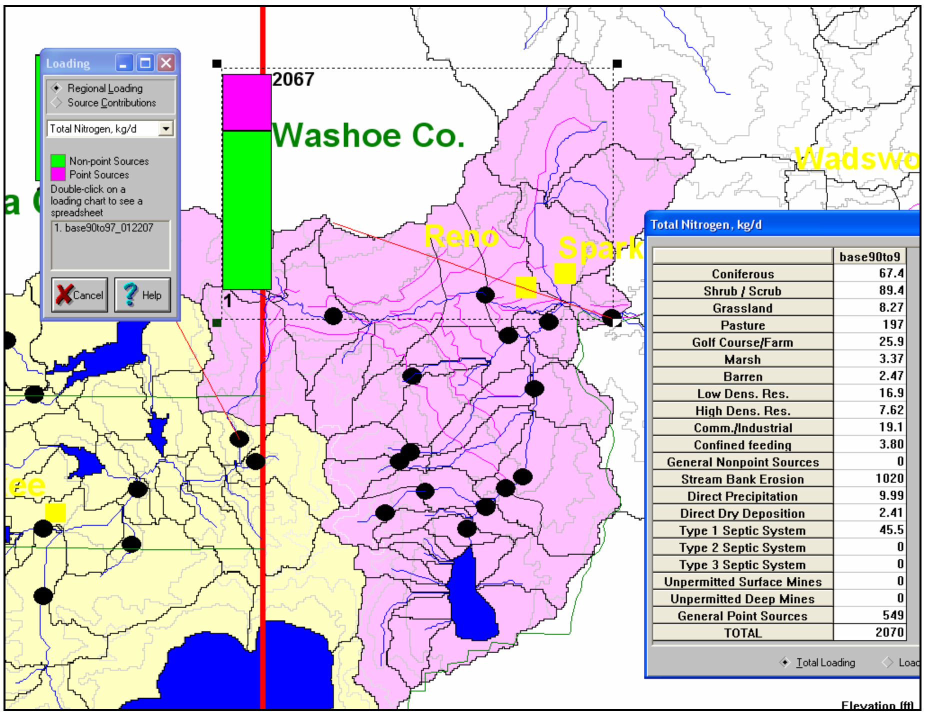


Figure 4.166 Point and nonpoint total nitrogen loading from the Reno/Sparks/Steamboat Creek Regions.

In addition to loading in units of mass per time, WARMF can also normalize the calculated loading into units of "yield" (mass / time * area). Table 4.1 shows the calculated yield of Total Nitrogen and Total Phosphorus for all simulated time periods.

Table 4.1 Simulated Nonpoint loadings for Reno/Sparks/Streamboat Creek Regions of the Truckee River Watershed.

	Total Nitrogen (lb/acre/yr)			Total Phosphorus (lb/acre/yr)		
	1985-1990	1990-1997	1998-2004	1985-1990	1990-1997	1998-2004
Low Density Residential	0.53	0.45	0.62	0.05	0.04	0.06
High Density Residential	0.89	0.76	0.85	0.09	0.08	0.09
Comm/Industrial	0.64	0.62	0.72	0.11	0.11	0.11

For comparison, a small amount of data were available for Reno and Sparks, based on two urban surface runoff loading studies (URS Company 1977 and City of Reno 1991). Table 4.2 presents the nonpoint source loads of nitrogen and phosphorus from residential and commercial/industrial lands. WARMF-predicted total nitrogen loadings compare well with calculated total nitrogen loading from the 1991 Reno study. The URS data was developed for a time period much earlier than was simulated and showed much higher loading yields that were predicted by WARMF. For total phosphorus, WARMF calculated loadings were slightly lower than determined by the Reno study and notably lower than was measured during the 1977 URS study. Though a direct match would not be expected when comparing WARMF simulated loading to these two data sets, it is useful to note that WARMF predictions are in the same order of magnitude as the measured yields and it is appropriate that WARMF loadings would match better with the 1991 study than the 1977 study due to the time periods selected for calibration / verification.

Table 4.2 Observed Nonpoint Loadings for Truckee River Watershed

	Total Nitrogen (lb/acre/yr)		Total Phosphorus (lb/acre/yr)	
	City of Reno 1991*	**URS 1977**	**City of Reno 1991***	**URS 1977**
Residential	0.58	4.75	0.27	1.46
Commercial / Industrial	0.58	2.96	0.27	0.62

* This study did not separate residential and industrial loading

Model adaptation and calibration were successful to produce a tool that is useful for predicting watershed conditions and evaluating the impact of land use change and watershed management on flow and water quality. That said, it is important to remember that models are only theoretical tools used to represent a watershed as closely as possible to real conditions. The model must be used with the understanding that it is simply an attempt to replicate actual conditions; it does not represent actual conditions. Appendix F provides several sample scenarios that were developed for and tested during the WARMF hands-on training workshops.

5. WARMF Linkage with TRHSPF

As part of the Truckee River 3rd Party TMDL effort, one key use of WARMF will be to link the tool with another model, TR-HSPF, which will be used to predict flow, temperature, nutrient and dissolved oxygen concentrations in the Truckee River. TR-HSPF was developed with a finer spatial resolution than WARMF and runs with a shorter timestep (30 minute).

5.1 Motivation for Model Linkage

Several issues motivated the linkage of WARMF with TR-HSPF. The modeling domain of TR-HSPF includes just the main stem Truckee River from Glendale Bridge down to Pyramid Lake. TR-HSPF relies on external boundary conditions for flow and water quality upstream of Glendale Bridge as well as for major tributaries (e.g. Steamboat Creek and North Truckee Drain) and for local flows and diversion return flows directly draining to the Truckee River. Previously, boundary conditions were estimated based on monthly data. Daily predictions from WARMF will provide a more complete flow and water quality prediction for boundary conditions. WARMF will also be useful to predict the impact of land use change on water quality. WARMF can incorporate future land use projections as well as modified reservoir operations, best management practices, septic system conversions and predict how these management practices will impact flow and water quality in the watershed.

5.2 Scenario Runs

Generating scenario output for import to TR-HSPF will involve the following steps:

1. Select the historical time period to use for meteorological conditions. For test cases the water year 1988 was used because it was a very dry year. Run a base case scenario for this time period.
2. Create a new scenario as a copy of the base case run.
3. Import the projected 2020 land use.
4. Process the required TROM data for input to WARMF. These data will be supplied from an external model and will include reservoir releases, diversions, and TMWRF discharges. Update the appropriate *.FLO files using the processed TROM data.
5. Update relevant point source files to represent future conditions (e.g. TMWRF, TTSA, smaller point sources) based on available projection data.
6. Apply any additional watershed changes (e.g. septic system conversion, stream restoration).
7. Run the scenario and look for any problems. Compare it with the base scenario created in Step 1. Expect some differences with look for any major anomalies.
8. Export the data using the *File / Export / Output* feature. The postproc.inp file in project directory contains locations and parameters which correspond with the setup for TR-HSPF. A zip file containing the exported boundary conditions will be prepared and transferred to the TR-HSPF modeling team.

6. Summary, Conclusions and Recommendations

6.1 Summary

The Watershed Analysis Risk Management Framework (WARMF) was applied to the Truckee River Basin of California and Nevada. The purpose was to provide stakeholders with a tool to explore the effects of potential management alternatives on the reduction of nutrient and total dissolved solids loads. It will also be used to develop anticipated nonpoint source loadings for input to the regional water quality models for the determination of total maximum daily loads (TMDLs).

For the site-specific adaptation, WARMF was enhanced to model the diversion and irrigation activity in the Truckee River basin. Algorithms were also implemented to model septic systems and periphyton.

Digital elevation model (DEM) data was imported into WARMF to delineate the watershed into catchments, rivers, and reservoirs. The input data was entered for land use, meteorology, air quality, point sources, channel and lake bathymetry, and surface loading to pastures, golf courses and urban areas. The stream flow and water quality data monitored at various locations were imported for comparison to the simulated results.

While WARMF was set up for the entire Truckee River, including the Tahoe basin, the focus of the study area was the Truckee River downstream of the outlet of the Lake Tahoe basin. Therefore, extensive calibrations were not performed for locations upstream of Lake Tahoe. Calibration / verification simulations of hydrology and water quality were performed for the time periods of 1985-1990, 1990-1997, and 1998-2004.

WARMF accurately predicted flow and concentrations of key water quality parameters in the Truckee River and major tributaries. Constituents compared with observed data include: flow, nitrogen species (NH_4, NO_3, TKN, total organic nitrogen, total nitrogen), phosphorus, organic carbon, and TDS). For hydrology, plotted output indicated a reasonable match of simulated flows with observed flows. For most locations and time periods, the calculated relative error was less than the desired +/- 10%. Water quality predictions yielded a reasonable match of simulated to observed concentrations for all parameters and locations. Locations and time periods with the largest discrepancies tended to have complicated diversion/irrigation activity and/or limited data to characterize watershed loadings such as point sources. The simulated nonpoint source loads of phosphorus and nitrogen from urban land use were compared to loading values measured in 1991 and 1977.

Local stakeholder information has been entered into WARMF. Examples have been developed to show stakeholders on how to apply WARMF to evaluate the water quality improvements that can result from various scenarios. The scenarios considered include water right purchases, livestock exclusion, river restoration, conversion of septic systems, and street sweeping. WARMF has also been set up and tested to link with TR-HSPF. Preliminary scenarios using future land use and TROA flows have been run to produce upstream (at Glendale) and tributary boundary conditions for input to TR-HSPF.

6.2 Conclusions

WARMF, like any other model, is only a simplified approximation of the real Truckee River Basin and its processes. However, the model has captured the major processes that control river flow, nonpoint source loads, and water quality of the Truckee River and Pyramid Lake. A good calibration requires not only a good model but also good input data and observed values. Limited data for inputs such as precipitation, diversions, point sources and nonpoint source loads from Steamboat Springs and the Fernley area precludes a perfect match between the simulated and observed values.

It is concluded that WARMF is ready for use **to evaluate management alternatives**. The stakeholders can develop nonstructural alternatives to examine various loading reduction scenarios and to evaluate their effectiveness in improving water quality.

6.3 Recommendations

Based on the results presented in this report, the following recommendations are made:

- Collect better diversion and irrigation data. This could involve some field measurements as well as better record keeping.
- Obtain additional loading data for specific land uses (residential, industrial, pasture, golf courses). The data can be used to improve the WARMF predictions of nonpoint source loads from various land uses.
- Obtain better data regarding the total dissolved solids loads coming from Steamboat Hot Springs and the Fernley area.
- Obtain better data for smaller point sources contributing loading to North Truckee Drain.
- Modify WARMF to improve simulations of diurnal fluctuations of dissolved oxygen due to periphyton. This can be accomplished by running WARMF with an hourly timestep and performing additional calibration adjustments for dissolved oxygen and periphyton.
- Continue to explore suspected but unquantified potential loading sources in the watershed (e.g. Huffaker Hills Reservoir, failing septic systems, confined feeding operations).

7. References

Ambrose, R.B., T.A. Wool, J.L. Martin, J.P. Connolly and R.W. Schanz, 1991. "WASP5x, a Hydrodyanmic and Water Quality Model - Model Theory, User's Manual, and Programer's Guide", Environmental Research Laboratory, Environmental Protection Agency, Athens, Georgia.

AGRA. 2000. "Strategies to Reduce the Cost of Converting Septic Tanks to Community Sewers in Washoe County (Sepic to Sewer Conversion Study)". Prepared for Washoe County Water Resources/Resource Planning and Management by AGRA Infrastructure Reno, NV Job No. 99050.30.

Beasley, D.B., L.F. Huggins, and E.J. Monke, 1980. "ANSWERS - a model for watershed planning", Transaction of ASAE, 23(4): 938-944.

Beasley, D.B. and L.F. Huggins, 1991. "ANSWERS User's Manual", Publication No. 5, Agricultural Engineering Department, University of Georgia, Coastal Plain Experiment Station, Tifton, GA.

Bohman, L. R. 1999. Estimation of Traveltime Characteristics for Truckee River Between Truckee, California, and Marble Bluff Dam Near Nixon, Nevada, and for Truckee Canal in Nevada. USGS Water-Resources Investigations Report 99-4226.

Brock, J. 1999. Personal Communication. Truckee River Cross Section Data from Steve Berris of USGS.

Carollo. 2001. Steamboat Creek Watershed Nonpoint Source Model Comparison Report. Draft Report. March 2001. Carollo Engineers. Walnut Creek, California.

Caupp, C.L., J.T. Brock, and H.M. Runke, 1998. "Application of the Dynamic Stream Simulation and Assessment Model (DSSAMt) to the Truckee River below Reno, Nevada: Model Formulation and Overview", Rapid Creek Research, Inc., Technical Report No. RCR98-1, Boise, Idaho.

CH2M Hill. 1999. Tahoe Truckee Sanitation Agency Water Reclamation Plant Expansion Project. Draft Environmental Impact Report. Vol. 1 and 2. CH2M Hill. April 1999.

Chen, C.W., S.A. Gherini, R.J.M. Judson, and J. D. Dean, 1983 "Integrated Lake-Watershed Acidification Study, Volume 1: Model Principles and Application Procedures", Final Report, Electric Power Research Institute, Palo Alto, California, EA-3221, Volume 1.

Chen, C.W. and R.P. Shubinski, 1971. "Computer Simulation of Urban Storm Water Runoff", Journal of Hydraulic Division, ASCE, Vol. 97, No. HY2, pp. 289-301.

Chen, C. W., J. Herr, L. Ziemelis, 1998. Watershed Analysis Risk Management Framework - A Decision Support System for Watershed Approach and TMDL Calculation. Documentation Report TR110809. Electric Power Research Institute, Palo Alto, California.

Chen, C.W., L.H.Z. Weintraub, R.A. Goldstein, R. I. Siegrist, S. Kirkland. 2001. Framework to Account for Onsite Wastewater Systems in Calculating Total Maximum Daily Loads. On-Site

Wastewater Treatment: Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems. American Society of Agriculture Engineers.

Crompton, E. J. and L. R. Bohman. 2000. Traveltime Data for Truckee River Between Tahoe City, California, and Marble Bluff Dam Near Nixon, Nevada, 1999. USGS Open-File Report 00-363.

Eppley, R.W. 1972. Temperature and phytoplankton growth in the sea. Fishery Bulletin 70:1063-1085.

EPRI. 2000. Peer Review of the Watershed Analysis Risk Management Framework (WARMF): An Evaluation of WARMF for TMDL Applications by Independent Experts Using USEPA Guidelines. TR1000252. Electric Power Research Institute. Palo Alto, California: 2000.

Gherini, S.A., L. Mok, R.J. Hudson, G. Davis, C.W. Chen, and R.A. Goldstein, 1985. "The ILWAS Model: Formulation and Application, Water, Air, and Soil Pollution 26: 425-459.

Guariso, G. and H. Werthner, 1989. Environmental Decision Support Systems. Ellis Horwood, Ltd., Chichester, West Sussex, England., p31.

Huber, W.C. and R.E. Dickinson, Storm Water Management Model User's Manual, Version 4, EPA/600/3-88/001a (NTIS PB88-236641/AS), Environmental Protection Agency, Athens, GA 1988

Katzer, T., J. F. Leising, K. Brothers, and G. W. Ball, Jr. 1998. Hydrogeological Evaluation and Groundwater Modeling of the Wadsworth-Dodge Flat Area, Washoe County, Nevada. Prepared for Town of Fernley by Watersource Consulting Engineers, Inc. Reno, Nevada.

Reno, City of. 1991. NPDES Permit NV0021768. Stormwater Discharge Permit. Twelve Month Report. August 29, 1991.

Systech Engineering, 2002. Adaptation of WARMF to the Truckee River Basin of California and Nevada. March 2002. Systech Engineering, Inc. San Ramon, CA.

Siegrist, R. L., J. McCray, L. Weintraub, C. Chen, J. Bagdol, P. Lemonds, S. Van Cuyk, K. Lowe, R. Goldstein, and J. Rada. 2005. Quantifying Site-Scale Processes and Watershed-Scale Cumulative Effects of Decentralized Wastewater Systems. Project No. WU-HT-00-27. Prepared for the National Decentralized Water Resources Capacity Development Project, Washington University, St. Louis, MO, by the Colorado School of Mines, Golden, CO.

URS Company, 1977. "Urban and Agricultural Non Point Waste Loadings to the Truckee River". Prepared for Washoe Council of Governments. Washoe County, Nevada.

USEPA. 1992. SWMM: Storm Water Management Model, Version 4.2. Center of Exposure Assessment Modeling. Environmental Protection Agency. Athens, GA.

Weintraub, L., C.W. Chen, W. Tsai, J. Herr, R.A. Goldstein, R. Siegrist. 2002. "Modifications of WARMF to Assess the Efficacy of Onsite Wastewater Systems on Public Health". Proceedings from WEFTEC 2002. Chicago, Il. September 30 – October 2, 2002.

Welsh Engineering Science and Technology, Inc. (WESTEC). 1994. Phase I and II of Fluvial Geomorphology Study Steamboat Creek Restoration Project. Project 13016, Report 959. – Qualitative, Particle Size Distribution for Lower Steamboat Creek.

Wood Rodgers, 2005. Irrigation Ditches on the Lower Truckee River. Wood Rodgers. Reno, NV

Appendix A: Model Enhancements

In order to adapt WARMF to the Truckee River watershed, it was necessary to implement several enhancements. The funding for these enhancements was provided by the Cities of Reno and Sparks, Washoe County and Electric Power Research Institute (EPRI).

A.1 Diversions and Irrigation

The Truckee River watershed is a highly managed system. Upon crossing the California stateline into Nevada, a significant portion of the Truckee River flow is diverted for municipal, industrial and irrigation use. The irrigation water is applied to agricultural and pasture lands. Some of the diverted water is also lost to other land uses during transport, livestock watering and evaporation.

WARMF was enhanced to handle the managed transfer of water in the basin. Water can be diverted from any river segment or reservoir by setting the appropriate *.flo* file in the *diversions from* column of the input dialog. The *.flo* file contains daily records of the water diverted. This data was obtained from the Federal Water Master. Ditches are shown on the basin map with a pink line and are linked to the river segment from which the water is diverted. Water quality in a ditch is modeled like a natural stream because it has the same concentration as the river it was drawn from and it is subjected to processes such as nitrification and reaeration. However, unlike natural streams, the flow in a ditch is specified by the *.flo* data file. Ditches are linked back to streams, and any water not used for irrigation will be return flow to that stream.

Diverted water is removed from ditches and applied to land as irrigation. For each catchment receiving diverted flow, the user can set the fraction of water coming from each diversion. This diverted flow will be applied to a particular land use, such as farmland, pastureland, or golf courses. An estimated volume of water may be applied to other land uses to account for the water lost during transport. Irrigation water will either percolate into the soil or run off depending on the current moisture level in the soil and the hydraulic conductivity. The irrigation water may pick up constituents as it passes through the soil or flows over the land surface. The water will be routed through the system and eventually returns to a river segment or reservoir.

A.2 Periphyton

Observed water quality data in the Truckee River indicates a decrease in nutrient levels between Vista and Marble Bluff Dam. This section of river receives very little precipitation to cause dilution, and given the agricultural return flows in the area, a nutrient increase might even be expected. Previous studies in the lower Truckee River have attributed this nutrient reduction to uptake by periphyton (attached algae) growing on the streambed.

Initially, WARMF did not simulate periphyton, and results indicated a significant over-prediction of nitrate in the lower Truckee River, especially during the summer months. As periphyton processes are an important river process, the addition of periphyton processes was vital to accurately model the river system. To account for this nutrient uptake, a periphyton algorithm was implemented based on the DSAMMt model (Caupp et. al 1998). WARMF differs from DSAMMt in that it models river water quality with a daily timestep instead of hourly.

A maximum growth rate for periphyton production, G_{max} (day^{-1}), is input, which can range from 1.0 to 10.0 day^{-1}. This periphyton growth rate would occur if the periphyton experienced no environmental limitations. However, the growth is limited by several factors including nutrient availability (*f*(*F*), *f*(*P*)), temperature (*f*(*T*)), light (*f*(*I*)), stream velocity (*f*(*V*)) and surface area availability (*f*(*S*)). Each of these limiting factors is determined and the maximum growth rate is adjusted as follows:

$$G = G_{\max} \times f(T) \times \min(f(N), f(P), f(I)) \times f(S)$$

where *f(T)* is temperature limitation, *f(N)* is nitrogen limitation, *f(P)* is phosphorus limitation, *f(I)* is light limitation, and *f(S)* is spatial limitation.

A.2.1 Temperature Limitation

Using the approach developed by Eppley (1972), the maximum growth rate at 20° C is adjusted for temperature as follows:

$$f(T) = \theta^{T-20}$$

where θ = 1.066; *T* = the stream temperature.

A.2.2 Stream Velocity

Elevated river velocities increase the availability of nutrients to periphyton. In quiet waters, a nutrient-deficient film forms at the surface of the cell. This film is swept away in faster moving waters resulting in a smaller gradient between the cell surface and the nutrient rich waters. However, the velocity can reach a point where higher velocities no longer increase the uptake. Similar to nutrient limitation, a Michaelis-Menten approach is used to calculate the stream velocity growth reduction factor:

$$f(V) = \frac{V}{V + K_V}$$

where *V* = stream velocity (m/s); K_V = half saturation constant for algal growth with respect to stream velocity (m/s).

A.2.3 Nutrient Limitation

Periphyton require both nitrogen and phosphorus to grow. The nitrogen requirement can be satisfied by ammonia, nitrite and nitrate, or a combination of both. The phosphorus requirement is satisfied by phosphate. To determine the limiting nutrient, the model uses the Michaelis-Menten approach and the stream velocity growth reduction factor to calculate two growth factors, one assuming nitrogen is limiting and the other assuming phosphorus is limiting:

$$f(N) = \frac{N \times f(V)}{N \times f(V) + K_N}$$

$$f(P) = \frac{P \times f(V)}{P \times f(V) + K_P}$$

where N = the concentration of nitrogen derived from ammonia and nitrate; K_N = half saturation of nitrogen; P = total dissolved phosphorus concentration; K_P = half saturation constant of phosphorus; $f(V)$ = stream velocity growth reduction factor.

A.2.4 Light Limitation

Light is the ultimate source of energy for periphyton growth. The growth rate peaks at an optimal light level. Too much or too little light will reduce the growth rate. The following equation is used to determine the growth factor for light.

$$f(I) = \frac{I}{I_S} \exp\left(1 - \frac{I}{I_S}\right)$$

where I = solar radiation attenuated to the stream bed; I_S = saturating light intensity.

A.2.5 Spatial Limitation

Since periphyton are attached algae, the amount of available space influences the growth rate. As the surface becomes more crowded, there is less room for the algae to grow and there is less light available. The following relationship represents the reduction in growth rate due to crowding:

$$f(S) = \frac{a \times Per + K_S}{Per + K_S}$$

where K_s = the spatial limitation half saturation constant (g/m^2); Per = periphyton density (g/m^2); a = spatial limitation intercept.

A.2.6 Periphyton Sinks

First order kinetics are used to model both sink terms for algae:

$$\frac{dPer}{dt} = -(K_r + K_{sc} + K_m \theta^{T-20}) \times Per$$

where $dPer/dt$ = sinks of periphyton ($g/m^2/sec$); K_r = respiration rate coefficient (day^{-1}); K_{sc} = biomass removal due to scour (day^{-1}); K_m = mortality rate (day^{-1}) based on herbivory; θ = 1.047; T = stream temperature; and Per = periphyton density (g/m^2). K_r is calculated from stream temperature and the adjusted maximum growth rate as follows:

$$\mathrm{K_r} = \mathrm{K_{rend}} \mathrm{e}^{\mathrm{K_{rexp}} \times \mathrm{T}} + \mathrm{F_{photo}} * \mathrm{G}$$

where K_{rend} = endogenous respiration coefficient, K_{rexp} = endogenous respiration exponential coefficient, T = stream temperature, F_{photo} = fraction of photosynthetic productivity that is oxidized by photorespiration, and G = periphyton production rate (day^{-1}) adjusted for light, temperature, nutrient and spatial limitation as described above. K_m is an input coefficient. K_{sc} is calculated from an empirical relationship as follows:

$$K_{sc} = a \times e^{bV}$$

where a = regression coefficient for periphyton removal (day^{-1}); b = velocity exponent coefficient for periphyton removal (m^{-1}); V = stream velocity (m/s).

A.2.7 Uptake and Release

When periphyton grows, it will consume a stoichiometric amount of nitrogen and phosphorus from the water. The stoichiometry assumes that periphyton composition by weight is 50% carbon, 1.2% phosphorus, and 9% nitrogen.

For phosphorus, the uptake will simply be removed from the total dissolved phosphorus in the water. For nitrogen, it can be removed from ammonia and nitrate. Like any algae, periphyton has a preference for ammonia over nitrate. The ammonia uptake is calculated as follows:

$$U_{NH4} = \frac{PF_N \times NH_4}{\left(PF_N \times NH_4\right) + \left(NO_3 + NO_2\right)}$$

where U_{NH4} = fraction of nitrogen uptake from ammonia; NH_4 = ammonia concentration; NO_3 = nitrate concentration; NO_2 = nitrite concentration; PF_N = preference factor.

The nitrate uptake is calculated by:

$$U_{NO3} = 1 - U_{NH4}$$

During photosynthesis, periphyton release oxygen to the water. During respiration, oxygen is consumed from water. The model properly accounts for these sink and source terms in the mass balance equation for dissolved oxygen.

The nutrients associated with respired periphyton are recycled back to the water column based on stoichiometry. For grazed and scoured periphyton, a fraction of the nutrients is removed from the mass balance and the remaining is recycled back to the water column. This fraction is a user input. The recycled fraction of grazed and scoured periphtyon is converted to organic carbon (20%) and detritus(80%). Organic carbon and detritus will decay based on the stoichiometry to consume oxygen and produce inorganic carbon, and nutrients.

A.3 Septic Systems

A significant portion of the residences in the Truckee River watershed use septic systems, also called onsite wastewater systems (OWS) for waste disposal. To account for this loading to subsurface flow, a septic system algorithm was developed. Initially, WARMF was modified to accept septic tank effluent discharged to a soil layer, much like an underground point source. Water and pollutants are added to the infiltrating water. Original algorithms for soil reactions were used to simulate groundwater quality. Thus, ammonia was retained by the soil through competitive cation exchange and was nitrified according to a kinetic rate coefficient. Phosphorus was adsorbed to soil according to an adsorption isotherm. The results showed that the model was able to track the transport and fate of nutrients through soil to the surface waters. However, the soil nitrification rate had to be increased substantially over the typical value normally used in the simulation of forested watersheds, where nitrogen was typically limiting (Chen et al. 2001).

Improvements upon this original approach were developed with EPA funding under the National Decentralized Water Resources Capacity Development Project (Siegrist et. al 2005). The model now calculates the "edge-of-drainfield" pollution loads rather than requiring them as input. The research conducted in this study clearly showed that OWS effluents created a biozone which enhanced treatment of pollutants (e.g., accelerated nitrification and pathogen removal and deactivation). To reflect this, the biozone algorithm was formulated and incorporated into WARMF to process the OWS effluents before releasing them to the underlying natural soil (Weintraub et al. 2002). The biozone algorithm simulates the growth of bacteria biomass in the top 2 cm of soil that receives a daily dose of septic tank effluent. The bacteria biomass acts like a sponge to absorb water that contains ammonia, pathogens and other pollutants. The process accelerates the ammonia nitrification and pathogen deactivation. It also leads to the gradual build up of plaque (dead bacteria and solid residue), which reduces effluent infiltration. Over time, a hydraulic failure can occur. Under such conditions, WARMF will store the septic tank effluent on top of the soil and spread the effluent across the surface of land catchment. The stored effluent can then infiltrate into soil in the areas without the biozone. It can also be transported offsite as surface runoff.

The biozone module was tested with data collected in the laboratory column experiments using an accelerated dosing rate. The tested module was then incorporated into WARMF to process the septic effluent before releasing it to a soil layer. Hydrology and water quality simulations were run for the Blue River watershed (CO) and the model was calibrated to available observed data. After establishing a base case, various management scenarios related to OWS were tested. These scenarios included the conversion of existing OWS to centralized sewers. The scenario runs provide information to evaluate the trade-offs between OWS and centralized sewer systems as well as the general impact of OWS on surface water quality.

For each catchment, WARMF can accept the input data of *population served by septics* (Figure A.1). The data can be estimated from GIS data and household size (see Section 3.2.10). WARMF accepts input for up to three (3) types of septic systems (e.g. standard, advanced treatment). The percent of each type can be specified in the catchment input dialog. The WARMF help system provides a compilation of literature sources regarding septic tank effluent quality for standard and advanced systems. Coefficients for the biozone algorithm are also specified in the catchment input dialog (e.g. initial biomass, biomass thickness, biozone area, biomass respiration and biomass mortality). Figure A.1 shows biozone coefficient values used for the Truckee River application. In the same dialog (Figure A.1), but under the *Reactions* tab, reaction rates for the soil and the biozone are set. Septic system effluent discharge quantity and quality is required for each type of septic system and specified in the System Coefficients input dialog under the *Septic Sys.* tab. (Figure A.2). Table 3.12 shows the input values used for the Truckee River application. Only standard septic systems were assumed for the Truckee River system.The biozone algorithm can be turned off for any catchment by setting the *Biozone Area* to zero. Turning this algorithm off will make simulation time faster. WARMF will follow the original septic system approach mentioned at the beginning of this section and use the soil reaction rates to process the septic system effluent.

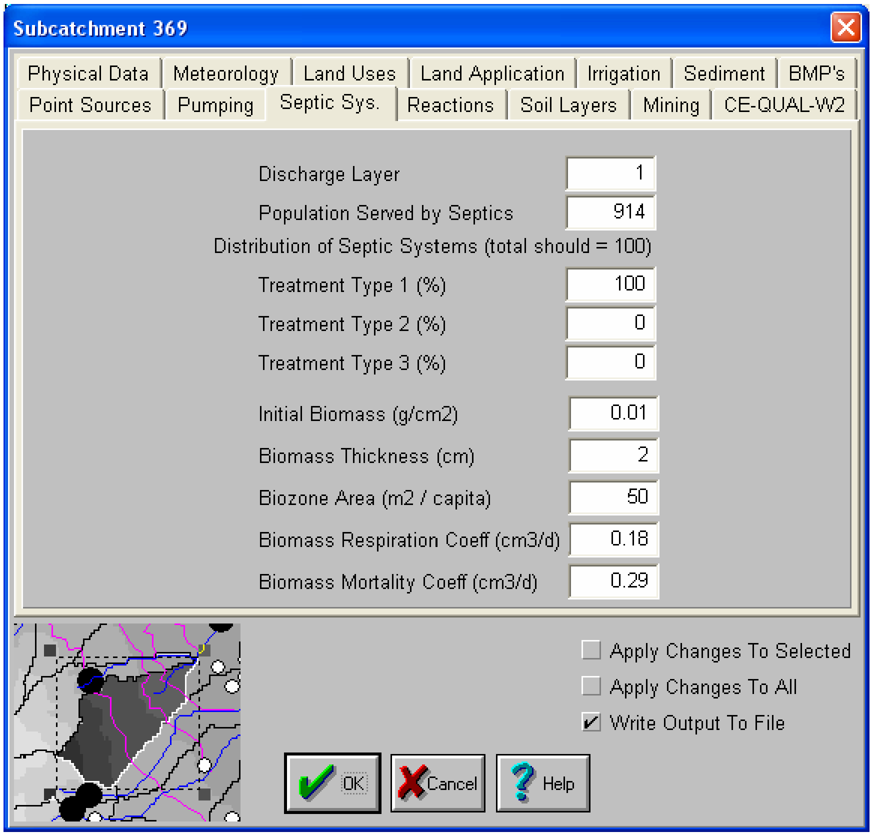


Figure A.1 Catchment input dialog for septic systems.

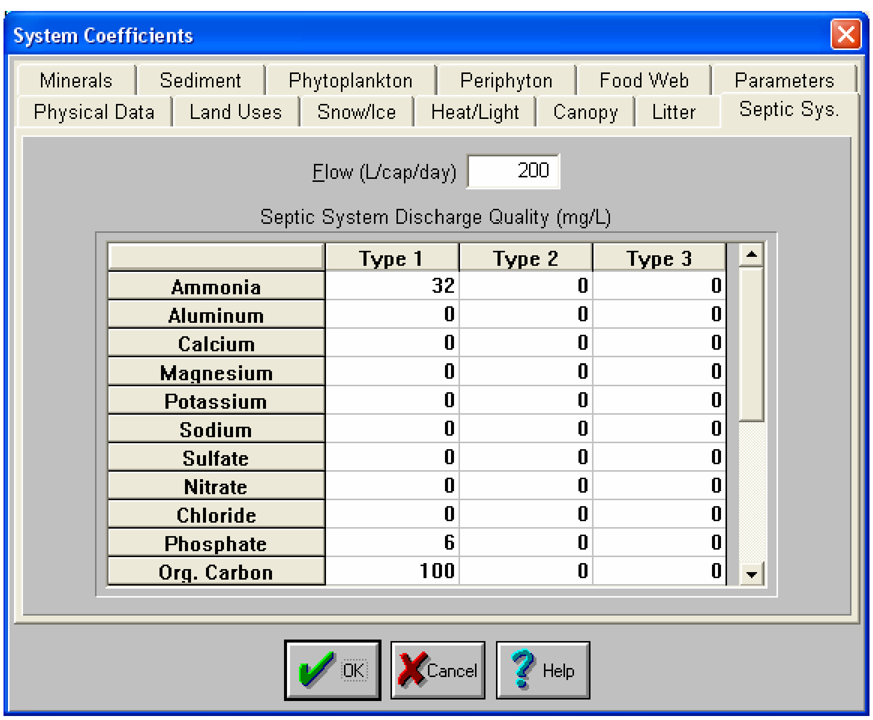


Figure A.2 System coefficient input dialog for septic systems

Appendix B: Data Source Websites

The following list includes several sources of data used for input to WARMF.

USEPA BASINS

http://www.epa.gov/waterscience/BASINS/

Meteorological Data

http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgr.html

http://cdo.ncdc.noaa.gov/CDO/mapproduct

Air Quality Data

http://www.epa.gov/castnet/data.html

http://nadp.sws.uiuc.edu/

Digital Elevation Model Data

http://edcsns17.cr.usgs.gov/EarthExplorer/

Streamflow Data

http://waterdata.usgs.gov/nwis/sw

Point Source Data

http://www.epa.gov/enviro/html/pcs/adhoc.html.

STORET Data

http://www.epa.gov/storet/

Reservoir Storage and Elevation Data

http://cdec.water.ca.gov/

US Census Septic System Data

http://arcdata.esri.com/data/tiger2000/tiger_download.cfm

http://www.census.gov/

Appendix C: Stakeholder Data

C.1 Stakeholder Meetings

The stakeholder process is a key component of a successful watershed program. An initial Truckee River stakeholder group was formed, which included five core stakeholders: City of Reno, City of Sparks, Washoe County, Nevada Division of Environmental Protection (NDEP), and Pyramid Lake Paiute Tribe (PLPT). These parties have vested interests related to the Truckee River total maximum daily loads (TMDLs), the TMWRF waste load allocation, future growth in the region, and the impact of activities on the water quality in the lower Truckee River and Pyramid Lake.

A series of stakeholder meetings were held to introduce the stakeholders to WARMF and its capabilities. During the workshops stakeholders provided model input by identifying waterbodies of concern, potential sources of loading, available data, and comments on the model. Throughout the stakeholder process, the stakeholders provided local knowledge of the watershed. As interest in the watershed modeling developed and knowledge of the project grew, the stakeholders group has grown into a group of over twenty, including the USEPA, USGS, USBR, DRI, FWM, and USFWS.

In August 1999, stakeholders were given a beta version of WARMF for review and comment. Several stakeholders provided feedback that was valuable for the continuing calibration and development of WARMF. Two hands-on WARMF training courses, sponsored by the Cities of Reno and Sparks, were taught for interested stakeholders in 2004 and 2006.

C.2 Stakeholder Data

WARMF can be used to store stakeholder information. Information for approximately 50 groups was collected and entered into WARMF's Consensus Module. Table C.1 documents a list of the stakeholders involved in the Truckee River WARMF application. The stakeholder information entered into WARMF includes the name, address, phone number, fax number, email address and area of expertise for each stakeholder. In a 1999 survey, stakeholders were asked to list their specific concerns and rank them on a scale of 1 to 5 for their relative importance, this information was also included in the database.

Table C.1 Truckee River Stakeholder Groups.

Stakeholder Groups	
Bureau of Indian Affairs, Western Nevada Agency	Stetson Engineers
California Department of Fish and Game	Storey County Public Works
Carson Truckee Water Conservancy District	Tahoe Resource Conservation District
Churchill County	Tahoe Truckee Sanitation Agency
City of Fallon	The Nature Conservancy
City of Fernley	Truckee Carson Irrigation District
City of Reno	Truckee Meadows Water Authority
City of Sparks	Truckee Meadows Water Reclamation Facility
Desert Research Institute	Truckee River Flyfishers
Fallon Paiute-Shoshone Tribe	Truckee River Yacht Club
Federal Water Master's Office	Univ. of Calif. Davis
Lahontan Regional Water Quality Control Board	Univ. of Nevada Cooperative Extension
LIMNO Tech	Univ. of Nevada Reno
Lyon County	University of Nevada Reno
Naval Air Station Fallon Environmental Dept.	US Army Corp of Engineers
Nevada County	US Bureau of Land Management
Nevada Department of Wildlife	US Bureau of Reclamation
Nevada Div. of State Lands	US Environmental Protection Agency
NV Division of Environmental Protection	US Fish and Wildlife Service
NV State Water Resources Division	US Geological Survey
Otis Bay Ecological Services	USFS Tahoe National Forest
Placer County Public Works	Washoe County
Pyramid Lake Paiute Tribe	Washoe-Storey Conservation District
Sierra County	

In the early stages of WARMF-Truckee development, the stakeholders developed the following mission statement for entry to WARMF:

> *The Truckee River Watershed Program's goal is to help ensure that current and future uses of the Truckee River watershed's resources are sustained, restored, developed and where possible enhanced, while promoting long-term social and economic vitality of the Region through a watershed approach.*

In addition, a feature of WARMF permits for the tracking of activities and meetings conducted by the stakeholder group as related to the watershed. The tasks performed by stakeholders to date have been entered, including workshops, meetings, and milestones of tasks.

C.3 Designated Uses and Water Quality Criteria

WARMF allows stakeholders to assign designated uses to various river and lake sections in the watershed. For each designated use, one or more water quality criteria may be specified. When those criteria are met, the water body is meeting the designated use. For the Truckee River application, criteria were dependent on three (3) different governing bodies: State of Nevada (NDEP), State of California (LRWQCB), and the Pyramid Lake Paiute Tribe (PLPT). Because the water quality criteria varied for each governing body it was necessary to set separate designated uses and standards for CA, NV, and PLPT.

Table C.2 lists the designated uses set for each governing body and the water quality parameters that have criteria established for each designated use. The numerical water quality criteria for Nevada and the Pyramid Lake Paiute Tribe have been entered into WARMF. For California, there is no direct link between the designated uses and the water quality standards contained in the LRWQCB Basin Plan. Therefore, it will be up to the stakeholders to assign the appropriate criteria on a site-specific basis when using WARMF.

Table C.2 Designated Uses in the Truckee River Watershed.

Governing Body	Designated Use	Water Quality Criteria
California (LRWQCB)	Agricultural Supply	set by stakeholder
	Biological Habitat of Special Significance	set by stakeholder
	Cold Freshwater Habitat	set by stakeholder
	Commercial/Sport Fishing	set by stakeholder
	Freshwater Replenishment	set by stakeholder
	Groundwater Recharge	set by stakeholder
	Industrial Service Supply	set by stakeholder
	Migration of Aquatic Organisms	set by stakeholder
	Municipal/Domestic Supply	set by stakeholder
	Navigation	set by stakeholder
	Hydropower Generation	set by stakeholder
	Rare, Threatened, Endangered Species	set by stakeholder
	Contact Recreation	set by stakeholder
	Non-Contact Recreation	set by stakeholder
	Spawning	set by stakeholder
	Wildlife Habitat	set by stakeholder
Nevada (NDEP)	Irrigation	pH, Cl, TDS, Na, Fecal
	Watering of Livestock	pH, DO, Cl, TDS, Fecal
	Contact Recreation	Temp, pH, DO, P, N, Fecal
	Non-Contact Recreation	DO, P, N, Fecal
	Industrial Supply	pH
	Municipal or Domestic Supply	pH, DO, Cl, TDS, Na, SO_4, P, N, Fecal
	Propagation of Wildlife	pH, DO, Cl, Fecal
	Propagation of Aquatic Life	Temp, pH, DO, TSS, P, N
Paiute Tribe (PLPT)	Aquatic Life	Temp, pH, DO, Cl, P, N, TDS, TSS, SO_4, Chl-a
	Contact Recreation	pH, P, N, TSS, Fecal, Chl-a
	Non-Contact Recreation	pH, P, N
	Wildlife Habitat	pH, TDS
	Water of Special Ecological Significance (WSES)	Temp, DO, P, N, Cl, TDS, TSS, SO_4, Na, Chl-a
	Extraordinary Aesthetic Value	N, TDS, TSS, Chl-a
	Freshwater Replenishment	TDS
	Municipal Supply	TDS
	Irrigation	Na
	Indigenous Aquatic Life	SO_4
	Coldwater/Spawning/Rare Species	Chl-a

C.4 Watershed Photographs

Photographs of the landscape or other aspects of the watershed can be imported into WARMF. For the Truckee River application, photographs taken during field visits and provided by stakeholders are included in the model. By using the view menu, one can view the locations of the photographs included in the model. The user can point and click at a location to view a photograph. Figures C.1 through C.4 show some of the Truckee River watershed pictures included in WARMF.

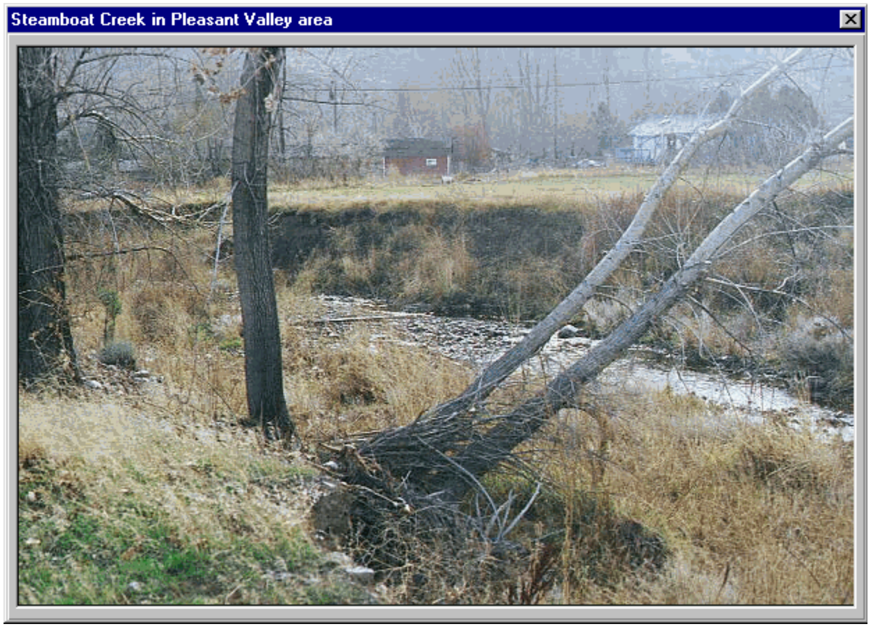


Figure C.1 Steamboat Creek in Pleasant Valley Area.

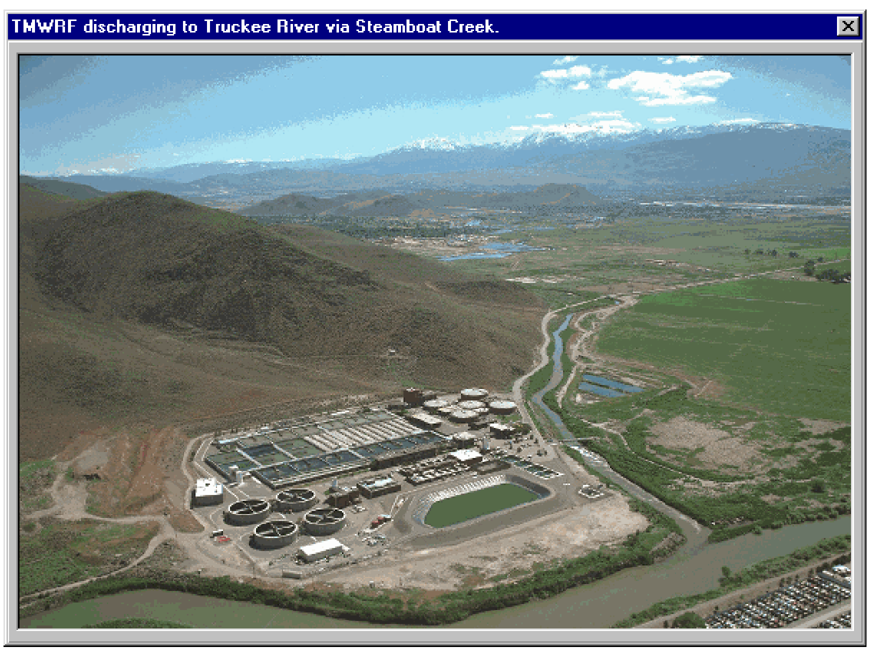


Figure C.2 Truckee Meadows Water Reclamation Facility at the Confluence of the Truckee River and Steamboat Creek.

Figure C.3 Derby Dam on the Truckee River and the Truckee Canal Diversion to Lahontan Reservoir on the Carson River.

Figure C.4 Truckee River Downstream of Reno, Nevada.

Figure C.5 Truckee River at McCarran Ranch restoration site.

Figure C.6 Truckee River at Marble Bluff Dam.

Appendix D: Documents Reviewed for Qualitative Information

The following documents and reports were reviewed the WARMF application effort to gain better understanding of the Truckee River system.

Source	Report
United States Geologic Survey	• Water Quality in the Las Vegas Valley Area and the Carson and Truckee River Basins 1992-1996, H. Bevans, M. Lico, S. Lawrence, Circular 1170 • Evaluation of Hydrogeology and Hydrogeochemistry of the Truckee Meadows Area, Washoe County, NV, P. Cohen, O. Loetz, 1964, Geological Survey Water-Supply Paper 1779-S • Planning and Design of Studies for River-Quality Assessment in the Truckee and Carson River Basins, California and Nevada, J. Nowlin, W. Brown, L. Smith, R. Hoffman, 1980, Open-File Report 80-435. • Phosphorus in the Truckee River Between Vista and Patrick, Storey and Washoe Counties, Nevada, August 1984, R. Hoffman, Water-Resources Investigations Report 89-4175 • Approximate Relationships Between River Inflows and the Lake Level and Dissolved-Solids Concentration of Pyramid Lake, Washoe County, Nevada, 1981, L. Smith, Open-File Report 82-80 • Hydrology, Activity and Heat Flow of the Steamboat Springs Thermal System, Washoe County, Nevada, 1968, D. White, USGS Paper 458-C • Daily Flow-Routing Simulations for the Truckee River, California and Nevada, 1996, S. Berris, Water-Resources Investigations Report 96-4097
Nevada Department of Environmental Protection (NDEP)	• Water Quality Conditions in Steamboat Creek, Washoe County, Nevada, 1987-1991, October, 1993, J. Reuter, C. Goldman, UC Davis Institute of Ecology Publication #39
Washoe County, NV	• Areawide Water Quality Management Plan, Phase I, Washoe County, Nevada, Nov. 1975, Walters Engineering, Metcalf and Eddy Engineers
Washoe-Storey Conservation District	• Steamboat Creek Restoration Plan, 1998, Jeff Codega Planning/Design Inc., WESTEC Inc.
US District Court Water Master's Office	• The United States of America vs. Orr Water Ditch Company, et al., Final Decree, 1944
University of Nevada, Reno	• Streamflow and Water Quality Effects of Groundwater Discharge to Steamboat Creek, Nevada, 1985, K. Shump • Evaluating the Efficacy of Artificial Wetlands in Removing Nitrogen from a Low-Strength Hatchery Effluent, February 1996, J. Warwick, D. Spinogatti

University of Nevada, Reno – Desert Research Institute (DRI)	• Hydrology of Truckee Meadows, NV, 1971, R.L. Cooly, J.W. Fordham, J.A. Westphal , Project Report No. 15 • A Preliminary Study of the Relationship Between Stream Water Quality and the Watershed Characteristics for the Truckee River, 1970, R.J. Morris, C.M. Skau, V. Vitale, Publication # 44007 • Algal Growth Potentials in the Truckee River, Lahonton Reservoir, and Pyramid Lake, NV, 1980, E. Lider, C. Bailey, D. Koch, Publication #50017 • Characterization of the Impact of Agricultural Activities on Water Quality in the Lower Truckee River, February 1995, D. Cockrum, J. Warwick, W. McKay, Publication No. 41147
University of California, Davis	• Pyramid Lake, Nevada Water Quality Study 1989-1993, Vol. I – IV, M. Lebo, J. Reuter, C. Rhodes, C. Goldman • Water Quality Conditions in Steamboat Creek, Washoe County, Nevada, 1987-1991, With Particular Emphasis on Nonpoint source Loading of Nitrogen, Phosphorus and Selected Metals, October 1993, J. Reuter, C. Goldman, Institute of Ecology Publication #39
Lahontan Regional Water Quality Control Board	• Truckee River Loading Study, 205(j) Program, June 1996, CH2M Hill
City of Sparks	• Overview of Existing and Potential Surface Water Storage, January 1992, CH2M Hill and Kennedy/Jenks Consultants, Technical Memorandum 6.6

Appendix E: Irrigation Model Inputs

Catchment	ID	**PASTURE**													
Farad	420	Stmboat	10	Katz	70										
Dog	164	Coldron	60												
Bull Ranch	419	Coldron	5												
Truckee-Mogul	418	Stmboat	3	Coldron	5	Highland	10								
Truck.-Alrington	2274	Highland	15												
Truck.-Glendale	2276	Highland	5	Eastman	30	Sessions	30								
Truckee-Reno	395	Eastman	40	N. Truck.	15	Sessions	40	Glendale	70	Pioneer	24				
Evans	368	Stmboat	4	Last Ch.	5	Lake	5								
Dry	369	Stmboat	6	Last Ch.	10	Lake	10								
Boyton	365	Last Ch.	18	Lake	40	Cochran	70								
Lower Thomas	371	Stmboat	6	Last Ch.	27	Lake	10								
Lower Whites	373	Stmboat	10	Last Ch.	10										
Whites-Thomas	372	Crane-Cl.	30												
Rhodes-Whites	676	Big	42	Hughes-C	42	Hansen	42	Chandler	70	Crane-Cl.	40	Steambt	10		
Galena-Rhodes	52	Big	28	Hughes-C	28	Hansen	28								
Lower Galena	693	Crutch.	52	N Call.	52	S Call.	52	E Call.	52	Smith	52	U. Sauer	48	L. Sauer	52
Browns-Galena	696	Crutch.	18	N Call.	18	S Call.	18	E Call.	18	Smith	18	U. Sauer	18	L. Sauer	18
N. Truck. Drain	127	Orr	40	N. Truck.	55										
Abv NTD.	130	Orr	1												
Abv NTD.	129	Orr	5												
Truckee-Vista	353	Noce	70	Murphy	21										
Truckee-Tracy	121	Murphy	14	McCarran	31										
TruckeeBelTracy	119	Hill	70												
Truckee-blwDerby	90	Washburn	66												
Truckee-abvWads	95	Herman	30	Gregory	35	Pierson	75								
Truckee-Wads.	105	Herman	30	Oling. 1	73	Proctor	50	Fellnagle	50	Oling. 3	50				
Truckee-Nixon	99	Gardella	61												
Marble Bluff	93	Indian	70												

Appendix E: Irrigation Percentages for WARMF Catchments (cont.)

Catchment	ID	**GOLF COURSES**			
Truck.-Alrington	2274	Highland	15		
Truck.-Glendale	2276	Highland	5		
Truckee-Reno	395	TMWRF	20	Pioneer	16
SB Term	364	Pioneer	8		
Dry	369	TMWRF	5		
Boyton	365	Lake	5		
Lower Thomas	371	TMWRF	16		
Lower Whites	373	TMWRF	9		
Lower Galena	693	U. Sauer	4		
Abv NTD.	129	Orr	5		

Catchment	ID	**GRASSES**			
Truck.-Alrington	2274	Highland	20		
Truckee-Reno	395	Pioneer	8		
SB Term	364	TMWRF	30		
Lower Thomas	371	TMWRF	14		
Rhodes-Whites	676	TMWRF	2		
N. Truck. Drain	127	TMWRF	4	Orr	19
Truckee-Tracy	121	Murphy	14	McCarran	24

Appendix E: Irrigation Percentages for WARMF Catchments (cont.)

Catchment	ID	**SHRUB/SCRUB**													
Farad	420	Stmboat	3	Katz	30										
Dog	164	Coldron	22												
Bull Ranch	419	Coldron	4												
Truckee-Mogul	418	Stmboat	7	Coldron	5	Highland	5								
Truck.-Alrington	2274	Stmboat	4	Highland	25	Last Ch.	8	Lake	10	Orr	5				
Truck.-Glendale	2276	Orr	5												
Truckee-Reno	395	Orr	5	Eastman	30	N. Truck.	8	Sessions	30	Glendale	30	Pioneer	24		
Evans	368	Stmboat	2	Last Ch.	6	Lake	2								
Dry	369	Stmboat	6	Last Ch.	2	Lake	4								
Boyton	365	Last Ch.	6	Lake	7	Cochran	30								
Lower Thomas	371	Stmboat	2	Last Ch.	4	Lake	7								
Lower Whites	373	Stmboat	4	Last Ch.	4										
Whites-Thomas	372	Chandler	15	Crane-Cl.	15										
Rhodes-Whites	676	Big	20	Hughes-C	20	Hansen	20	Crane-Cl.	15	Stmboat	2	Chandler	15		
Galena-Rhodes	52	Big	10	Hughes-C	10	Hansen	10								
Lower Galena	693	Crutch.	25	N Call.	25	S Call.	25	E Call.	25	Smith	25	U. Sauer	25	L. Sauer	25
Browns-Galena	696	Crutch.	5	N Call.	5	S Call.	5	E Call.	5	Smith	5	U. Sauer	5	L. Sauer	5
NTD	127	Orr	10	N. Truck.	22										
Abv NTD.	130	Orr	5												
Truckee-Vista	353	Noce	30												
Truckee-Tracy	121	Murphy	21	McCarran	30										
TruckeeBelTracy	119	Hill	30												
Truckee-blwDerby	90	Washburn	30												
Truckee-abvWads	95	Herman	15	Gregory	35	Pierson	25								
Truckee-Wads	105	Herman	15	Oling. 1	27	Proctor	30	Fellnagle	30	Oling. 3	30				
Truckee-Nixon	99	Gardella	26												
Marble Bluff	93	Indian	30												

Appendix F: Sample Model Scenarios

Stakeholders can use WARMF to explore various management alternatives and identify potential load reduction opportunities in the watershed. By following the Consensus Roadmap, stakeholders can see whether or not specific locations of the watershed are meeting their designated uses and how alternatives may reduce the point and nonpoint loading.

Stakeholders can also use the TMDL module of WARMF to calculate a TMDL for a specific water quality limited section. However, the application of WARMF to calculate TMDLs was not the initial goal of WARMF application to the Truckee River. Instead, the WARMF model, in the Truckee River application, was applied to quantify nonpoint source loads to the river for input into the existing water quality model and to support management decisions regarding nonstructural alternatives.

In the following sections, hypothetical examples will be provided to demonstrate how to develop and evaluate various management scenarios. Potential management scenarios include water rights purchases, livestock exclusion as a nonpoint source best management practice (BMP), stream restoration for sediment control, septic tank conversions as a nonpoint source BMP, street sweeping as an urban nonpoint source load reduction, and the development of a nitrogen TMDL. It is suggested that the user refer to the WARMF User's Guide for more information creating and running scenarios using the scenario manager.

F.1 Septic System Conversion

The Reno-Sparks-Truckee Meadows area contains roughly 10,000 septic systems that contribute nitrogen, phosphorus, fecal coliform, enteric virus and BOD loading to the system. About 5,000 additional septic systems are located elsewhere in the Truckee River watershed. WARMF can simulate the water quality improvements that can result from removal of septic systems completely or upgrading the existing septic systems to advanced treatment septic systems.

1) **Create New Scenario:** First re-select the base scenario (e.*g. 98to04_82406)* to be the active scenario. Under the **Scenario** menu, select **Scenario Manager**, and click on **Copy**. You will be asked if you want to copy the active scenario. Click **Yes**, and provide a new scenario name (e.g. ConvSeptic). Highlight the new scenario in the *Project Scenarios* column and use the **Open** button to open the new scenario. The new scenario should now appear in the *Open Scenarios* column. You may want to close other open scenarios. Click **OK** to close the Scenario Manager. Make the new scenario active by selecting it from the list under the **Scenario** menu item.

2) **Remove Septic Systems:** From the Engineering Module, make sure WARMF is in input mode by selecting **Mode / Input** from the main menu. Double click on one of the catchments listed in Table 1. To find a catchment on the map based on catchment ID number, select **Edit / Find** from the main menu. Enter the ID number (e.g. 418) in the *Find by ID Number* cell and click **OK**. Then the map will show this catchment highlighted. Double click on that catchment. Once a catchment is open, select the **Septic System** tab. Change the *Population Served* field from the existing value shown in column 2 of Table F.1 to the new value listed in column 5 (Figure F.1). Click **OK** and repeat changes for each catchment in the table. This change

reduces the number of septic systems operating within that catchment area. Select **Scenario / Save** to retain changes.\

Table F.1 Septic System Conversion Plan

Catchment	Existing Population Served	Tanks Converted	Converted Population	New "Population Served"
418	1296	540	1296	0
2274	1654	87	209	1445
419	31	22	31	0
2273	485	157	377	108
420	250	118	250	0
Total	3716	924	2163	1553

Assumptions: 1 septic system serves 2.4 people (Systech Engineering 2002, WARMF Adaptation Report, p.3-16), Average flow from septic system is 378 L/cap/day, (Systech Engineering 2002, WARMF Adaptation Report, p.3-16)

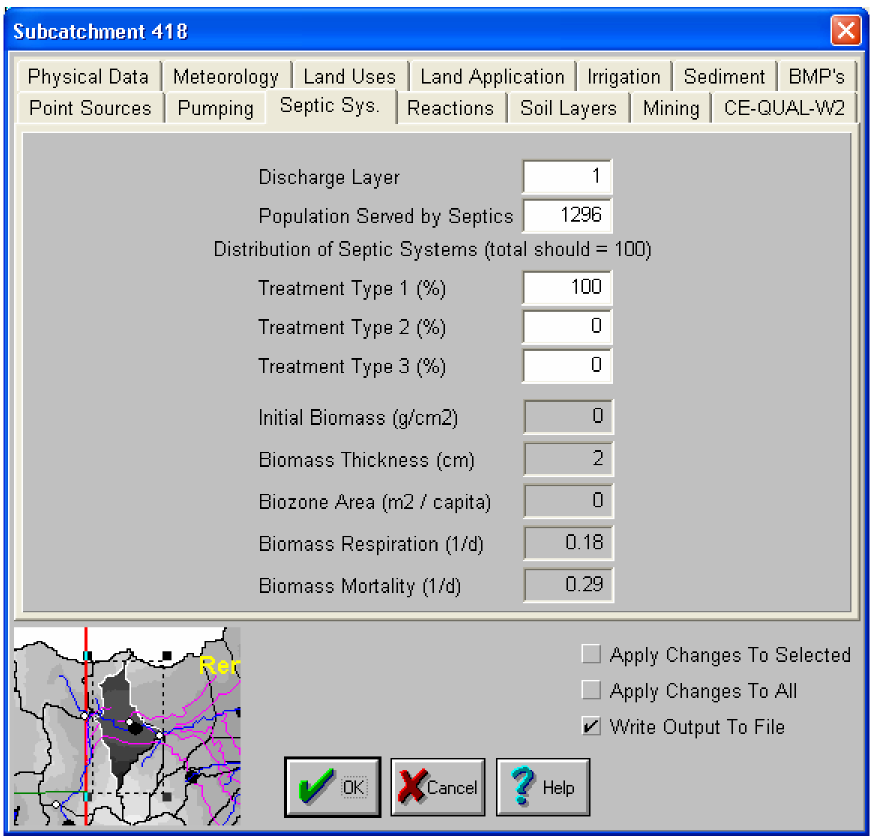


Figure F.1 Septic System input dialog for a catchment.

3) **Updated TMWRF File:** Now that the septic systems have been removed, the domestic waste from these homes has to be added to the TMWRF discharge. An updated point source file for TMWRF was prepared ahead of time. First, find the stream segment where the TMWRF discharge is added. It is a very short stream segment, near the confluence of Steamboat

Creek and the Truckee River (Figure F.2). The segment can be found using the **Edit / Find** feature for segment 67. Double click on this segment to open the input coefficients. You may need to zoom in the map using either the **View / Zoom In** feature from the main menu or the zoom "quick button" shaped like a magnifying glass located right under the main menu. Once the magnifying glass is selected, you can "click and drag" to create a box-shaped area to zoom into. Once you see the stream, double click to open it. The name of the segment should be "TMWRF Discharge" with a stream ID of *67*. Select the **Point Sources** tab. The only point source in the list should be *nv0020150.pts*. First add the new point source by clicking on **Add** and selecting *TMWRFConvSeptic.pts* from the list (Figure F.3). Once this shows up in the list, remove the original file (*nv0020150.pts*) by selecting it in the list and clicking **Remove**. Click **OK** and select **Scenario / Save** to retain changes.

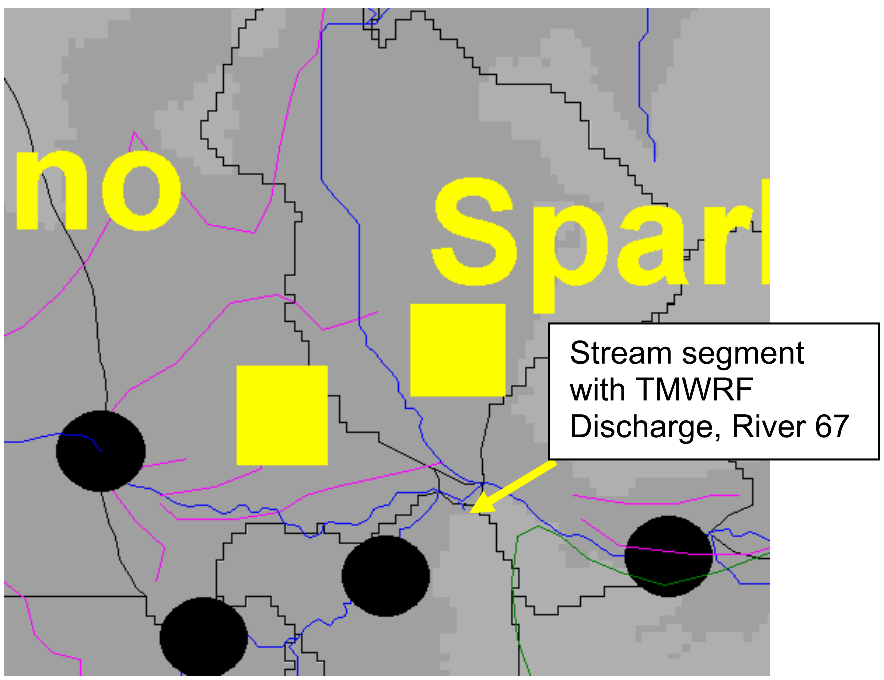


Figure F.2 Zoom in of stream segment with TMWRF discharge, River 67.

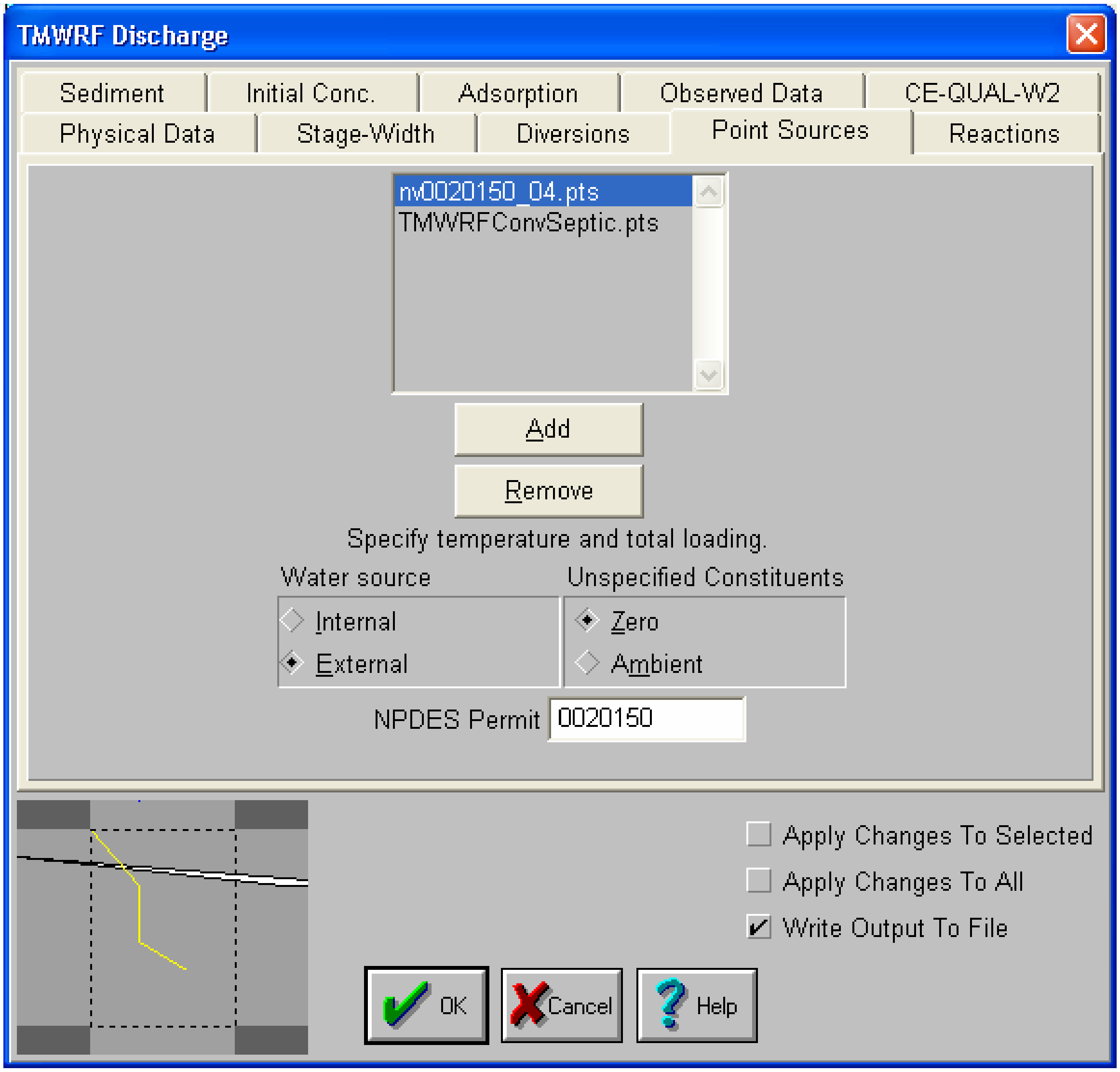


Figure F.3 River Point Source input dialog

4) **Run Simulation:** In the **Engineering** module, select **Scenario / Run**. Make sure the **Generate Loading Data** switch is on. Click **OK** to run the simulation with the existing settings for beginning date (10/1/1997), ending date (12/31/2004), etc. Wait for the simulation to complete. When the simulation finishes, close the black dialog box using the "x" in the upper right corner or using **File / Exit**.

5) **View Loading Output:** From the Consensus module, click on **Loading (step 4)** to see how the reduction of point sources affects the overall loading. The point source loading is shown in magenta and the nonpoint loading is shown in green. Double click on the loading chart to obtain numerical values for the loading.

6) **View Water Quality Output:** Shift WARMF into output mode by using the **Mode / Output** menu item. Double click on any river segment to view hydrology and water quality results.

F.2 Water Augmentation / Land Use Change

This example demonstrates how reduced diversions to agricultural lands and a projected future land use condition will affect loading and instream water quality.

1) **Create New Scenario:** Under the **Scenario** menu, select **Scenario Manager**, select a base scenario, and click on **Copy**. You will be asked if you want to copy the active scenario. Click **Yes**, and provide a new scenario name (e.g. BuyWaterLU). Highlight the new scenario in the *Project Scenarios* column and use the **Open** button to open the new scenario. The new scenario should now appear in the *Open Scenarios* column. Click **OK** to close the Scenario Manager. Make the new scenario active by selecting it from the list under the **Scenario** menu item.

2) **Reduce Diversions**: Under the **Module** menu, select **Consensus**. Go to step 5. Click the pull down arrow for **Edit** box and select **Diversions**. Push **Edit** button to display global reduction factors for various diversions. Reduce the diversion amount by changing the weighting factor from 1.0 to the level specified in Table 2 for each diversion. See Figure F.4. Click **OK** and select **Scenario / Save** to retain changes.

Table F.2 Reduced Diversions for Example 2.

Diversion	% of Historic Diversion	WARMF Multiplier
Orr	8%	0.08
Last Chance	15%	0.15
Lake	15%	0.15
Steamboat	10%	0.10

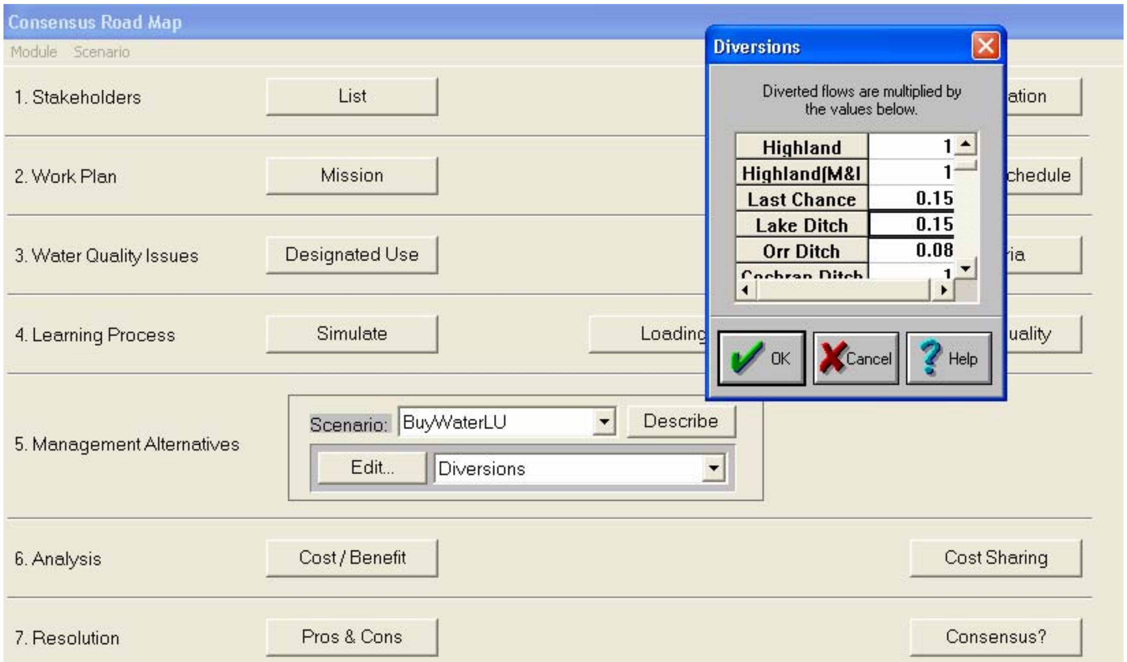


Figure F.4 Diversion reduction factors for Example 2.

3) **Import Future Land Use:** Switch back to the Engineering module. Select **File / Import / Land Use** from the main menu. Select the ArcView shape file, *2020lu_dd.shp* from the Truckee directory and click **Open**. Choose the field which represents the land use code for each polygon in the shapefile (**GRIDCODE)**. Press OK, and another dialog box will appear (Figure F.5). Match the GIS land use codes (Code) with the watershed's land use IDs. The watershed's land uses are listed on the right. The land use codes found in the shapefile are shown in the row headers of the spreadsheet. Within the spreadsheet, enter the number of the land use on the right corresponding to each land use code. Table F.3 shows how the table should look for this example. When **OK** is pressed, the polygons in the shapefile will be overlayed with the catchments in the watershed. This step may take a few minutes and will be complete when the "hourglass" disappears and the GUI is once again active. Click on **Scenario / Save** to retain changes.

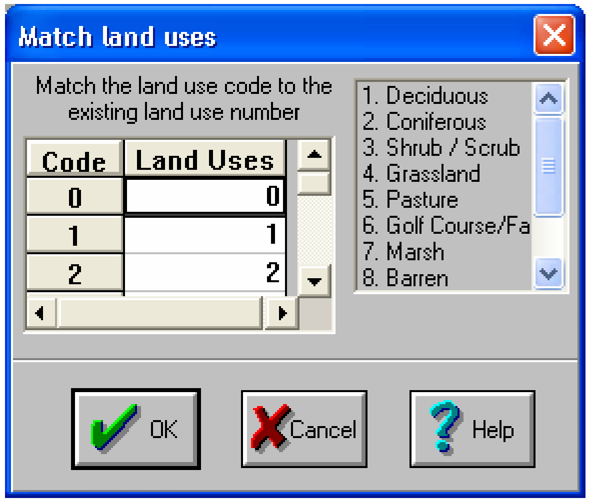


Figure F.5 Dialog for matching GIS land use codes with WARMF land use IDs.

Table F.3 GIS land use codes compared with WARMF land use codes

Land Use	GIS Code	WARMF Land Use
Water	0	0
Deciduous Forest	1	1
Coniferous Forest	2	2
Shrub / Scrub	3	3
Pasture	4	5
Grassland	5	4
Marsh	6	7
Barren	7	8
Low Dens. Residential	8	9
High Dens. Residential	9	10
Commerical / Industrial	10	11
Golf Course / Farm	11	6

4) **Run Simulation:** In the **Engineering** module, select **Scenario / Run**. Make sure the **Generate Loading Data** switch is on. Click **OK** to run the simulation with the existing settings

for beginning date, ending date, etc. Wait for the simulation to complete. When the simulation finishes, close the black dialog box using the “x” in the upper right corner or using **File / Exit**.

5) From the Consensus module, click on **Loading (step 4)** to see how the reduction of point sources affects the overall loading. The point source loading is shown in magenta and the nonpoint loading is shown in green. Double click on the loading chart to obtain numerical values for the loading.

6) Shift WARMF into output mode by using the **Mode / Output** menu item. Double click on any river segment to view hydrology and water quality results.

F.3 Stream Restoration / Livestock Management

This scenario investigates the effects of stream restoration sediment and nutrient loading in the Steamboat Creek region.

1) **Create New Scenario:** First re-select *98to04_82406* to be the active scenario. Under the **Scenario** menu, select **Scenario Manager**, and click on **Copy**. You will be asked if you want to copy the active scenario. Click **Yes**, and provide a new scenario name (e.g. StRest). Highlight the new scenario in the *Project Scenarios* column and use the **Open** button to open the new scenario. The new scenario should now appear in the *Open Scenarios* column. You may want to close other open scenarios. Click OK to close the Scenario Manager. Make the new scenario active by selecting it from the list under the **Scenario** menu item.

2) **Add BMPs:** From the Engineering Module, make sure WARMF is in input model by selecting **Mode / Input** from the main menu. While holding down the *shift* key and doing single clicks, select multiple catchments in the Steamboat Creek area (Figure F.6). Double click on one of the catchments that is selected and select the **BMPs** tab (Figure F.7). Under *Livestock Exclusion*, change the % loading to stream for *Pasture* from the current value to **0**. This change represents a fencing of all livestock in pasture areas away from the streams. Under *Buffer Zone*, change the *Percent Buffered* from the current value to **100**. This change represents increased buffering along all stream segments. Select the **Apply Changes to Selected** box in the lower right corner to set these coefficients for the pre-selected catchments in the Steamboat Creek region. Click **OK** and select **Scenario / Save** to retain changes.

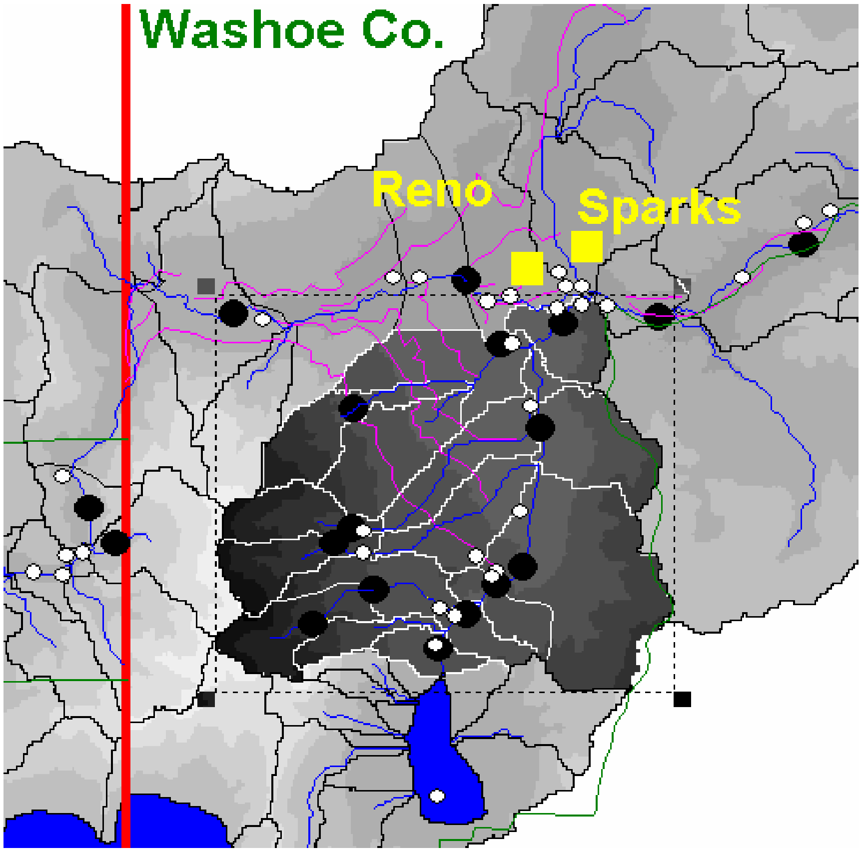


Figure F.6 Selection of multiple catchments in the Steamboat Creek region.

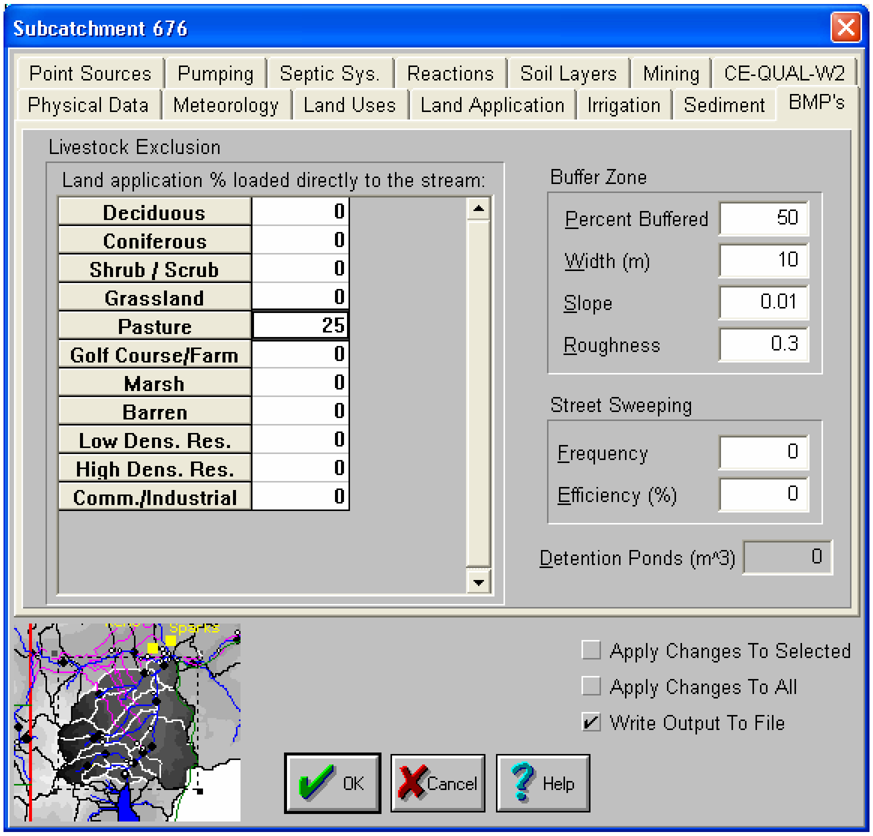


Figure F.7 BMP input dialog

3) **Reduce Bank Erosion:** As was done while selecting multiple catchments, hold down the shift key and single click on several rivers in the Steamboat Creek region to select them as a group. They will turn yellow once they are selected (Figure 8). It is a little more difficult to select rivers. You may want to zoom into the region to make it easier. Double click on one of the rivers that is selected and select the **Sediment** tab (Figure 9). Change both the Vegetation Factor and Bank Stability Factor from the current value to 0. This change represents and increase in bank stability do to re-grading, vegetation, restricting animal access, etc. Select the **Apply Changes to Selected** box in the lower right corner to set these coefficients for the pre-selected rivers in the Steamboat Creek region. Click **OK** and select **Scenario / Save** to retain changes.

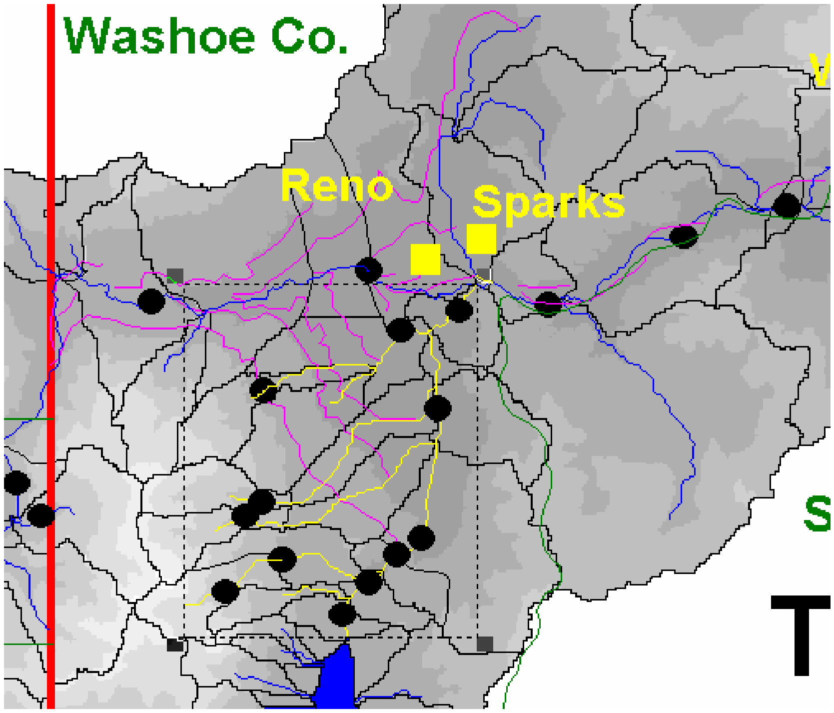


Figure F.8 Selection of multiple rivers in Steamboat Creek region.

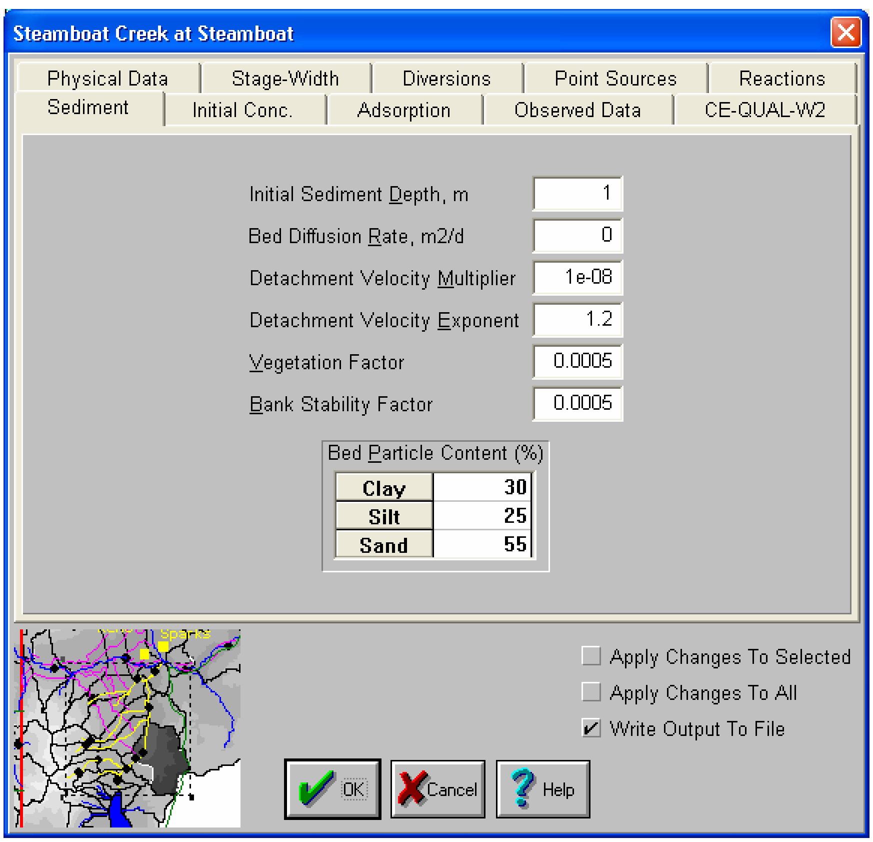


Figure F.9 River sediment input dialog

4) **Run Simulation:** In the **Engineering** module, select **Scenario / Run**. Make sure the **Generate Loading Data** switch is on. Click **OK** to run the simulation with the existing settings for beginning date, ending date, etc. Wait for the simulation to complete. When the simulation finishes, close the black dialog box using the "x" in the upper right corner or using **File / Exit**.

5) **View Loading Output:** From the Consensus module, click on **Loading (step 4)** to see how the reduction of point sources affects the overall loading. The point source loading is shown in magenta and the nonpoint loading is shown in green. Double click on the loading chart to obtain numerical values for the loading.