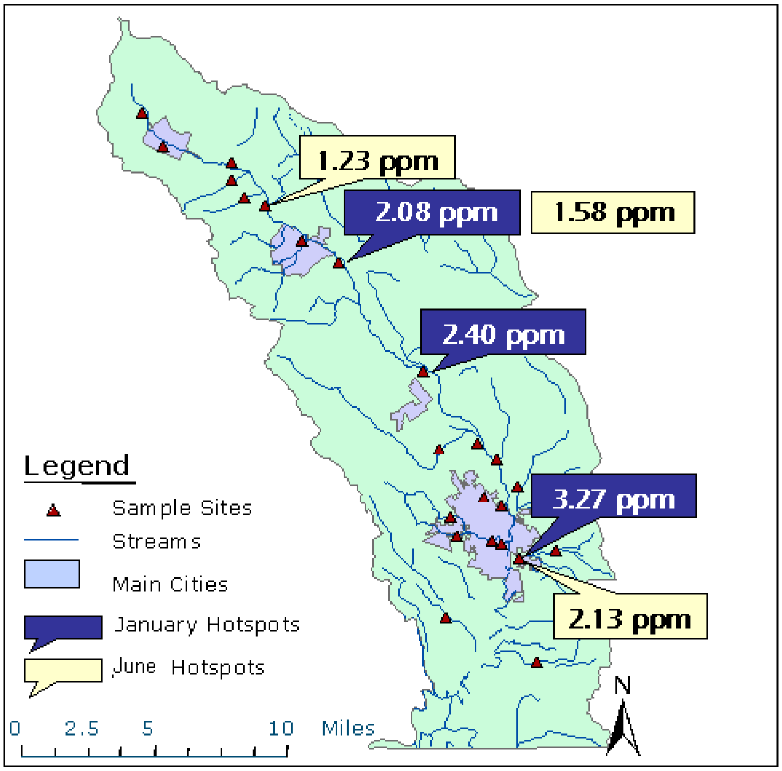
Developing a Nutrient Management Plan for the Napa River Watershed



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1.0 - ABSTRACT

The Napa River Watershed is impaired due to excessive sediment loading, nutrient loading, and pathogens. This project focuses on the nutrient impairment in the watershed and aims to assist in total maximum daily load (TMDL) development. The San Francisco Bay Regional Water Quality Control Board (RWQCB) will submit the final nutrient TMDL to the Environmental Protection Agency by December 31, 2005. Potential sources for nutrient loading have been identified as fertilizer and livestock runoff, defective septic system seepage, wastewater treatment plant (WWTP) effluent, and urban runoff. This project delivers a nutrient management plan designed to reduce nutrient input into the watershed to achieve target concentrations. The watershed modeling programs BASINS (Better Assessment Science Integrating point and Non-point Sources) and WARMF (Watershed Analysis Risk Management Framework) were run in parallel to identify sources, calculate estimated daily loads, determine a linkage analysis, and to assist in simulating load reduction scenarios. Based on the models' results, a TMDL was identified for the wet season target; however, the dry season target was unattainable, even in the absence of all anthropogenic point and non-point sources. The best management practices (BMPs) examined for each of the major contributing sources were evaluated primarily for cost-effectiveness. Recommended measures consist of retrofitting the WWTPs with 3-stage nitrification-denitrification system, Nitrex^{TM} filter retrofits for faulty septic systems; and fertilizer reduction through the installation of grass swales or constructed wetlands. Management measures for the urban land use sector are less cost-effective in comparison to BMPs in other land use sectors and thus were not the focus of this projects reduction recommendations.

2.0 - EXECUTIVE SUMMARY

The EPA identified the Napa River as an impaired water body under section 303 (d) of the Clean Water Act in 1998. Excess sediment, pathogen, and nutrient loading have contributed to the impairment of the water body. This project focuses specifically on the nutrient impairment in the river. The nutrient loading of water-soluble nitrate and ammonia has resulted in high levels of dissolved nitrogen throughout the river, which in turn has led to eutrophication in the watershed- impeding the use of the river and its tributaries for recreational activities and fish and wildlife habitat. Among the fish spawning in the river are the endangered Chinook Salmon and Steelhead Trout. Eutrophication leads to increased algal growth and reduced oxygen levels in the river, damaging its aesthetic quality and natural habitat. World renowned for its fertile soil and extensive high quality wine production, the recent listing of the Napa River as impaired by nutrient loading may seem connected primarily to agricultural development, yet extensive modeling of source loading identifies numerous contributors, including point sources such as wastewater treatment plants, and non-point sources such as septic system seepage, agricultural and urban runoff, and atmospheric deposition.

The San Francisco Bay RWQCB conducted sampling events in January and July of 2003 at 23 sites throughout the Napa River and its tributaries in effort to document seasonal levels of nutrient indicators such as nitrate, ammonia, dissolved oxygen, and chlorophyll A. In particular, field surveys examined the concentration of the excess nitrogen, as total dissolved nitrogen (TDN), in water due to nitrate and ammonia from anthropogenic and natural sources. At this time the RWQCB has not yet established numeric nutrient targets for the Napa River TMDL, nor has it established numeric water quality objectives for the region. For the purposes of this report, targets of 0.2 mg/L TDN in the dry season, and 1.0 mg/L TDN in the wet season will be used. It is believed that these values are similar to the numeric targets that the RWQCB will establish for the Napa River

Nutrient TMDL (P. Krottje, personal communication). A comparison of the TDN concentrations from wet and dry season samples indicate that the TDN levels in both seasons exceeded water quality targets along the main river stem, except at the northernmost site. In the tributaries, TDN concentrations mostly remained below water quality targets in the wet season, but exceeded the target levels at almost all sites during the wet season. These initial findings served as a benchmark for further studies exploring the allocation of nutrient load reduction.

Computer models were used to estimate the reduction in nutrient loading needed in order to achieve TDN levels in compliance with water quality standards. Using observed levels of TDN as a calibration reference, nutrient loads to the Napa River were approximated using the watershed models SWAT (Soil and Water Assessment Tool) and WARMF (Watershed Analysis Risk Management Framework). The calibrated watershed models were then used to determine the nutrient loading capacity through a simulation of the physical, chemical, and biological processes in each of the computer generated sub-watersheds units. From the modeling output, a nutrient management plan was developed to reduce the current nutrient loading to the desired nutrient loading target concentrations.

The nutrient management plan considers a number of cost-effective best management practices designed to reduce nutrient loads from the various sources. In order to determine the effectiveness of the scenarios, the calibrated models were run to replicate the reduced loads possible from the implementation of best management practices. These predicted TDN levels were then compared to target levels. From an analysis of these scenarios, best management practices have been recommended on the basis of cost-effectiveness for nutrient management; other factors, such as social acceptability and equity, were not prioritized in the nutrient management plan. The nutrient management plan proposed in this project is designed to contribute to the development of the

Napa River watershed nutrient total maximum daily load (TMDL) reduction plan which will be submitted by the San Francisco Bay Regional Water Quality Control Board (RWQCB).

Summarized results from computer modeling and data evaluation are as follows:

- The watershed models WARMF and SWAT were both calibrated using measured hydrological and nutrient data. To assess the accuracy of hydrological output values for both models, the Nash-Sutcliffe coefficient of efficiency and R-squared values were calculated. Nash-Sutcliffe coefficients were determined to be 0.59 and 0.75, for SWAT and WARMF, respectively; R-squared values were found to be 0.60 and 0.78, for SWAT and WARMF, respectively.

- The WARMF model indicates that background TDN concentrations in the river due to residual nutrients from the groundwater prevent the river from achieving dry season water quality target levels. The SWAT model produced similar results.

- The WARMF air quality sensitivity analysis indicates that contributions from wet and dry air deposition to nutrient loading into the river are negligible. The SWAT model also displays a minor contribution to nutrient loading from wet air deposition.

Based on the results of field investigations, sample analyses, watershed model calculations, simulations of BMP scenarios and cost-effectiveness, the following strategies for nutrient reduction management are proposed:

- For wastewater treatment plants, nutrient load reduction can be refined with advanced systems using microbial processes. Through biological treatment of wastewater, a three-stage nitrification-denitrification (NDN) process retrofit to existing plants can lower the TDN concentration in the effluent to 6 mg N/L and phosphorus effluent quality of 2 mg P/L. In comparison to other NDN processes, the three-stage process was proven in a previous study to be most favorable based on its costs, process control flexibility, and ease of operation. Another recommended option for wastewater treatment plants is to increase the dilution ratio of effluent to 50:1 for the Napa and Calistoga plants, since these plants have been shown in model simulations to contribute significantly to TDN levels in the main river channel.

- For faulty septic tanks, the addition of a retrofitted Nitrex filter can achieve an overall average removal rate of 87% for nitrogen (NH_4^+ and NO_3^-) and 97% for nitrate (NO_3-). Installation of a filter onto a typical residential size septic system costs approximately $2,900. Annual inspection and maintenance of the tanks should also occur to monitor performance. In addition, educational materials on septic tank maintenance can be provided to the septic tank users by regulatory agencies.

- Agricultural load reductions can be implemented by modifying fertilizer application to the lowest viable rate of fertilization. Based on vineyard drip irrigation practice analysis performed by AgroTech Supply, it was determined that fertilizer application rates may be reduced to 42-kg/ha year. This figure reduces the assumed current fertilization rate of 84-kg/ha year by one-half. Under the assumption that the modified rate does not affect crop productivity, decreasing fertilization would also reduce costs. For the entire agricultural acreage in the Napa valley, the modification of fertilizer application could possibly reduce costs by approximately $700,000 per year.

- For urban and agricultural runoff, structural stormwater BMPs may be constructed. The structural stormwater BMPs would reduce nutrient loading by filtering sediments, pathogens, and nutrients from runoff. Runoff filtration can be accomplished with retention ponds or wetlands, infiltration trenches and basins, sand filters, filter strips, grass swales, and bioretention systems. The approximate cost per kilogram of nitrate reduced varies for each BMP type.

Recommended allocations for the Napa River Watershed include strategies for nutrient load reductions based on cost-effective best management practices, and suggestions for further investigation through field studies and computer modeling. Both models concur that in order to attain water quality target levels, nutrient loading of TDN in the Napa River watershed would need to reduce by approximately 50%. Specifically, WARMF suggests the reduction should be 45%, and SWAT calls for a 52% reduction.

- It is recommended that a substantial reduction in nutrient loading occur at wastewater treatment plants, the agricultural sector, and for septic tanks. A summary of suggested allocations for nutrient loading reduction in the catchments is presented in the table below. The percentage reductions allocated to each land use and BMP measure were assigned using the available source loads derived from each source and using the most cost effective options to their fullest reduction capability. The loading figures presented are those modeled by WARMF, since the calibration performed on this model was considered to represent a better fit.

Table 2.0a: Percentage anthropogenic contributions and reductions of TDN of sources of N for the entire watershed, as modeled by WARMF

Land use sector	Loading to impaired sub-watersheds [kg N/day]	Average contribution of TDN for the entire watershed (%)	BMP	Cost per kg N removed [$/kg N]	Reduction of TDN throughout the entire watershed [kg N/day]
WWTPs					
Napa	125	14%	Retrofit with 3-stage NDN process	$538	87
Yountville	59	7%		$123	38
St. Helena	28	3%		$498	14
Calistoga	32	4%		$403	28
Septic	62	7%	Nitrex™ filter retrofit	$51	8
Residential†	18	2%	Infiltration basin	$595	0
			Wetlands	$606	0
			Ponds	$766	0
Agriculture†‡	427	49%	Fertilizer reduction	-$10	188
			Grass swales	$243	31
			Wetlands	$308	0
			Infiltration basins	$315	0
TOTAL	603	86%			394

Notes:
** - Costs here represent the total cost over a 20-year period.*
† - Costs here represent the total cost of the BMP over a 5-year period
‡ - Represents both orchards and pastures.
NA – Estimates not available.
$ - Does not include the cost of maintenance or a septic survey to identify faulty tanks.

The combined load reductions from these measures totals 394 kg N/day, which would achieve N concentrations below the wet season target of 1.0 mg N/L. Anthropogenic sources currently account for approximately 86% of the N loads to the Napa River. Implementing the above recommended BMPs to achieve the wet season target would call for a 65% reduction in anthropogenic loads, such that the anthropogenic loads would subsequently account for 45% of total load contributions to the Napa River.

Finally, it is recommended that an additional investigation of irrigation management be conducted in another field study to understand the dynamics between soil nitrate concentrations and nutrient content in groundwater. According to both model simulations, soil nitrate concentrations alone cause the TDN levels in the main river channel to exceed the dry season target level of 0.2 mg/L after 10 years of simulation. The soil nitrate concentrations contribute to nutrient loading into the Napa River watershed through the groundwater. Therefore, the target level of 0.2 mg/L in the dry season may be unattainable at this point due to the summer influx of groundwater into the river.

3.0 - SCOPE AND OBJECTIVES

This project was aimed at designing a cost-efficient and socially acceptable process to reduce excess loading of nutrients, such as ammonia and nitrate, into the Napa River. Sources likely to be contributing to the excess loading of nutrients consist of a combination of point sources, such as wastewater treatment plant effluent, and non-point sources, such as faulty septic system seepage, fertilizer run-off from agricultural lands, accretion from livestock land uses, and other sources. The loads of nutrients coming from these sources and their subsequent effects on water quality were previously not well known and/or quantified.

The main objective of this project was to develop scientifically based recommendations for nutrient load reductions, while considering the economic and social welfare of the stakeholders and relevant technical and policy implications as well. Ideally, if the load reductions proposed were implemented, excess algal growth due to nitrogen-limiting conditions would be reduced or eliminated. We followed a systematic procedure to develop a reduction plan.

The procedure included the identification and analysis of nutrient sources, the determination of linkages between inputs of nutrients to the water body and of the river's water quality, and the recognition of area-specific economic, social and financial issues that may influence proposed TMDL reduction scenarios.

Although the Napa River Watershed is listed as impaired by sediments, nutrients, and pathogens, the focus of this analysis is on nutrient loading and specifically on nitrogen loads. The nutrient phosphorous was not considered in the reduction plan because the proportion of phosphorus relative to nitrogen was predetermined by the RWQCB to be in excess. Identification and analysis of nutrient loading sources were based on those sources geographically near to sampled hotspots and those observed to have potentially significant impacts on nutrient water quality. The time series of data input into the computer models focused on the years 1990 to 2000, and assumptions were made as necessary to compensate for data gaps within this period.

4.0 - PROJECT SIGNIFICANCE

The project deliverables will contribute to the nutrient TMDL implementation plan currently being created for the Napa River Watershed by the San Francisco Bay RWQCB. Based on field surveys and computer modeling, the nutrient management plan will offer recommendations for cost-effective measures for nutrient load reduction in an effort to remedy the current water impairment. The results may also serve as a reference for nutrient reduction programs throughout Northern California.

5.0 - BACKGROUND

The federal Clean Water Act, amended in November 2002, stipulates in section 303(d) that states are required to identify waters that do not meet set technology-based water quality standards or narrative water quality objectives. The U.S. EPA implementation guidelines for placing a water body on the 303(d) list instruct that a water is defined as impaired if more than 10% of the samples taken from it violate water quality standards (Borsuk, 2002). Once identified, the waters are placed on a priority list based on the urgency of the impairment, which thereby determines the order in which a total maximum daily load (TMDL) report will be established for it. A separate TMDL report is usually filed for each impairment found in a water body. The TMDL process requires a source analysis, which is performed to determine individual point and non-point source contributions to the river's current impaired condition. A TMDL is developed to establish the maximum amount of a pollutant that the water body can assimilate without violating state water quality standards associated with the water's designated use. After the TMDL is established, the difference between the loads coming from sources and the TMDL is the desired load reduction. A variety of best management practices are evaluated to determine which procedure or combination of processes most cost effectively achieves load reduction goals.

The nutrient impairment designation in Napa River is based on a narrative water quality objective for bio-stimulatory substances described in the Water Quality Control Plan (Basin Plan) implemented by the San Francisco Bay RWQCB. The narrative water quality objectives for bio-stimulatory substances advise that they "shall not cause nuisance" or "adversely affect beneficial uses" (San Francisco Bay RWQCB, 1995). Excessive nutrient loading induces bio-stimulation that results in eutrophication.

Eutrophication is the increased growth of plant and algal matter in a water body due to a high influx of nutrients. Once these plants die, their decomposition process removes oxygen from the water thereby creating an anaerobic environment. Fish and other organisms dependent on oxygen for survival are often debilitated or killed as a result. According to the 1995 Basin Plan, beneficial uses of the Napa River include aquatic habitat and migration as well as recreational uses, each of which are significantly impaired by eutrophication.

Thus the excess nutrient loading into the Napa River has not met the narrative water quality objectives by impairing the beneficial uses of the water and requires the development of a nutrient TMDL management plan.

5.1 – WATERSHED DESCRIPTION

The Napa River bisects the heavily cultivated, gently sloping Napa Valley, which ranges in elevation from 0 to 180 m (600 ft) above sea level. The valley is bounded by the Mayacamas Mountains in the West and North, peak elevation 780 m (2,560 ft) above sea level, and by the Vaca Mountains in the East, peak elevation 0.85 km (2,755 ft) above sea level. The Napa River runs 88 km (55 mi) from the headwaters of Mt. St. Helena in the Mayacamas Mountain Range, elevation 1.2 km (3,935 ft), to the San Pablo Bay. Spanning 2.59 sq km (426 sq mi), the Napa River watershed and its 47 tributaries are spawning grounds for the endangered Chinook Salmon and Steelhead Trout, and provide habitat for dozens of other threatened and endangered birds, mammals, reptiles, fish and plants.

5.11 – River and Tributaries

The Napa River starts as a small creek at its northern headwaters, and develops into a fully navigable, tidally influenced river in the lower southern portions. The last 27 km (17 mi) of the 88 km (55 mi) river, from Trancas Street in Napa to Vallejo, are an estuary system and tidally influenced. For this reason, although the watershed depicted in Figure 5.11a is complete from headwaters to bay, future maps in this paper include data for only the upstream 61 km (38 mi) of the river.

The river gradient (Figure 5.11b) ranges from 0 to 5% in the valley, and up to 19% in the mountain tributaries, many of which run dry in the summer. The Napa River's peak flows are correlated with the wet season, which generally runs from November to April. Within the watershed, the highest rainfall occurs on the western side contributing to landslides and increasing erosion and nutrient transport from sources to the Napa River. USGS flow gauges located throughout the watershed record and store the river's flow rate on a daily basis. One gage in particular, #11458000 (Figure 5.11a), was used for the purposes of this report because it had the most regular measurements throughout the time period of study, the years 1990 – 2000.

Figure 5.11a: Watershed focus area and utilized gage station.

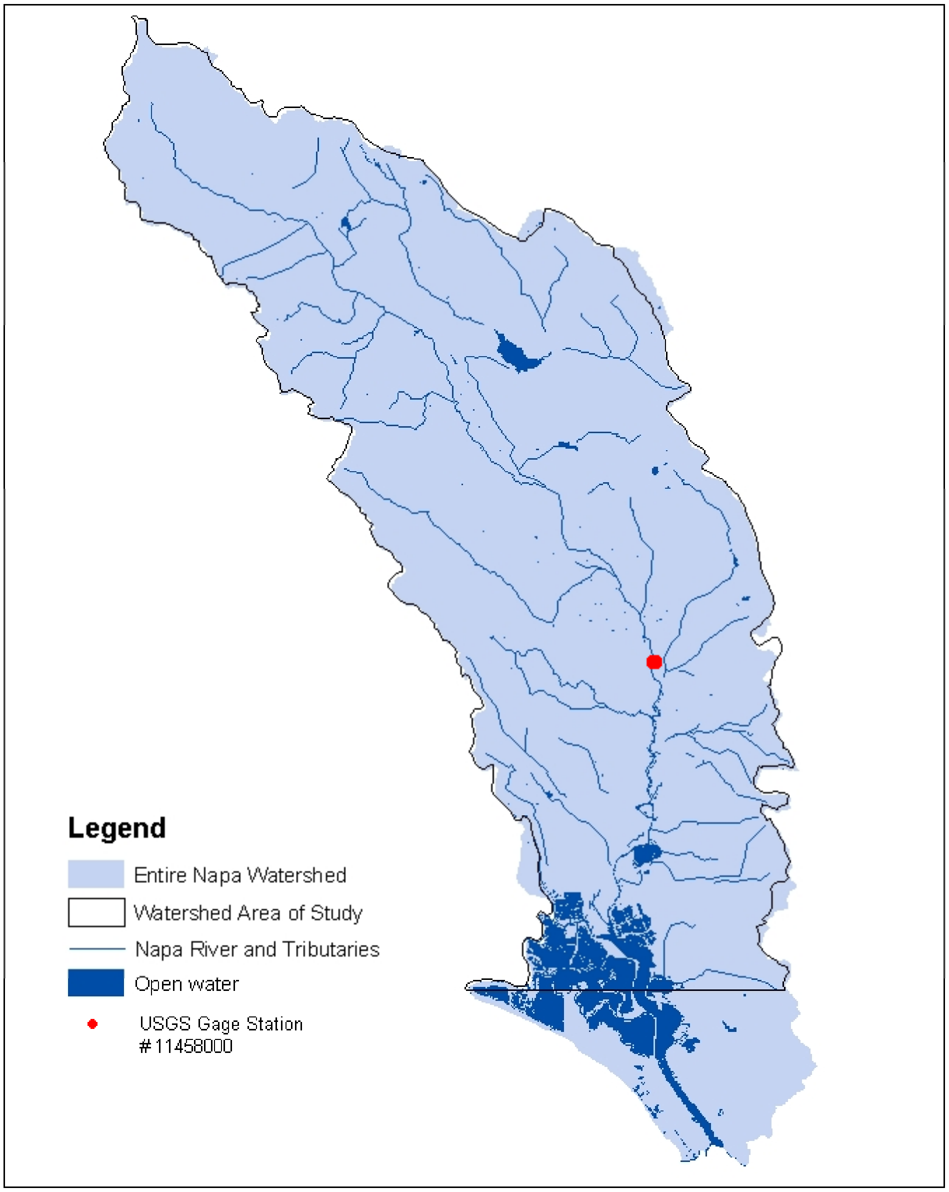
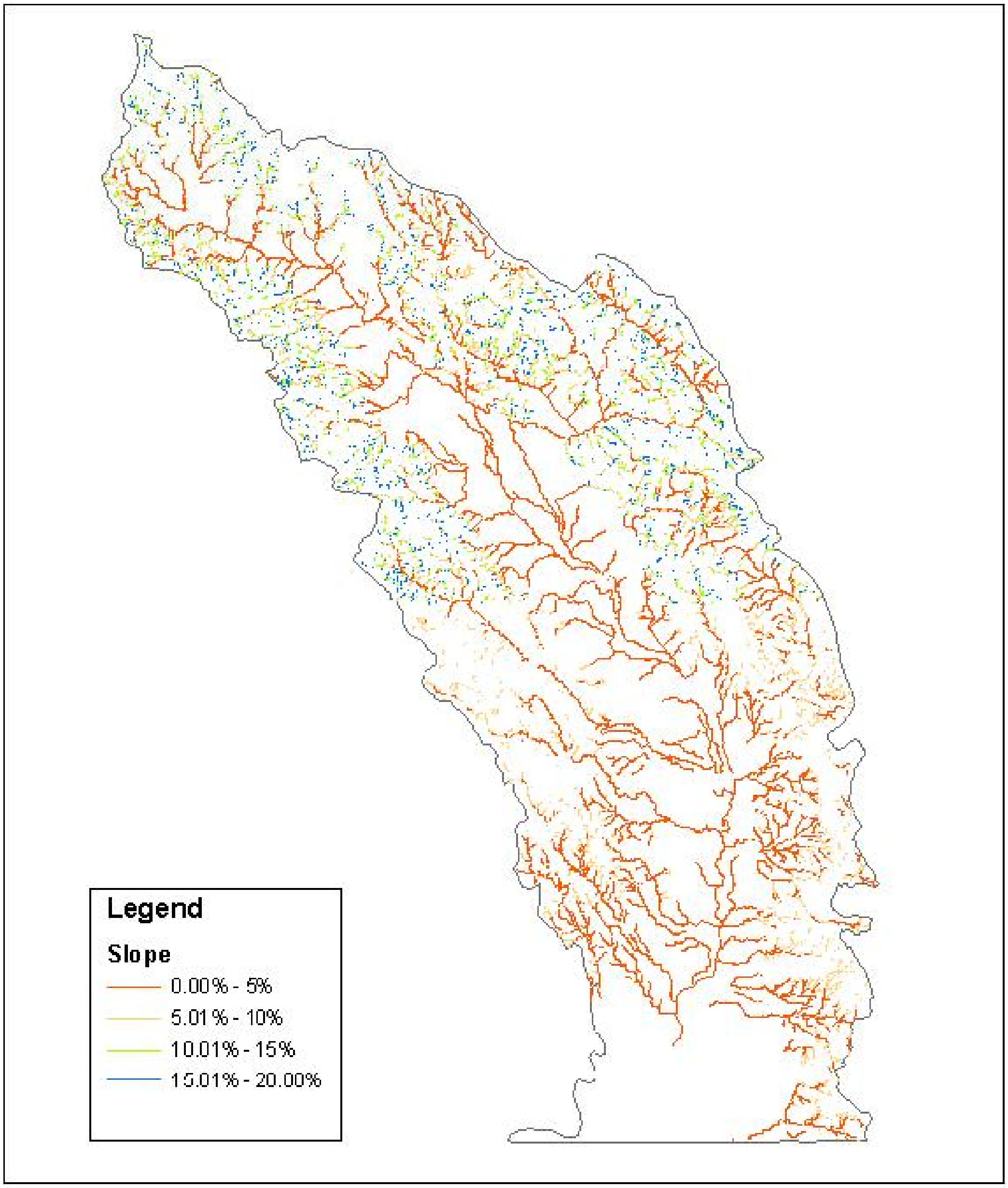


Figure 5.11b: Stream Network and Gradient

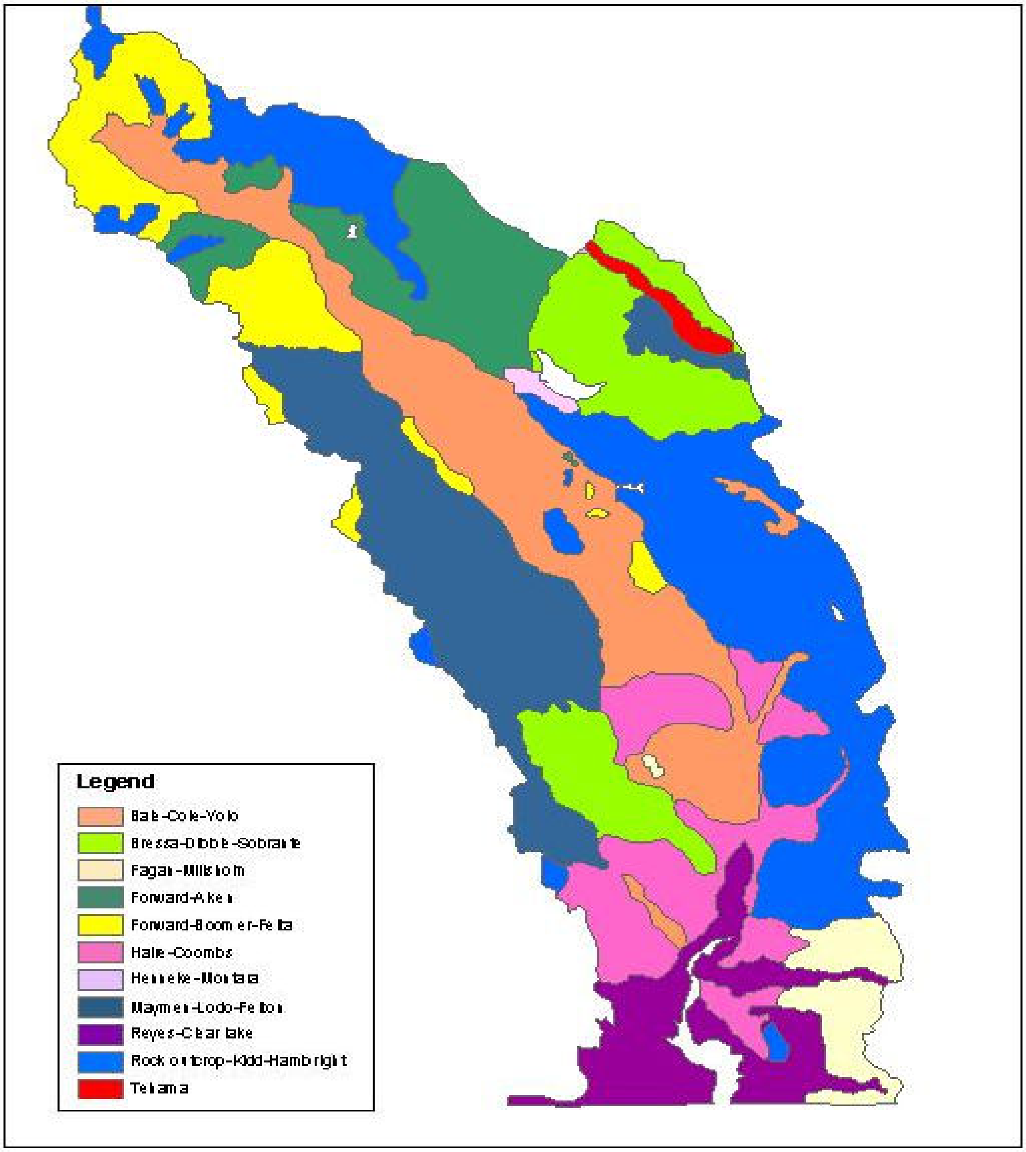


Sources: USGS 1:24,000 DLG and UC Berkeley Department of Plantary Sciences
Created by Stillwater Sciences Professor William Dietrich for the "Napa River Basin Limiting Factor Analysis"
April 2002

5.12 – Soils and Vegetation

The soils of Napa are volcanic, marine, and alluvial in origin and range from moderately well drained gravelly loams to moisture retaining silty clays (Napa Vintners, 2003). Figure 5.12a displays the soil layout within the watershed and Table 5.12a describes their properties.

***Figure 5.12a**: Soil classifications in the Napa River Watershed*



Source: Natural Resources Conservation Service – Napa County Soil Survey August 1978

Table 5.12a: Napa soil classifications and associated properties

Soil Type	Hydrologic Group	Texture Class	Prime Farmland	Absorption Field Limitations
Bale-Cole-Yolo	C and B	Clay loam, Silt Loam, Loam	X	Moderate-Severe
Bressa-Dibble-Sobrante	C	Loam		Severe
Fagan-Milsholm	C and D	Clay loam, Loam		Severe
Forward-Aiken	B and C	Loam		Severe
Forward-Boomer-Felta	B and C	Loam		Severe
Haire-Coombs	B and C	Clay loam, Loam	X	Severe
Henneke-Montara	D	Clay loam		Severe
Maymen-Lodo-Felton	D and C	Loam		Severe
Reyes-Clear lake	D	Silty clay loam	X	Severe
Rock outcrop-Kidd-Hambright	D	Loam, Rock outcrop		Severe
Tehama	C	Silt loam	X	Severe

The majority of the soils underlying the Napa Valley floor have properties consistent with hydraulic groups B and C. Group B soils have moderately fine to moderately coarse texture, and have a moderate infiltration rate when thoroughly wet. Group C soils have a slower infiltration rate than Group B and generally consist of moderately fine to fine-textured soils. These valley soils are also characterized by the U.S. Department of Agriculture as prime farmland. Prime farmland soils have the best combination of physical and chemical characteristics for agricultural production; have tolerable acidity or alkalinity, acceptable salt and sodium content, and few or no rocks. These soils do not tend to erode and have a slope range of 0 to 6 percent.

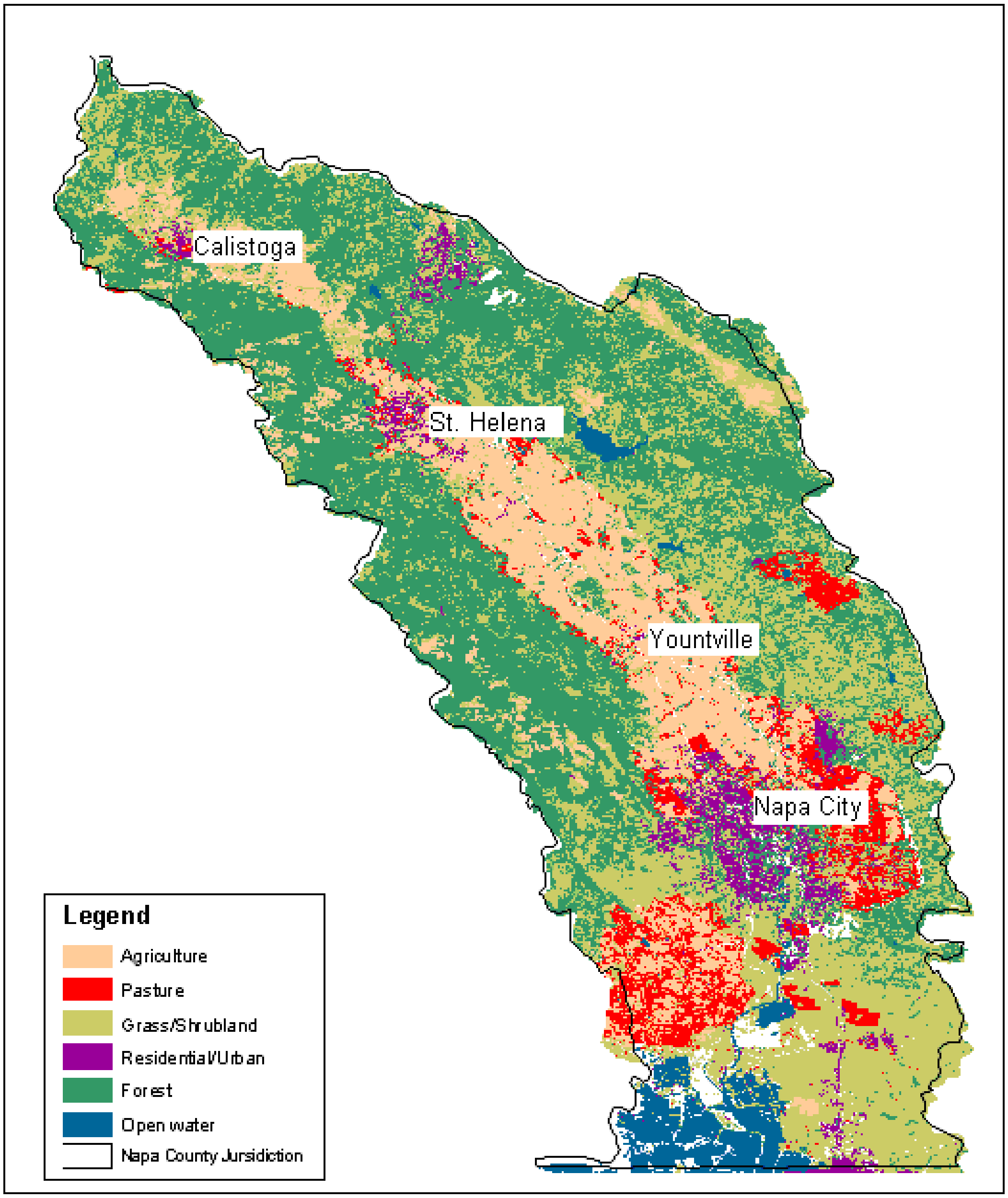
The remainder of the watershed primarily consists of Group D soils, which have a very slow infiltration rate and high runoff potential when thoroughly wet. Generally these soils exhibit the following characteristics: they are clays that have a high shrink-swell potential; they are prone to contain perched water tables; they have a clay layer at or near the surface; and they are shallow over nearly impervious material.

Residences outside of the main urban areas of the watershed rely on septic tanks for their wastewater treatment. Each of these tanks must include an absorption field in which effluent from a septic tank is distributed into the soil through subsurface tiles or a perforated pipe. Soil suitability for absorption fields is evaluated by analyzing soil permeability properties, slope, depth to a water table, and the effect of flooding on the absorption of effluents. Several areas where septic tanks are likely to be located are designated as severe, or consisting of soil that has one or more features that are unfavorable for septic construction and use (Lambert, 1978).

5.13 – Land Use

Lands within the Napa River Watershed are divided into a variety of land use types. Evergreen, deciduous, and mixed forests cover approximately 35 percent of the watershed and primarily occupy the mountainous regions. Grasslands and other herbaceous-cover types are typically used as rangeland and cover about 22.6 percent of the watershed area. While this cover is primarily interspersed with forested areas, a patch of concentrated pastureland is located northeast of Napa City. Agricultural land accounts for nearly 19 percent of the watershed, the majority of which is located in the valley region (Figure 5.13a). Residential and commercial areas comprise urban land use, and cover approximately 8 percent of the watershed. The majority of urban land uses are characterized as low density residential and are concentrated in the four cities (from north to south): Calistoga; St. Helena; Yountville; and Napa City. Populations range from approximately 2,900 in Yountville to 72,590 in Napa City; with Calistoga and St. Helena housing 5190 and 5,950 people respectively. The population of the entire Napa County is approximately 124,280 (Bay Area Census, 2000).

***Figure 5.13a**: Napa River Watershed land use*



Source: County of Napa, 2003

5.2 - NUTRIENT-RELATED WATER QUALITY

5.21 - Target Levels

Numeric or measurable indicators and target values of water quality should be used to evaluate the TMDL and the restoration of water quality in the listed waterbody. The indicators tested should be appropriate to the waterbody and local conditions, and the target values should represent achievement of water quality objectives to accomplish the conditions, indicative of the waterbody listings.

The San Francisco Bay RWQCB in the 1995 Basin Plan established numeric and narrative water quality objectives. Table 5.21a below lists the water quality objectives as reported in the Basin Plan.

Table 5.21a: Numeric water quality objectives of Napa River per the Basin Plan

Impairment to water body	Water quality objectives
Ammonia	25 *ug*/L
Nitrate	10 mg/l
Dissolved Oxygen:	
Warm water habitat	>5 mg/l
Cold water habitat	>7 mg/l

Although the Basin Plan objectives listed above for dissolved oxygen and algal biomass were based on well-accepted scientific considerations, the objective for nutrients has become somewhat outdated. The nitrate concentration objective was based more on concerns over nitrate toxicity of drinking water, which can cause chronic human health problems, than on concerns for toxicity to aquatic life, which exhibits lower thresholds. Nitrogen can pose acute toxic effects to aquatic life in either the un-ionized ammonia form or the nitrate form. As little as 2-mg/L total ammonia can be toxic to salmonids (Krottje and White, 2003). Elevated nitrate levels can be toxic to fish and amphibian eggs and juveniles. Studies have shown that nitrate can be chronically toxic to fish and amphibian eggs at 1.1 mg/L (Krottje and White, 2003).

The development of a more recent set of water quality targets has been based on studies of nitrate toxicity to aquatic life, and temporal considerations of excessive nutrient concentrations that cause excessive algal growth and thus lower dissolved oxygen concentrations. Table 5.21b lists the preliminary water quality objectives put in place by the San Francisco Bay RWQCB. Although not yet regulatory targets, the objectives are based on seasonal nutrient targets that could reduce algal biomass and increase dissolved oxygen concentrations.

Table 5.21b – Napa River Watershed nutrient water quality targets

Impairment to waterbody	Water quality objectives
Nitrate:	
Dry season	0.2 mg/L
Wet season	1.0 mg/L

According to the US EPA National Nutrient Guidance Document on rivers and streams, the setting of water quality targets should be based on site-specific extensive monitoring studies; however, in the absence of such studies, there are three approaches that water quality managers can use to derive numeric criteria for streams, which include: (1) the use of reference streams; (2) the application of predictive relationships to select nutrient concentrations that will result in appropriate levels of algal biomass; and (3) the development of criteria from thresholds established in the literature (EPA, July 2000). The water quality targets proposed for Napa River have been based on criteria (2) and (3).

5.22 – Sampling and Analysis

In order to determine the extent of Napa River's nutrient impairment, the San Francisco Bay RWQCB took two sets of water samples. The first sampling occurred in January 2003, and the second in July 2003. Nutrient data retrieved from these sampling events served as a baseline measurement for the current nutrient loading and later served as the basis for load reduction allocations.

Samples were taken at 23 sites throughout the Napa River and its tributaries, 21 of which were located north of the tidal zone and were therefore the sites of concern (Figure 5.22a). Samples were analyzed for a suite of nutrient indicators, which helped determine nitrogen as the limiting nutrient. Total dissolved nitrogen data was then analyzed to determine which sample sites exceeded nutrient target levels, and to observe trends of nitrogen concentration in tributaries versus the main river stem (Table 5.22a and Figures 5.22b and 5.22c).

Figure 5.22a: *Sample location map*

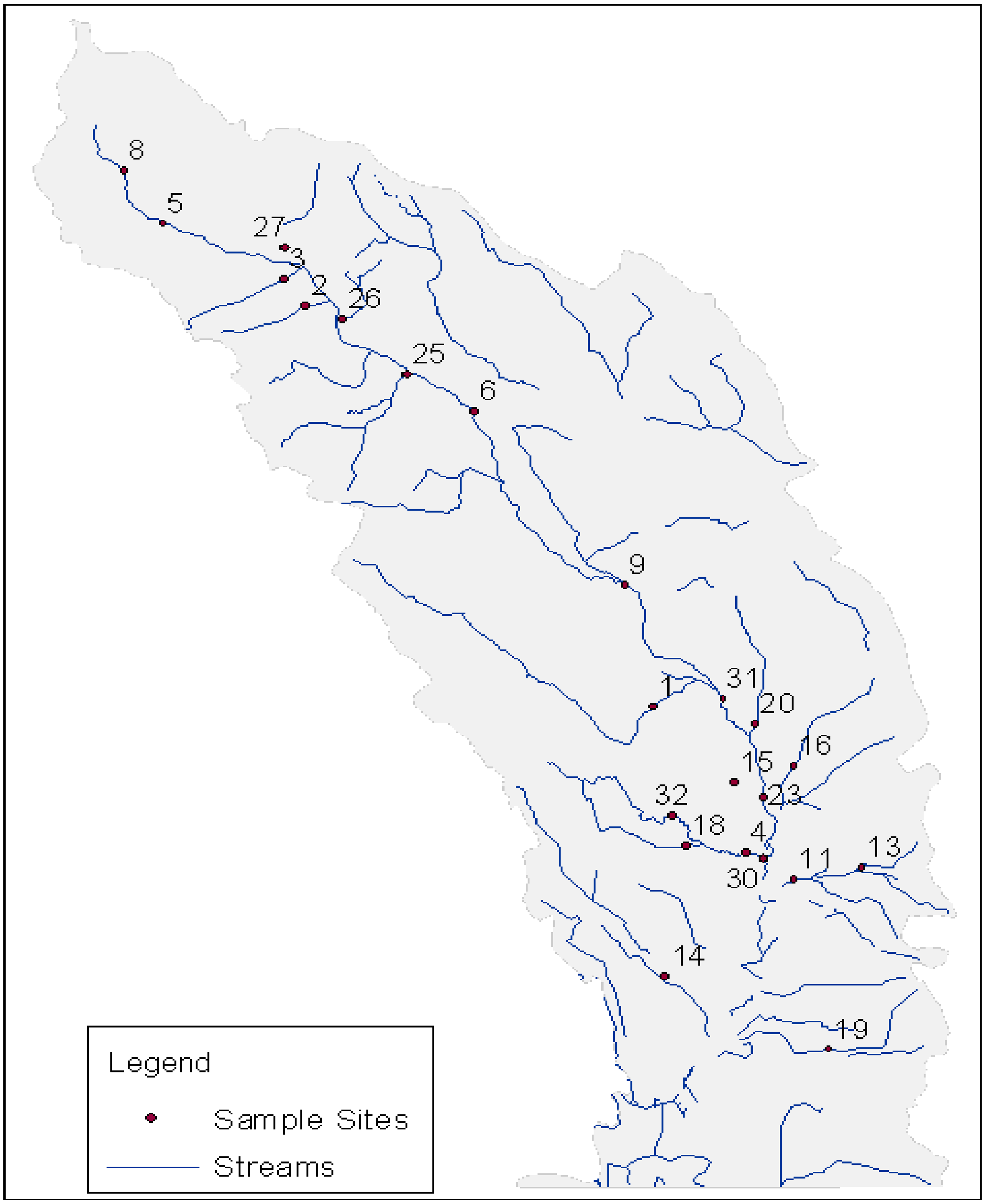


Table 5.22a: January and June 2003 Napa River and tributary sampling results.

Main River Nutrient Data			Tributary nutrient data		
Sample site number	January 2003 TDN [mg/L]	June 2003 TDN [mg/L]	Sample site number	January 2003 TDN [mg/L]	June 2003 TDN [mg/L]
8	0.7	0.19	27	0.4	Not sampled
5	1.4	0.30	3	0.1	0.14
26	1.9	1.23	2	0.6	0.14
25	1.1	0.33	20	1.0	Not sampled
6	2.1	1.58	16	1.0	0.34
9	2.4	1.12	15	2.8	1.07
31	1.6	0.77	32	0.7	0.19
23	2.1	0.61	18	1.0	0.59
30	2.0	0.54	4	1.0	0.64
			11	3.3	2.13
			13	0.7	0.32
			1	0.3	0.48

Notes:
– Indicates sample exceeded TDN water quality target. Target values are 0.2 ppm TDN for the dry season, 1.0 ppm TDN for the wet season.

Figure 5.22b: Total Dissolved Nitrogen in Main River Samples

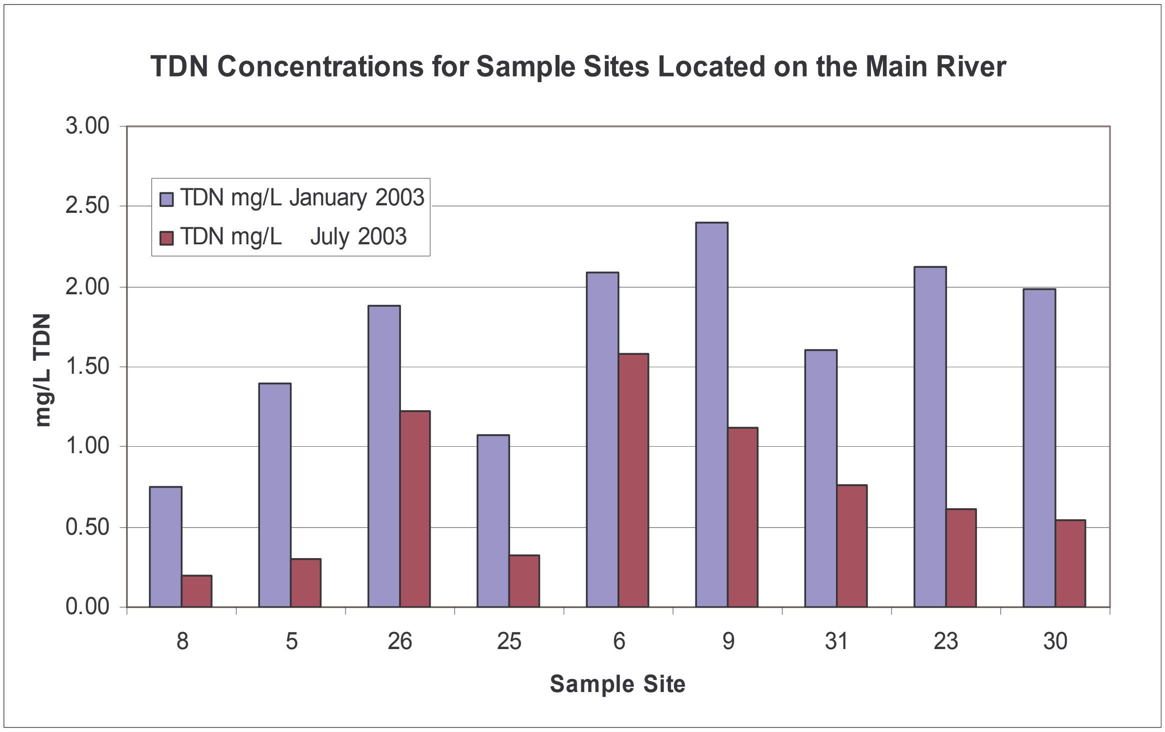
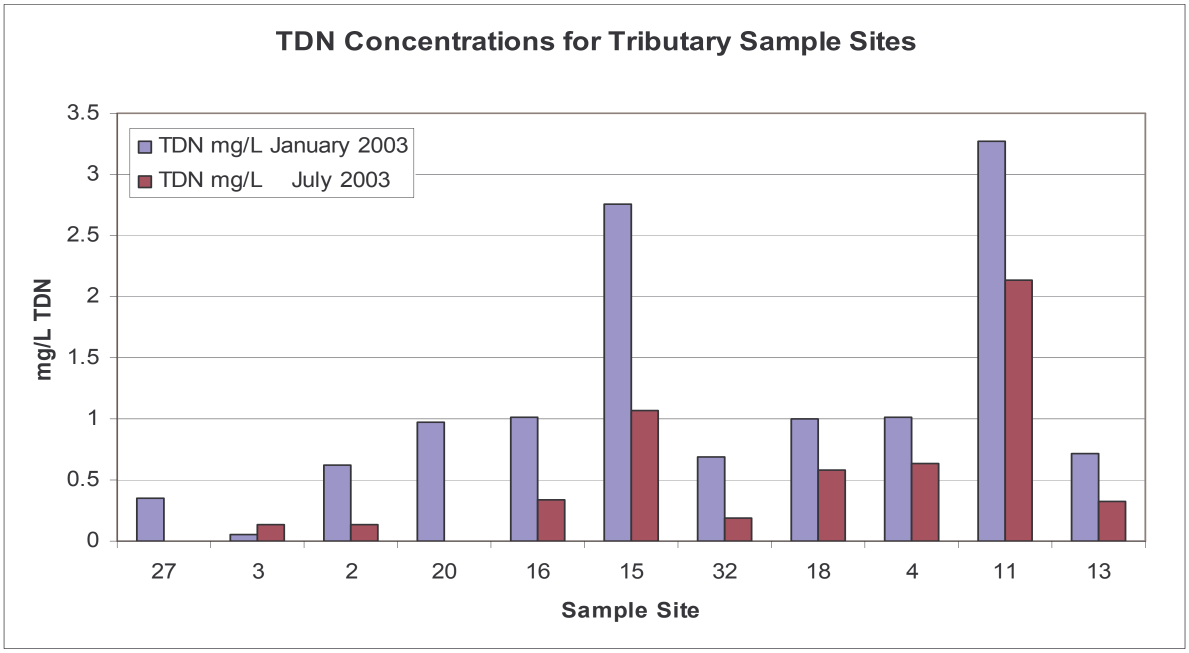


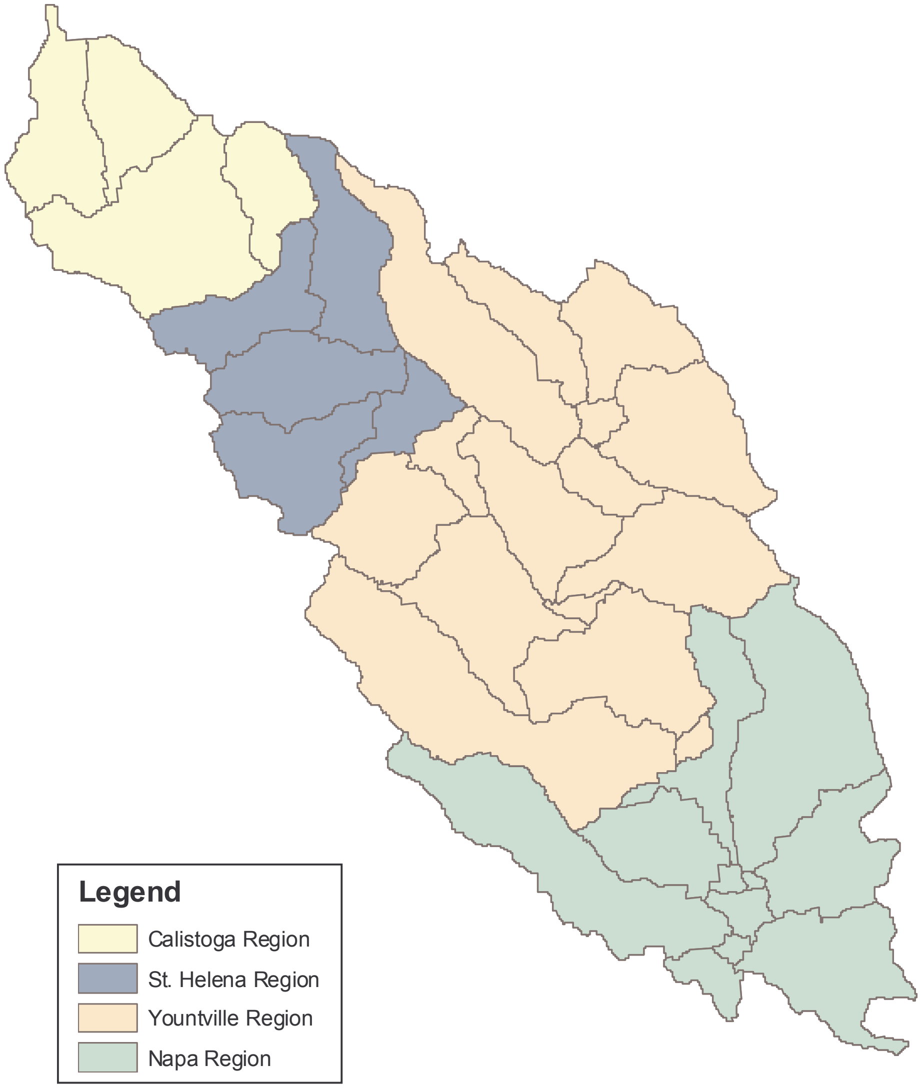
Figure 5.22c: Total Dissolved Nitrogen in Main River Samples



Nutrient concentrations in tributary sample sites only exceeded target concentrations twice in January 2003, whereas every site sampled along the main river stem exceeded nutrient objectives, with the exception of the northernmost location. During the July 2003 sampling event, the sites along the main river exceeded the objective again, except the northernmost, and this time many of the tributary sites also violated target concentrations.

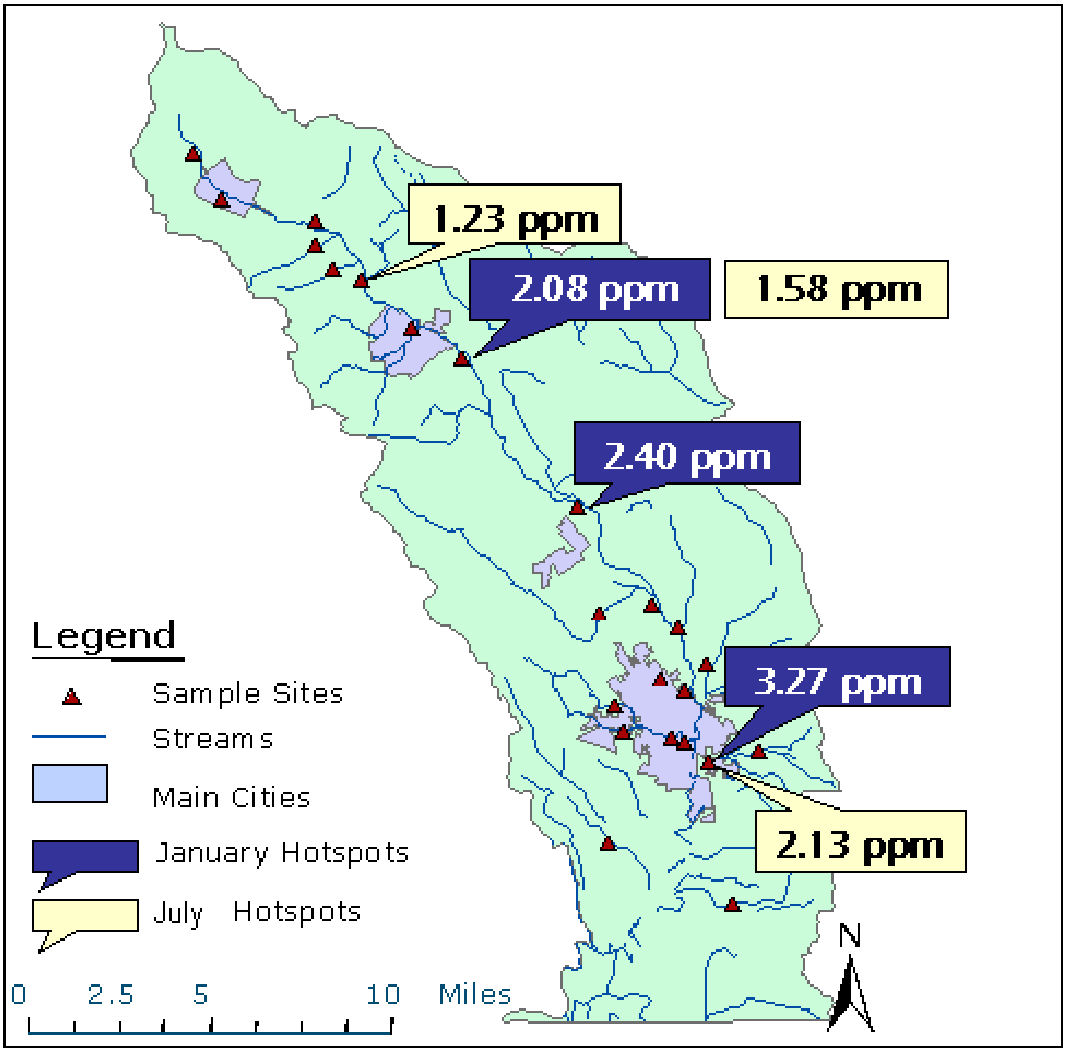
Spatial relationships of the measured data can be inferred if the Napa River Watershed can be further divided into 4 sub-regions that correspond to the locations of the wastewater treatment plants. These sub-regions are the Calistoga, St. Helena, Yountville, and Napa sub-regions, and the delineation of these sub-regions are presented in Figure 5.22d.

Figure 5.22d: Napa River Watershed sub regions



According to the measured data, the higher TDN concentrations occurred at the outlets of each sub-region as marked in Figure 5.22e in both January and July.

Figure 5.22e: Measured TDN concentrations along Napa River



In order to determine the source of water quality impairment, a source analysis for nutrient loading was performed. The source analysis attempted to determine the source of nutrient loading and the subsequent effect on water quality. Sources of nutrient loading include point sources such as WWTPs and non-point sources such as septic system effluent, run-off from agricultural and urban land uses, and atmospheric deposition.

6.0 - SOURCE ANALYSIS

6.1 – NONPOINT SOURCES

The non-point sources in the Napa River watershed include agricultural and urban runoff, in addition to seepage of septic system effluent.

6.11 - Runoff from Agriculture/Livestock

Fertilizer and irrigation water are vital to productive farms and harvests. However, water and nutrient use can be inefficient, resulting in leaching and runoff of nutrients that migrate toward groundwater and surface water, adding excess nutrients in a watershed. Agricultural lands introduce nutrients into waterways from both surface runoff and erosion during storms, from irrigation runoff, and through shallow groundwater flows. Agricultural nutrient sources include inorganic fertilizers, manure, organic amendments applied during cultivation; crop residues or plant debris, erosion of surficial soils; waste accumulation from grazing animals; and soluble nutrients released during the decomposition and mineralization of plant litter and animal waste (EPA Region 9, March 2003). Manure is produced on pastureland that is used by animals such as cattle, sheep, goats, hogs, birds, and other wildlife in the watershed. The loads of manure are a source of both nutrients and bacteria, and they typically occur as non-point sources, contributing mostly during storm runoff (EPA Region 9, March 2003).

Most of the agricultural land uses within the watershed are concentrated in a continuous strip along the crescent shaped Napa Valley floor in between the cities of Calistoga and Napa. Smaller agricultural areas are located in the following areas: the northwest slopes of the watershed from the Richie Creek area down to the Sulfur Creek area; the southwest portion of the watershed north of the marsh lands; and east of Lake Hermessey. The agricultural sector in Napa County is dominated by the production of wine grapes, which occupy about 11% of the available 1,620 sq km (400,000 acres) of the land available for in Napa County (Jackson, 2003). Wine grape land use comprised a total of approximately 174 sq km (43,000 acres) of bearing and non-bearing (grape producing and non-grape producing) land in Napa County in 2002, which accounted for 98% of the County's production value in that year as compared to the other varieties of agricultural/livestock production. Wine grapes and other types of agriculture/livestock and associated production values within Napa County are summarized in Table 6.11a below.

Table 6.11a: Summary of Napa County Agricultural Crop Report, 2002

Production variety	Item(s)	2002 Total value
Fruit and nut crops	Wine grapes	$379,930,000
	Walnuts	$31,000
	Miscellaneous fruits and nuts	$148,000
Floral and nursery crops	Ornamental grapevine nursery stock, Christmas trees, cut flowers, etc.	$4,655,000
Livestock	Cattle and Calves	$1,779,000
	Sheep and lambs	$104,000
	Hogs	$28,000
Field crops	Hay	$126,000
	Range	$394,000
	Irrigated pastures	$42,000
	Miscellaneous field crops	$21,000
Livestock and poultry products	Eggs, milk, and cheese	$433,000
Vegetable crops	All vegetables	$172,000
2002 Grand Total		**$387,863,000**

Napa County Agricultural Commissioner, 2002

6.12 - Runoff from Urban Land Sources

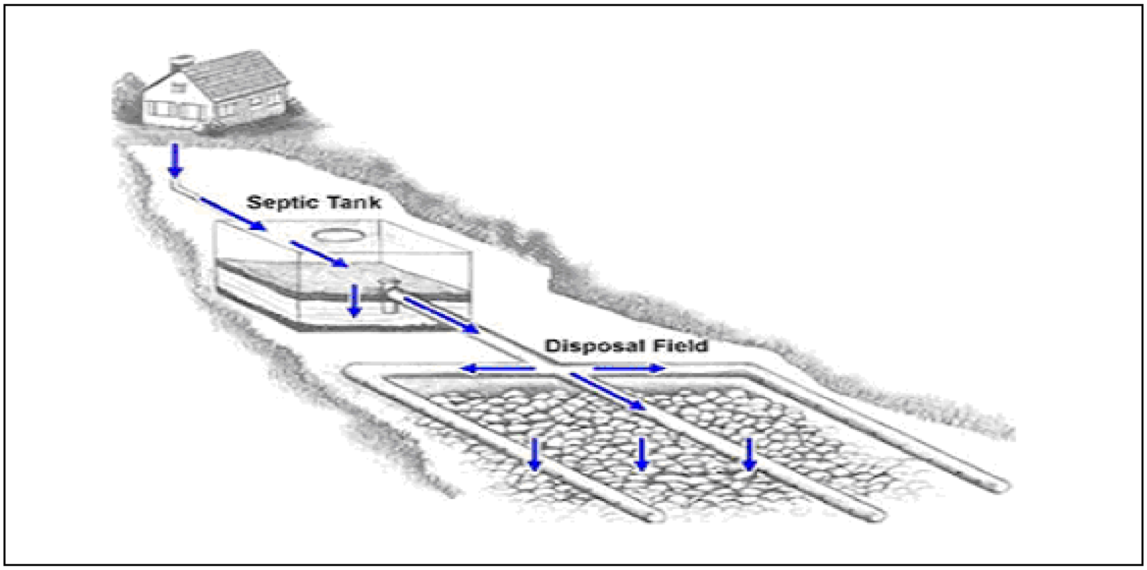
Runoff from residential and commercial areas can be important sources of nutrients, as well as bacteria. Urban areas within the watershed are characterized as mostly low density residential. The potential sources of nutrients include fertilizer used for lawns and landscaping, organic debris from gardens, landscaping, and parks; phosphorus in detergents used to wash cars or driveways; trash such as food wastes; domestic animal waste; and human waste from areas inhabited by homeless. Human and domestic animal waste are also sources of bacteria. These pollutants accumulate, especially on impervious surfaces, such as parking lots, driveways, and roads. During rainfall events, pollutants collect in runoff and enter into waterways through storm drains. A portion of the nutrients from these sources will also infiltrate into the soils of the pervious areas, and may enter the waterways through shallow groundwater flows. These loads are typically highest during the first major storms after extended dry periods, when pollutants have accumulated. In addition, non-rainfall events or runoff from dry periods can contribute pollutants between storms, due to activities such as watering lawns and landscaping, washing cars, and washing parking lots and driveways (EPA Region 9, March 2003).

Major regulations covering stormwater within the watershed include National Pollutant Discharge Elimination System (NPDES) Phase II storm water permits, which require permits for stormwater discharges from small MS4s and from construction sites disturbing between 0.004 and 0.02 sq km of land. MS4s are separate municipal storm sewer systems, which are defined by the EPA as conveyance or systems of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels or storm drains) owned or operated by municipalities and local sewer districts among others. Phase II is an expansion of the Phase I program promulgated in 1990 under the Clean Water Act, which is founded on using the NPDES permit system to regulate polluted storm water runoff from urbanized areas. While Phase I was primarily focused on large and medium-sized MS4s serving populations of around 100,000 or greater, Phase II extends the coverage of the program to include smaller systems serving urbanized areas defined mainly by population density (EPA, July 2003). The cities of Napa, St. Helena, and Calistoga, the Town of Yountville, and the County of Napa, applied for the Phase II permit between March and October of 2003, and have since submitted the Napa County Stormwater Management Plan (NCSWMP) covering the years 2003 to 2007 to meet the NPDES Phase II regulations. The NCSWMP seeks to reduce or eliminate all pollutants from stormwater runoff, with top priority given to those causing TMDL impairments, through implementation of six program elements according to Phase II permit requirements. The program elements include: Public Education and Outreach, Public Involvement/Participation, Illicit Discharge Detection and Elimination, Construction Site Runoff Control, Post-Construction Runoff Management, and Municipal Operations (Napa County Flood Control and Water Conservation District, 2003).

6.13 - Septic System Effluent Seepage and Runoff

A septic tank is a watertight container into which raw sewage is discharged. The sewage stays in the septic tank long enough for most of solids to decay and liquid is slowly drained off to a leach field (Figure 6.13a) from where the wastewater percolates downward through soil to eventually enter groundwater (Ministry of Water, Land & Air Protection, Govt. of British Columbia).

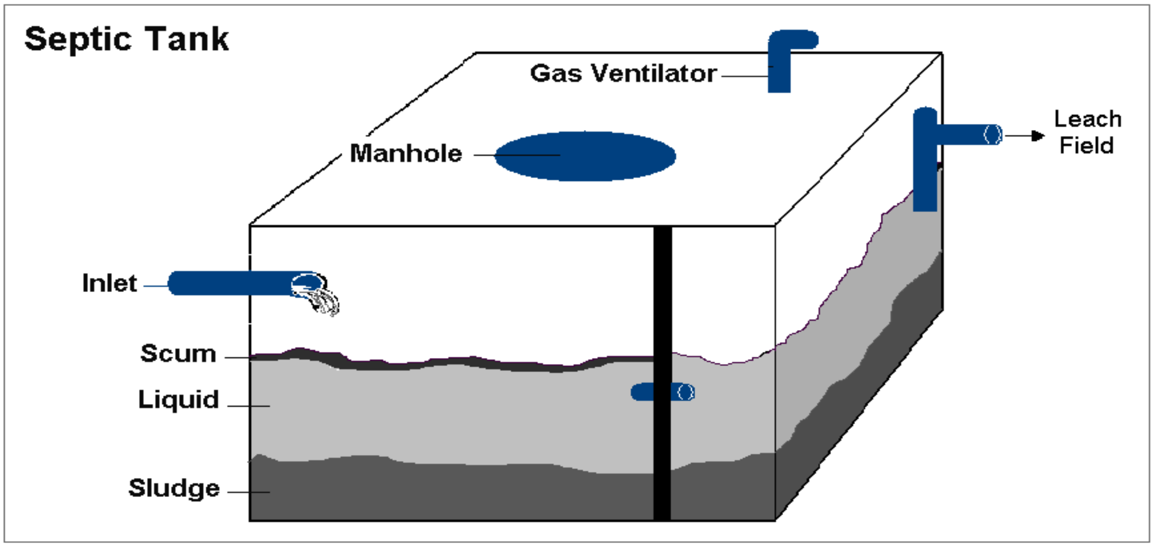
Figure 6.13a: *Typical septic system schematic.*



Source: The Soap and Detergent Association

Septic tanks can be made of bricks, clay, concrete or fiberglass. The tank provides conditions for anaerobic digestion of the solids in the wastewater, separating them as scum and sludge before the effluent is discharged to the leach field (Figure 6.13b).

Figure 6.13b: Septic tank schematic.



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Most septic tanks have a baffle inside that improves the settlement of solids and prevents the scum from floating out of the tank with the discharged effluent. The solids are biologically digested by bacteria in an anaerobic condition and produce some gases as byproduct, including carbon dioxide (CO_2), methane (CH_4) and hydrogen sulfide (H_2S). A vent is provided on the top of septic tank for removing these gases. The non-biodegradable materials that microorganisms cannot digest in the septic tank are accumulated as sludge. To help prevent septic tank failure, these layers of sludge and scum must be removed periodically. The liquid effluent from a septic tank flows to a leach field for disposal by gravity or by use of an electric pump, and is absorbed onto soil particles where it moves downward through the soil pores. The physical, chemical and biological characteristics of this wastewater effluent change as it percolates through the soil pores and enters into a groundwater aquifer.

In Napa County most residences outside urban areas utilize septic systems, some of which may have been causing problems to water bodies due to failure. Some of these tanks have out-lived their functional life; others are not properly maintained and some of the leach fields have matured thus reducing the percolation rate.

Three scenarios (Fig 6.13c) for septic system failure were considered:

<u>Scenario-I: Septic tank leaks</u>

- Structure outlived its useful life
- Cracks due to roots of trees and vegetation
- Natural faults/earthquakes

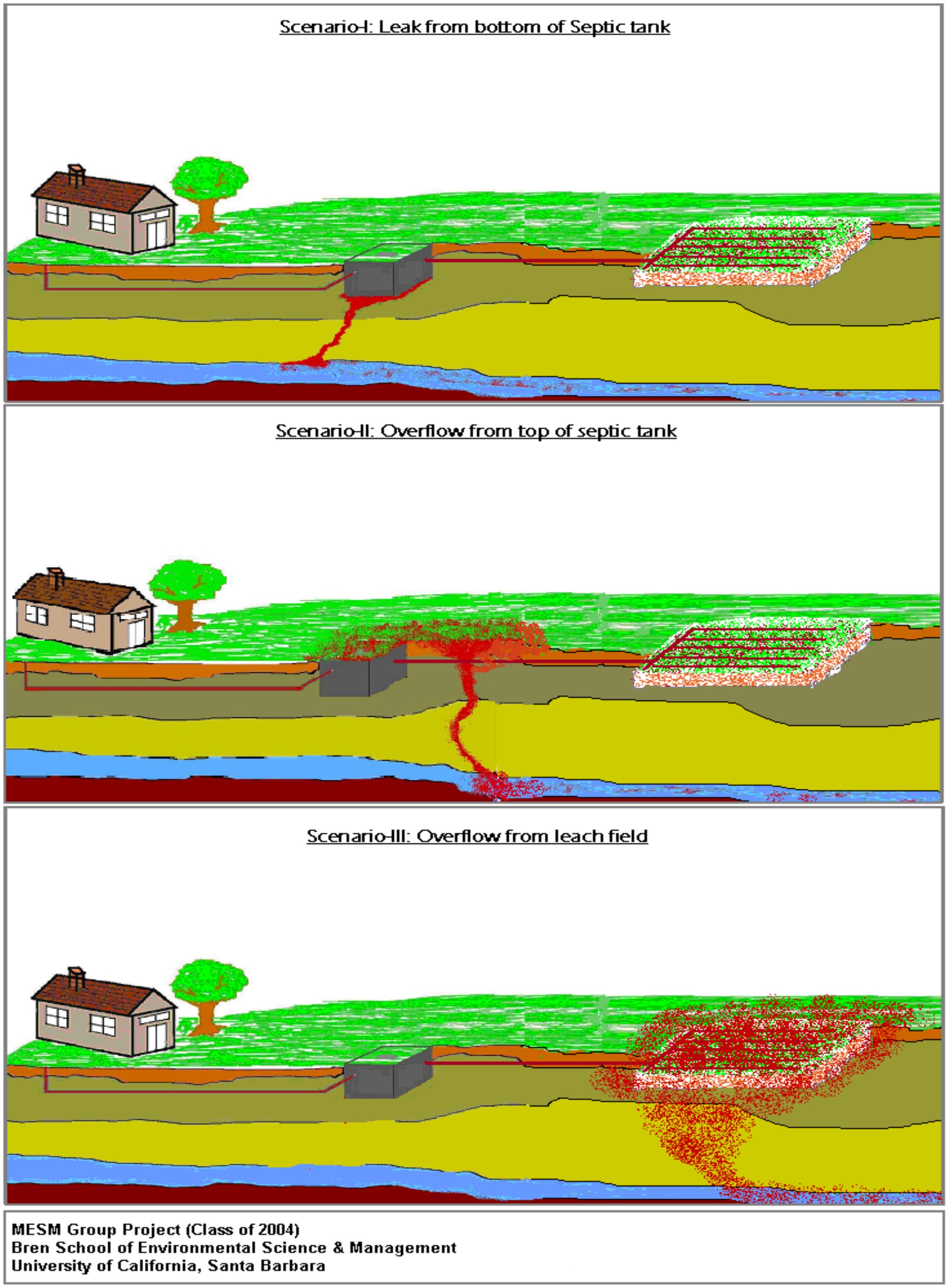
<u>Scenario-II: Overflow from top of septic tank</u>

- Irregular maintenance (not pumping out the sludge frequently enough)
- Septic tank is too small to handle the waste load
- Overuse of water results in excessive flow into leach field

<u>Scenario-III: Overflow from leach field</u>

- Overload of leach lines
- Leach field has too small an area
- Leach fields located too close together
- Soil pores get clogged by solid particles (sludge or scum)
- Poor soil conditions
- Insufficient retention time

Figure 6.13c: *Three common scenarios for septic system failure.*



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In all three scenarios, the failures of septic systems or leach fields could lead to impairments in surface and/or groundwater quality from excess nutrient and pathogen loading.

6.14 - Atmospheric Deposition

Atmospheric Deposition includes wet deposition and dry deposition. Wet deposition is from pollutants present in rain. Dry deposition is the gradual accumulation of particles on the ground and leaf surfaces during dry weather. Dry deposition includes particulate matter and uptake of gases including NOx. NOx is converted to nitrate upon uptake by vegetation. Atmospheric deposition may be assimilated in the soil and in vegetative uptake, with some portion reaching surface waters through the natural hydrologic cycle.

6.2 - POINT SOURCES

6.21 - Wastewater Treatment Plant Effluent

About 15,000 wastewater treatment plants (WWTPs) exist in the United States, the majority of which are small and treat one million gallons (3.8 million liters) or less of wastewater per day. WWTPs are usually constructed to treat both domestic and industrial wastes. Domestic wastewater consists of sewage, gray water (water collected from washing, bathing, and cooking), and wastewater from food processing. Industrial wastewater can consist of effluent from the petrochemical, pesticide, food and dairy, plastics, pharmaceutical, and metallurgical industries. Wastewater treatment facilities reduce organic and inorganic materials in wastewater to try to achieve a level that no longer supports microbial growth and contains no toxic materials (Madigan, et al, 2003).

The efficiency of a plant is expressed in the terms of reduction of biochemical oxygen demand (BOD), the relative amount of dissolved oxygen consumed by microorganisms to completely oxidize all organic and inorganic matter in a water sample. Typical values of domestic wastewater are approximately 200 BOD units, while industrial BOD levels can reach as high as 1,500 BOD units. An efficient wastewater treatment plant reduces BOD such that effluent contains less than 5 BOD units. Treatment is a multi-step process; primary, secondary, and sometimes tertiary treatment of water involving physical, biological, and physicochemical methods, respectively (Madigan, et al, 2003).

Within the Napa Watershed, each of the four main cities, Calistoga, St. Helena, Yountville and Napa have their own WWTP. The nitrogen loading from each of these WWTPs varies depending on the type of treatment process used and on its capacity. All the WWTPs in this watershed involve at least the first two steps of wastewater treatment.

- Primary treatment – process to separate suspended solids and greases from wastewater
- Secondary treatment - process to remove dissolved organic matter from wastewater

During the months of May to October, wastewater is stored at the WWTPs, whereas during the wet season, which spans from November through April, wastewater effluent is discharged into the river when flows are high enough to achieve either 10:1 or 50:1 dilution.

Few of these plants have an advanced treatment system (tertiary treatment) that is used to remove nutrients from wastewater that is eventually used to irrigate golf courses, pasture land and a variety of crops; the WWTPs have no regulatory requirement for nutrient loading after the secondary treatment, which can result in undesirable nutrient levels.

The sources described above, as well as naturally occurring sources, each contribute loads of nutrients that either are discretely piped into the river as point sources, or are conveyed from the nonpoint sources to the river by run-off or groundwater seepage. The loads and waste loads that ultimately make it to the water bodies as in stream loading are attenuated to a degree by several physical and chemical factors. Point and non-point sources that are likely significant sources of nutrient loading to the Napa River include WWTPs, effluent from faulty septic systems, runoff and groundwater seepage from urban and agricultural land uses, and possibly atmospheric deposition. In summary, both point and non-point contributors have been identified as potential key sources of nutrient loading into the Napa River watershed. To determine the linkage between water quality and nutrient loading, a linkage analysis was performed (Section 7) to determine to what degree each of the sources contributes to in-stream loading.

7.0 - LINKAGE ANALYSIS

The purpose of a linkage analysis is to determine the relationships between the pollutant loads coming from the various sources and the resultant water quality of the receiving tributaries and/or river segments. Preliminary source estimates are determined in the sources analysis. The linkage analysis quantifies the changes that occur from each source to a river segment through subsequent attenuation and assimilation of those loads by transport through soil, vegetation, and other media between the source and the receiving waters, and through in stream processes such as mixing, biogeochemical reactions, and dilution. The key to the linkage analysis is a watershed model capable of simulating the physical and biogeochemical processes that affect river hydrology and water quality. A model is useful in simulating hydrology, the nonpoint source loads from land catchments, and then the resulting receiving water quality from the initial point and nonpoint source loads of pollutants (Systech Engineering, 2002). The model is also useful in developing the TMDL for the river segment, by determining the loading capacity, which is the amount of pollutants that can be released without exceeding the water quality objectives (USEPA, 1998).

Due to the varying nutrient loading condition across the Napa River Watershed and relatively short residence time of nutrients, episodic load estimates and spatial representation are needed, which can be realized using distributed parameter-based, continuous time models.

Distributed parameter-based modeling approaches have become prevalent in the literature in recent years (Fitzhugh, et al., 2000; Lenhart, et al., 2002). There are numerous distributed parameter-based simulation models available. The major advantage in using these models is that they include specific routing, transport and transformation mechanisms, and can be calibrated to measured concentrations. The major disadvantage of distributed parameter-based models is that they are typically spatially-averaged (lumped) parameters models. Accuracy of model simulation is highly related to the available data and their quality.

Generally speaking, most of the distributed parameter based models require the delineation of watersheds into physically interconnected sub-watersheds, within which most watershed parameters are considered uniform. In recent years, GIS (Geographical Information System) has been used to assist the parameterization of distributed parameter models, greatly facilitating the process of watershed delineation and characterization.

In this nutrient management project, two models were applied in parallel: Soil and Water Assessment Tool– SWAT (Section 7.12) and Watershed Analysis Risk Management Framework – WARMF (Section 7.13). Both are distributed parameter-based and continuous water quality simulation models. In addition to these functionalities, these models were chosen for this portion of the analysis for the following reasons:

- Ability to model physical, chemical, and biological processes
- Success of the models in nearby watersheds
- Software accessibility

7.1 – WATERSHED MODELS

7.11 - SWAT and BASINS

SWAT, supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory, Texas, considers all hydrological processes within the watershed (Arnold, et al. 1995). The U.S. EPA currently supports SWAT in developing TMDLs and has incorporated SWAT into its BASINS (Better Assessment Science Integrating Point and Nonpoint Sources), a watershed management model framework. BASINS is a multipurpose environmental analysis system developed by the EPA's Office of Water to help regional, state, tribal and local agencies perform water quality-based studies at the watershed level. BASINS organizes data on water quality and quantity, land uses, soil, Digital Elevation Model (DEM), etc., as well as site specific point and non-point source loading, into an ArcView GIS environment, significantly facilitating the model implementation process. The databases included in the BASINS system were compiled from a wide range of federal sources including U.S. Geological Survey (USGS), Bureau of the Census, USEPA, U.S. Department of Agriculture (USDA), and National Oceanic and Atmospheric Administration (NOAA). The quality of this data is adequate for most of the modeling simulations. BASINS is public domain software and has been widely used across the USA and in some locations internationally. This project used BASINS 3.0 to prepare the input data files for SWAT.

SWAT consists of three major components: (1) sub-basins; (2) reservoir routing; and (3) channel routing. The sub-basin component consists of eight major divisions. These are hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, agricultural management, and pesticides. Channel inputs include reach length, channel slope, channel depth, channel width, channel side slope, flood plain slope and other characteristics. SWAT is based on a routing command language, which allows definition of how the water budget moves inside the catchments, spatially relating the different units (i.e. sub-basins, reservoirs, ponds, river reaches) considered. Application of SWAT in California has produced satisfactory results (Flay, 2001).

Though SWAT is not designed to simulate a storm event, it allows the user to assess predictive scenarios using alternative input data, such as climate, land use practices, land cover, nutrient cycling, pesticide fate and transport, water movement, water quality, and other outputs. Although data intensive, the integration of SWAT into a GIS environment allows for the acceptance of readily available datasets from governmental sources on climate, soil, topography, and land use.

Several studies, using SWAT individually, or in combination with BASINS, have been successful in modeling water budgets and pollutant loading (Arnold, et al.

1995; N. Fohrer, et al 2002; Weber, et al, 2002; Tripathi, et al 2003; Cotter, et al. 2002).

7.12 - WARMF

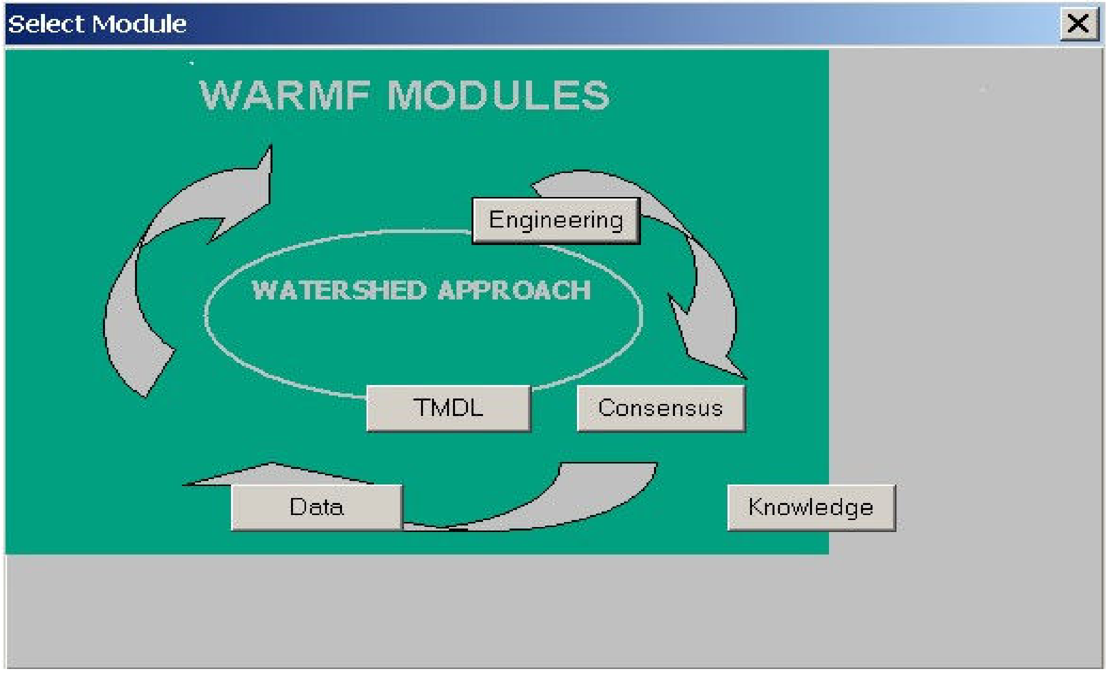
WARMF, developed by Systech Engineering under sponsorship by the Electric Power Research Institute (EPRI), is a decision support system (DSS) designed to support the watershed approach and TMDL calculation (EPRI, 2001). Like SWAT, WARMF is a physically-based, continuous time watershed model, which forms the basis of the linkage analysis and TMDL calculation. On the other hand, because WARMF is especially created for TMDL development, it provides a series of steps to guide stakeholders to calculate TMDLs and come up with the most feasible, affordable, and socially acceptable allocation of load reduction, elements which are not present in SWAT (Neitsch, et al, 2001; EPRI, 2001).

WARMF is organized into five linked modules under one, GIS-based graphical user interface (GUI) (Figure 7.12a). The Engineering module is the dynamic, simulation model that drives WARMF. The Data module provides time series input data (meteorological, point source) and calibration data. The Knowledge module is a utility to store important documents for the watershed. At the center of WARMF are the two watershed approach modules for Consensus building and TMDL calculation. These two modules are roadmaps that provide guidance for stakeholders during the decision making process.

In WARMF, a watershed is divided into land catchments, river segments, and reservoir segments. Each is linked together in a network so that output from catchments is automatically input to the adjacent river segment. Each river segment is connected to the one downstream, to reservoir segments, and back to river segments to form a complete network. Each segment is also divided into the canopy, land surface, and several soil layers. Below the surface, it is assumed that each soil layer has uniform hydrology and water quality within a catchment; each river segment is modeled as completely mixed.

WARMF can be run with any simulation time step (in units of hours). It is typically run with a daily (24 hours) time step in the project, which is the same as in SWAT, because most available data is at this temporal resolution.

Figure 7.12a: Schematic Structure of WARMF



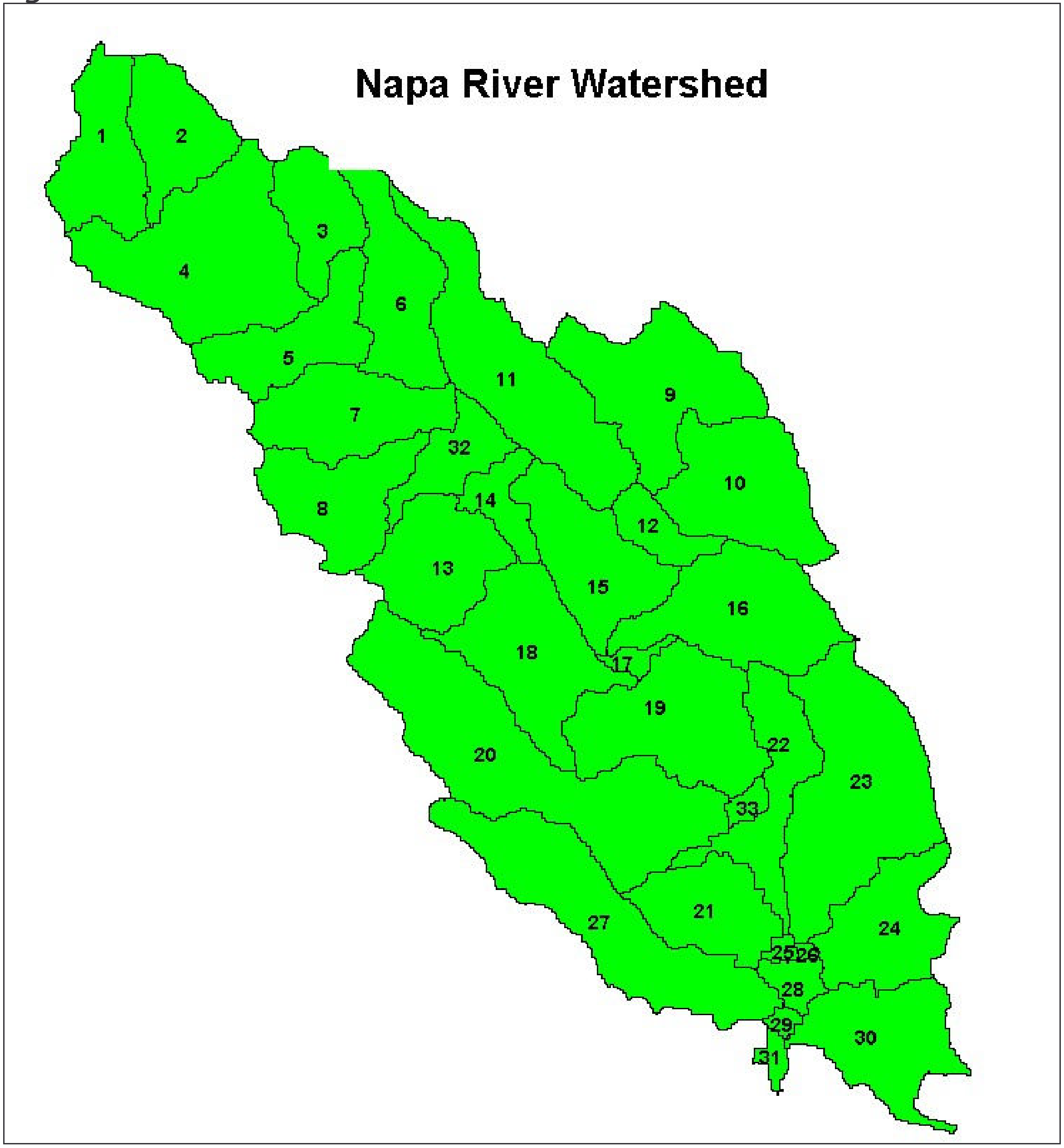
7.2 - WATERSHED DELINEATION

7.21 - SWAT and BASINS

Like other distributed-parameter models, SWAT uses spatially variable input parameters to predict watershed response. The first step to set up the model is to delineate the watershed into sub-watersheds or catchments. BASINS provides an automatic delineation tool in the ArcView GIS interface. The watershed delineation is then exported to SWAT. The user can control the size and number of sub-watersheds in the watershed of interest by specifying a stream definition area threshold. Each sub-watershed can be further partitioned into multiple hydrologic units (HRU) by applying user-specified land-cover and soil area thresholds. An HRU is considered homogeneous in all aspects, representing a spatially averaged area with the same land use and soil types within a sub-watershed. The HRU is the smallest computational unit in SWAT.

It should be noted that terrain parameters, e.g. slope and slope length, are identical for all HRUs within a given sub-watershed, except the channel length, which varies depending on the size of the HRU. Given the size of the Napa River watershed and the resolution of the imported DEM, the maximal number of subwatersheds delineated using SWAT was 33 (Figure 7.21a). In this project, the land-cover and soil area thresholds were uniform for all delineations and sub-watersheds, where a minimum 10% area of a specific land cover type and 15% area of a specific soil type need to be present in a sub-watershed to be considered in the model. This means that the HRUs are composed of land-cover types that occupy at least 10% of the area in each sub-watershed, combined with soil types that occupy at least 15% of the area of that land-cover type. All combinations of land-cover and soil type that meet the above criteria will then be distributed proportionally throughout the whole sub-watershed, displacing all land-cover and soil types that fall below the threshold percentages. Given both characteristics of soils and land use distributions within Napa River watershed, these land-cover and soil type threshold values were believed to be reasonable.

Figure 7.21a: SWAT sub-watershed delineation



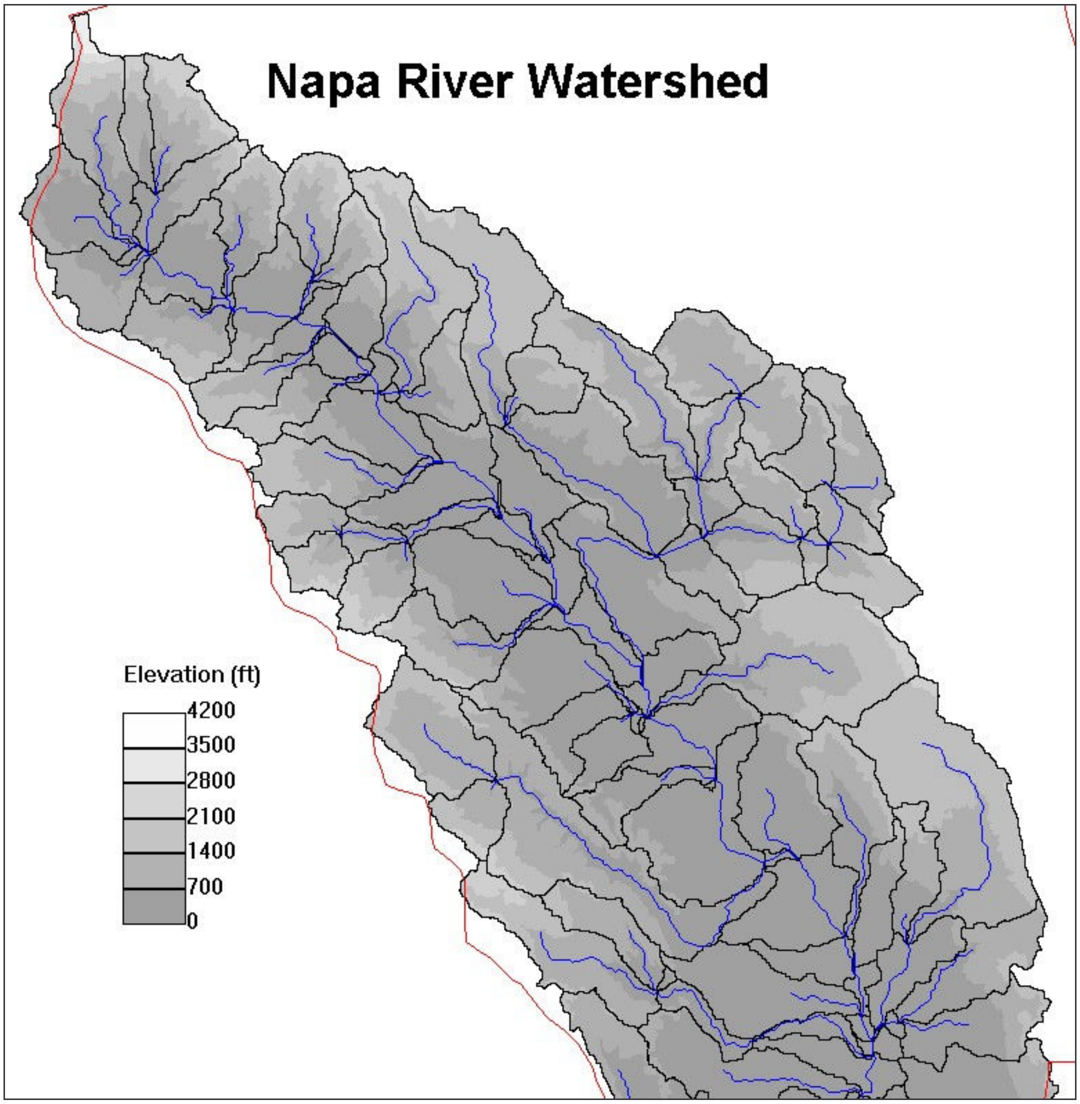
7.22 - WARMF

Systech Engineering, developer of WARMF, provided us a version of WARMF implemented for the Napa River Watershed. The version was preliminarily set up with a pre-delineated watershed, meteorology, land use, and soil data.

Hydrological and nutrient calibrations were performed by our project team. The watershed delineation done by Systech Engineering is shown in Figure 7.22a.

The WARMF delineation of Napa River Watershed has 104 sub-watersheds, which is much more than the 33 sub-watersheds delineated in SWAT. However, when considering the total number of HRU in SWAT, the smallest computational unit, we found that the two models are comparable in terms of delineation.

Figure 7.22a *- WARMF catchment delineation, with the stream network shown as blue lines.*



7.3 - MODEL INPUT DATA

7.31 - SWAT and BASINS Input Data

Data inputs needed for executing SWAT include climate, soil, topography, land use, and agricultural management. Some of the data were loaded in the form of GIS maps into BASINS while others were in ASCII format, which can be modified via the editor provided by BASINS. Key SWAT input data used in the project is described below. All GIS data (e.g. topography, soils, land use, streams network) were re-projected into Lambert Conformal Conic grids regardless of their original format.

Climatic input

SWAT requires daily precipitation, maximum/minimum air temperature, radiation, wind speed, relative humidity and potential evapotranspiration. Values of these parameters may be read from records of observed data or generated by using the SWAT weather generator. SWAT provides weather generator input files for more than 400 climate observation stations across the United States (Neitsch, et al., 2001). The weather generator input files contain the statistical data required to generate representative daily climate data for most watersheds in the USA. Ideally, at least 20 years of records should be used to calculate parameters in the input file. Climate data will be generated by SWAT in two instances: when the user specifies that simulated weather will be used, or when measured data is missing. In both cases, SWAT will call the weather generator that operates on long-term historic statistics provided by SWAT databases.

The geographical information of the weather observation stations within the Napa watershed, which have measurement data available, is presented in Table 7.31a.

Table 7.31a: Profile of weather observation stations

Station Name	Location		Elevation (m)	Period of record	
	Latitude	Longitude		From	To
Napa County Airport	38.22	-122.28	4.3	1965-08-01	Present
Napa State Hospital	38.28	-122.28	10.7	1931-01-01	Present
Calistoga	38.60	-122.60	121.9	1932-01-01	Present

For all three stations, only daily precipitation and maximum/minimum temperature measurements were considered. No radiation, wind speed, relative humidity or potential evapotranspiration measurements were available, so they were generated by using the SWAT weather generator, which in the Napa River watershed was based on the long-term historic measurements from the Napa State Hospital weather station.

Topographic input

Topography is defined by a Digital Elevation Model (DEM) in BASINS. DEM data is processed to calculate sub-basin parameters such as slope, stream length, differences in elevation, and to define the digital stream network in conjunction with a pre-defined stream network from the National Hydrography Dataset (NHD). Characteristics of the resulting stream network, such as channel slope, length, and width, were all derived from the DEM.

For each HUC (Hydrological Unit Code) a 30-m elevation contour interval DEM is available from BASINS (http://www.epa.gov/ost/BASINS). All DEMs in this website have a horizontal resolution of 300 m x 300 m, which appeared to be sufficient for estimating the topographical features in the Napa River watershed. This conclusion was made when comparing the calculated and digitized river networks reveled that the simulated stream network matched closely the stream network from the NHD. The DEM used in the project was prepared by the USGS according to 1990 elevation data.

Soil data input

Soil data downloaded from the BASINS website corresponds to the State Soil Geographic (STATSGO) Database. The STATSGO data consists of digital maps that display general soil association along with a linked database of attributes. The STATSGO data used was prepared according to the National Cooperative Soil Survey of 1994(USEPA, 1998). The soil map for Napa River Watershed is presented in Figure 7.31a and some key properties of these soils are presented in Table 7.31b.

Figure 7.31a: Soil distribution in the Napa River Watershed.

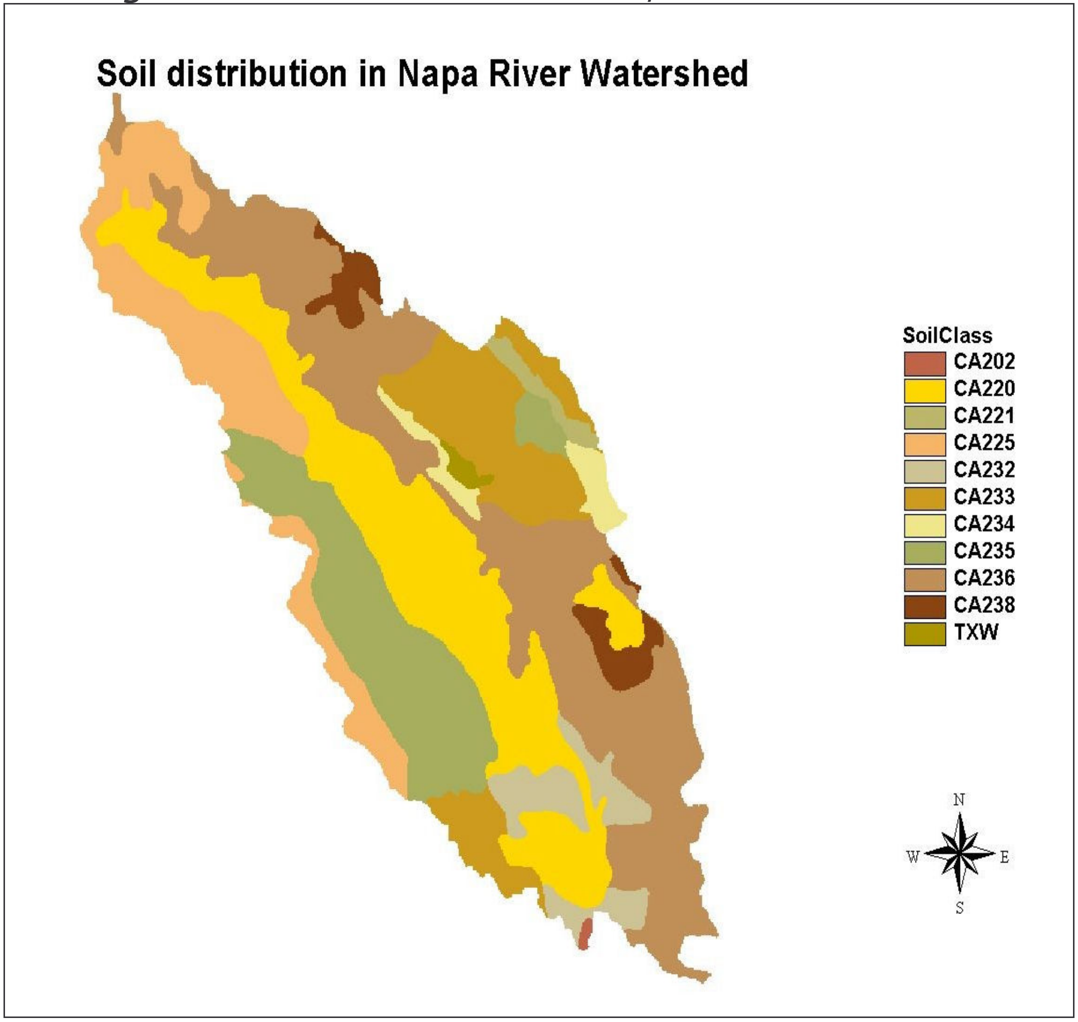


Table 7.31b: STATSGO Soil Characteristics

STATSGO Map Unit	Soil Name	Hydrologic Group	Area (Hectares)	Area (%)	Bulk density (g/cm^3)	Organic carbon (% soil weight)	Soil erodibility factor	Saturated hydraulic conductivity (mm/hr)
CA202	REYES	D	98.70	0.13	1.46	1.05	0.24	0.94
CA220	BALE	B	16822.30	22.35	1.43	1.16	0.28	2.30
CA221	YOLO	B	772.10	1.03	1.44	1.16	0.37	3.70
CA225	FORWARD	B	9405.90	12.50	1.39	1.74	0.17	8.90
CA232	HAIRE	C	3323.90	4.42	1.45	1.16	0.32	3.60
CA233	BRESSA	C	8266.40	10.98	1.43	1.02	0.37	1.50
CA234	HENNEKE	D	1496.40	1.99	1.32	2.62	0.20	4.20
CA235	MILLSHOLM	D	10423.60	13.85	1.46	1.02	0.37	3.20
CA236	HAMBRIGHT	D	22058.50	29.31	1.45	2.91	0.15	4.45
CA238	AIKEN	B	2269.40	3.02	1.30	2.91	0.28	6.70

The U.S. Natural Resource Conservation Service (NRCS) classifies soils into four hydrologic groups based on infiltration characteristics of the soils. NRCS Soil Survey Staff defines a hydrologic group as a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that impact the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties include depth to seasonally high water table, saturated hydraulic conductivity, and depth to a very slowly permeable layer. Soils may be placed in one of four groups, A, B, C, and D, or three dual classes, A/D, B/D, and C/D (Neitsch, et al., 2001).

Definitions of the classes are:

- A: Low runoff potential. The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.
- B: The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep-to-deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

- C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine-to-fine texture. They have a slow rate of water transmission.
- D: High runoff potential. The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent water table, soils that have a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

- Dual hydrologic groups are given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the undrained. Only soils that are rated D in their natural condition are assigned to dual classes.

In Napa river watershed, the soils of hydrologic group of D represent about 45%, while the soils of hydrologic group of B and C account for 39% and 16% respectively. Since TDN is mostly transported with surface runoff in dissolved forms, under the same land use cover, higher runoff potential means higher TDN load during rainstorms.

Land Use/Land Cover Data

Land use/land cover is the most important GIS dataset in this project since nutrient load is highly related to the land use types. The land use/land cover theme indicates the amount and distribution of agricultural land, rangeland, urban land, and forest in the watershed. These land cover types are very different in terms of hydrological and biological processes, management practices, and, therefore, pollutant generation and transport. Forested areas contribute little to nutrient loading, while agricultural land, primarily orchards in the Napa River Watershed, is thought to be a significant source of nutrients entering the Napa River. Urban land has a high fraction of impervious area, which increases the amount of surface runoff from this land type. The land use theme provided in the BASINS website was prepared using 1985 land use data, therefore it was not used in the project because land has undergone significant change during the last two decades.

A more current land use map of the Napa River watershed from the year 2001 was obtained from NLCD (National Land Cover Data) (http://water.usgs.gov/GIS/metadata/usgswrd/landuse.html). NLCD land use maps use the modified Anderson classification system, which is different from that of GIRAS (Geographic Information Retrieval and Analysis System). Because GIRAS is the only classification system accepted by SWAT, a land use conversion table (Table 7.31c) was created to convert Modified Anderson land classes to SWAT model classes. Figure 7.31b and Table 7.31d represent the land use distribution in 2001 in the Napa River Watershed after conversion of Anderson classification system land use classes to SWAT classes. Note that some Anderson classes were combined into one GIRAS/SWAT class.

Table 7.31c: Modified Anderson and SWAT land use class conversion table

NLCD LU Code	Modified Anderson Class	SWAT Class
11	Open water	WATR (Water)
21	Low Intensity Residential	URLD (Residential-Low Density)
22	High Intensity Residential	URHD (Residential-High Density)
23	Commercial/Industrial/ Transportation	UCOM (Commercial)
31	Bare Rock/Sand/Clay	RNGB (Range-brush)
32	Quarries/Strip Mines/ Gravel Pits	RNGB (Range-brush)
33	Transitional	RNGB (Range-brush)
41	Deciduous Forest	FRSD (Forest-deciduous)
42	Evergreen Forest	FRSE (Forest-evergreen)
43	Mixed Forest	FRST (Forest-mixed)
51	Shrub Land	RNGB (Range-brush)
61	Orchards/Vineyards/Other	ORCD (Orchard)
71	Grasslands/Herbaceous	RNGE (Range-grasses)
81	Pasture/Hay	PAST (Pasture)
82	Row Crops	AGRR (Agricultural Land-Row Crops)
83	Small Grains	AGRR (Agricultural Land-Row Crops)
84	Fallow	RNGE (Range-grasses)
85	Urban/Recreational Grasses	RNGE (Range-grasses)
91	Woody Wetlands	WETF (Wetland-forested)
92	Emergent Herbaceous Wetlands	WETF (Wetland-forested)

Figure 7.31b: 2001 land use in the Napa River Watershed after conversion to SWAT classification.

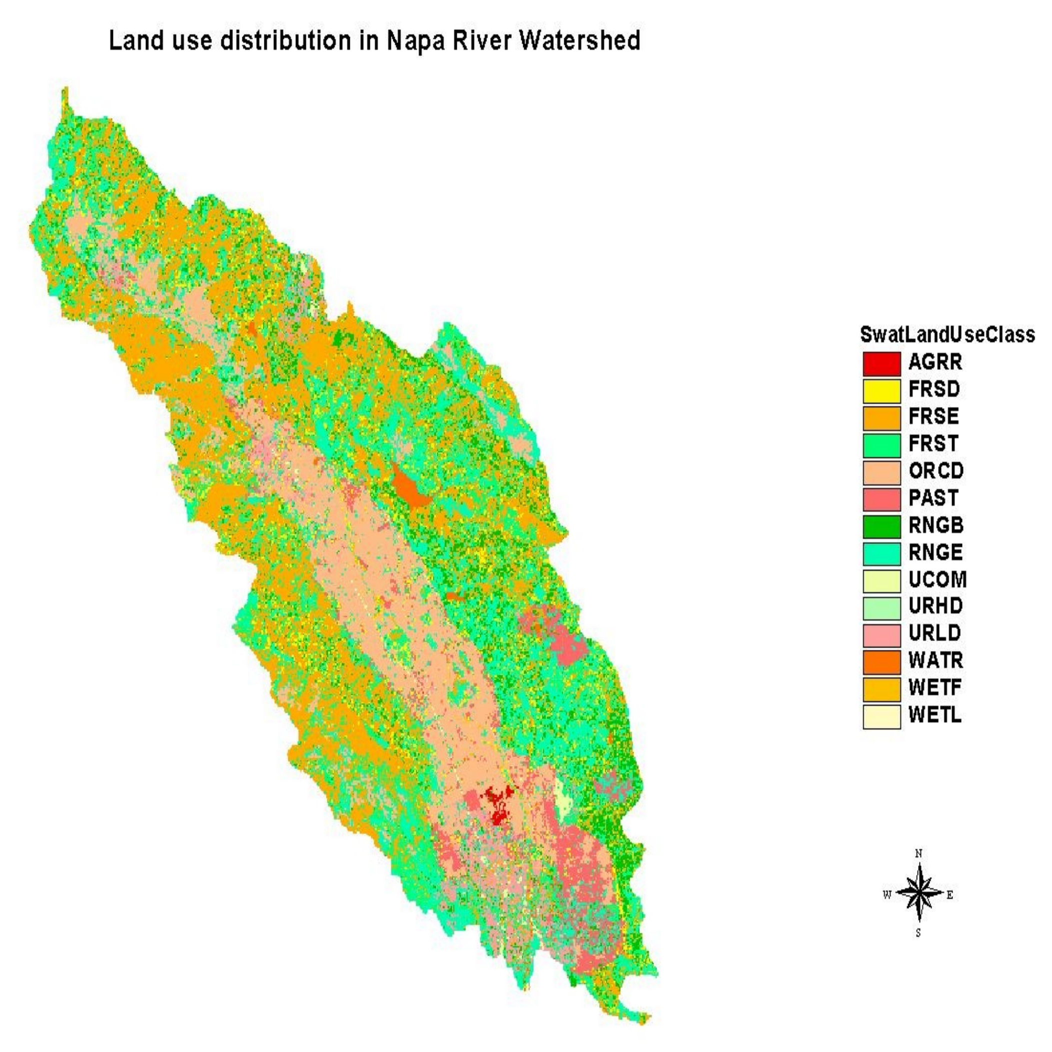


Table 7.31d: *2001 land use in the Napa River Watershed (SWAT classification)*

SWAT Land use name and code	Area (Hectares)	Percentage (%)
AGRR (Agricultural Land-Row Crops)	129	0.2%
FRSD (Forest-deciduous)	4904	6.5%
FRSE (Forest-evergreen)	22319	29.7%
FRST (Forest-mixed)	8468	11.3%
ORCD (Orchard)	12444	16.6%
PAST (Pasture)	3745	5.0%
RNGB (Range-brush)	6308	8.4%
RNGE (Range-grasses)	13149	17.5%
UCOM (Commercial)	496	0.7%
URLD (Residential-Low Density)	2590	3.4%
URHD (Residential-High Density)	5	0.0%
WATR (Water)	498	0.7%
WETF (Wetland-forested)	128	0.2%
Total	75185	100.0%

According to the land distribution calculation, forest is the most dominant land use type, followed by rangeland, with forest representing 47.5% and rangeland occupying 27.8% of the total area of the watershed. Both forest and rangeland are distributed away from the main channel of the Napa River.

Spreading mostly along the Napa River channel, agricultural land, including orchard, row crop and pasture, comes third, making up 21.7% of the total land. Urban land use, on the other hand, constitutes only 4.1% of the total area of the watershed and is dispersed across the watershed.

Agricultural Management

SWAT defines management as a series of individual operations. The timing of these operations may be defined by a date, or as a fraction of the total heat units (described below) required by the crop. Each land is assigned a set of management operations.

Heat units are accumulated when the average daily temperature exceeds the base temperature of the plant. The base temperature is the minimum temperature required by the plant to grow. The amount of heat units accumulated by each plant is equal to the average daily temperature minus the base temperature of the plant. When no plants are growing the SWAT model uses a base temperature of 0 °C and keeps a separate running total. This base 0 °C running total is used to schedule planting dates because no heat units can be accumulated until plant growth begins.

In WARMF, the only scheduling option for agricultural management is by date. Therefore, in order to have comparable output from both WARMF and SWAT models, date scheduling was chosen based on heat unit scheduling from SWAT.

As shown in Table 7.31d and Figure 7.31c, in 2001, row crops represented only 0.17% of the total land area while orchards accounted for 16.55% of total land area in Napa River Watershed. According to the Napa County Agricultural Crop Report (2002), wine grape is the major fruit grown in the orchard in Napa River Watershed, so all management operations were formulated for wine grapes and were distributed uniformly across the watershed in orchard land.

Fertilization

The nutrient loading from row crops is deemed negligible compared with that from orchards given that they represent only 0.17% of the total land use. Therefore, special agricultural management was not formulated for row crops. Instead, we assumed that all row crops had the same management operations as orchards.

Actual nutrient application rates vary greatly and recommended application rates should be based on soil analysis results for each field and crop requirement.

However, since this data is not available for aggregate land use, average values were considered in the model. Since fertilizer application data was most readily available for Thompson seedless grapes, we used them as a surrogate for all grapes. It was determined that Thompson Seedless grapevines annually needed approximately 39 kg nitrogen per hectare for the leaves, 11 kg nitrogen per hectare for the stems (main axis of the shoot) and 34 kg nitrogen per hectare for the fruit (Williams, 1987). Thus, a total of 84 kg nitrogen per hectare is needed per growing season for wine grapes and the requirement of phosphorous is assumed to be one half that of nitrogen. This number is based on grape growth requirements, regardless of the form of nitrogen applied.

Fertilization is assumed to occur each month and, given the higher runoff potential in the wet season, the fertilizer application rate in the wet season is assumed to be half that in the dry season. The simulated fertilizer application rate for each month appears in Table 7.31e below.

Table 7.31e: Agricultural Fertilizer application rates for each month in SWAT (kg/hectare)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Mineral N	4.2	4.2	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	4.2	4.2
Mineral P	2.1	2.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	2.1	2.1

We assumed that fertilization occurs in the middle of each month and all fertilizer applied is assumed to be in mineral form, i.e. either mineral nitrogen (Ammonium nitrogen and nitrate nitrogen) or mineral phosphorus. No manure or poultry litter application was considered in simulation due to the lack of related information. Ammonium nitrogen and nitrate nitrogen are considered equally applied.

Potassium application is not considered since SWAT does not route the potassium for plant growth. Therefore, it has no effect on simulation results and was not important for our analysis.

Irrigation

In each simulation step, SWAT determines whether available water present in soils provides all of the water needed during the growth season. If the available water in the soil falls short of the amount of water needed for plant growth, the model automatically detects water stress, and plant growth starts suffering until enough water is added to compensate the water stress, either by precipitation or irrigation.

In SWAT, water stress is calculated by comparing actual and potential plant transpiration (Neitsch, et al., 2001):

$$wstrs = 1 - \frac{E_{t,act}}{E_t} = 1 - \frac{w_{actualup}}{E_t} \qquad (7\text{-}1)$$

Where $wstrs$ is the water stress for a given day, E_t is the maximum plant transpiration on a given day (mm H_2O), $E_{t,act}$ is the actual amount of transpiration on a given day (mm H_2O), and $w_{actualup}$ is the total plant water uptake for the day (mm H_2O). SWAT has a routine to calculate the E_t, $E_{t,act}$ and $w_{actualup}$ on a daily basis.

Since no direct information on irrigation practices throughout the Napa River Watershed was available, the automatic irrigation option in SWAT was chosen for agricultural land, including both orchard and row crops. Automatic irrigation applies water to the soils in both land use types whenever SWAT simulates water stress in excess of a user-specified threshold value, which was set to be 0.90. For orchards and row crops, SWAT will add water to the soil until it is at field capacity (Neitsch, et al., 2001). In the project, we specified all irrigation water to be from outside the watershed, so the irrigation water flow would not be able to present unexpected influence on water balance in the watershed.

It should be noted here that all forestland and rangeland are assumed to be unmanaged in the SWAT simulation, i.e. no irrigation or external fertilizer application.

Urban Land Input

Urban areas differ from rural areas in the fraction of total area that is impervious. During dry periods, dust, dirt and other pollutants build up on the impervious areas. When a precipitation event occurs and runoff from the impervious areas is generated, the runoff will carry the pollutants as it moves through the drainage system and enters the stream network of the watershed. In SWAT build up/wash off algorithm is used to simulate the nutrient load from impervious land area (Neitsch, et al., 2001).

In pervious areas of urban land, on which Bermuda grass was assumed to grow, 10 kg mineral nitrogen per hectare and 5 kg mineral phosphorous per hectare were applied annually as fertilizer inputs to maintain the growth of the grass. We assumed that the fertilizer application in urban land occurs in the middle of each month, the same timing as in agricultural lands (Table 7.31f).

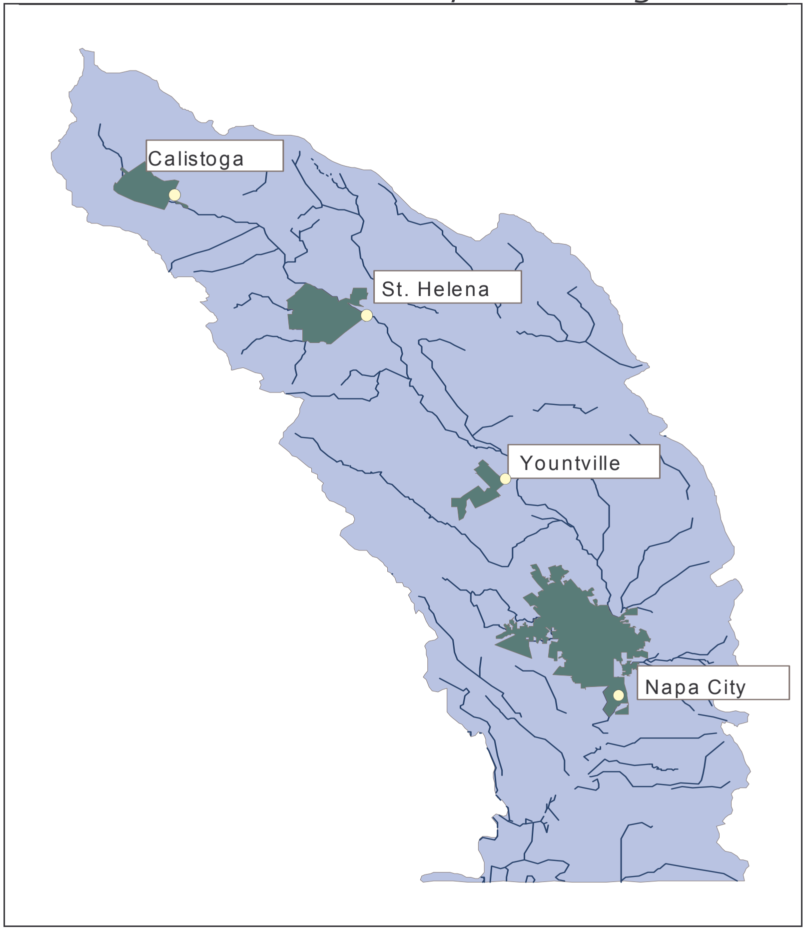
Table 7.31f: Urban fertilizer application rates for each month in SWAT (kg/hectare)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Mineral N	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
Mineral P	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.25	0.25

Point Source Input

The variable characteristics and data available for each treatment plant in the Napa River Watershed caused calculations of loading to be determined differently for each facility. Discharge locations for each treatment plant appear in Figure 7.31d.

Figure 7.31d: Wastewater treatment plant discharge locations.



Calistoga WWTP - The Calistoga wastewater treatment process currently includes a headwork; primary clarification; secondary treatment by two oxidation ponds; tertiary treatment by coagulation, clarification and filtration; and disinfection. The Discharger is in the process of implementing a major upgrade to the wastewater treatment plant. The existing plant is presently in service, and will continue to be in use until completion of the new facilities. The new plant will use an extended aeration activated sludge treatment process for primary and secondary treatment, replacing the existing primary clarification and oxidation pond system. The new process requires less land area than the existing pond system, allowing for conversion of existing ponds to use as effluent storage and flow equalization.

Calistoga discharges into the Napa River for seven months, between October and May. In order to determine daily nutrient loading, ammonia, nitrate, and total organic nitrogen concentrations collected for 2003 from the NPDES reports were used. Calistoga primarily discharges tertiary treated wastewater at a dilution ratio of 10:1 into the river (SFRWQCB, 2004). Effluent flows to the Napa River from the Calistoga WWTP were calculated by assuming a dilution ratio of 10:1 waste to river water. Based on this ratio, the Calistoga WWTP effluent discharge was calculated to range from 0.1 to 3.0 MGD (Million Gallons per Day), the plant's maximum capacity.

Documented concentrations for ammonia, nitrate and total organic nitrogen are 8, 0.8, and 0.1 mg N/L, respectively.

Table 7.31f: Estimated yearly nutrient loading from Calistoga WWTP (kg N/year)

Year	NO_3^-	NH_4^+	Yearly Total
1995	1,161	11,609	12,771
1996	1,155	11,547	12,702
1997	917	9,167	10,084
1998	1,280	12,799	14,079
1999	956	9,555	10,511
2000	717	7,164	7,880
2001	833	8,329	9,162
2002	1,075	10,752	11,827
Grand Total	8,094	80,922	89,016
Yearly Average	1,012	10,115	11,127

St. Helena WWTP- The St. Helena treatment plant consists of a headwork, an integrated oxidation pond system, and disinfection (chlorination) and de-chlorination systems. During the wet season (November through April), secondary-level treated effluent is discharged intermittently to the Napa River provided the discharge receives a minimum 50:1 river to wastewater dilution ratio. Because no discharge data was recorded for the years simulated by the model, daily discharge estimates were based upon data obtained from USGS flow gauge #11456000. St. Helena wastewater discharge rates were calculated using the required dilution ratio of 50:1, or 2% of recorded daily flow rates. It is important to note that discharge does not exceed the plant's maximum capacity of 3.2 MGD. Based on this information, the calculated effluent discharge ranged from 0.1 to 3.2 MGD.

Documented concentrations for ammonia, nitrate and total organic nitrogen were available from the City of St. Helena for January 2003 and applied to the years modeled. Concentrations for ammonia, nitrate, and total organic nitrogen loading were assumed to be 11, 0.2, and 1.0 mg N/L, respectively.

Table 7.31g: *Estimated yearly nutrient loading from St. Helena WWTP (kg N/year)*

Year	NO_3^-	NH_4^+	Yearly Total
1995	227	12,464	12,691
1996	233	12,829	13,062
1997	161	8,849	9,010
1998	245	13,476	13,722
1999	191	10,499	10,689
2000	135	7,411	7,546
2001	157	8,623	8,780
2002	159	8,759	8,918
Grand Total	1,508	82,911	84,418
Yearly Average	189	10,364	10,552

Yountville WWTP - Yountville's trickling filter treatment plant achieves secondary wastewater treatment and is therefore allowed to discharge into the Napa River only when it can achieve a dilution ratio of 50:1. Since no discharge or nutrient sampling data is available for the Yountville treatment plant, in order to determine the plant's daily discharge, data from USGS flow gage #11456000 was used for years 1990 to 2001. Yountville wastewater discharge was calculated using its dilution ratio requirement of 50:1 of the daily river flow while acknowledging that the maximum discharge from the Yountville plant cannot exceed its capacity of 2 MGD. Observing this maximum capacity limit and dilution ratio, the calculated effluent discharge ranged from 0.2 to 2 MGD.

Flow rates were then used to estimate nutrient loading to the Napa River. Trickling filter facilities have an average nutrient effluent of approximately 6 mg/L of nitrate-nitrogen (Biesterfeld, 2003) and the ammonia concentration is assumed to be 4 times the nitrate concentration (USEPA, 1999).

Table 7.31h: Estimated yearly nutrient loading from Yountville WWTP (kg N/year)

Year	NO_3^-	NH_4^+	Yearly Total
1995	4,143	16,572	20,715
1996	4,119	16,475	20,594
1997	3,288	13,153	16,441
1998	4,561	18,244	22,805
1999	3,402	13,606	17,008
2000	2,568	10,271	12,839
2001	2,980	11,920	14,900
2002	3,895	15,579	19,474
Grand Total	28,955	115,820	144,775
Yearly Average	3,620	14,478	18,097

Napa City WWTP - The Napa Sanitation district employs a Dynasand tertiary wastewater treatment process allowing the plant to discharge into the Napa River at a dilution ratio of 10:1. During the six-month wet season period (November through April), approximately 14.7 MGD of treated wastewater is discharged into the Napa River adjacent to the wastewater recycling facility on Soscol Ferry Road near Rattos Landing. The discharge pipe is 160 feet from shore and 13.4 feet below the water surface and has a diffuser (SFRWQCB NPDES No.

CA0037575, 2000). This flow was multiplied by the Dynasand average effluent nutrient concentration of 10 mg/L (NY DEP, 2000) to determine total nutrient loads. The ratio between ammonia and nitrate was assumed to be 4:1 (USEPA, 1999).

Table 7.31i: Yearly nutrient loading from Napa WWTP (kg N/year)

Year	NO_3^-	NH_4^+	Yearly Total
1995	10,163	35,570	45,732
1996	10,122	35,428	45,550
1997	7,943	27,799	35,741
1998	11,227	39,294	50,521
1999	8,410	29,435	37,845
2000	6,206	21,722	27,928
2001	7,350	25,723	33,073
2002	6,315	22,104	28,419
Grand Total	67,735	237,073	304,809
Yearly Average	8,467	29,634	38,101

In sum, the daily average TDN loading from each WWTP was calculated and appears in Table 7.31j. The total average TDN loading from WWTPs was calculated to be 428 kg N/day, with Napa WWTP contributing nearly 50% of the total. Due to the lower dilution ratio, the Calistoga WWTP discharged more TDN than the St. Helena WWTP.

Table 7.31j: Daily average loading from WWTPs (kg N/day)

WWTP	Calistoga	St. Helena	Yountville	Napa	Total
Daily Average	61	58	100	209	428

Note: the daily average was calculated based on 181 days per year, which is the number of days in the wet season (November through April next year).

For all four WWTPs, no effluent was discharged directly into the river channel during the dry season. Instead, all effluent was directed into nearby retention ponds and was used as irrigation water when necessary. In SWAT and WARMF, nutrient loading from WWTPs was simulated as fertilizer application within the sub-watersheds where the WWTPs were located.

Non-Point Source Input

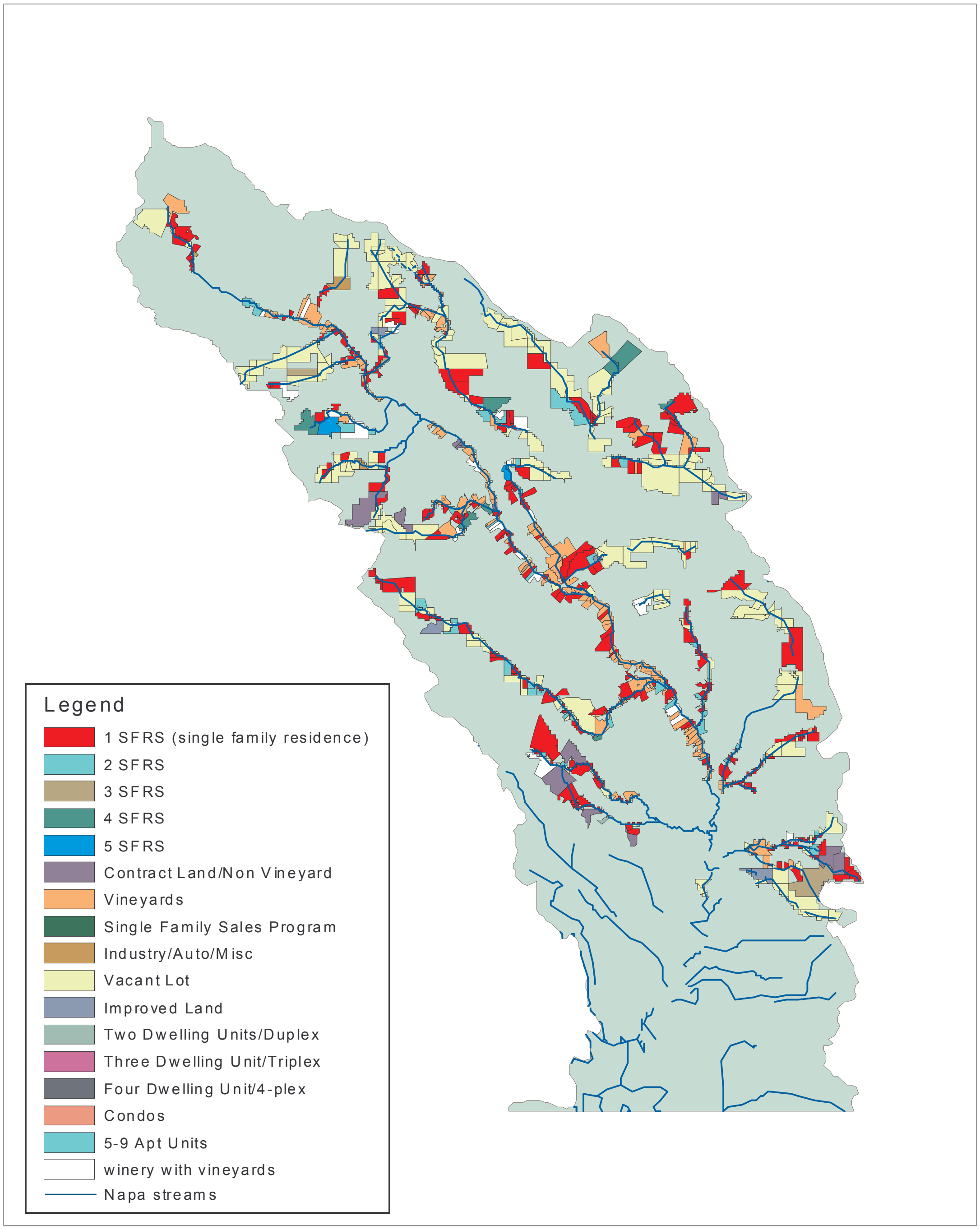
Air deposition input- SWAT does not consider nitrogen dry deposition, but can consider a constant total nitrogen concentration in rainfall. The long-term mean of nitrogen concentration in rainfall in the Napa Watershed was calculated to be 0.62mg N/L (Refer to Section 7.31). Therefore, the SWAT input for total nitrogen concentration was set to be 0.62 mg N/l.

Septic Input- The estimation of the number of septic tanks in the Napa River Watershed was a multi-step process. Sewer maps were obtained from Calistoga, St. Helena, Yountville, and Napa City during the summer of 2003. These maps were then overlaid on a map of parcel data through GIS applications. Most residential parcels on the sewer line were taken off the map plotting septic tank locations, except for residential parcels known not to be connected to the sewer line. The remaining residential parcels were assumed to have septic tanks as their main wastewater treatment. In SWAT, calculations for septic tank loads were based on the number of residential parcels within 15 meters from the river (Figure 7.31e). Single-family homes were assumed to have a population of 4 people. Septic tank estimates for parcels representing duplexes, triplexes, apartment buildings with up to 50 units and motels were all done by making a preliminary population estimate followed by a septic tank estimate based on residents. Based upon average household flow rates, which identify a four-person household to discharge, the flow rate of septic effluent was calculated per SWAT sub-basin. Nutrient loading from septic tanks was then estimated from septic effluent studies which document an average total nitrogen concentration of 42.5 mg/L and the amount of the effluent was estimated to be 50 gallon/day-person (Edvardsson, 1999). Table 7.31K presents our estimated total number of septic tanks in each sub-watershed, and the number of septic tanks within 15 meters of the rivers in each sub-watershed.

Table 7.31k: Total estimated septic tanks within the watershed, and septic tanks estimated within 15 meters of Napa River or its tributaries.

Subwatershed	Total estimated septic tanks	Septic tanks estimated within 15 meters of Napa River or its tributaries
1	244	23
2	129	0
3	43	4
4	395	23
5	168	26
6	695	30
7	400	26
8	77	9
9	104	15
10	70	22
11	800	77
12	30	0
13	310	23
14	189	4
15	158	24
16	76	6
17	32	2
18	316	25
19	186	5
20	589	127
21	702	0
22	303	58
23	807	38
24	736	68
25	8	0
26	62	15
27	707	100
28	83	0
30	748	101
31	39	5
32	168	0
33	45	2
Total	9419	861

Figure 7.31e: Septic parcel selection



Initial load estimations from septic tanks were calculated differently for SWAT and WARMF. SWAT does not have a specific module to include septic tanks as a source. For this reason, nutrient loading from septic tanks was simulated in two parts. One part was treated as direct point-source discharge into the stream to simulate the occurrence of septic tank system failure; normally functioning leach field loads were simulated as fertilizer application to the surrounding soil. Calculations were determined per SWAT delineated sub-watershed.

Annual septic tank failure rates reported for areas across the U.S. range from about 1 to 3 percent. For average annual conditions, it is conservative to assume that septic tank systems failures would go unnoticed or ignored for five years before repair or replacement occurred. Therefore, during an average year, 5 to 15 percent of the septic tanks systems in the watershed are assumed to be failing. This is consistent with the results of a survey recently conducted in Jacksonville, Florida, by the Department of Health and Rehabilitative Services (National Decentralized Water Resources Capacity Development Project, 2003).

For the SWAT simulation, the number of septic tanks per sub-basin within 15 meters from the stream was estimated assuming that only nutrient loading within this area can enter the stream network directly due to tank failure. Therefore, only this fraction of nutrient loading from septic tank systems were simulated as direct point sources in SWAT.

7.32 - WARMF Input Data

In WARMF, the database contains data for input into the model and data to evaluate simulation results. The model input includes DEM, land use, agriculture management, air quality, meteorology, and point source discharge. For the purpose of model calibration and validation of the simulated results, the WARMF database also contains data for measured stream flow and water quality from monitoring stations within the watershed of concern.

The pre-delineated WARMF model was setup based on the same DEM, land use, soil and meteorological data as SWAT, which is discussed in Section 7.31.

Our group provided the model with agricultural management, point source discharge, and air quality data and certain modifications were made to make use of some of WARMF's special features.

Land use

Although WARMF was set up based on the same land use data as the SWAT, some small inconsistencies occurred in land use classification because the models use different classification systems. Since the WARMF land use database was prepared by Systech Engineering, we did not attempt to modify it. A comparison of WARMF and SWAT land use nomenclature is presented in Table 7.32a.

Table 7.32a: WARMF land use vs. SWAT land use

WARMF	SWAT
Deciduous	FRSD (Forest-deciduous)
Mixed Forest	FRST (Forest-mixed)
Orchard	ORCD (Orchard)
Coniferous	FRSE (Forest-evergreen); FRST (Forest-mixed)
Shrub / Scrub	RNGB (Range-brush)
Grassland	RNGB (Range-brush); RNGE (Range-grasses)
Pasture	PAST (Pasture)
Farm	AGRR (Agricultural Land-Row Crops)
Marsh	WETF (Wetland-forested)
Water	WATR (Water)
Residential	URLD (Residential-Low Density); URHD (Residential-High Density)
Comm./Industrial	UCOM (Commercial)

Soil Data

WARMF does not adopt the concept of HRU; it considers various land use types, but only one soil type within one sub-catchment. In WARMF, the area-dominant soil type in one catchment was pre-chosen as the soil type uniformly distributed within the sub-catchment. However, in some cases, the area-dominant soil does not necessarily affect water quality in a river segment. For instance, in some cases the area-dominant soil may be distributed too far from a river segment to pose a significant effect on the water quality of that river segment. Therefore, a modification was made to consider this effect. In each sub-catchment, the area-dominant soil was replaced with the soil that is immediately adjacent to the river segment.

Fertilization

The same fertilizer application rate used by SWAT in orchard land was applied in WARMF, and fertilizer applications were carried out on a monthly basis. WARMF applies fertilizer on a daily basis, using the monthly rate as a basis.

Table 7.32a: Fertilizer application rate for each month in WARMF (kg/ha)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Ammonia N	2.1	2.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	2.1	2.1
Nitrate N	2.1	2.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	2.1	2.1
Mineral P	2.1	2.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	2.1	2.1

Irrigation

Although WARMF does take irrigation flow as an input parameter, it does not consider water stress during plant growth. Therefore, whether or not there is enough water present in the soil for a plant to grow will not affect the status of the plant growth and the uptake of nutrients. Also, as mentioned before, since we don't have observed irrigation flow data, irrigation water was not used as an input to the WARMF simulation; thus irrigation does not have an impact on the water balance equations of the model.

Urban fertilizer application

The same fertilizer application rate used by SWAT in urban land was applied in WARMF. Fertilizer applications were carried out on a monthly basis except that for mineral nitrogen which was equally divided between ammonia nitrogen and nitrate nitrogen.

Table 7.32b: Fertilizer application rate in urban land for each month in WARMF (kg/ha)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Ammonia N	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.25	0.25
Nitrate N	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.25	0.25
Mineral P	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.25	0.25

Atmospheric Deposition

Unlike SWAT, which considers only a constant nitrogen dry deposition, WARMF takes into account both dry and wet deposition of nitrogen-related compounds including nitrate, nitrite, NOx and ammonia, and some others such as SOx, calcium, sulfate, and phosphate.

In WARMF, the following equations govern the collection of pollutants through atmospheric deposition (Chen 2001).

Wet deposition to land use j D_{jw} (kg/d) is a function of the amount of precipitation, the concentration of the precipitation, and the land area, as shown in the following equation (7-2).

$$D_{jw} = \frac{PC_pA_j}{10^9} \qquad (7\text{-}2)$$

P is the precipitation rate (cm/d), C_p is the precipitation concentration (mg/l), and

A_j is the area of land use j (cm^2). The dry deposition to land use j D_{jd} (kg/d) is the sum of the particulate deposition to leaf surfaces D_{jdl}, the particulate deposition to the ground D_{jdg}, and the gaseous uptake by leaves U_{jdl} as shown in equations (7-3)-(7-6).

$$D_{jd} = D_{jdl} + D_{jdg} + U_{jdl} \tag{7-3}$$

$$D_{jdl} = \frac{e_d V_d C_a L_j A_j}{10^{15}} \tag{7-4}$$

$$D_{jdg} = \frac{V_d C_a A_j}{10^{15}} \tag{7-5}$$

$$U_{jdl} = \frac{e_d U_d C_a L_j A_i}{10^{15}} \tag{7-6}$$

Parameter e_d is the dry collection efficiency (assumed 0.6 from Chen 1983), V_d is the particulate deposition velocity (cm/d), U_d is the gaseous uptake velocity (cm/d) and C_a is the atmospheric concentration (ug / m^3). Since gaseous uptake means that nitrogen is absorbed to meet the nutrient demand of vegetation, this is not available for watershed loading, and it is omitted from the atmospheric loading in this analysis (U_d = 0). The linkage analysis takes this effect into account in determining the uptake needed by vegetation beyond NO_x uptake.

In this project, the air quality data for the simulation period was retrieved from California Ambient Air Quality Data CD, released by Planning & Technical Support Division of Air Resources Board of the State of California EPA (2000). The air quality input file prepared for WARMF was on a daily basis.

Figure 7.32a:

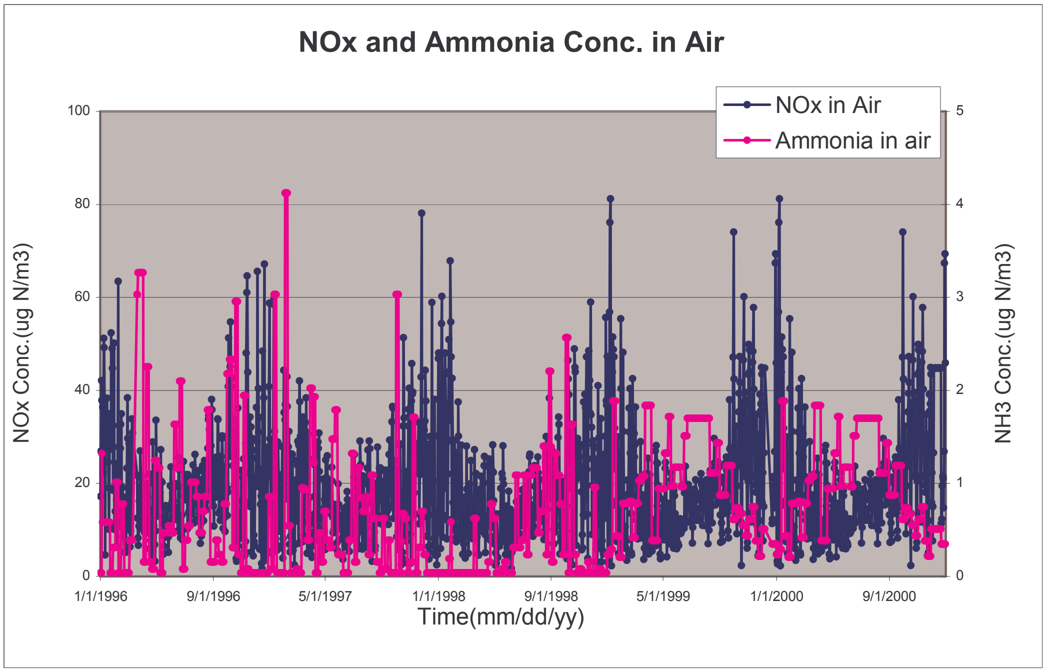
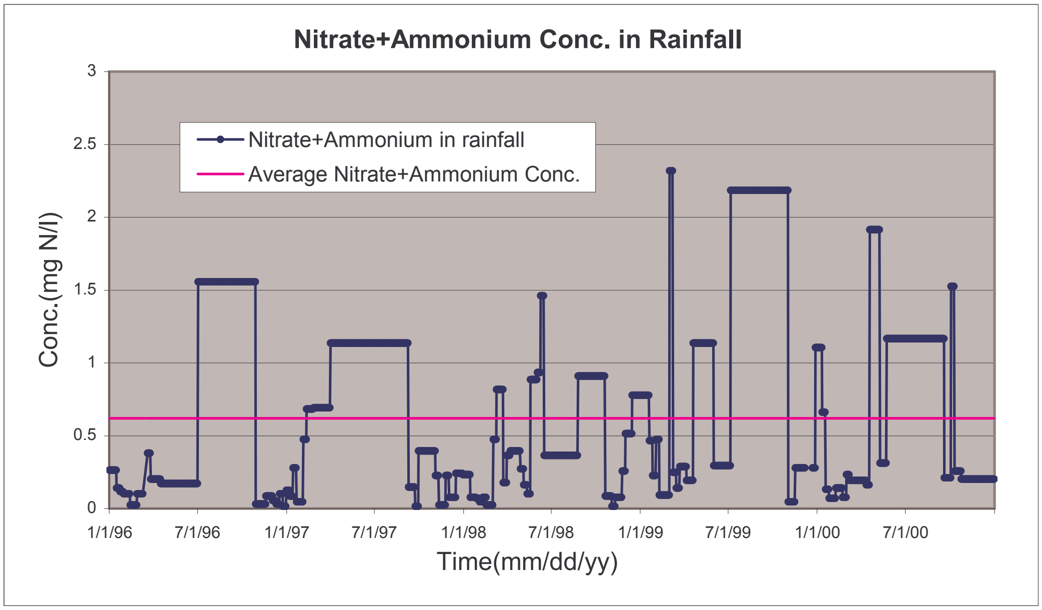


Figure 7.32b:



The long-term mean of the total nitrate and ammonium concentrations in rainfall for the Napa Watershed was calculated to be 0.62mg/L nitrogen.

Septic Input

WARMF considers septic tank effluent discharged to a soil layer, much like an underground point source. Individual septic systems within a catchment are lumped and evenly distributed in the subsurface of the catchment. Nutrients are considered in the infiltrating water.

For each catchment, WARMF requires only the input data of the population served by septic systems, which was calculated through the same processes as in SWAT as mentioned in section 7.1. The estimated population served by septic tanks for each catchment was based on the same parcel selection map as in SWAT (Figure 7-32).

The same data produced for SWAT septic tank determination was used for the WARMF simulation as well. The difference in model input is twofold. First the WARMF delineation divides the watershed into smaller catchments than SWAT, and second the WARMF model allows direct input of septic numbers instead of the non point source application used with SWAT.

7.4 - MODEL CALIBRATION

General calibration procedure

The models were first calibrated for hydrology and then Total Dissolved Nitrogen (sum of ammonium, nitrate, and nitrite). Usually between hydrological and nutrient calibration, there is calibration for sediment because sediment transport significantly influences nutrient transport during rainstorm events, especially organic nitrogen and phosphorus transport. Unfortunately, lack of measured sediment loading data makes it impossible for us to calibrate the models for sediment. On the other hand, in our case, all nutrients of concern, i.e. ammonium, nitrate and nitrite, are transported through the watershed in dissolved forms, instead of attached to sediments. Therefore, sediment loading would not significantly affect the simulation results.

Once calibration was complete it was not adjusted to make the other component fit. For example, once hydrology was calibrated, the hydrologic component of the model was not adjusted to make the nutrient component fit. Once both components were calibrated, the hydrology was rechecked to make sure that modification of nutrient levels had not been affected by the hydrology calibration.

Assessment Criteria

To determine the accuracy of the models' outputs to measured values, the Nash-Sutcliffe coefficient of efficiency and R-squared values were utilized. These tests compare simulated and measured monthly values for stream flow.

The Nash-Sutcliffe is calculated using equation (7-7):

$$EF = \frac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2 - \sum_{i=1}^{n}\left(P_i - O_i\right)^2}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \qquad (7\text{-}7)$$

Where O_i is the i^{th} measured or observed value; P_i is the i^{th} simulated or predicated value; n is the total number of comparisons and is the average of the observed data.

Nash-Sutcliffe values greater than 0.6 are generally considered a reasonable fit. R-square values will tend to be higher than Nash-Sutcliffe values. This is because an outlying value on a single event will significantly lower the Nash-Sutcliffe value while only slightly affecting R-squared values.

Key Assumptions

First, for some parameters, we didn't have more information than just assuming they were uniform within the entire watershed, such as organic nitrogen decomposition rate or algae growth rate in the river for both models. In SWAT, all groundwater parameters were considered uniform in the entire watershed.

For hydrological calibration, no attempt was made to separate baseflow and runoff for the water balance calculation because uncertainties associated with estimated flow from point sources in conjuction with the lack of data on irrigation water flow, usually make the baseflow separation program fail. Therefore, the hydrological calibration was made only for total streamflow.

Simulation periods

Since land use and agricultural management data was considered based on current information, they might not match older climatic data, measured streamflow and water quality data. Therefore, no attempt was made to run the models for a long time period. Both models were run for the same simulation period, which is from June 1, 1996 to June 30, 2001. The ending simulation time point was chosen because no newer meteorological and measured streamflow data was available at the point when the project started.

Because SWAT needs about one year of simulation to stabilize before it can produce credible results, the first simulation year was discarded for both models.

This selection of simulation period is deemed reasonable because it brackets three wet years from 1996 through 1998, one dry year in 2001, and two regular years from1999 to 2000 as shown in Figure 7.41.

The time step on which both models run is one day, and daily output was chosen to present the simulation results.

7.41 - Hydrological Calibration

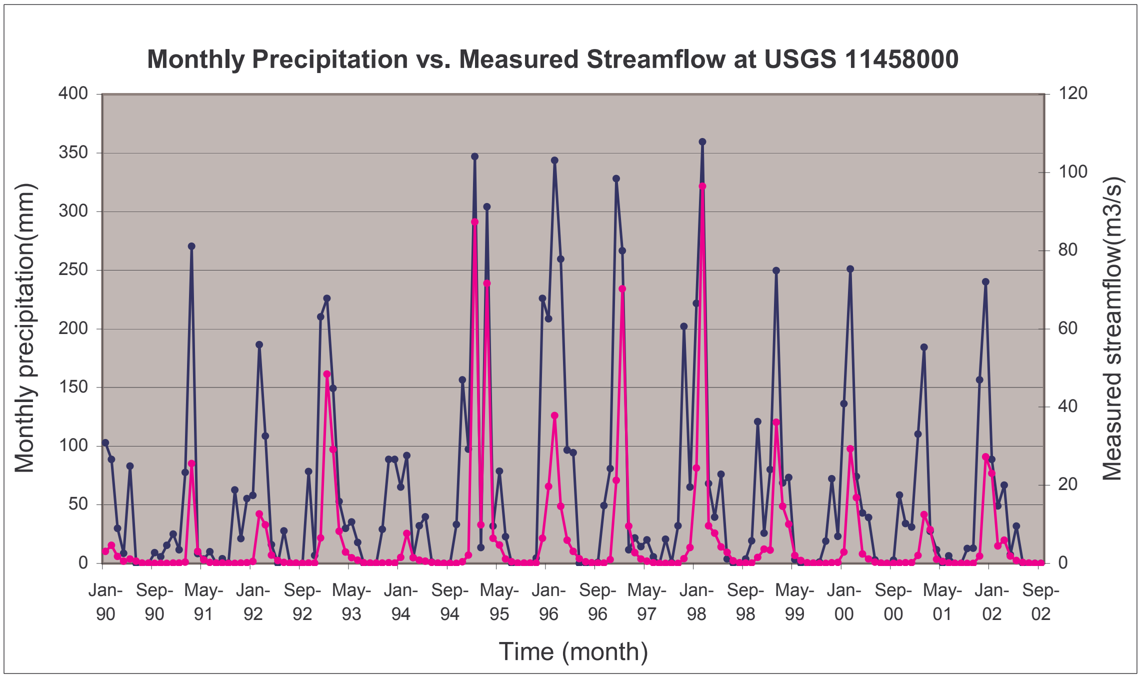
Measured Data

As mentioned before, there are two USGS gage stations located within the Napa River Watershed, USGS 11456000 and USGS 11458000, but only USGS 11458000 has measured data for our entire simulation period. Thus, both models were calibrated against measured streamflow data from USGS gage station

11458000. To analyze the quality of measured streamflow at USGS 11458000, a comparison between measured streamflow and observed precipitation was made (Figure 7.41a). From the comparison, it was found that the measured streamflow data at USGS 11458000 matched the measured precipitation reasonably well except for the period from October 1995 to April 1996. Presumably, the mismatch was caused by error of measurement either for precipitation or streamflow, which suggests that the period should not be incorporated into simulation periods. This further justified the simulation period we selected.

The mean and standard deviation of measured streamflow data at USGS 11458000 over the last ten years was calculated to be 5.90 and 24.41 m^3/s respectively.

Figure 7.41a: *USGS measured streamflow vs. observed precipitation.*



Tables 7.41a and 7.41b present the parameters, along with their values, which were adjusted basin-wide during the hydrological calibration for both models.

Table 7.41a: Parameter modifications for hydrological calibration of SWAT.

Parameters	Values
Threshold depth of water in shallow aquifer for return flow to occur (mm)	0.0
Threshold depth of water in shallow aquifer for 'revap' to occur (mm)	0. 005
Deep aquifer percolation fraction	0.45
Ground water 'revap' coefficient	0.12
Effective conductivity in tributaries and the main channel (mm/hr)	0.5
Maximum canopy storage (mm)	5
Soil evaporation compensation factor	0.2
Manning's 'n' values in the tributaries and main channel	0.04
Manning's 'n' values for overland flow	0.15

Table 7.41b: Parameter modifications for hydrological calibration of WARMF.

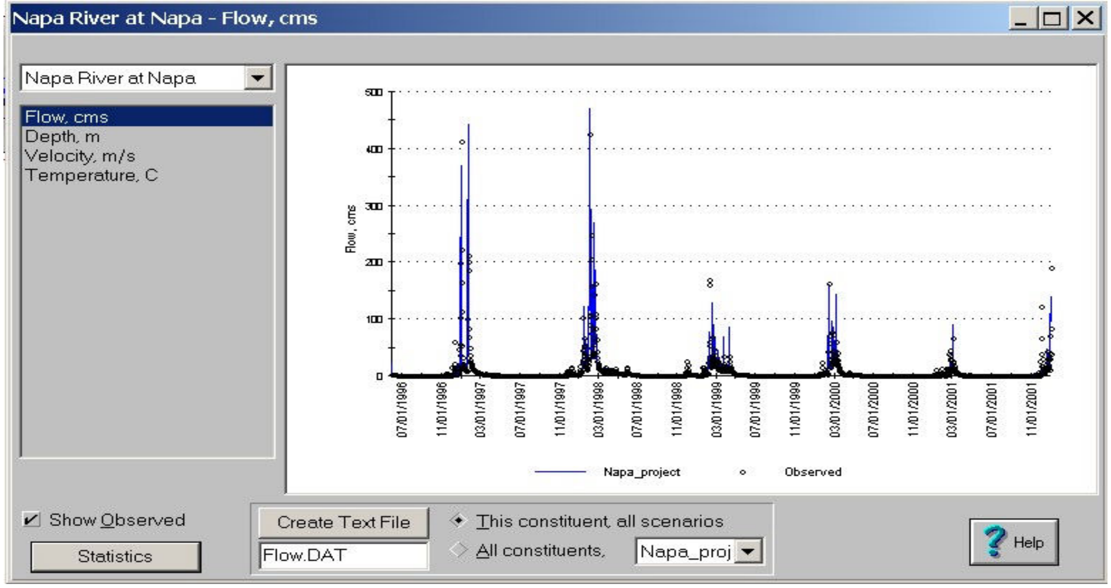
Parameter	Values
Manning's 'n' values for catchment	0.15
Precipitation weighting factor	1.2
Initial soil moisture (mm/mm)	0.25
Manning's 'n' values in the tributaries and main channel	0.04

The calibration results of both models are presented below in Table 7.41c and Figures 7.41b through 7.41g.

Table 7.41c: Model hydrological calibration results (m^3/s).

Parameter	SWAT	WARMF	Observed
Mean	6.1	6.5	6.4
Minimum	0.0	0.0	0.0
Maximum	318.3	469.2	424.8
R-Squared	0.6	0.8	
Nash-Sutchliffe	0.6	0.8	

Figure 7.41b: WARMF simulated vs. measured stream flow at USGS 11458000.

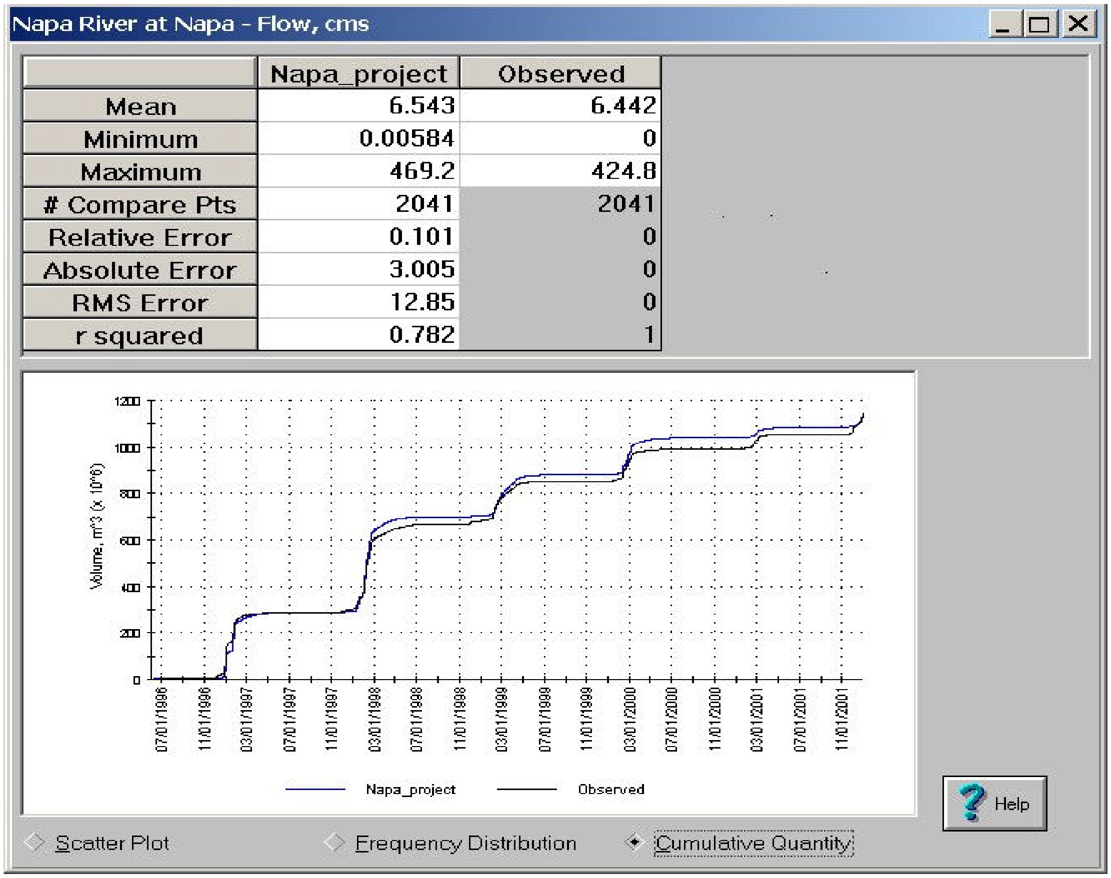


☑ Show Observed

● This constituent, all scenarios

○ All constituents, Napa_proj

Figure 7.41c: WARMF cumulative simulated vs. measured stream flow at USGS 11458000.



	Napa_project	Observed
Mean	6.543	6.442
Minimum	0.00584	0
Maximum	469.2	424.8
# Compare Pts	2041	2041
Relative Error	0.101	0
Absolute Error	3.005	0
RMS Error	12.85	0
r squared	0.782	1

○ Scatter Plot ○ Frequency Distribution ● Cumulative Quantity

***Figure 7.41d**: Scatter plot of WARMF simulated and measured stream flow at USGS 11458000.*

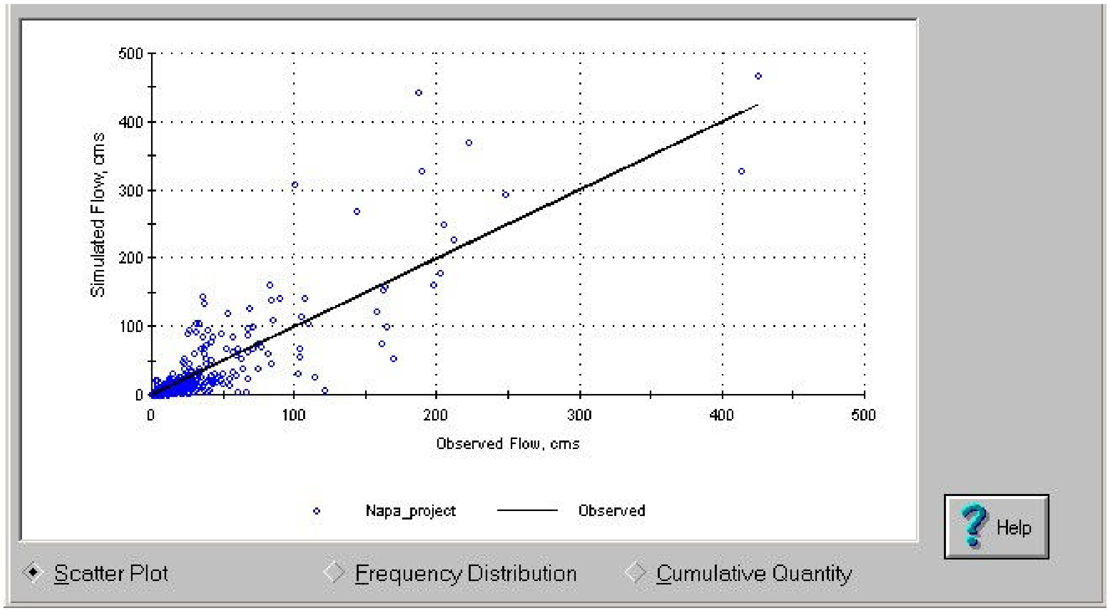


***Figure 7.41e**: SWAT simulated vs. measured stream flow at USGS 11458000.*

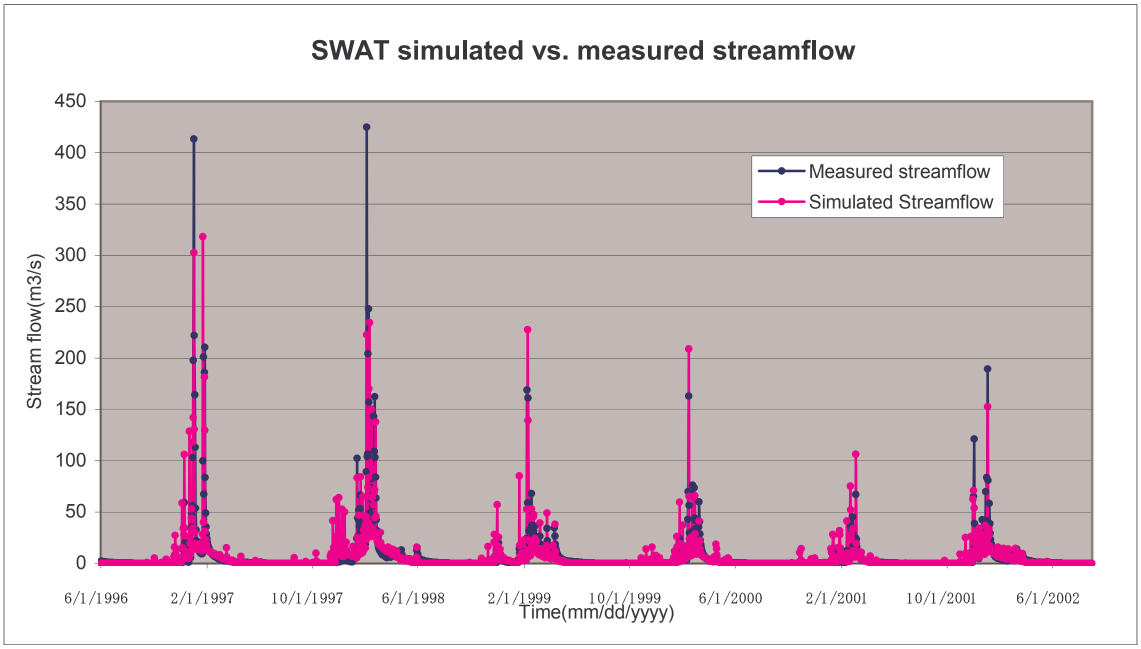


Figure 7.41f: Scatter plot of SWAT simulated and measured stream flow at USGS 11458000.

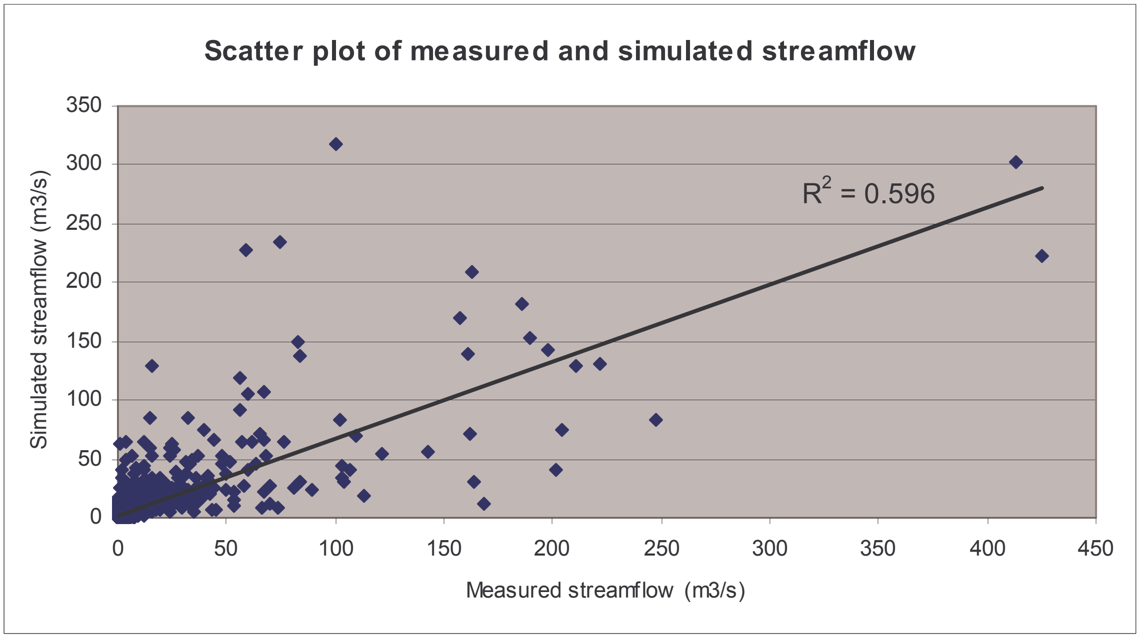
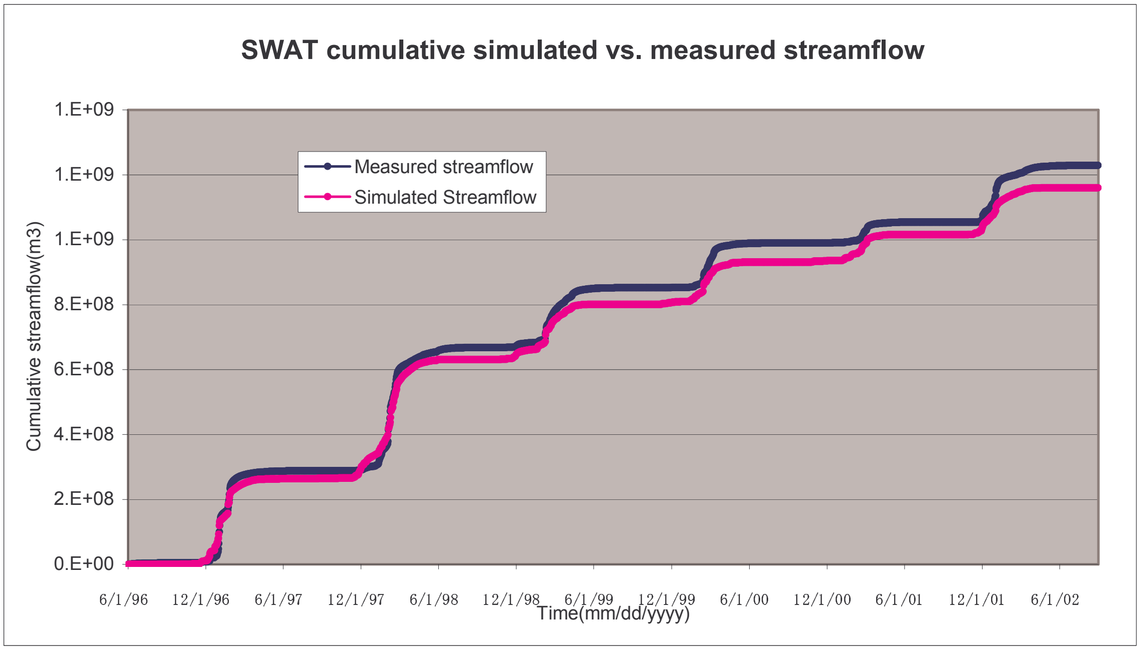


Figure 7.41g: SWAT cumulative simulated vs. measured stream flow at USGS 11458000.



It can be seen that the cumulative simulated stream flow for both models matched cumulative measured stream flow quite closely (Figure 7.41b and 7.41g).

WARMF simulated stream flow matched the measured peaks well, while SWAT simulated stream flow was off the measured peaks during the large rainstorms. This can be partially explained by the fact that SWAT was designed to assess the effect of long-term land use change on water quality, not intended to be responsive to an individual rainstorm. Also, the difference could be caused by the allocation of meteorological data to each sub-watershed. In SWAT, the meteorological data from the closest adjacent weather station to a sub-watershed is automatically assigned to the watershed. In WARMF, the user has the freedom to assign the meteorological data to an individual sub-watershed. Due to time constraints, no comparison of meteorological data in each sub-watershed between the two models was made.

Because the peaks simulated by SWAT were off at two time points, this helps explain why its R-squared and Nash-Sutcliffe coefficient were lower than those of WARMF. However, in both cases, the simulation results were considered a reasonably good fit.

In SWAT, groundwater and runoff can be adjusted separately, while in WARMF there is not a separate module for adjusting groundwater routing. Because we did not attempt to separate base flow and runoff due to previously mentioned reasons, there was no need to make these adjustments.

7.42 - Nutrient Calibration

In the project, both models were calibrated for TDN as a total and no attempt was made to calibrate the models for ammonium, nitrate, and nitrite nitrogen separately. The reasons for this approach are the following:

First, the proposed nitrogen target level is measured in Total Dissolved Nitrogen (TDN). Second, in both models, we assumed that ammonium nitrogen and nitrate nitrogen were applied equally, but there is no clear basis for this particular ratio. Last, for point sources, the assignment of the ratio between ammonium and nitrate in their effluent concentration is uncertain. Therefore, comparison of specific loading of ammonia and/or nitrate between the two models is also uncertain.

Although there are a few water quality measurements for USGS 11458000, all of them are prior to 1993. Since the watershed land use has changed significantly since 1993, those water quality data were not considered in model calibration, either for SWAT or WARMF. Instead, water quality data measured by the SFBRWQCB in 2003 was used for model calibration. The measurements took place only twice in 2003, with participation from our group members, one in January and the other in June.

The year of 2003 was considered regular in terms of precipitation. The dates in which the measurements took place were chosen deliberately so as to represent the regular water quality conditions of the Napa River in both dry and wet seasons. Based on this, the measured TDN data was taken as representative of normal conditions occurring in the watershed and used to calibrate both models. Again, due to data limitations, no calibration for annual nitrogen loading was made.

To facilitate the calibration, the Napa River watershed was further divided into 4 sub-regions as shown in Figure 5.2d. These sub-regions are the Calistoga sub-region, St. Helena sub-region, Yountville sub-region, and Napa sub-region. Each of the 4 sub-regions contains one wastewater treatment plant, as presented in Figure 7.31d. According to the measured data presented in Table 5.2a and Figure 5.2e, the higher TDN concentrations occurred at the outlets of each sub-region in both January and June. The outlets of each sub-region, therefore, were selected to be TDN calibration points.

During the dry season, the most significant sources of stream flow are groundwater seepage and sometimes irrigation return flow. The nutrient content of both groundwater and irrigation return flow will significantly affect the nutrient concentration in the stream. In such a place as Napa where orchards are a significant fraction of the land and stream flow in the dry season is very low, the effect of nutrient content in the irrigation return water might be more significant than that in groundwater. However, due to the lack of measured irrigation flow data, the effect of irrigation return flow on the nutrient concentration of the stream in the dry season was not taken into account during the modeling process. As a consequence, for both models, groundwater was the only modeled external nutrient contributor to the stream other than direct air deposition, which is considered negligible in this case. This renders it difficult to calibrate both models correctly in the dry season. In WARMF, initial nitrate concentration in groundwater is a major parameter, which significantly affects the amount of TDN flowing into the stream during the dry season; this is discussed in more detail in the sensitivity analysis (Section 8.0). The initial groundwater nitrate concentration significantly affects the nutrient concentration in stream flow in the dry season, compared with its relatively small effect on the nutrient concentration in stream flow during the wet season when irrigation is carried out infrequently. Therefore, WARMF was adjusted only to approach the January (wet season) measured TDN data and no additional adjustment was made to match the June (dry season) measured data. The initial groundwater nitrate concentration under agricultural land was set to be 1.5 mg/L according to some field tests in similar areas and the others was set to be 0.1 mg/L. (Below, 1992; Westcott, 1997; Heckman, 2001).

Similarly, SWAT was only adjusted to the January measured data and no adjustment was made to match the June measured data. Besides the effect of irrigation return flow, our method for simulating septic tanks in SWAT also contributed to in stream nutrient loading. According to the USGS measured data and our simulated data, during the summer, the stream flow nearly goes to zero.

On the other hand, as stated before, part of the septic tank nutrient loading to the river was simulated as point source discharge directly discharging into the river, which is the case throughout the year. Therefore, in the dry season, when there is no runoff or point source discharge, even a small quantity of septic tank loading would cause nutrient concentrations in the river to rise significantly because of the low streamflow. In this case, the simulated result was not considered credible. As a result, due to the limitation of the model in terms of septic system input, no SWAT nutrient calibration was attempted for the dry season.

Since there was only one data set to match, it was not possible to do a rigorous quantitative comparison between model output and measurements. Instead, we matched the simulation output visually to approximately correspond with observed values. Table 7.42a presents the measured TDN concentration at each calibration point in January and June 2003. The simulated TDN concentrations for each model is presented in Table 7.42b. It should be noted that only simulated TDN concentrations for the months of January from 1997 to 2001 were used in calculating statistics in Table 7.42b.

Table 7.42a: Measured TDN Concentrations in Calibration Points.

	Calistoga	St. Helena	Yountville	Napa
January	1.39	1.85	2.21	3.16
June	1.23	1.58	1.80	2.13

Table 7.42b: Comparison of WARMF and SWAT simulation results for TDN in January.

	Calistoga		St. Helena		Yountville		Napa	
Models	WARMF	SWAT	WARMF	SWAT	WARMF	SWAT	WARMF	SWAT
Mean	2.36	1.54	1.78	1.69	1.41	1.64	1.73	1.88
Standard Deviation	1.55	1.14	1.06	1.18	0.76	1.35	0.96	1.45
Minimum	0.48	0.10	0.48	0.22	0.51	0.18	0.49	0.26
Maximum	8.34	5.78	5.96	6.69	4.75	7.80	5.68	8.84

Note: all parameters have units of mg N/L.

The detailed results of the calibration of both models are presented below.

SWAT calibration for TDN

To calibrate SWAT for measured TDN concentrations, certain parameters were adjusted. The parameters, which were adjusted basin-wide, and their values after adjustment appear in Table 7.42c.

Table 7.42c: Parameter modification for TDN calibration of SWAT

Parameters	Values
Nitrogen percolation coefficient	2
Biological mixing efficiency	0.15 (Range and forest land) 0.5 (Agricultural land)
Rate factor for humus mineralization of active organic nitrogen (/day)	0.002
Nitrogen uptake distribution factor	50
Fraction of algae that is nitrogen	0.08
Initial groundwater nitrate concentration under agricultural land (mg/L)	1.5
Initial groundwater nitrate concentration under non-agricultural land (mg/L)	0.1
Algal preference for ammonia	0.5

Figures 7.42a through 7.42d present the SWAT calibration results for TDN. In each figure, the measured TDN concentration is represented by the plum straight line, though the measurement only happened at one time point which is not bracketed by the simulation periods. For comparison, simulated daily TDN

concentrations for the months of January from 1997 to 2001 were used in Figures 7.42a through 7.42d.

As can be seen in these figures, daily TDN fluctuates in all locations. Therefore, it would not be realistic to expect that the one-time (Jan 2003) measurement would fall exactly within the mean for the months of January for any particular location. The comparison is only to provide some idea of the reasonable level of simulated concentrations.

Figure 7.42a:

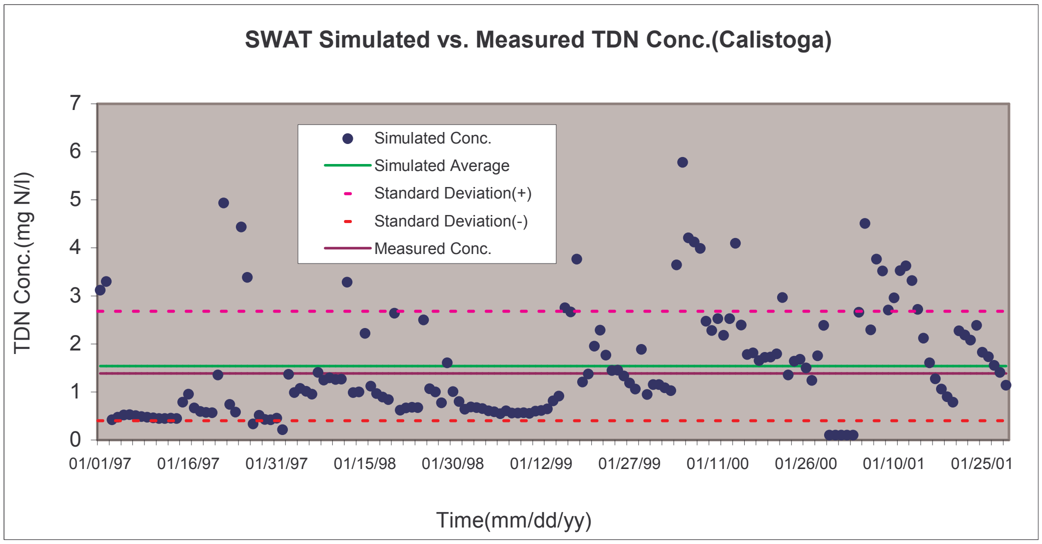


Figure 7.42b:

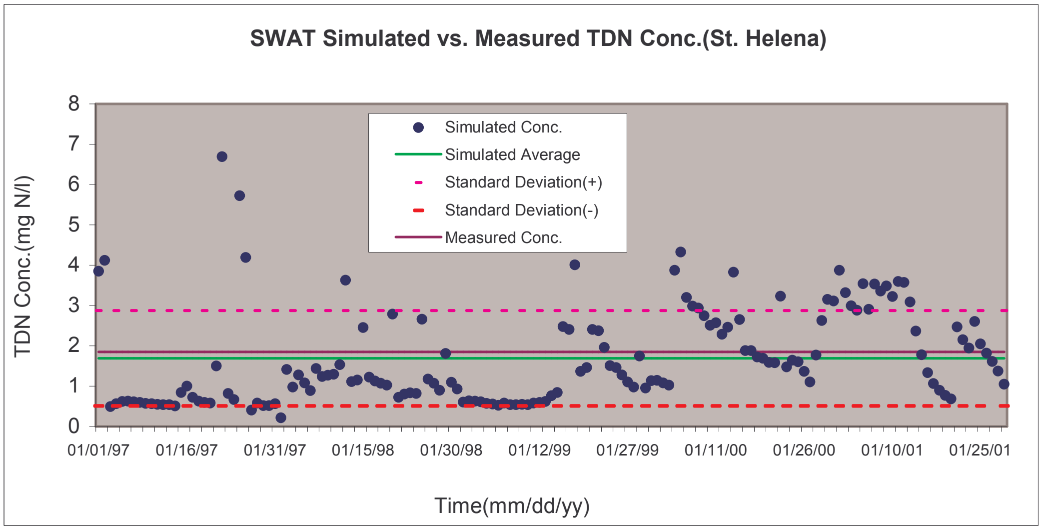


Figure 7.42c:

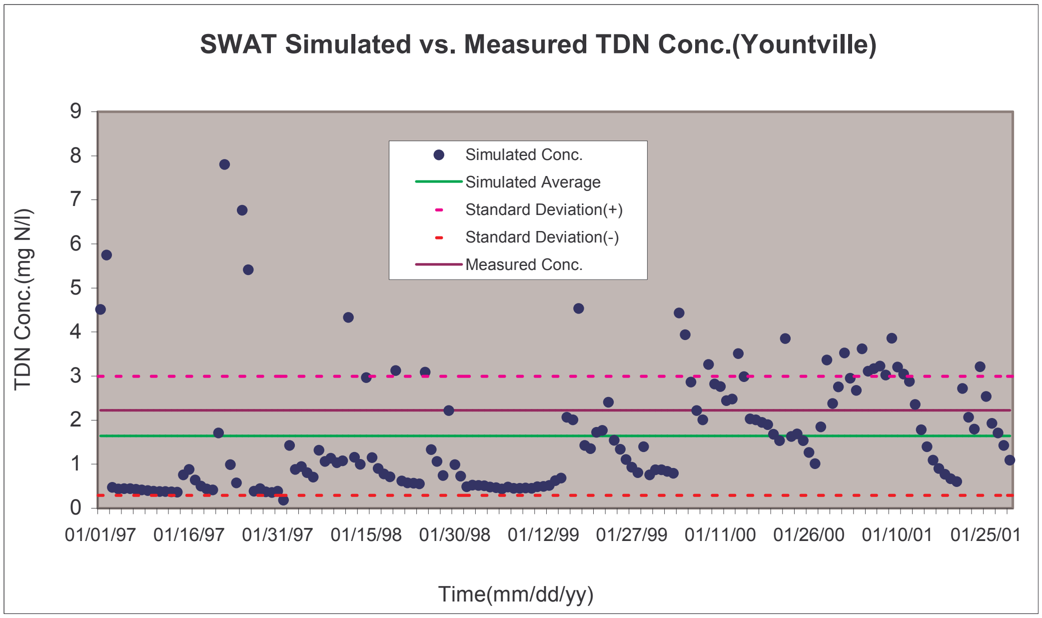
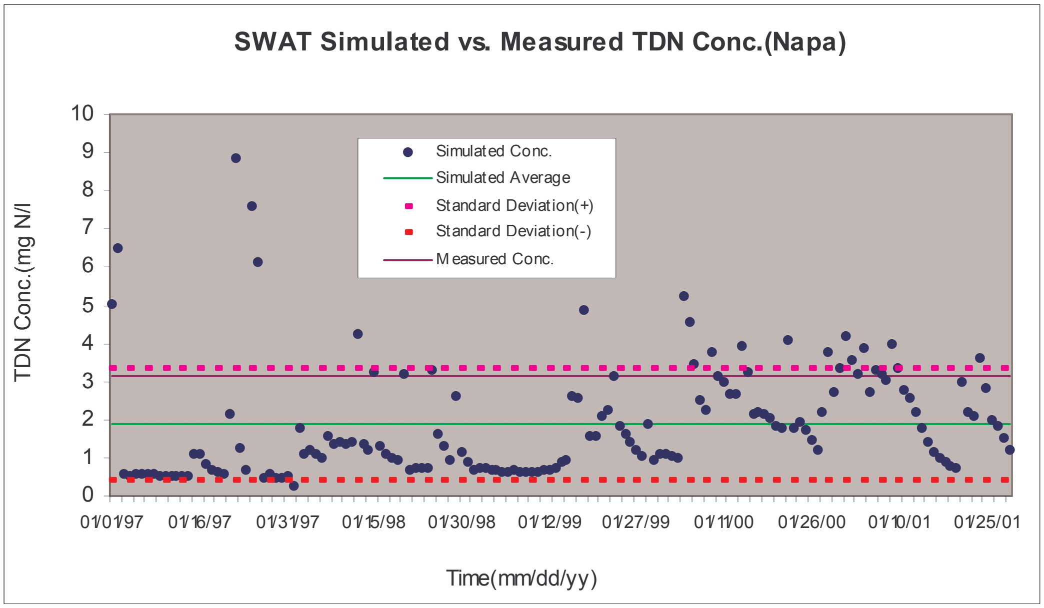


Figure 7.42d:



WARMF calibration for TDN

To calibrate WARMF for measured TDN concentrations, certain parameters were adjusted. The parameters, which were adjusted basin-wide, and their values after adjustment are presented in Tables 7.42d and 7.42e.

***Table 7.42d**: Parameter modification for TDN calibration of WARMF.*

Parameters	Values
Adsorption coefficient for NO_3^- (l/kg)	5
Nitrification rate in river (day^-)	0.1
Denitrification rate in river (day^-)	0.1
Initial groundwater nitrate concentration under agricultural land (mg/L)	1.5
Initial groundwater nitrate concentration under non-agricultural land (mg/L)	0.1
Initial based saturation for NH_4^+	0.1%

***Table 7.42e**: Adjusted plants uptake distribution of WARMF.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deciduous	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Brdlf Evergreen	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Mixed Forest	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Orchard	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Coniferous	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Shrub / Scrub	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Grassland	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Pasture	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Farm	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Marsh	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Water	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Residential	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Comm./Industrial	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05

Figures 7.42e through 7.4.2.2d represent the WARMF calibration results for TDN. In each figure, the measured TDN concentrations are represented by the straight plum line, though the measurement only happened at some time point that was not bracketed into simulation periods. For comparison, only simulated daily TDN concentration for Januarys were used in the Figures 7.42e through 7.42h.

Note that although there appears to be an upward trend in WARMF simulation output, there is no data to confirm the trend or adjust the model.

Figure 7.42e:

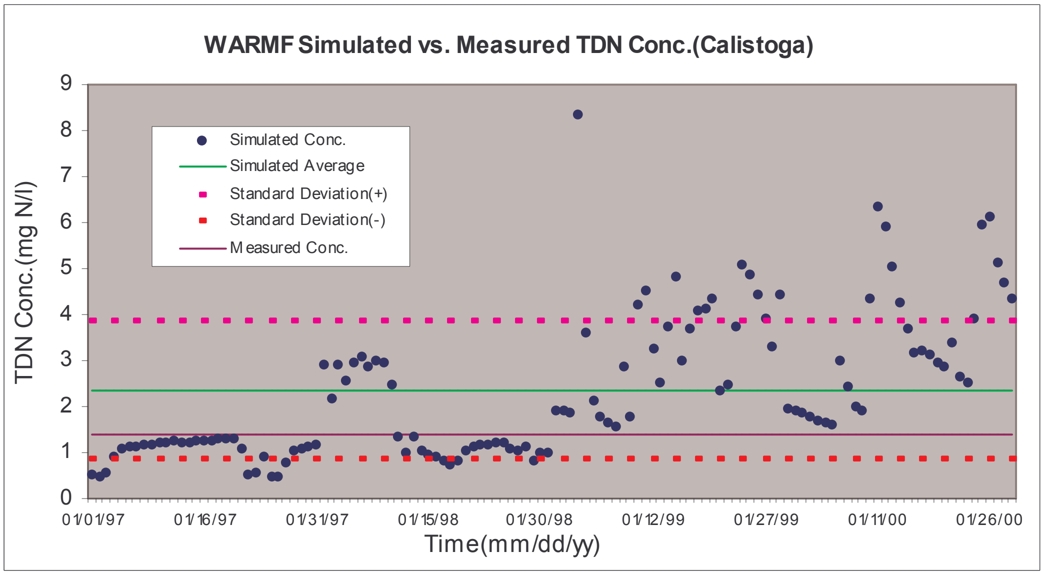


Figure 7.42f:

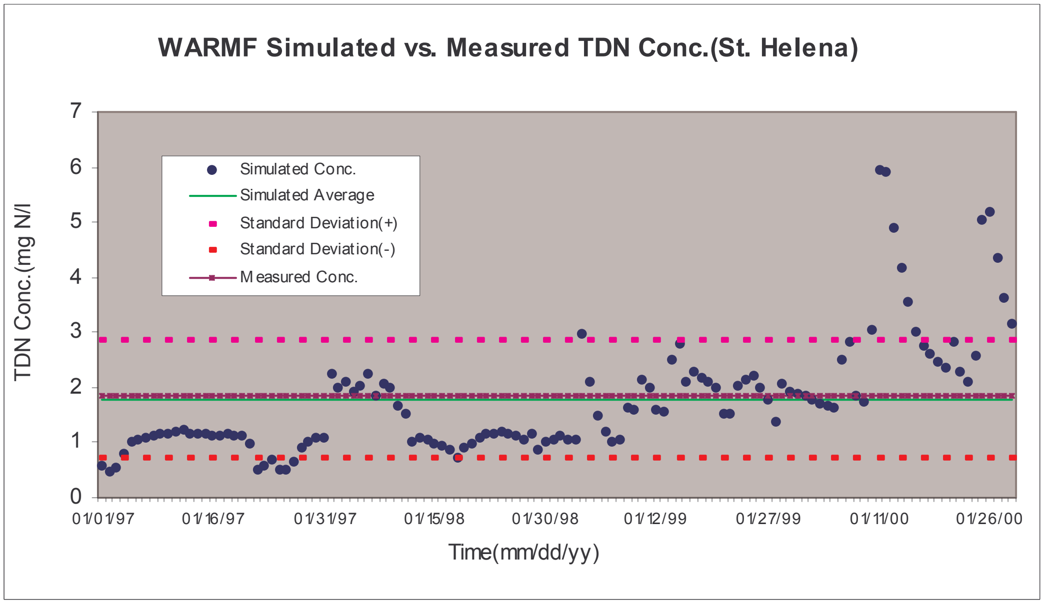


Figure 7.42g:

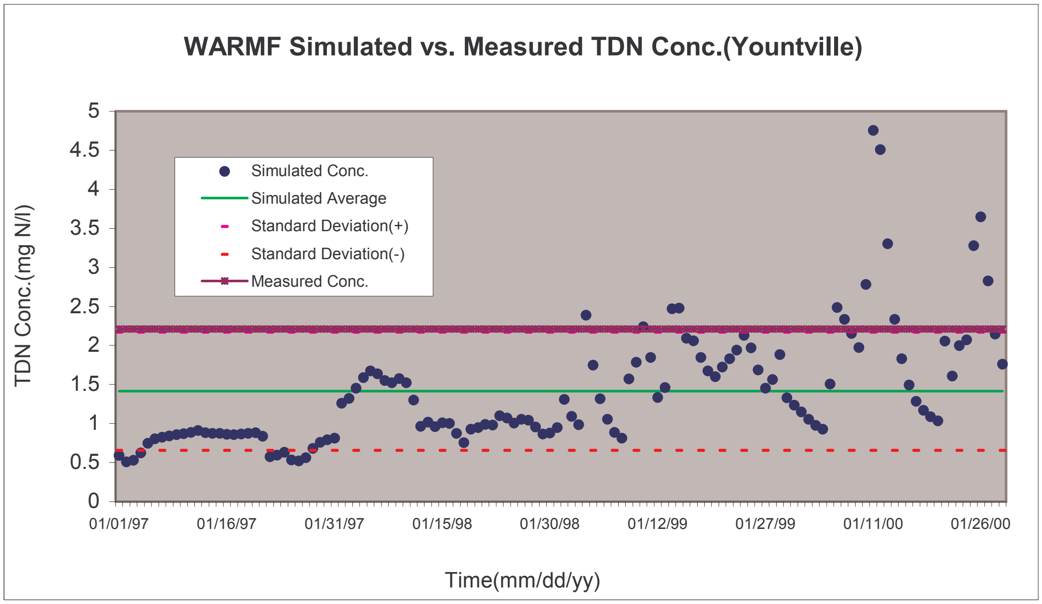
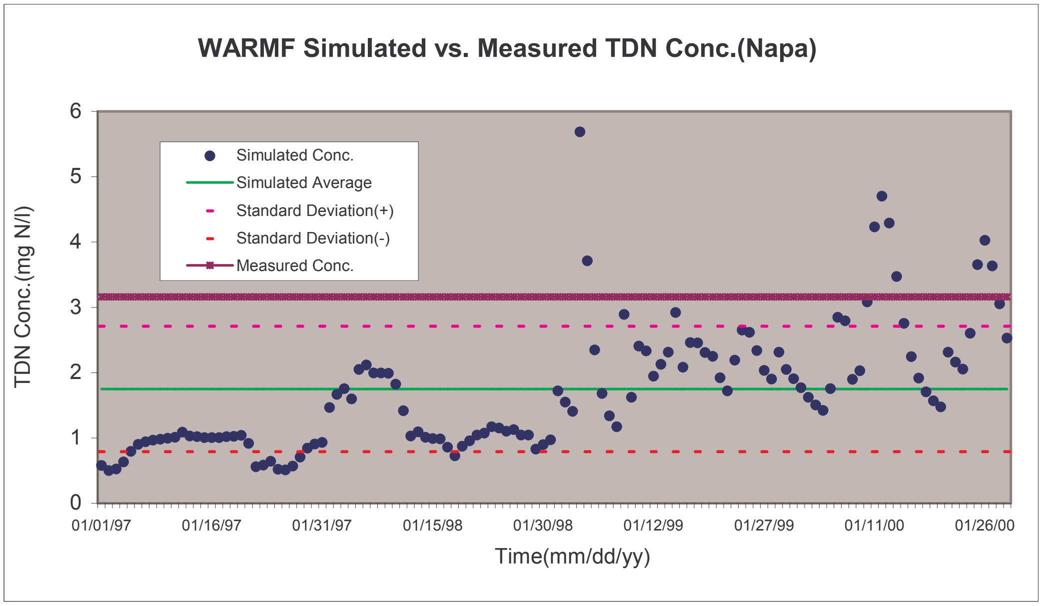


Figure 7.42h:



As one can see, at both the Calistoga and St. Helena sampling points, measured concentrations fall within the one standard deviation range, either below or above the corresponding mean. On the other hand, in Yountville and Napa, both measured concentrations are higher than the mean plus one standard deviation, but still smaller than the mean plus two times the standard deviation.

7.5 - SENSITIVITY ANALYSIS

Each model used in this analysis has a variety of input parameters. Most of the input parameters are consistent between the two models, however some parameters differ in terms of how they can be adjusted, which introduces a certain level of uncertainty when comparing the models' results. As mentioned before, WARMF and SWAT deal with nutrient concentration in groundwater and air deposition in quite different ways. Accordingly, in this section, the sensitivity of both calibrated models to these two input parameters was examined.

Model sensitivity to initial groundwater nitrate concentration

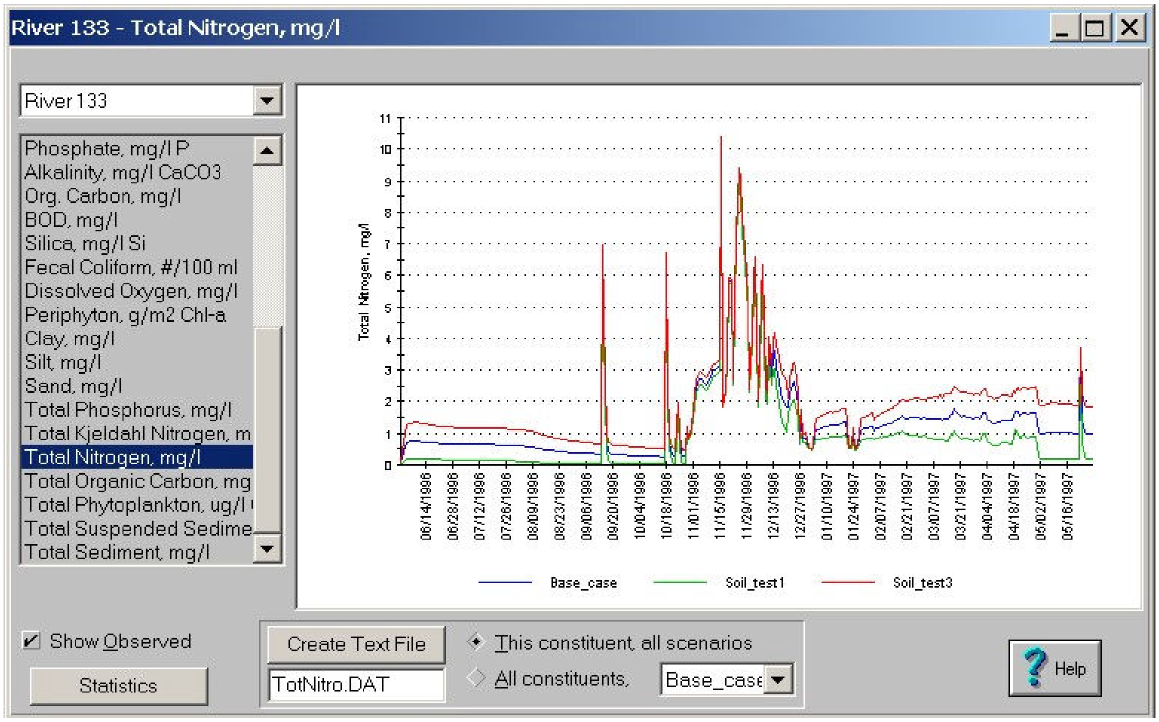
Napa River reaches receive inputs of water that can be derived from groundwater seepage. This input is especially important during the dry season, when rainfall and thus run-off potential is low. Initial groundwater nitrate concentrations can influence the resultant nutrient load in the river, an impact that is increased during the dry season. Below is an examination of the sensitivity of the river nutrient concentrations to initial groundwater nitrate concentrations in both models.

7.51 - WARMF sensitivity to initial soil nitrate concentration

In WARMF, an initial soil nitrate concentration can be set for each soil layers in each subcatchment. In our case, the soil layers underneath the first soil layer were considered groundwater-contributing layers. Therefore, initial soil nitrate concentrations in these layers were varied to test the model's sensitivity to initial conditions.

The base case assumed an initial nitrate concentration of 1.5 mg/L (labelled *base_case* in the figure) for groundwater in catchments with significant agricultural land, including orchard, farm, and pasture. For the test case, the concentration was raised to 2.5 mg/L (labeled *Soil_test3* in the figure) and then lowered down to 0.1 mg/L (labeled *Soil_test1* in the figure). The initial nitrate concentration of groundwater under non-agricultural land remained unchanged, which was 0.1 mg/L for all three cases. A relatively short simulation period, from June 1, 1996 to May 31, 1997, was chosen in order to reduce computer-run time. A comparison of the three cases is shown in Figure 7.51a.

***Figure 7.51a**: Comparison of WARMF TDN output in the Napa River for variable initial nitrate concentrations in groundwater at the Calistoga calibration point.*



River 133 - Total Nitrogen, mg/l

River 133

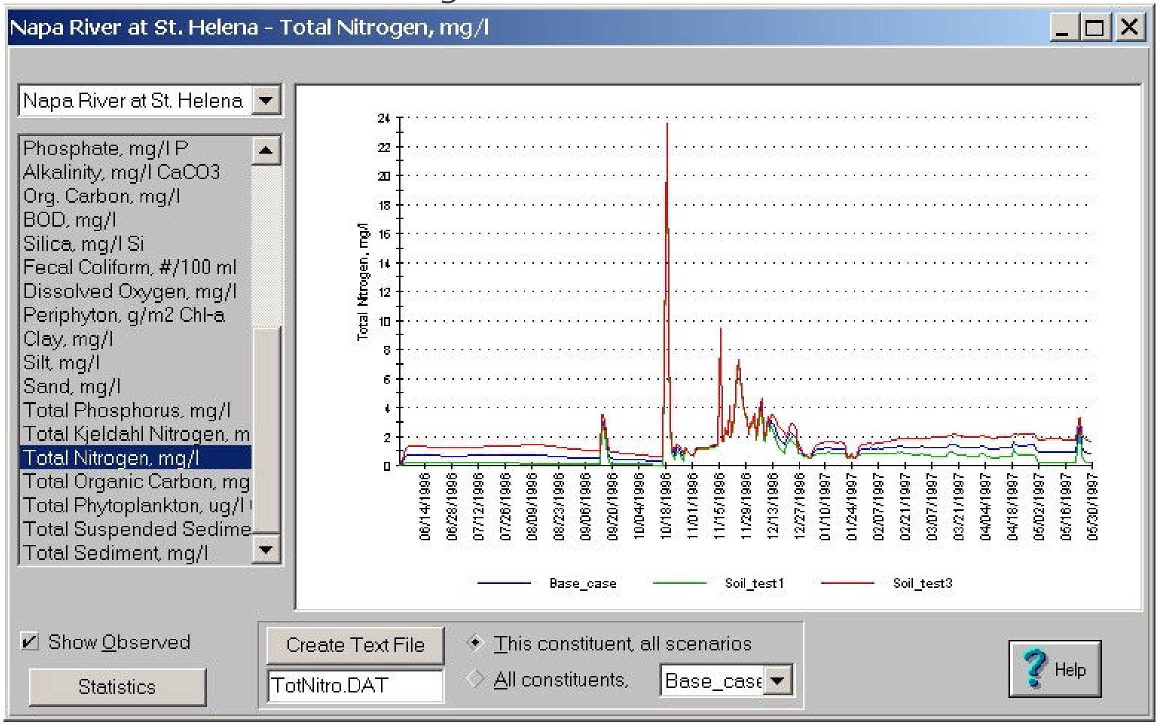
Total Nitrogen, mg/l

☑ Show Observed

● This constituent, all scenarios

TotNitro.DAT

Figure 7.51b: *Comparison of WARMF TDN output in the Napa River for variable initial nitrate concentrations in groundwater at the San Helena calibration Point*



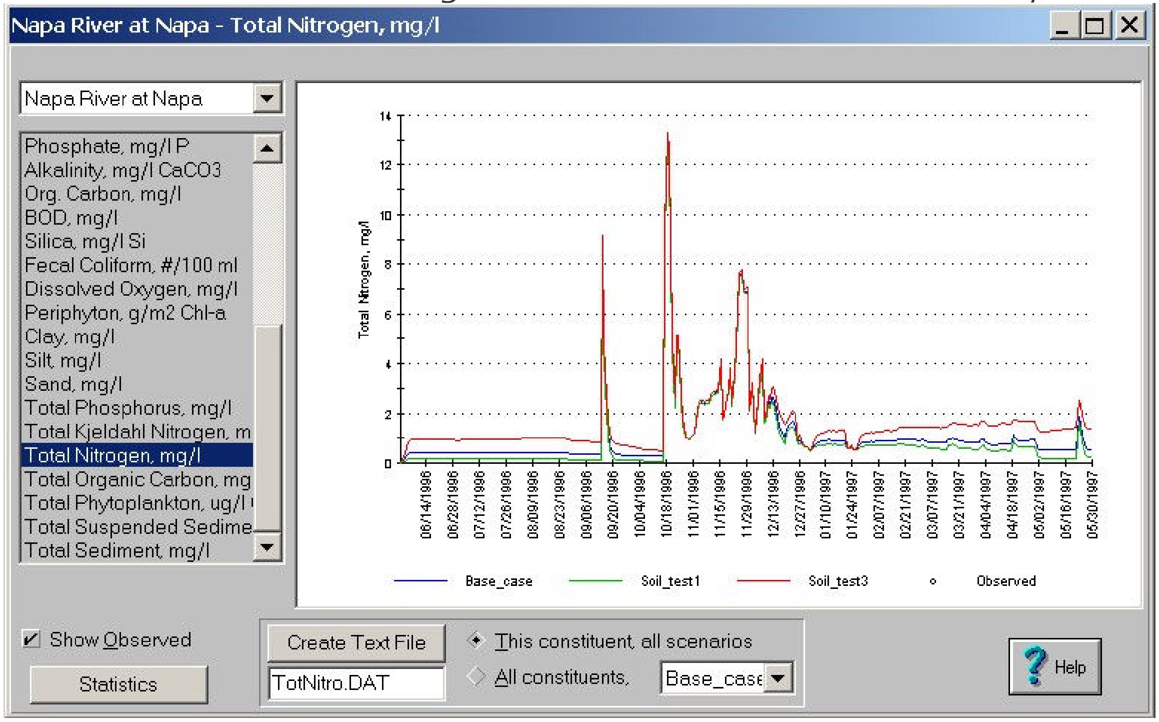
☑ Show Observed

TotNitro.DAT

● This constituent, all scenarios

○ All constituents, Base_case

Figure 7.51c: *Comparison of WARMF TDN output in the Napa River for variable initial nitrate concentrations in groundwater at the Yountville calibration point*



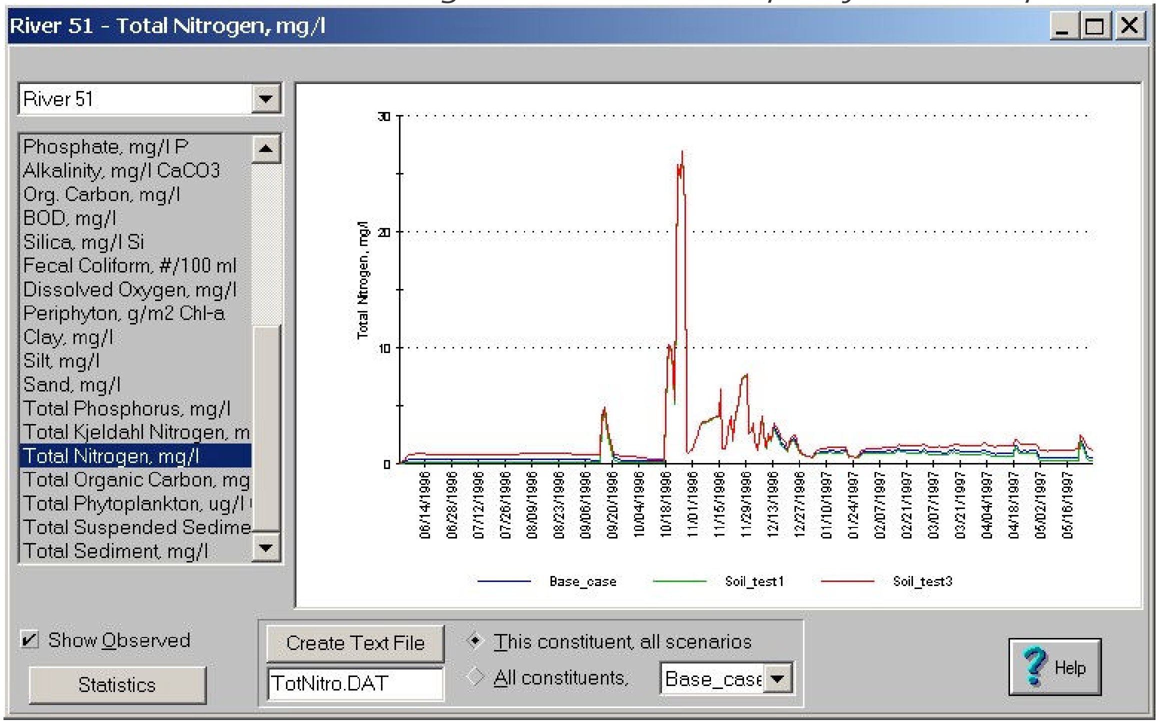
☑ Show Observed

TotNitro.DAT

● This constituent, all scenarios

○ All constituents, Base_case

Figure 7.51d: *Comparison of WARMF TDN output in the Napa River for variable initial nitrate concentrations in groundwater at the Napa city calibration point*



☑ Show Observed

TotNitro.DAT

● This constituent, all scenarios
○ All constituents, Base_case

The results indicate that in-stream nitrate concentrations at the four calibration points are sensitive to the initial nitrate concentration of groundwater in the watershed, especially during the dry season when the groundwater return flow is a significant source of stream flow. The sensitivity is further influenced by nutrient inputs from agricultural land, which is well distributed in the Napa River Watershed along the main river channel. This is indicative of the relative importance of groundwater accretion to the water quality in the Napa River. In the wet season, due to the significant river nutrient load contribution from both point sources and agricultural runoff, the ground water nutrient contribution becomes relatively small, although the absolute flux of nutrients actually increase. Also, it can be appreciated that as the stream water flows downstream, the impact of initial groundwater nitrate concentrations on river TDN concentrations diminish. This occurs because as nutrient-laden water moves downstream, it becomes increasingly diluted by water coming from nonagricultural areas; which have lower initial nitrate concentrations than groundwater.

7.52 - SWAT sensitivity to initial soil nitrate concentration

To save computer run time, the simulation period chosen was from June 1, 1995 to May 31, 1997, but only the wet season months, between October 1, 1996 and April 30, 1997, were used to conduct a comparison. Also, the base case, which simulates the initial groundwater nitrate concentration as 1.5 mg/l under agricultural land and 0.1 mg/l under non-agricultural land, was compared to only the test case of zero initial groundwater nitrate concentration.

Figure 7.52a: Comparison of TDN output from SWAT under different groundwater nitrate concentrations at the Calistoga calibration point.

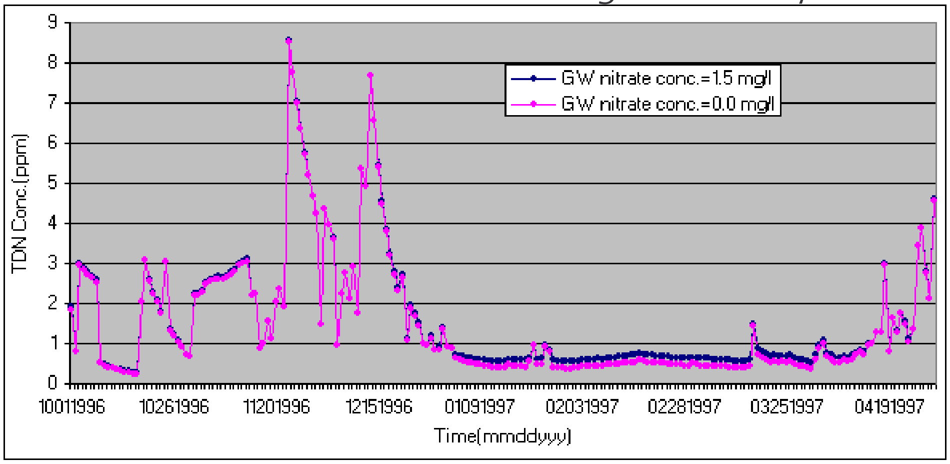


Figure 7.52b: Comparison of TDN output from SWAT under different groundwater nitrate concentrations at the St. Helena calibration point.

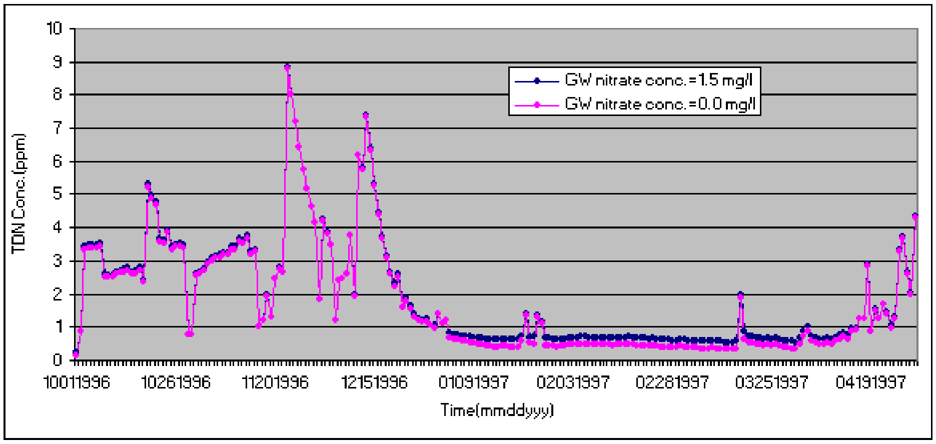


Figure 7.52c: *Comparison of TDN output from SWAT under different groundwater nitrate concentrations at the Yountville calibration point.*

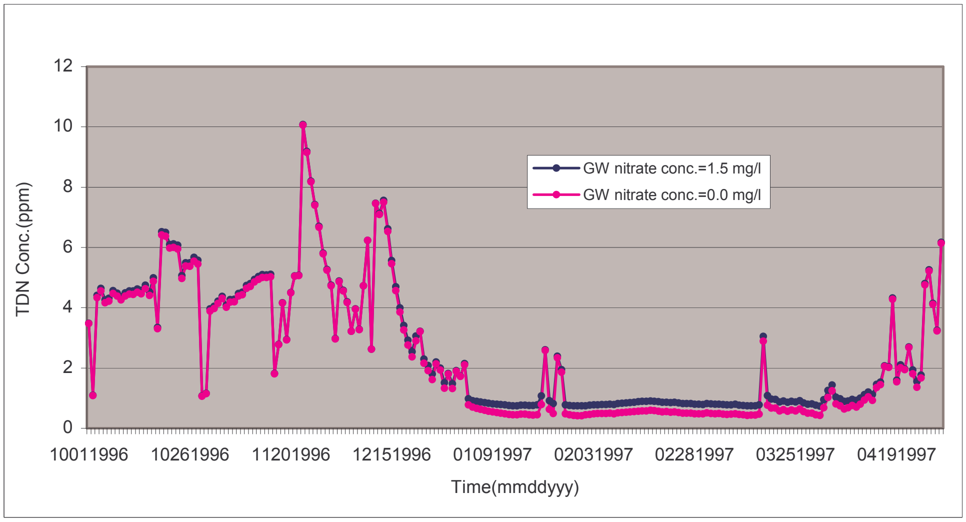
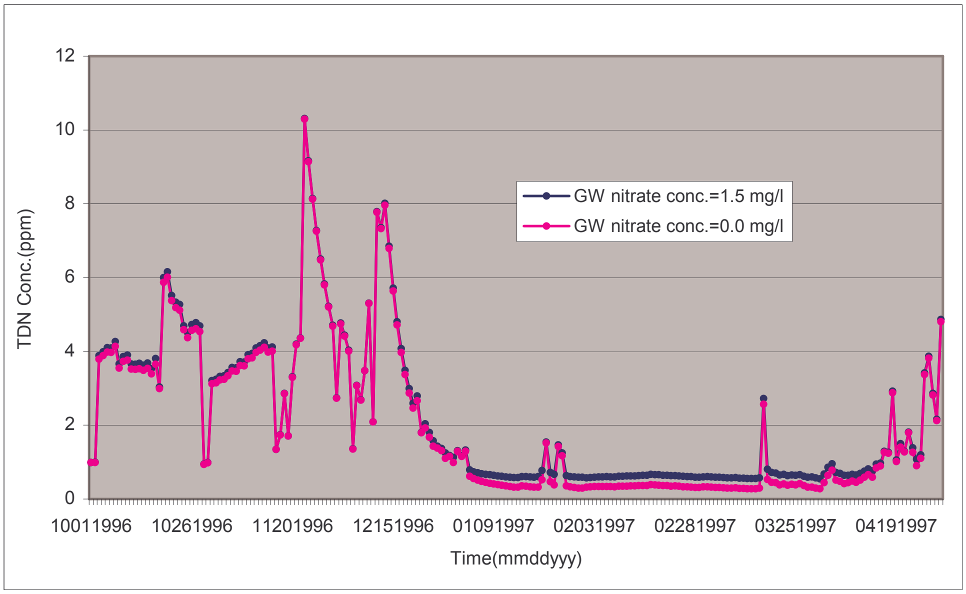


***Figure 7.52d**:* *Comparison of TDN output from SWAT under different groundwater nitrate concentrations at the Napa City calibration point.*



Simulation results from SWAT showed patterns similar to WARMF in terms of sensitivity to initial the groundwater nitrate concentration. The initial soil nitrate concentration makes less difference in TDN concentration in the river in the wet season, while relatively high differences were shown during the dry season under the same initial soil nitrate concentrations.

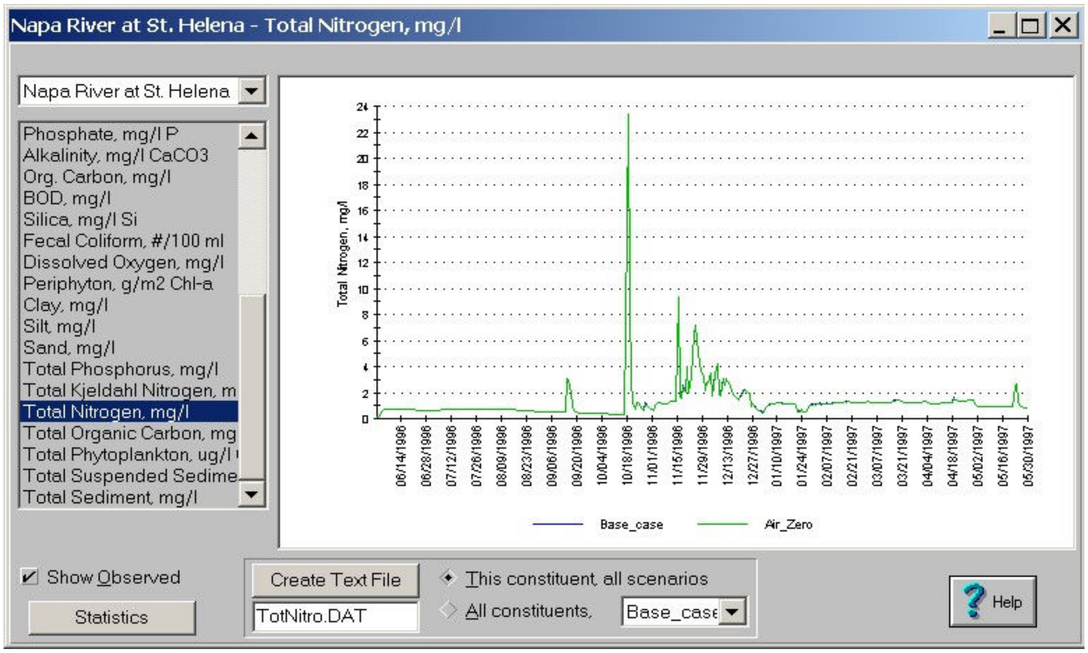
Model Sensitivity to Atmospheric Deposition

Atmospheric deposition, either dry or wet, is considered a nonpoint source of nutrient loads to the Napa River, and has different parameters in each of the two models. In WARMF, air quality is one of the input files, while SWAT only takes a constant mineral nitrogen concentration in rainfall as an input parameter. This limitation in SWAT was overcome by making wet deposition calculations in WARMF using measured air quality data and then inputting them into SWAT as a constant mineral nitrogen concentration in rainfall. This assumption allowed a sensitivity analyses to be conducted for both models using similar parameter values.

7.53 - WARMF Sensitivity to air quality

A test case of no air deposition was compared with a base case at the St. Helena calibration point. This point was chosen because the whole watershed is considered equally responsive to air deposition and St. Helena is located in the middle of the Napa River (Figure 5.3a).

Figure 7.53a: *Base case vs. zero air deposition case.*

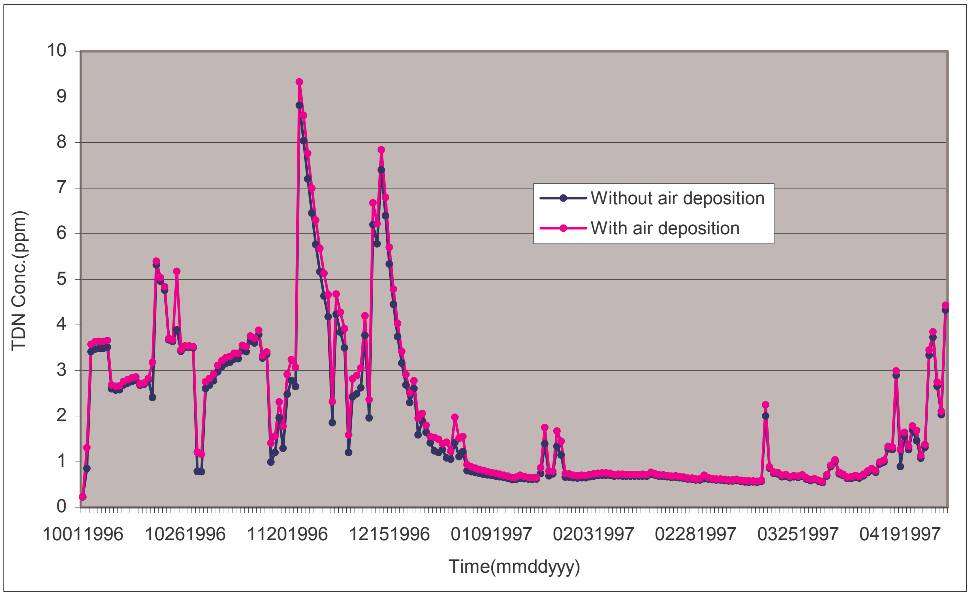


As one can see, the base case and zero air deposition case in WARMF yield essentially the same results on nitrogen loading to Napa River. Therefore, air deposition has little effect on TDN concentrations in the river. For this reason, we conclude that WARMF output is not sensitive to air deposition.

7.54 - SWAT Sensitivity to air quality

Figure 7.53b presents the comparison of TDN at St. Helena between base case and no air deposition case.

***Figure 7.53b**: SWAT comparison of TDN output with and without air deposition at St. Helena*



Although SWAT is slightly more sensitive to air deposition than WARMF, the scenarios with and without air deposition did not make a significant difference in terms of TDN output. SWAT considers only wet air deposition with rainfall, which results in a very minor effect on TDN when there is no rainfall. There is a slight TDN increase when there is precipitation.

Overall, according to our simulation results, the models are not sensitive to air deposition at these air concentrations, and therefore atmospheric deposition is considered a negligible source of nutrient loading in the Napa River watershed.

7.6 - WATER QUALITY AND TDN LOADING

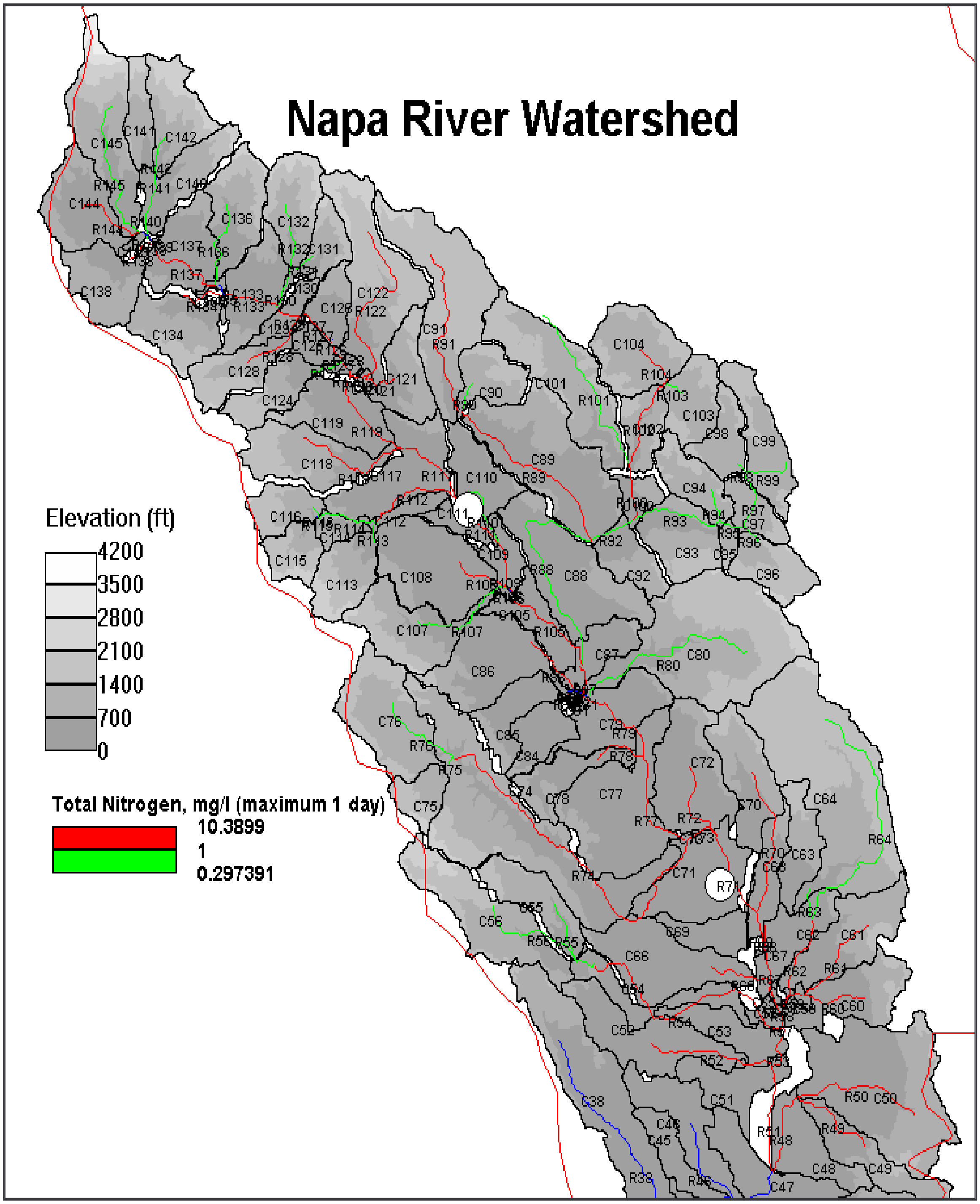
7.61 - Current Condition

As stated before, the wet season target level of TDN in Napa River Watershed is 1.0 mg/L. Both calibrated models (WARMF and SWAT) were run for the same period used for calibration modeling, which was from June 1, 1996 to May 31, 2001.

The two models produced similar water quality, but due to the inability of SWAT to present spatial water quality results graphically, only the produced water quality map from WARMF is presented here to illustrate the simulated extent of the water quality impairment in the Napa River watershed.

The water quality results simulated by WARMF are presented in Figure 7.61a. Stream segments that exceed the wet season TDN target level of 1.0 mg/L appear in red, while the segments below the target appear in green. The results in SWAT were similar to WARMF, with some minor differences, which are discussed later in this section.

Figure 7.61a: Water quality of Napa River under current conditions as simulated by WARMF



As shown in the figure, under the status quo, WARMF simulation results showed that all of the main river reaches on the Napa River are impaired, which is consistent with the measured data. Impairments also occurred in some tributaries situated within either dense agricultural or residential areas.

7.62 - TDN Loading

The calculated average TDN loads from various sources are presented in Tables 7.62a through 7.62d. The locations of the points used for this analysis (Calistoga, St. Helena, Yountville, and Napa) are presented in Figures 5.2d and 5.2e.

Table 7.62a: *SWAT estimated daily average TDN load for each sub region (kg N/day)*

Sources	Calistoga	St. Helena	Yountville	Napa	Total
Forest-deciduous	0	0	0	1	1
Forest-evergreen	26	17	34	5	82
Forest-mixed	0	1	11	7	19
Orchard	43	48	173	46	311
Pasture	0	0	0	62	62
Range-brush	2	2	8	6	17
Range-grass	12	4	18	14	49
Commercial	0	0	0	1	1
Residential-low density	0	0	0	19	19
Air Deposition	0	0	0	0	0
Septic System	2	5	11	6	24
Point Sources	32	28	59	125	244
Grand Total	118	106	314	292	830
Percentage Contribution	14%	13%	38%	35%	100%

Table 7.62b: *WARMF estimated daily average TDN load for each sub region (kg N/day).*

Sources	Calistoga	St. Helena	Yountville	Napa	Total
Deciduous	0	0	0	0	0
Mixed Forest	2	0	0	2	4
Orchard	42	73	249	36	399
Coniferous	10	28	62	9	108
Shrub / Scrub	2	1	3	2	7

Grassland	0	0	0	1	1
Pasture	2	1	9	14	26
Farm	0	0	0	1	2
Water	0	0	0	0	0
Residential	1	3	1	13	18
Air Deposition	0	0	0	0	0
Septic System	6	15	27	14	62
Point Sources	32	28	59	125	244
Grand Total	96	149	411	217	873
Percentage Contribution	11%	17%	47%	25%	100%

Table 7.62c: Percentage contribution of TDN for sub-regions and the entire watershed from the SWAT simulation of current loading.

Sources	Calistoga	St. Helena	Yountville	Napa	Entire Watershed
Forest-deciduous	0%	0%	0%	0%	0%
Forest-evergreen	22%	16%	11%	2%	10%
Forest-mixed	0%	1%	4%	2%	2%
Orchard	37%	45%	55%	16%	38%
Pasture	0%	0%	0%	21%	8%
Range-brush	2%	1%	2%	2%	2%
Range-grass	10%	4%	6%	5%	6%
Commercial	0%	0%	0%	1%	0%
Residential-low density	0%	0%	0%	6%	2%
Air Deposition	0%	0%	0%	0%	0%
Septic System	2%	5%	4%	2%	3%
Point Sources	27%	27%	19%	43%	30%
Grand Total	100%	100%	100%	100%	100%

Table 7.62d: Percentage contribution of TDN for sub-regions and the entire watershed from the WARMF simulation of current loading.

Sources	Calistoga	St. Helena	Yountville	Napa	Entire Watershed
Deciduous	0%	0%	0%	0%	0%
Mixed Forest	2%	0%	0%	1%	1%
Orchard	43%	49%	61%	17%	46%
Coniferous	10%	19%	15%	4%	12%

Shrub / Scrub	2%	0%	1%	1%	1%
Grassland	0%	0%	0%	0%	0%
Pasture	2%	1%	2%	7%	3%
Farm	0%	0%	0%	1%	0%
Water	0%	0%	0%	0%	0%
Residential	1%	2%	0%	6%	2%
Air Deposition	0%	0%	0%	0%	0%
Septic System	6%	10%	7%	7%	7%
Point Sources	34%	19%	14%	58%	28%
Total	100%	100%	100%	100%	100%

As one can see, both models simulated very similar total daily TDN loading for the entire Napa River watershed, with SWAT estimating 830 kg N/d and WARMF estimating 873 kg N/d; although some inconsistencies occur in regional load and percentage contribution from each source.

As shown in Tables 7.62a and 7.62b, agricultural TDN loads in Calistoga, St. Helena, and Yountville are the major contributors of TDN to the river. In the Napa city region, WWTP discharge is the major TDN source. In both models, the upstream three sub-regions (Calistoga, St. Helena, and Yountville), where most of the orchards are situated, have agricultural loads that contribute approximately one half of the total TDN load to the river.

In the Calistoga and Napa regions, TDN loads from point sources have higher contributions than the other regions. This is the case because both WWTPs in Calistoga and Napa used lower dilution ratios of 10:1, as compared with the 50:1, currently used at the St. Helena and Yountville WWTPs.

According to the WARMF simulation, among all regions, Napa has the highest percentage TDN contribution from urban land, at 6.5%, compared to 1.3%, 2.0% and 0.4% in Calistoga, St. Helena and Yountville, respectively. However, in the SWAT simulation, no TDN contribution from urban land came from Calistoga, St. Helena or Yountville. This is the case because of the land use threshold value of 10% used in the SWAT HRU delineation. As mentioned before, under this threshold, all land uses less than 10% of the total area in a sub-basin, was discarded and replaced proportionally by the land uses with areas higher than 10%. Therefore, sparsely distributed urban land in the upstream regions was not simulated in SWAT. This also happened to row-crops. Due to its sparse distribution, no row-crops were incorporated into the SWAT simulation.

Septic tanks contributed relatively consistent loads to the river in all sub regions, with the highest percentage in St. Helena (10%) and the smallest in Calistoga (6%) in the WARMF simulation. The results were somewhat different in the SWAT simulation where septic effluent contributed 5% in St. Helena and 2% in Calistoga. The consistent difference in the percentage contribution of TDN from septic tanks in the two models were assumed to have been caused by the different ways in which septic tanks were simulated. SWAT appears to consistently underestimate the TDN load from septic tanks.

In both models, air deposition is a negligible nitrogen source in all regions, with 0.03% of the total contribution in SWAT and 0.05% in WARMF.

Due to the different land use classification systems used in the two models, it is not possible to compare the TDN loads for specific land use types directly. In order to identify the major TDN sources in each region and the entire watershed, a broader categorical classification was used to conduct the comparison of outputs. All TDN sources were categorized into five broad categories: background, agricultural nonpoint sources, septic tanks, point sources, and urban. Table 7.62e provides the correspondence between land uses falling into these five categories for each model.

Table 7.62e: Land use lookup table for category classification.

Categories	SWAT	WARMF
Background	FRSE, FRSD, FRST, RNGE, RNGB, Air Deposition	Deciduous, Mixed Forest, Coniferous, Shrub / Scrub, Grassland, Air Deposition
Agricultural Nonpoint	ORCD, PAST,	Orchard, Pasture, Farm

Sources		
Urban	UCOM, URLD	Residential
Septic Tanks	Septic Tanks	Septic Tanks
Point Source	WWTPs	WWTPs

Figures 7.62a though Figure-7.62f present the comparison of simulated categorical TDN load from each sub region and the entire watershed.

Figure 7.62a: *Comparison of simulated TDN loads from Calistoga.*

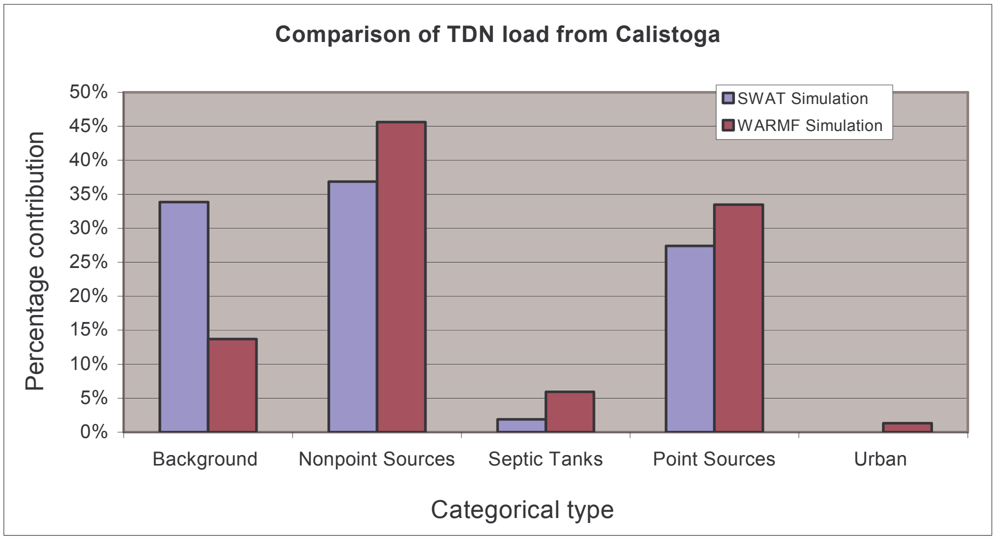


Figure 7.62b: *Comparison of simulated TDN loads from St. Helena.*

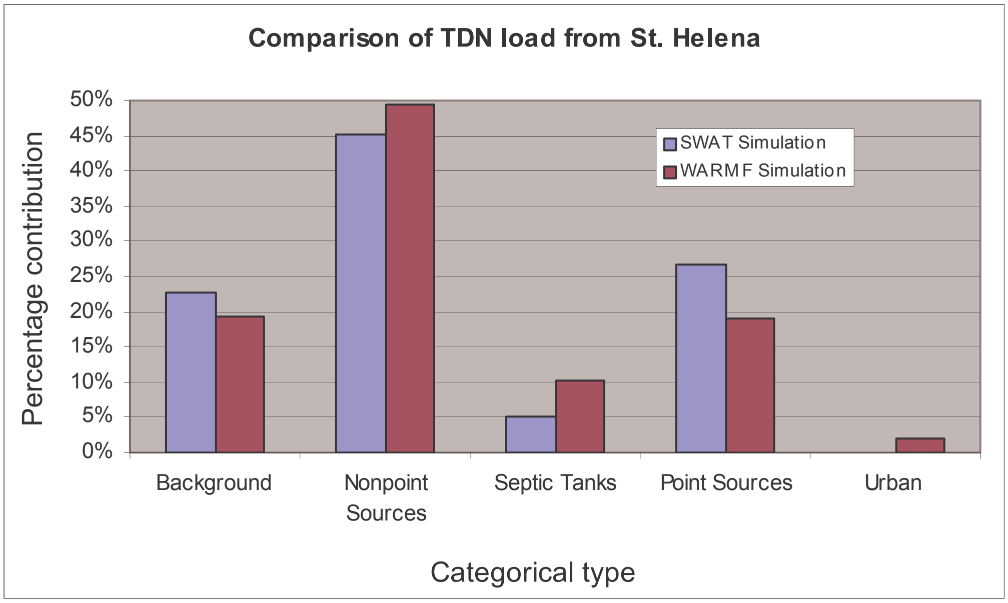


***Figure 7.62c**: Comparison of simulated TDN loads from Yountville.*

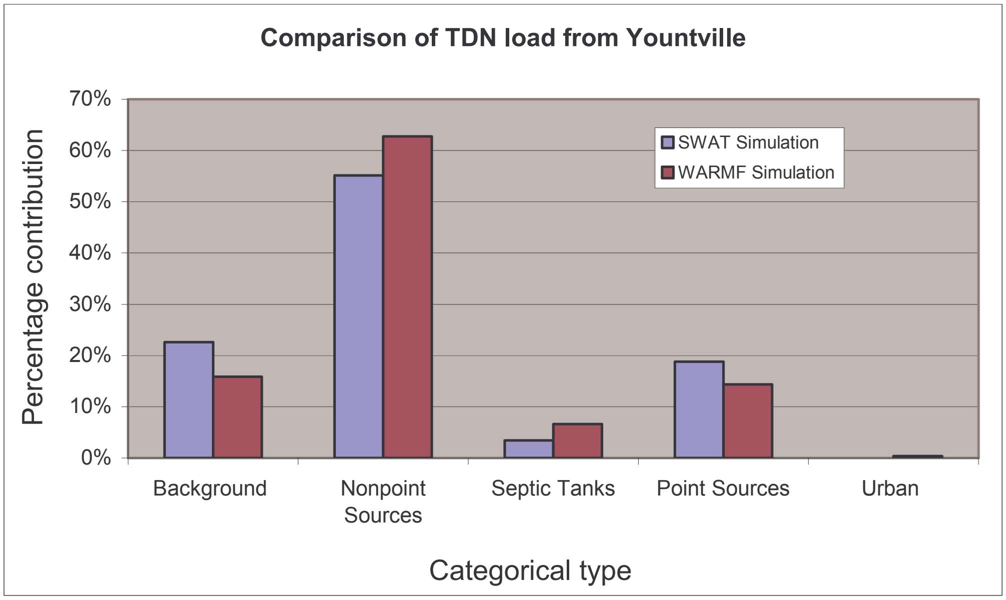


***Figure 7.62d**: Comparison of simulated TDN loads from Napa.*

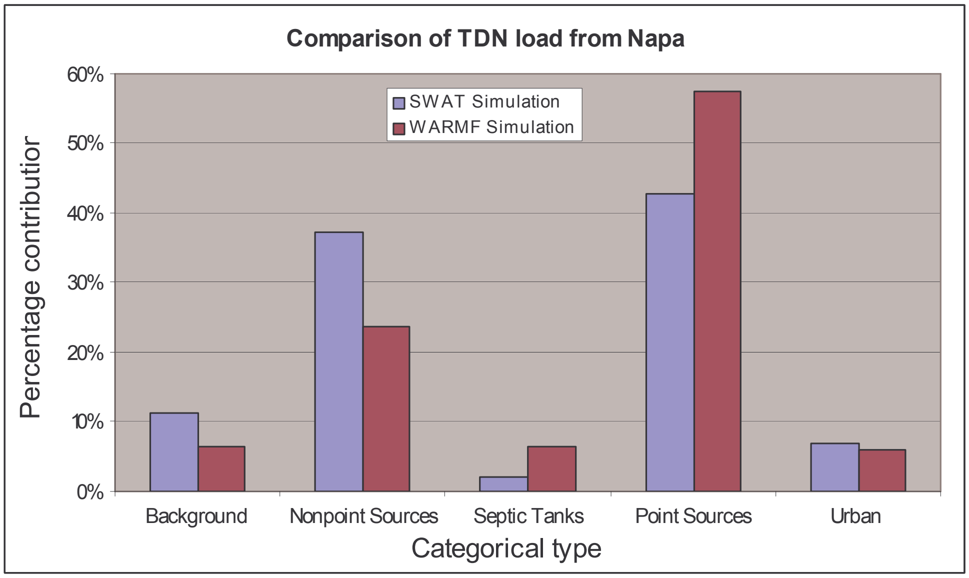
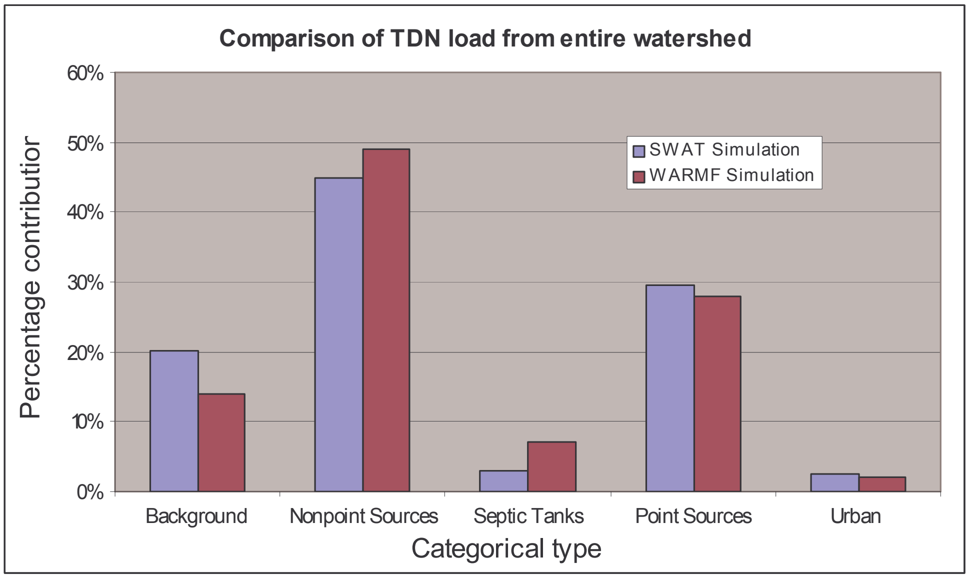


Figure 7.62e: Comparison of simulated TDN loads from the entire watershed.



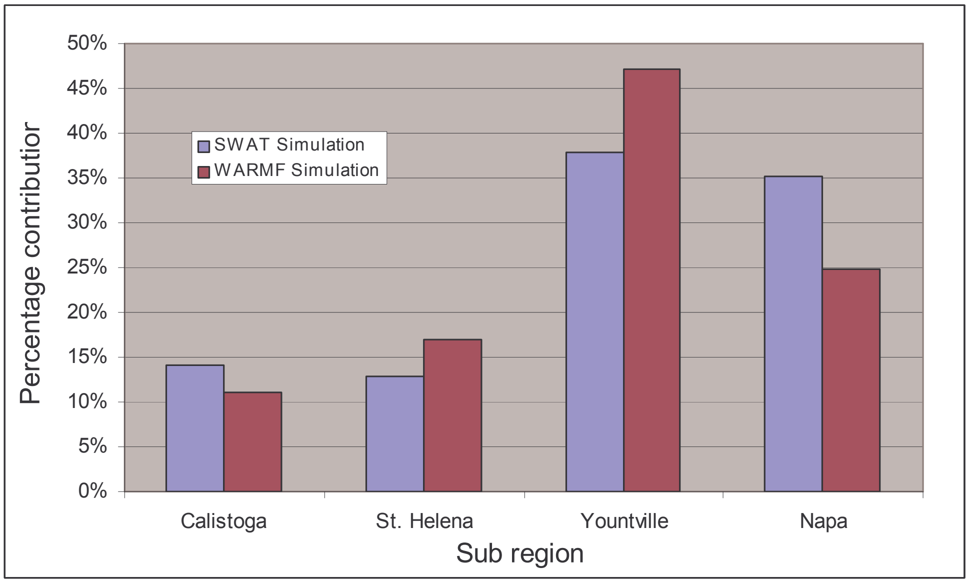
As shown in the figures above, SWAT consistently estimated higher TDN background contributions than WARMF, while WARMF simulated more agricultural nonpoint TDN load in the three upstream regions than SWAT.

At the scale of the entire watershed, the two models produced very similar results (Figure 7.62e). Among all TDN sources, agricultural nonpoint sources are the greatest contributor, representing almost one half of the total. Point source discharge from WWTPs constitutes one fourth of the total. Among all agricultural nonpoint sources, orchard represented the majority of the total TDN load.

TDN load from background sources constitute 14% in WARMF and 20% in SWAT, while agricultural nonpoint sources, septic tank effluent, point sources, and urban runoff in combination contribute the rest This indicates that anthropogenic TDN sources are the major causes of the water quality problem in the Napa River Watershed.

Looking at the regional TDN load, in both models, the Yountville region was identified as the biggest TDN contributor of the total TDN load (Figure 7.62f), followed by the Napa City region. In both models, TDN load from these two regions constituted more than 70% of the total TDN load in the entire watershed. The upstream regions contributed around 30% of the total TDN.

Figure 7.62f: Comparison of regional TDN load from each sub region.



8.0 - LOAD REDUCTION ALTERNATIVES

8.1 - INTRODUCTION

This section explores various options for reducing point and non-point waste loads and loads. Various load and waste load reduction scenarios were evaluated for several source categories including septic system effluent, agriculture and livestock runoff, urban runoff, and wastewater treatment plant releases. The reduction options consist of source management activities and control measures designed to either reduce nutrient loading or reduce the adverse impacts of loading within the watershed. The options presented here are based on an extensive literature review of currently available TMDL reports, scientific journals, guidance documents, and other sources. "The Practice of Watershed Protection" (Schueler et al, 2000) was a very useful source that presents a watershed protection approach applying 8 tools to protect or restore aquatic resources. The eight general watershed protection tools proposed by Schueler and Holland contain descriptions that not only include measures that can be taken to improve water quality and protect vital habitat, but also contain Schueler and Holland's conclusions from economic research on the costs and benefits of employing these watershed management tools. The majority of Schueler and Holland's tools are found in Section 8.23 on urban alternatives. Watershed protection has good intentions that seek to remedy the environment, however, every watershed is different. Developing a suite of practices to protect a particular watershed requires scientific data about the area, a degree of social acceptability and cooperation with the stakeholders involved, and should include economically feasible implementation scenarios for local agencies, landowners, and residents (Schueler et al, 2000). The proposed alternatives are designed to achieve water quality objectives, with consideration of the following issues (EPA, November 1999):

- Economics
- Feasibility
- Types of sources and management options
- Public Involvement
- Implementation
- Limits of Technology

The proposed reductions seek to attain acceptable loading (loading capacity) as determined by the source and linkage analyses. A number of these recommendations were evaluated using the simulation models to determine their overall effectiveness. The best load reduction allocation plan for each of the source categories is recommended to the RWQCB. Additionally, a follow-up monitoring plan is suggested.

8.2 - NUTRIENT LOAD REDUCTION ALTERNATIVES FOR THE VARIOUS SOURCE CATEGORIES

Reduction of pollutant loads can be achieved through wasteload reductions of point sources in the form of discharge limits specified in NPDES permits; or through load reductions of nonpoint sources by means of best management practices. Best management practices can be tailored for specific land uses and sources, and include non-structural controls such as street sweeping, educational outreach, and conserving land, as well as structural controls such as retro-fitting nutrient filters to faulty septic systems and installing stormwater treatment devices. Table 8.2a lists the various reduction measures that will be described and considered in this analysis. The alternatives presented consist of management practices that are structural and non-structural, as well as on-site or off-site. The considered approaches are managerial or community based, practical and economically feasible; and were developed by academic researchers, the EPA, land use planners, growers, fertilizer retailers, and crop consultants.

Table 8.2a: Potential nutrient management measures categorized by general nutrient source

Nutrient Source	Potential Management Measures
Domestic Wastewater facilities	• Introduce treatment technologies such as Nitrification-Denitrification (NDN) • Ensure adequate dry season storage and reuse to avoid dry season discharge • Reduce the probability of accidental discharge
Faulty septic systems	• Replace faulty septic systems • Connect to treatment plant • Construct decentralized wastewater treatment plants • Retrofit septic systems with sand filters, peat modules, or a Nitrex filter
Existing and future urban development	• Land use planning of impervious cover • Land conservation • Vegetative buffers

Nutrient Source	Potential Management Measures
	• Better site design in reducing impervious cover increasing conservation areas • Watershed stewardship programs • Structural stormwater treatment practices • Erosion and sediment control measures
Agriculture: vineyards and ranching	• Vegetative buffers • Structural stormwater treatment practices • Reduce fertilizer inputs • Agricultural management measures • Soil and plant tissue sampling • Cover crops • Manure management

8.21 - Waste Water Treatment Plant Alternatives

In order to reduce the nutrient loading in treated wastewater from the WWTPs, retrofitting or upgrading is necessary to remove a greater amount of nutrients (nitrogen and phosphorus) from discharges. In the past two decades there has been significant improvement in the wastewater treatment technologies that specifically deal with excessive nutrient loading problems. Some of these technologies are (EPA, September 2000):

- Trickling filter nitrification
- Ammonia stripping
- Oxidation ditches
- Sequencing batch reactors
- Nitrification-denitrification (NDN)

The existing technologies that are currently in use at the different WWTPs appear in table 8.2b.

Table 8.2b: Existing Technologies in WWTPs of each city.

Technology	WWTP			
	Calistoga	ST. Helena	Yountville	Napa
Trickling Filter	-	-	X	-
Ammonia stripping	-	-	-	-
Oxidation Ditches	X	X	-	X
SBR	-	-	-	-
NDN	-	-	-	-

Notes:
X – Technology currently in use.

Trickling Filter Nitrification

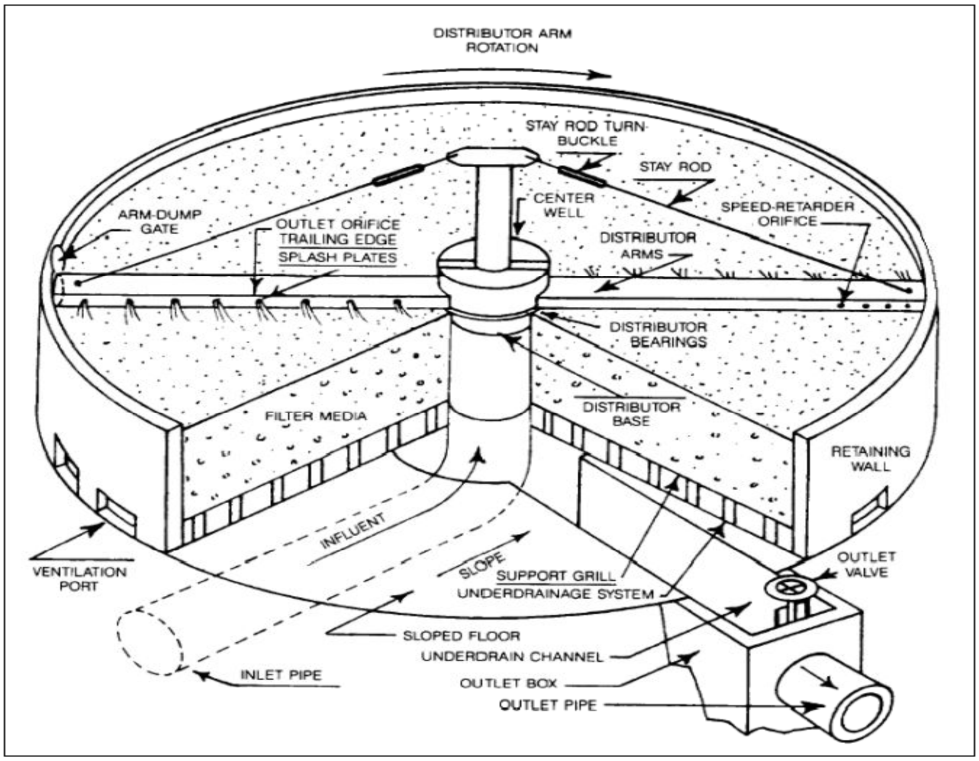
Trickling Filter (TF) is a wastewater treatment system that biodegrades organic matter and achieves nitrification. Organic matter is removed using an aerobic treatment system that utilizes microorganisms attached as biofilm to a medium to absorb organic matter from wastewater. In the nitrification/denitrification process, ammonia nitrogen is oxidized with the help of bacteria, which convert it to nitrate and then into nitrogen gas (National Small Flows Clearing House, 1998).

There are two types of Trickling filter nitrification configurations:

- Single-stage
- Two-stage

In "Single Stage" configuration, carbon oxidation and nitrification takes place in a single TF unit whereas in "Two Stage" configuration, reduction of organic material occurs in the first treatment stage and nitrification occurs in the second.

Figure 8.21a: Typical Trickling Filter.



Source: EPA, September 2000

This system is appropriate for small to medium size communities and is effective in treating high concentrations of organics. The drawbacks of this system include its sensitivity to chemical characteristics of effluent such as organics, temperature and pH. It also has limited flexibility and control in comparison with the activated sludge process (EPA Wastewater Technology Fact Sheet - 2000).

Table 8.21a: Cost Summary for a trickling filter (in million of dollars-1990)

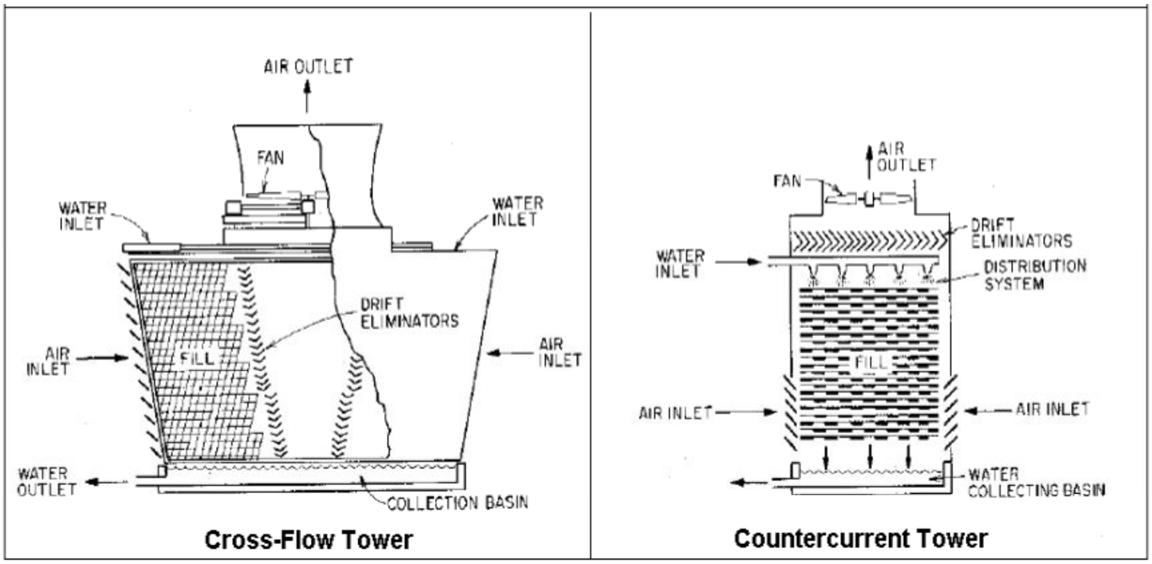
Wasterwater flow [m^3/sec]	Construction cost	Labor	O&M	Materials
0.04	0.76	0.05	0.063	0.009
0.4	6.34	0.23	0.15	0.05
4	63.4	1	1.3	0.2

Source: EPA Wastewater Technology Fact Sheet, 2000
Note: 1m^3 = 264.2 gallons

Ammonia Stripping

Ammonia stripping utilizes desorption processes to lower the ammonia content of wastewater. In this process, ammonia reacts with water and forms ammonium hydroxide, which later converts into ammonia gas and is discharged into the atmosphere. Ammonia stripping (Figure 8.21b) works well with wastewater that has ammonia concentrations between 10 to 100 mg/l. There are two types of stripping towers that can be installed; cross-flow and countercurrent (see Figure 8.21b below) (EPA, September 2000).

***Figure 8.21b**: Types of Stripping Towers*



Cross-Flow Tower

Countercurrent Tower

Source: EPA Wastewater Technology Fact Sheet, 2000 (Culp, et. al, 1978)

Ammonia stripping is a controlled process for selected ammonia removal. The efficiency of this system is highly dependent on temperature and air/water ratios. At 20°C, 90 to 95 % removal of ammonia can be achieved (EPA, September 2000). This process does not remove nitrate, nitrite or organic nitrogen.

Generally, the estimated cost for air stripping is \$0.01 to \$0.07 per m^3 (1,000 gallons), which includes installation, maintenance and operating costs. A major operating cost of air strippers is the electricity required for the air blower-method.

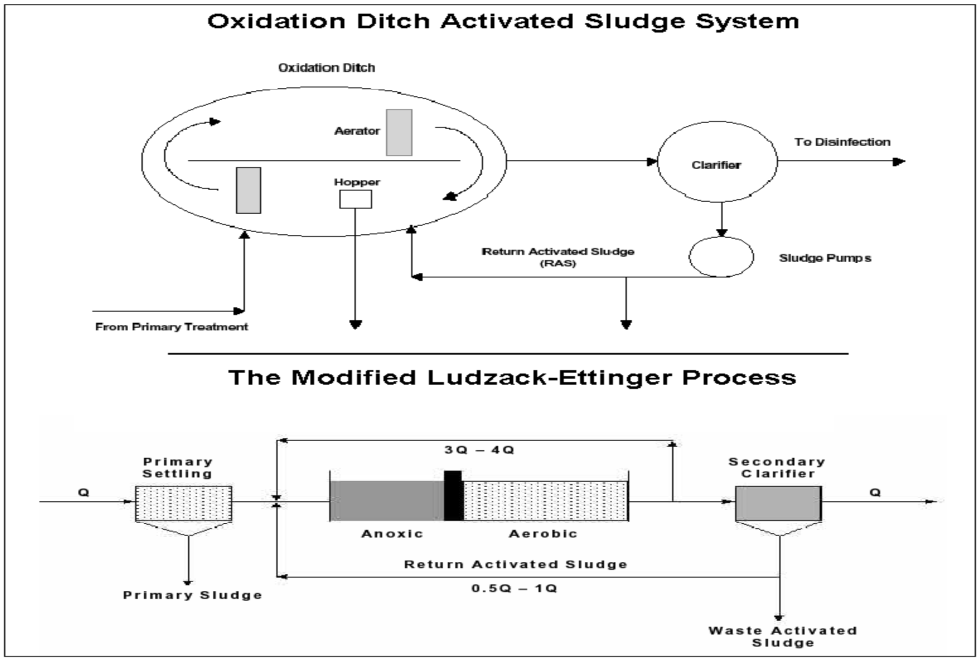
Estimations of blower motor power assumes that each foot of air stripper diameter requires 1.5 HP (Federal Remediation Technologies Roundtable, 2003).

Oxidation Ditches

This system is a modified activated sludge biological treatment process. It promotes long solid retention times to remove biodegradable organics and is used for long-term aeration. It consists of a long channel of an elliptical or circular shape equipped with aeration equipment (Figure 8.21c) called a rotor for generating a water flow and stirring water in the channel (EPA, September 2000).

One of the most common design modifications in oxidation ditches for enhanced nitrogen removal is known as the Modified Ludzack-Ettinger (MLE) process. In this design, an anoxic tank is added upstream of the ditch along with mixed liquor recirculation from the aerobic zone to the tank in order to achieve higher levels of denitrification. In the aerobic basin, ammonia is converted into nitrite and then to nitrate. In the anoxic zone, nitrate-nitrogen converts into nitrogen gas, which is released to the atmosphere.

***Figure 8.21c**: Oxidation Ditch.*



Source: EPA, September 2000

Oxidation ditches achieve up to 90 % BOD, suspended solids and ammonia removal (EPA, September 2000). The system can perform nitrification and denitrification easily and requires relatively little energy. This system is particularly suitable for a small community, as it requires more land than conventional treatment plants.

The cost of this system depends on the WWTP's capacity, effluents levels, and land cost. According to EPA in 1991, capital cost ranges from $0.52 to $3.17 /Liters/day. Using the consumer price index (CPI) to estimate this cost for the year 2003, i.e. 1.2% (Greater Phoenix Economic Council), the cost ranges from $0.52 to $3.21/Liters/day.

Sequencing Batch Reactors

A Sequencing Batch Reactor (SBR) is an activated sludge biological treatment process that is designed to operate under non-steady state conditions. It operates in a true batch mode with aeration and sludge settlement both occurring in the same tank. This process is capable of achieving biological P removal, nitrification, denitrification and BOD_5 removal in one reactor. It can be designed with the ability to treat a wide range of influent volumes.

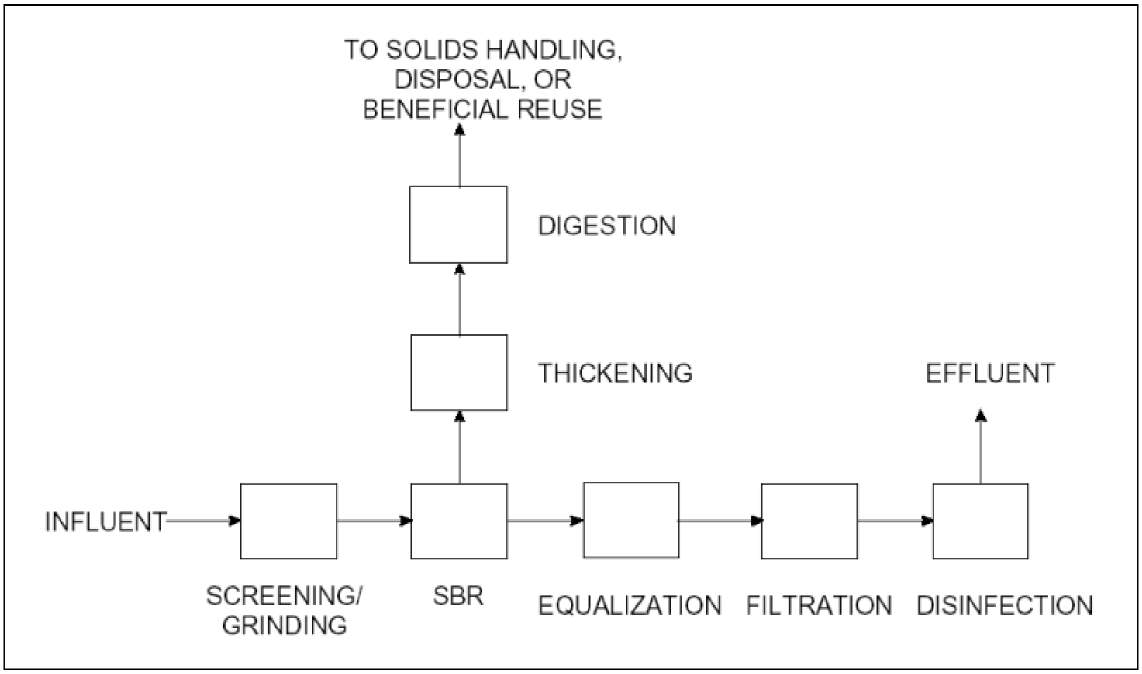
The SBR process is accomplished in a simple tank, through sequencing stages such as fill, react, settle, and draw. During the "fill-stage" influent is mixed with existing biomass. During the "react-stage" the biological reactions are finished and nitrification or denitrification removal can be accomplished. In the "settling-stage" gentle mixing occurs. In the "draw-stage" a decanter is used to remove treated effluent out of the top of the tank while bacteria settles at the bottom (Carter & Burgess, 2003).

Influent wastewater generally passes through a primary screen and grit removal section. It then enters into a partially filled reactor containing biomass until the reactor is full where it behaves like an activated sludge system. An activated sludge system is a biological wastewater treatment process in which a mixture of wastewater and activated sludge is agitated and aerated, and then separated from the treated wastewater. Once the biological reactions are complete, the aeration and mixing is discontinued; biomass settles, insoluble solids are removed, and wastewater is filtered and disinfected.

Nitrification in an SBR system will require the extension of the reaction time as well as extensions of the sludge stage. Adding denitrification to the sequence would require the addition of anoxic and aerobic steps after the initial react step (Sharman, 1998).

Ammonia removal ranges from 90 to 97 % (EPA 1992). The process is usually used in small wastewater treatment systems that have flows between 0 – 0.2 m^3/sec (i.e., 0-5 MGD) (EPA-Wastewater Technology Fact Sheet, 2000).

***Figure 8.21d**: Flow chart of Sequencing batch Reactor*



Source: EPA-Wastewater Technology Fact Sheet, 2000 (Parsons Engineering Science, Inc., 1999)

The disadvantages of the SBRs are poor sludge settling, floating clumps from denitrification, and the increased equipment requirements for effluent flow and air supply.

***Table 8.21b**: Costs for Sequencing Batch Reactor*

Design Flow Rate	Cost of Equipment (1998 Dollars)
0.04 m^3/sec	150,000-350,000
0.2 m^3/sec	459,000 -730,000
0.4 m^3/sec	1,089,000-1,370,000
0.6 m^3/sec	~ 2,100,000
0.8 m^3/sec	2,100,000-3,000,000
CPI (inflation rate) for 2003 = 1.2% ((Greater Phoenix Economic Council)	
Note: The equipment cost items provided do not include the cost for the tanks, site work, excavation/backfill, installation, contractor's overhead and profit, or legal, administrative, contingency, and engineering services. These items must be included to calculate the overall construction costs of an SBR system. Costs for other treatment processes, such as screening, equalization, filtration, disinfection, or aerobic digestion, may be included if required.	

Source: EPA-Wastewater Technology Fact Sheet, 2000

Nitrification-Denitrification (NDN)

NDN is a state-of-the-art and cost-effective solution to nutrient removal from wastewater. It uses naturally occurring microorganisms, rather than additional chemicals that use oxygen, to remove nutrients such as nitrogen and phosphorus from the wastewater stream. This process is climate friendly, indicating that it can function in both warm and cold climates.

The activated sludge process utilizes fermentation, anoxic, re-aeration and recycle zones. The effluents are directed to a clarifier from where the sludge is pumped to a secondary digester while some is returned to the BNR plant (Solley, 2002).

The mechanism of the NDN process involves the activated sludge process through two types of chemical reactions for nitrogen removal:

- Aerobic Conditions - Nitrification
- Anaerobic Conditions – Denitrification

Biological oxidation of ammonia to nitrate or nitrite occurs in the nitrification process, which is performed by bacteria under aerobic conditions. Then, denitrification converts the nitrate or nitrite into nitrogen gas through biological reduction under anoxic conditions (Oldham and Rabinowitz, 2002).

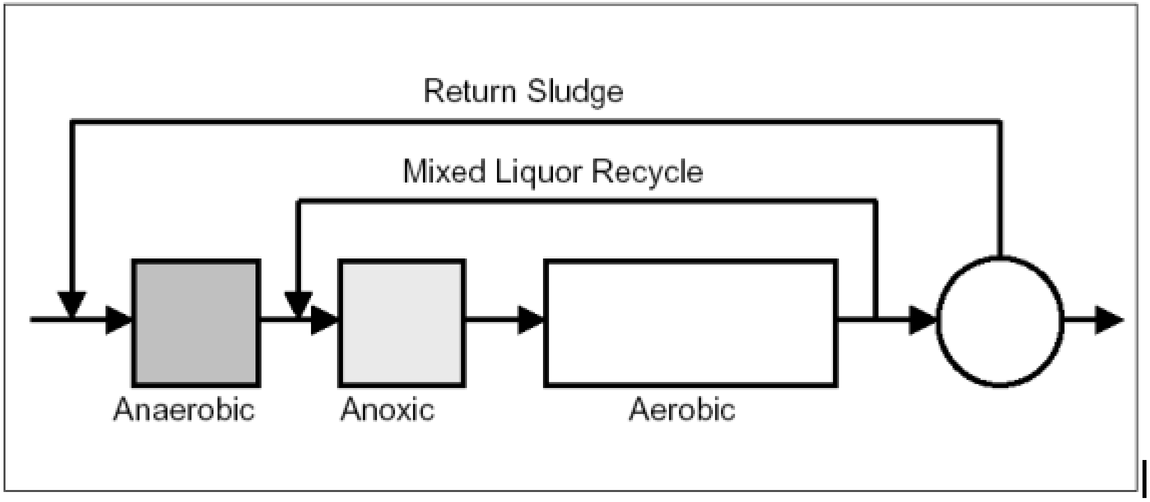
Phosphorus removal occurs through the selection of microorganisms capable of accumulating quantities of phosphorous in excess of that required for cell growth. This extra phosphorous is accumulated in the form of polyphosphate-energy storage product (Daigger & Buttz, 1992).

Biological removal of phosphorous also occurs under both aerobic and anaerobic conditions. Under anaerobic conditions, facultative bacteria will release soluble phosphorus into the water and adsorb BOD. The adsorbed BOD is stored until it can be utilized under aerobic conditions. The released phosphorus comes from adenosinetriphosphate (ATP), which is a stored energy formed inside the bacterial cell. The bacteria break the phosphate bonds of the ATP to obtain enough energy for metabolizing or decomposing the BOD. Following the anaerobic step, the bacteria begin to oxidize the stored BOD under aerobic conditions. The stored BOD is many times in the form of polyhydroxybutyrate (PHB). PHB is a form of stored carbon that shows up as an intracellular inclusion. Also during the aerobic step, the bacteria rebuild the stored energy ATP. To rebuild the ATP they remove soluble phosphorus from the waste stream. If the bacteria are conditioned to an anaerobic/aerobic cycle, the phosphorus uptake rate in the aerobic zone can be very high (*Sharman, 1998).*

Several systems have been developed for the NDN process along with different design elements. Of these, the most successful has been the Bardenpho process. The Bardenpho process is an advanced modification of the activated sludge process and allows for high levels of BOD, TSS, nitrogen, and phosphorus removal. It is a combined nitrification-denitrification process using both organic carbon in untreated wastewater and organic carbon released from endogenous respiration during denitrification. Separate aerobic and anoxic zones provide for nitrification and then denitrification (Metcalf and Eddy, 1991).

The Bardenpho process can consist of different configurations. In the three-stage Bardenpho configuration (Fig-8.21e), influent wastewater combines with return sludge from the clarifier in an anaerobic zone (un-aerated reactor zone). It is there that phosphorus is released and substrate is stored in the phosphorus accumulating bacteria when in the absence of nitrate. The flow then enters an anoxic zone where it combines with a nitrate recycle from the end of the aerobic zone where the returned nitrate is reduced to nitrogen gas. The flow then enters an aerobic zone, where ammonia is oxidized to nitrate. Phosphorus is removed from the process with the excess bio-solids, which are discharged to the river either from the clarifier underflow or the aerobic zone. Nitrogen is removed as nitrogen gas bubbling from the anoxic zone *(Solley, 2000).*

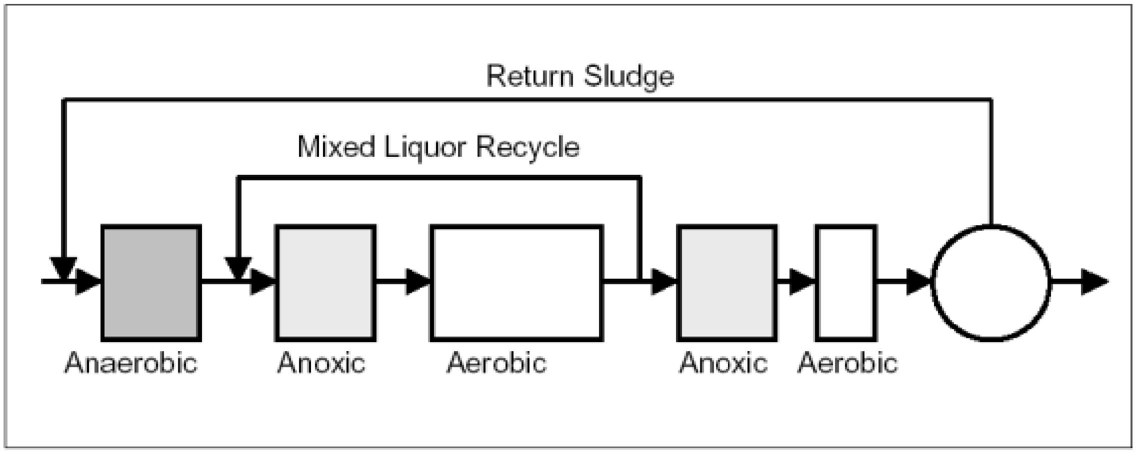
Figure 8.21e*: Three-stage Bardenpho process*



Source: David Solley –Churchill Fellowship 2000 Report

For greater removal of nitrate, five stage Bardenpho processes has been proposed (Solley, 2000). The modified Bardenpho process (Fig-8.21f) adds an anaerobic tank on the front end of the original process for phosphorus removal. Typically, a secondary anoxic zone is included after the primary aeration zone, where endogenous denitrification occurs. The five-stage Bardenpho process uses the following series for treatment of waste: anaerobic, anoxic, aerobic, anoxic and aerobic.

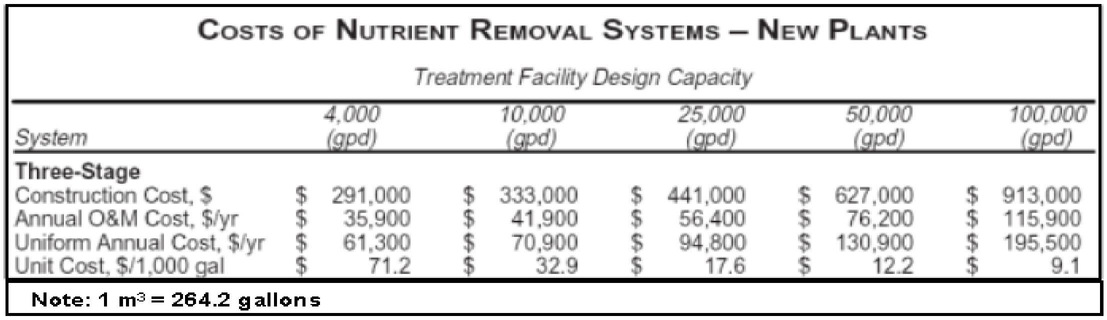
Figure 8.21f: Five-stage Bardenpho process



Source: David Solley –Churchill Fellowship 2000 Report

Very low nitrogen effluent concentrations (less than 5 mg/L) can be achieved using a five-stage Bardenpho (BNR) process. Energy is also saved through reduced aeration, and costs decrease due to lower excess bio-solids production in the Bardenpho process (Solley, 2000). The use of a three-stage system can achieve an effluent quality of 6 mg N/L, and although effluent quality is not as good as the five-stage process, a comparison of BNR new-plant alternatives performed by Foess et al. 1998, revealed that the three-stage system was most favorable based on its moderate costs, process control flexibility, and ease of operation. The costs of new three-stage system plants are presented below in Table 8.21c. These costs include construction cost, annual O & M cost, uniform annual cost, and use an interest rate of 6 percent for a 20-year period.

Table 8.21c: Costs for 3-Stage BNR Systems



COSTS OF NUTRIENT REMOVAL SYSTEMS – NEW PLANTS

	Treatment Facility Design Capacity				
System	*4,000 (gpd)*	*10,000 (gpd)*	*25,000 (gpd)*	*50,000 (gpd)*	*100,000 (gpd)*
Three-Stage					
Construction Cost, $	$ 291,000	$ 333,000	$ 441,000	$ 627,000	$ 913,000
Annual O&M Cost, $/yr	$ 35,900	$ 41,900	$ 56,400	$ 76,200	$ 115,900
Uniform Annual Cost, $/yr	$ 61,300	$ 70,900	$ 94,800	$ 130,900	$ 195,500
Unit Cost, $/1,000 gal	$ 71.2	$ 32.9	$ 17.6	$ 12.2	$ 9.1

Note: 1 m^3 = 264.2 gallons

Source: Foess et al, 1998

8.22 - Septic System Alternatives

WARMF model simulations indicate that septic tanks contribute 7.1% of TDN where as the SWAT model simulations indicate a 3 % contribution. For reductions to septic effluent, measures including replacing faulty septic systems, retrofitting septic systems with filters, extending municipal sewer coverage to septic areas, or constructing a decentralized WWTP that could serve residences currently using septic systems should be considered. The following is a description of these alternatives.

Replace faulty septic systems

This alternative involves the removal of the old septic systems, their replacement with new septic systems, and the construction of a new leach field.

The costs of replacing faulty septic systems vary with septic system efficiency. Costs for septic tank abandonment are estimated to be $1,500 to $2,500 (Central Contra Costa Sanitary District, 2003). The capital and installation cost of a conventional septic system at a single-family residence is approximately $5,000. More innovative septic systems that have a higher nutrient removal rate and a lower failure rate can cost 25% to 75% more and may have higher maintenance costs. The additional costs incurred with greater efficiency and reliability may be reasonable considering that if a septic system fails, it could cost homeowners from $3,000 to $10,000 to replace (Schueler et al, 2002).

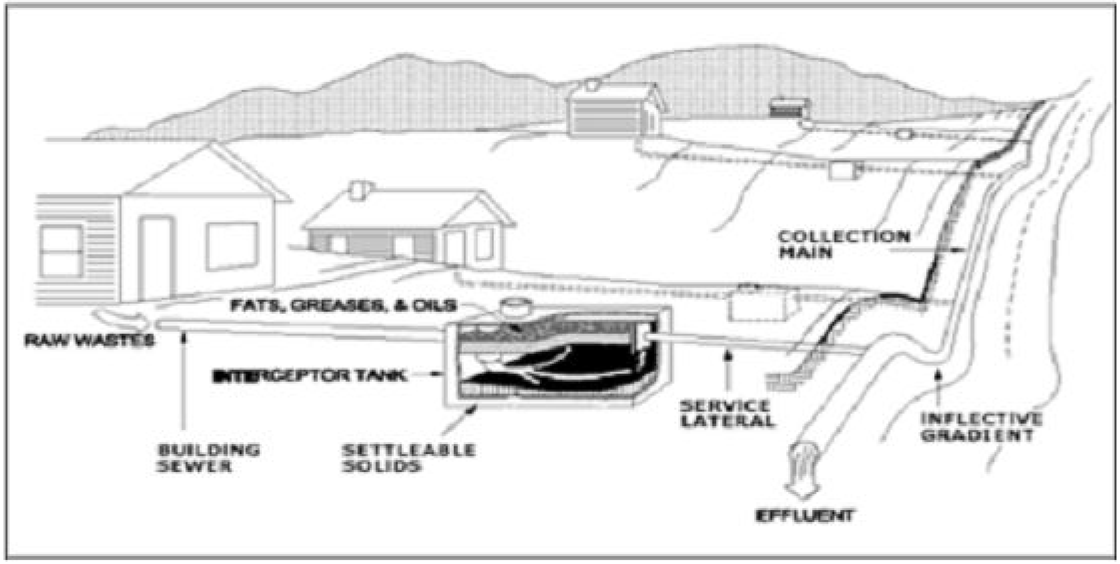
Extend municipal sewer coverage to septic areas

This alternative involves the connection of the septic systems to the nearby wastewater treatment plant. It is possible that existing septic tanks might be close enough to a nearby wastewater treatment facility of another town that it would be less expensive to convey wastewater to the treatment plant than to reconstruct a septic system. The costs to extend a public main sewer to ones property can run from less than $260 to over $490 per meter depending on the difficulty of the terrain (Central Contra Costa Sanitary District, 2003).

Construct small-decentralized wastewater treatment plants

This alternative involves the construction of a decentralized wastewater treatment facility that is designed to provide treatment of wastewater for a small number of homes located on or near the property it serves. This alternative is appropriate for those areas where septic tanks and leach fields are present on poor soil. It is a low cost treatment facility alternative that can serve sparsely populated communities. This option entails installation of a collection main extending into the areas serviced by the decentralized wastewater treatment facility, and hooking up each residence to the collection main via service laterals equipped with interceptor tanks (Figure 8.22a). Wastes would be treated at the wastewater treatment facility and eventually disposed of in surface waters or into lagoons/ponds for percolation to groundwater. Capital costs for such sewer projects range from $14,000-22,000 per user connection (Rural Community Assistance program, 2002).

Figure 8.22a: Schematic of decentralized wastewater hookup to dwellings.



Source: Tennessee Valley Authority

Retrofit septic systems with sand filters

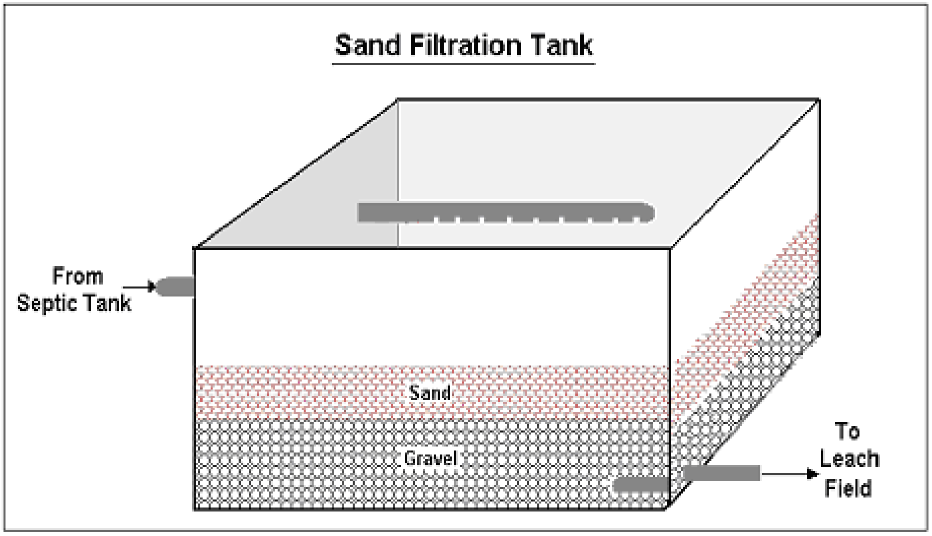
This method involves installing sand filters as an additional tank that would receive effluent from the septic tank before it drains to the leach field.

There are two types of sand filters:

- Periodic Sand Filters- effluent passes through the filter and is drained to the leach field.
- Re-circulating Sand Filter - effluent passes through the filter where a portion is recycled to the septic tank and the rest is drained to the leach field.

The septic effluent passes to the sand filter by spraying it directly on top of the sand surface using a perforated pipe where ammonia is converted to nitrate in the presence of air and bacteria. After passing through the sand filter, the effluent will be passed onto the leach field (Figure 8.22b). Sand filters can remove up to 50 percent of the total nitrogen from septic tank effluent (USEPA, 1993). The sand filter system helps to significantly decrease the biochemical oxygen demand (BOD) and total suspended solids (TSS). The cost of a shared sand-filtered system retrofitted to 10 homes is approximately $80,000 (ToolBass Services, 2004).

Figure 8.22b: Sand filtration retrofit for septic systems.



Retrofit septic systems with peat modules

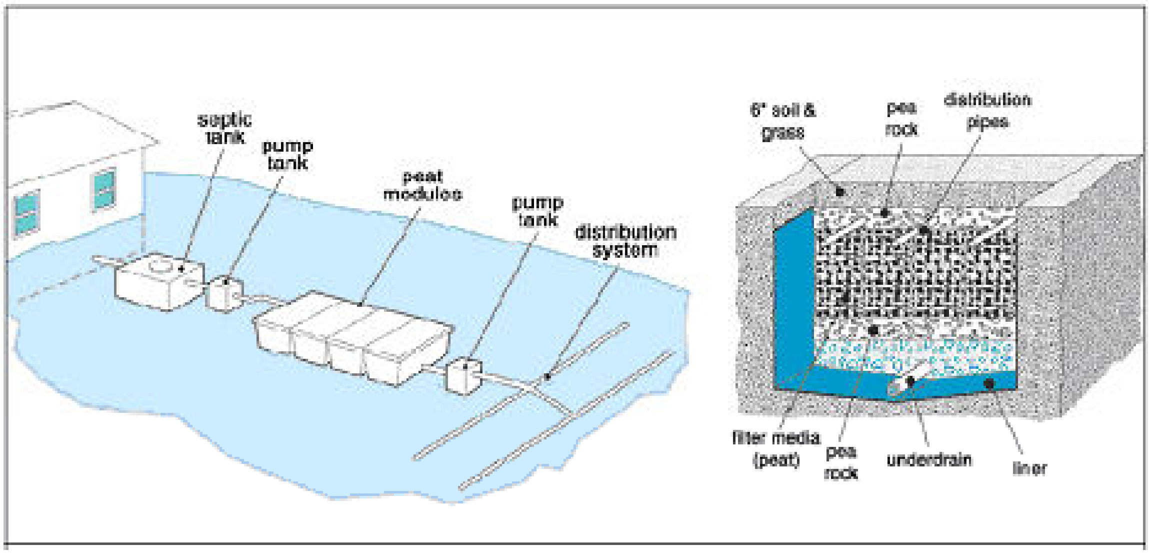
This method involves pre-treating effluent from the septic tank by filtering it through a thick layer of sphagnum peat (Figure 8.22c) before sending it to the leach field. Peat is a partially decomposed organic material that has a high water-holding capacity, making it very effective in treating wastewater. This could be used for an individual septic system or for a small cluster of houses with septic tanks.

Provided the hydraulic loading (i.e., flow rate per unit area) rates are between 1.5 and 4.1 cm/d, the removal efficiencies from peat filters are (Brooks, 1984):

- Phosphorous ~ 58–96%
- Total nitrogen ~ 69–83%
- Biochemical oxygen demand (BOD5) ~ 91–94%
- Chemical oxygen demand (COD) ~ 82–86%

Based upon 1999 costs, the peat bed could be installed onto an existing septic tank system for about $3500, with an additional $500 for a simple irrigation system (Patterson, 1999). Daily running costs for a peat filter are based on the operation of a small submersible pump, and averages less than one dollar per month for an individual home. Overall operational costs of $200-$500 per year include pumping, repairs, maintenance, and electricity (University of Minnesota-Extension Service, 2001).

Figure 8.22c: Peat module retrofit for septic systems.



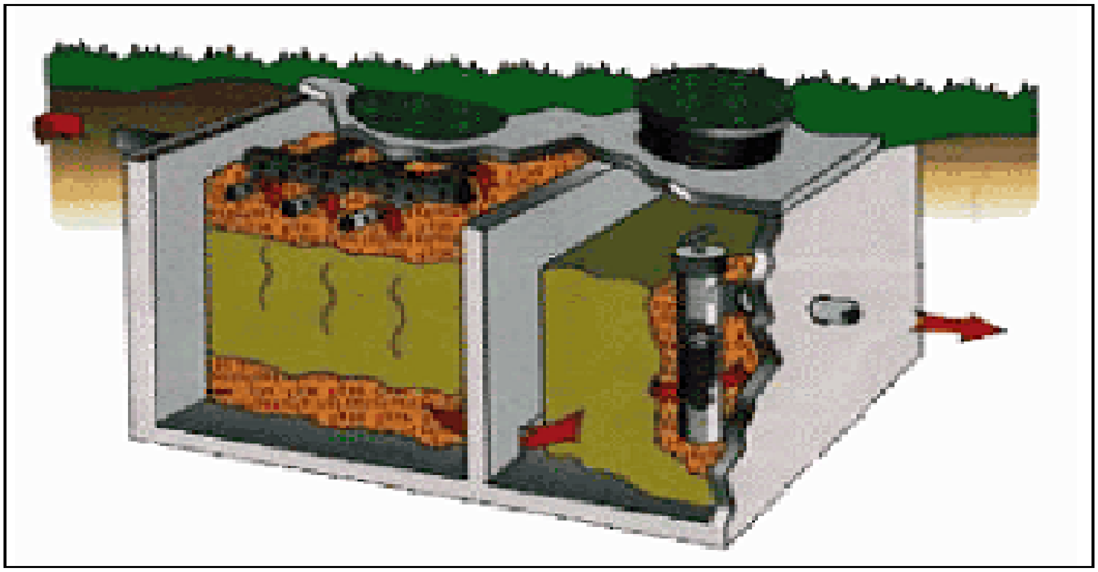
Source: College of Agriculture, Food and Environment Science, University of Minnesota

Retrofit septic tank with a Nitrex™ filter

A Nitrex™ filter at the discharge unit of the septic tank can achieve an overall average removal rate of 87% for nitrogen (NH_4^+ and NO_3^-) and 97% for nitrate (NO_3^-). This produces an effluent quality that meets the generally accepted surface water discharge criteria for ammonium (< 0.02 mg/L as NH_3-N) and the drinking water criteria for nitrate (< 10mg/L as N).

The Nitrex™ filter (nitrate-reactive media) converts nitrate to inert nitrogen gas (denitrification). The Nitrex™ reactive media is contained in a prefabricated tank. An oxidative pre-treatment step is required to first convert ammonium (NH_4^+) to nitrate (NO_3^-). Pre-treatment can be achieved with any of the existing oxidative technologies, for example sand filters, commonly used in septic tank treatment. Nitrate contaminated wastewater is gravitationally fed through the treatment module where the Nitrex™ filter performs the reductive denitrification step. The nitrate-free effluent from the Nitrex™ filter is then discharged to a conventional leach field.

Figure 8.22d: Nitrex™ filter for septic systems.



Source: University of Waterloo Nitrex ™

For a typical residential septic system installation, the Nitrex^{TM} filter costs approximately $2,900, whereas for wastewater flows that are greater than 660 Liters/day, a lined excavation Nitrex^{TM} filter application costs approximately $1/Liter/day. The operational and maintenance costs are very small for any Nitrex™ filter configuration (EPA, 2004).

8.23 - Urban Alternatives

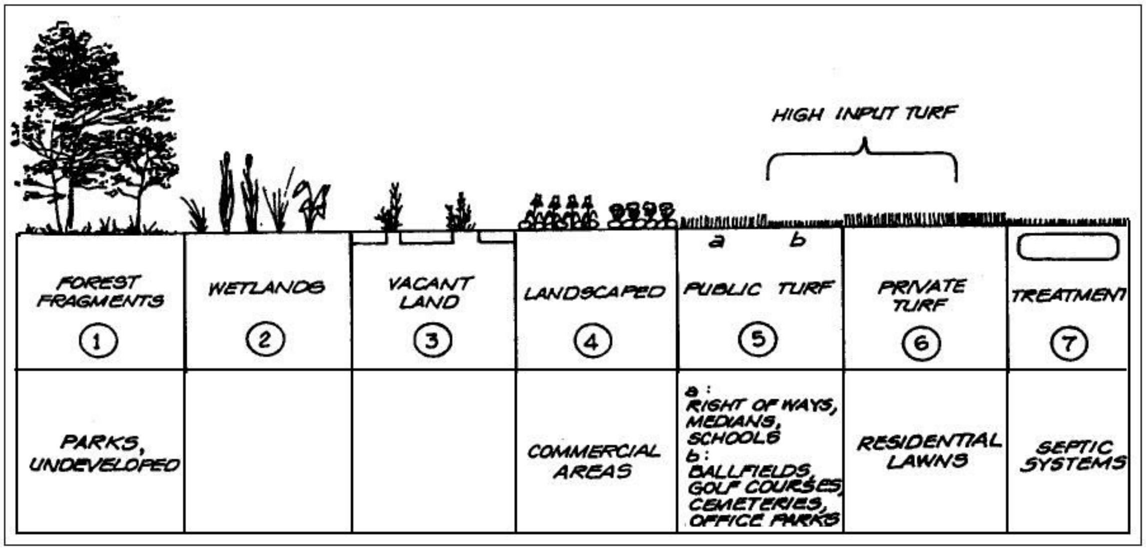
Urban load reduction alternatives presented here consist of both on and off-site measures. For reductions to occur at the source of urban runoff, alternatives include outreach and education to minimize loads, land use planning, controls on fertilizers available to the public, and other activities such as street sweeping. Reductions can also be off-site in the form of structural stormwater systems, such as filters, pits, ponds, and lagoons. Below are descriptions of the various measures.

Land Use Planning

Land use planning from a watershed management perspective involves managing land use and impervious cover in watersheds. Local land use planners can practice watershed management by first identifying key watershed uses, then directing the appropriate level of new growth to those areas that can best accommodate it. Key watershed uses can be identified by assessing stream conditions and critical habitats in order to determine what areas are in need of restoration. Some techniques include (Schueler et al, 2000):

Watershed-based zoning - Watershed-based zoning uses subwatershed boundaries as the basis for future land use decisions. This process could entail making estimates on current levels of impervious cover (see Figure 8.23a) and potential future impervious cover from development, then ultimately modifying master plans and zoning to shift the location and density of future development to the appropriate areas in order to sustain adequate levels of impervious groundcover.

Figure 8.23a: Six categories of pervious cover in urban landscape.



(Schueler, 2000)

Overlay Zoning - Overylay zoning is the addition of special restrictions or development criteria onto existing zoning provisions. These can be mandatory provisions that would be implemented for certain land-uses or densities; and can protect particular resources such as wetlands, forests, or historic sites.

Urban Growth boundaries - Urban growth boundaries establish boundaries between urban, agricultural, rural, and resource protection areas. These boundaries can be set for 10 to 20 year time horizons and can be altered between cycles if necessary. In establishing an urban growth boundary, several considerations must be made, such as availability of public resources, future growth areas, and the potential impact of growth on existing natural resources.

Large lot zoning - Large log zoning can mitigate the impacts of development on water quality by dispersing impervious land cover over large areas. This technique may have negative consequences that could exceed its benefits, though. Large lot zoning would promote urban sprawl, and would require an increase in road networks. This could actually increase impervious land cover, and would also increase the cost of utility infrastructure.

Land use planning contributes to the quality of a community or region. This increase in land quality, when utilizing a land use policy that is in line with citizens' desires to protect water resources, can increase the tax base of a locality due to increased property value. However, several hundreds of thousands of dollars can be spent obtaining scientific data to justify land use designs and from long-term implementation plans (Schueler et al, 2000).

Land Conservation

Land Conservation should be practiced to sustain the integrity of aquatic life and terrestrial ecosystems, as well as maintain desired human uses from its waters. Five types of land may need to be conserved (Schueler et al, 2000):

Critical habitats - Critical habitats can be designated to preserve plant and animal communities or populations. Examples include wetlands, forest clumps, springs, spawning areas in creeks, native vegetation areas, and areas for potential restoration.

Aquatic corridors - Aquatic corridors are areas that conserve space in and along streams and shorelines. These can include floodplains, stream channels, shorelines, and riparian forests.

Hydrologic reserve areas - Hydrologic reserve areas protected areas of undeveloped land that maintain the predevelopment hydrologic characteristics of catchments. These include forests, meadows, crop pastures, and managed forest (Schueler et al, 2000).

Water hazards - Water hazards are areas that have a high pollution potential, such as septic systems, landfills, impervious covers, and areas of hazardous material or waste storage or handling. From the watershed management perspective, these areas should be discouraged where they are in close proximity to beneficial uses of surface or groundwater (Schueler et al, 2000).

Cultural/historic areas - Cultural/historic areas include historic or archaeological sites, trails, parkland, scenic views, and recreational access ways (Schueler et al, 2000).

Property owners will likely have a greater willingness to pay for property in the vicinity of water, forested areas, and other natural areas. Sufficient amounts of open space can also contribute to the local economy by attracting tourists for recreational activities or fishing, and can also provide additional areas for flood control (Schueler et al, 2000).

Vegetative Buffers

Vegetative buffers are strips of vegetation planted around streams, lakes, or wetland channels. They function by protecting the water body from future disturbance, and slow the movement of stormwater runoff through filtration. The buffers can be effective as filters of nutrients, sediments, and bacteria from stormwater runoff and septic system effluent, in turn protecting wildlife habitat. The capacity of vegetative buffers to remove pollutants from runoff and stormwater is often limited, though, due to rapid channel flows breaching across the buffers. Some issues to consider when implementing buffers include how much of an aquatic corridor should be buffered, how they should be managed and crossed, whether restoration or stewardship of the buffer should be carried out, how much pollutant removal can be expected from the buffer network, and who will own and pay for the maintenance of the buffers (Schueler et al, 2000).

Vegetative buffers are also a critical BMP for agricultural land uses, especially when contiguous to a water body. Overgrazing in riparian areas removes bank grasses and woody plants, eliminating shade and overhanging vegetation. This results in higher temperature, less shade for hiding fish, and more sunlight for algae. Livestock grazing also destabilizes stream banks, leading to widespread bank erosion, and excessive sedimentation of the stream bottom, and channel widening. Shoreline fencing is a BMP that can be applied to agricultural land uses, and consists of fencing off stream banks to keep livestock away. Shoreline fencing allows vegetation to recover, allowing the stream channel to become narrow and deeper, thereby increasing fish habitat. In addition, shoreline fencing has been shown to reduce ammonia, nitrogen, and suspended sediment; increasing overall stream physical habitat quality (Wang et al, 2002).

As with the land use and land conservation strategy tools previously listed, vegetative buffers can increase property values for adjacent property owners. Vegetative buffers increase the value of a community in a variety of ways, such as providing additional flood control easements, and expanding recreational opportunities (Schueler et al, 2000).

Better Site Design

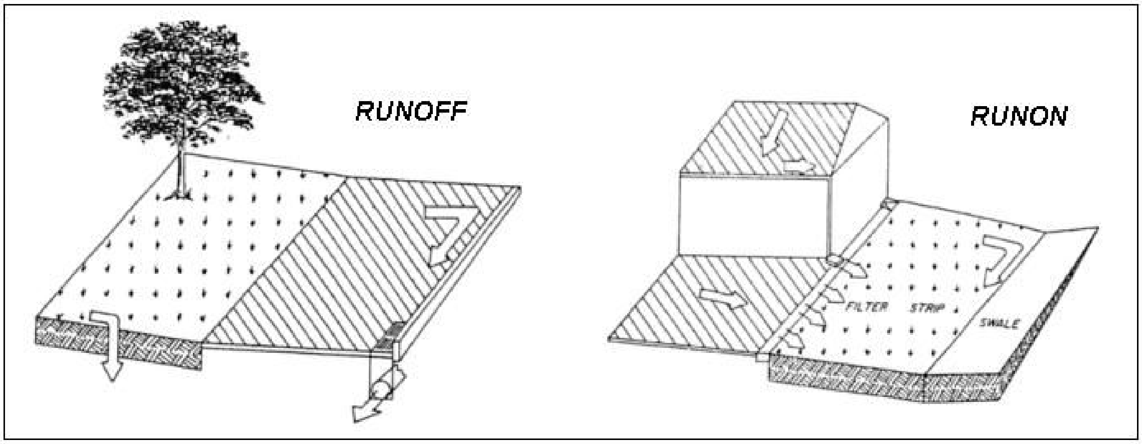
Better site design allocates greater protection to a watershed by reducing the amount of impervious cover in a watershed, and increasing the amount of area set aside for conservation. Listed and described below are four better design strategies (Schueler et al, 2000). One should bear in mind that several of these strategies are often not allowed in some localities because of outdated local zoning, parking, or subdivision codes. These ordinances can, however, be revised or changed; several methods are described in "Better Site Design: A Handbook for Changing Development Rules in Your Community" (Center for Watershed Protection, 1998).

Open space or cluster residential subdivision - These subdivisions are designs that minimize lot sizes to leave the remainder of a parcel or tract set aside for open space. These types of development can reduce impervious cover by as much as 10 to 50% (Schueler et al, 2000).

Green parking lots - Green parking lots minimize areas of impervious cover by downsizing parking lots or inserting structural stormwater areas, such as swales, between or along the margins of parking lots to promote recharge (Schueler et al, 2000).

Headwater Streets - This improvement involves re-evaluating daily trips made on streets, then decreasing the width of streets with low traffic. This would decrease impervious cover and increase areas of recharge (Schueler et al, 2000).

Figure 8.23b*: Better site design promotes 'runon' rather than runoff.*



(Schueler et al, 2000)

Roof top management - Roof top management involves redirecting rooftop runoff to pervious surfaces rather than routing it toward the storm drain system. This can reduce the pollutant loads to both streams and bays (Schueler et al, 2000).

Cost savings in better site design can be obtained through the implementation of 'cluster developments,' which minimize lot sizes and leaves the remainder of a parcel or tract designated for development as open space. Cluster developments can reduce grading and clearing operations by minimizing footprints from buildings and infrastructure for roads and utilities. The remaining open space can increase property values while implementing some of the watershed protection tools such as land conservation and aquatic buffers (Schueler et al, 2000).

Erosion and sediment control

Soil stabilization and erosion control measures prevent the movement of sediment into streams, rivers, and lakes. It can also be effective at filtering ammonia and nitrogen, and at increasing groundwater inputs through infiltration. Some of the main contributors to erosion problems are fallow and barren agricultural fields, dirt roads, and graded and cleared groundcover.

Sedimentation of waterways has been listed as the top priority impairment to water quality according to the TMDL schedule, and is thoroughly covered in the sediment TMDL for the watershed. Therefore, only a brief description of various sediment control measures is listed below (Keller and Sherar, 2003)

- Physical methods include measures such as surface armoring, armored ditches, berms, wood chips, ground cover mats, conservation tillage crop farming, and silt or sediment fences.
- Vegetative methods include planting grasses, brush, trees, and hedgerows.
- Biotechnical methods such as brush layering, live stakes, and contour hedgerows combine the benefits of vegetative and structural protection, while offering additional long-term root support and aesthetics.
- Non-structural practices include conservation areas, buffers, forests, and better sight design.

Watershed stewardship programs – six basic programs

Subsequent to the planning and development processes of an area, communities should still implement watershed management practices, such as educating the various residents of the area about typical activities that could have an affect on the watershed.

Watershed advocacy - The promotion of watershed advocacy is important because it can lay the foundation for public support and greater watershed stewardship.

Watershed education - Watershed education includes programs like watershed awareness that performs activities such as stenciling storm drains, promoting stewardship amongst residents, training professionals on how to apply the tools of watershed protection, and engaging the public in watershed protection and restoration.

Pollution prevention - If businesses can manage their operations to prevent pollution from occurring, they can prevent potential impacts to the watershed.

Watershed maintenance - Watershed maintenance includes watershed protection tools such as buffer networks, stormwater management practices, septic systems, and sewer networks.

Indicator monitoring - Monitoring the key indicators of health of a watershed should be ongoing to determine whether areas are out of compliance and in need of restoration.

Restoration - The rehabilitation of streams that have been invaded by exotic species, block migratory fish pathways, and degraded by past development is vital for the whole process that seeks to remove pollutants, enhance habitat, and restore urban streams.

Napa County already has programs in place that closely resemble the six basic watershed stewardship programs listed above. The NCSWMP, established in 2003, requires the following 6 program elements according to NPDES Phase II regulations: Public Education and Outreach, Public Involvement/Participation, Illicit Discharge Detection and Elimination, Construction Site Runoff Control, Post-Construction Runoff Management, and Municipal Operations. Many of these watershed program activities were already in place before the NPDES Phase II requirements were instated, and are outside the sphere of NCSWMP's influence. The programs are the combined efforts of many public agencies and departments, farmers, businesses, educators, and nonprofit organizations. They are listed and described at Napa County Flood Control and Water Conservation District website'03 (http://www.swrcb.ca.gov/stormwtr/docs/napa_swmp.pdf).

The Napa River has been a leader in respect to watershed management with its Napa River Watershed Integrated Resource Management Plan, coordinated by the Napa County Resource Conservation District (NCRCD) but first conceived by the San Francisco Bay RWQCB in 1992. Members of the NCRCD technical advisory committee direct watershed improvement efforts under decisions made by representatives from federal, state, and local agencies, vintners, environmentalists and developers. The goals of this committee have many similarities to the watershed protection tools described herein, and include: promoting stream stabilization along natural processes; promoting contiguous habitat; increasing biological diversity; increasing migratory and resident fish habitat; coordinating natural resource protection and planning efforts, encouraging land stewardship, reducing soil erosion, promoting sustainable land use concepts, and promoting and improving watershed management. Details about the goals and objective and land-use based BMPs are described in the "Napa River Watershed Owner's Manual" at the Napa River Resource Conservation District website (http://www.naparcd.org/ownermanual.htm).

Local governments typically cover the costs of ongoing watershed management programs. Additional financing can be picked up by water utilities, which could charge a fee on every unit of water. Table 8.23a below is an example of costs associated with a public education program conducted in Seattle, Washington.

Table 8.23a: *Public Education Costs in Seattle, Washington*

Item	Description	1997 Budget
Supplies for volunteers	Covers supplies for stewardship through the Environmental Partnership Program	$17,500
Communications	Communications strategy highlighting a newly formed program within the city	$18,000
Environmental education	Transportation costs from schools to field visits (105 schools with four trips each)	$46,500
Education services/field trips	Fees for student visits to various sites	$55,000

Item	Description	1997 Budget
Teacher training	Covers the cost of training classroom teachers for the environmental education program	$3,400
Equipment	Equipment for classroom education, including displays, handouts, etc.	$38,000
Water Interpretive Specialist: Staff	Staff to provide public information at two creeks	$79,300
Water Interpretive Specialist: Equipment	Materials and equipment to support interpretive specialist program	$12,100
Youth Conservation Corps	Supports clean-up activities in creeks	$210,900

Notes: Taken from EPA, August 1999

Street Sweeping

Street sweeping can also be effective at removing nutrients and sediments that would otherwise be washed into storm drains and ultimately be conveyed into surface waters. Street sweeping costs can be determined based on the costs of purchasing the equipment, maintenance and operational costs, and disposal costs. Maintenance, operation, and disposal costs can be gauged based on the frequency of street sweeping, and are tabulated below in Tables 8.23b and 8.23c.

***Table 8.23b**: Street Sweeper Cost Data.*

Sweeper type	Life [years]	Purchase price [$]	Operation and maintenance costs [$/curb mile]
Mechanical	5	75,000	19
Vacuum-assisted	8	150,000	9

Source: Adapted from EPA, 1999

***Table 8.23c**: Annualized Sweeper Costs ($/curb kilometer/year).*

Sweeper type	Sweeping Frequency					
	Weekly	Bi-weekly	Monthly	Four times per year	Twice per year	Annual
Mechanical	1,050	525	243	81	41	20
Vacuum-assisted	590	296	136	46	23	11

Source: Adapted from EPA, 1999

Evaluation of the costs in Tables 8.23b and 8.23c indicates that although mechanical sweepers can be purchased significantly cheaper, vacuum assisted sweepers have significantly less operation and maintenance costs, as well as a longer life.

Urban structural stormwater treatment systems

There are 5 broad groups of structural storm water management systems that can promote recharge, remove pollutants, and prevent and control stream bank erosion. As indicated in Table 8.23d, these systems are effective in removing only a portion of conventional pollutants, and some systems actually increase the level of a pollutant through natural processes. If these types of systems are used and the load reduction target is higher than the typical removal rate for one stormwater system, a series of systems can be constructed to achieve the desired load reduction. However, some pollutants can't be reduced any further once ato a certain level, and the addition of further treatment may not result in any further improvement.

Ponds, wetlands, infiltration basins, filtering systems, and open channels act as aquatic buffers to remove sediment, nutrients, and bacteria from storm water run-off and septic system effluent. They also promote groundwater recharge and control streambank erosion. Wetlands can provide water quality enhancement, flood management benefits, opportunities for recreation, habitat for valued species, stability to global environmental cycles, and more (Newbold, 2002). Where possible and technically feasible, wetlands should be reestablished to filter storm runoff and attenuate flooding.

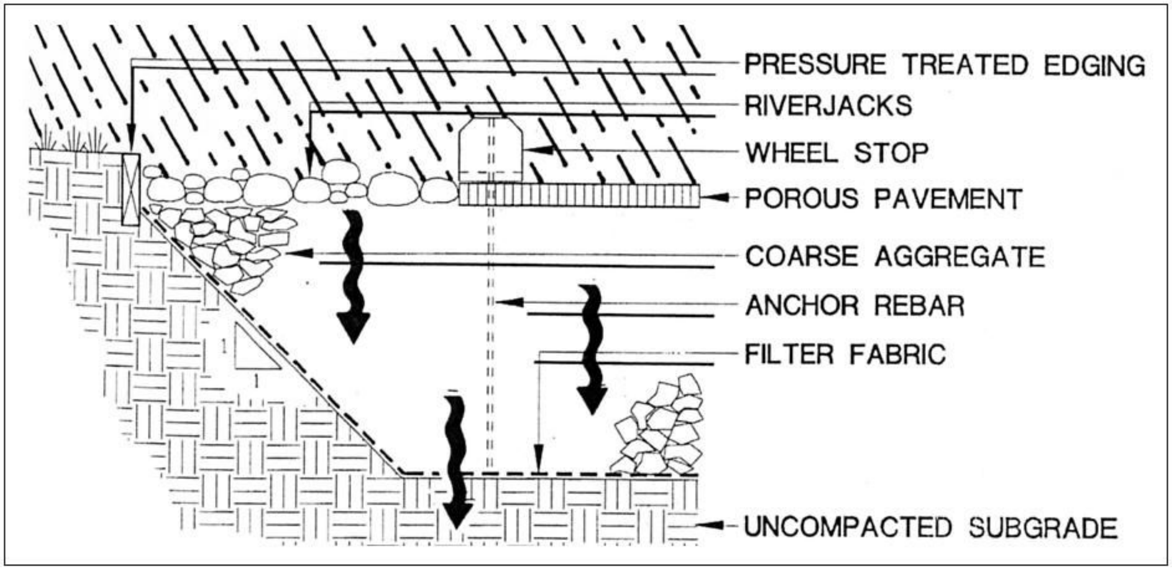
Ponds - Various designs exist, such as detention ponds, dry extended detention ponds, wet ponds, and wet extended detention ponds. Studies on pollutant removal performance from ponds reveal that they can have a low or negative ability to remove either soluble or total phosphorus, can remove approximately one third of total nitrogen, and have high removal rates of suspended sediments.

Problems arise if ponds are situated in a climate zone where they can freeze or dry out. This can drastically reduce or eliminate its storage volume and limit the filtering capacity (Schueler et al, 2000).

Constructed wetlands - Constructed wetlands include shallow marshes, extended detention wetlands, and intermediates between ponds and wetlands. Studies on pollutant removal performance of wetlands reveal they have a wide variation in phosphorus removal, and can remove approximately one third of total nitrogen. Like ponds, wetlands can present problems if situated in areas where they can freeze, or in arid areas where they can dry out (Schueler et al, 2000).

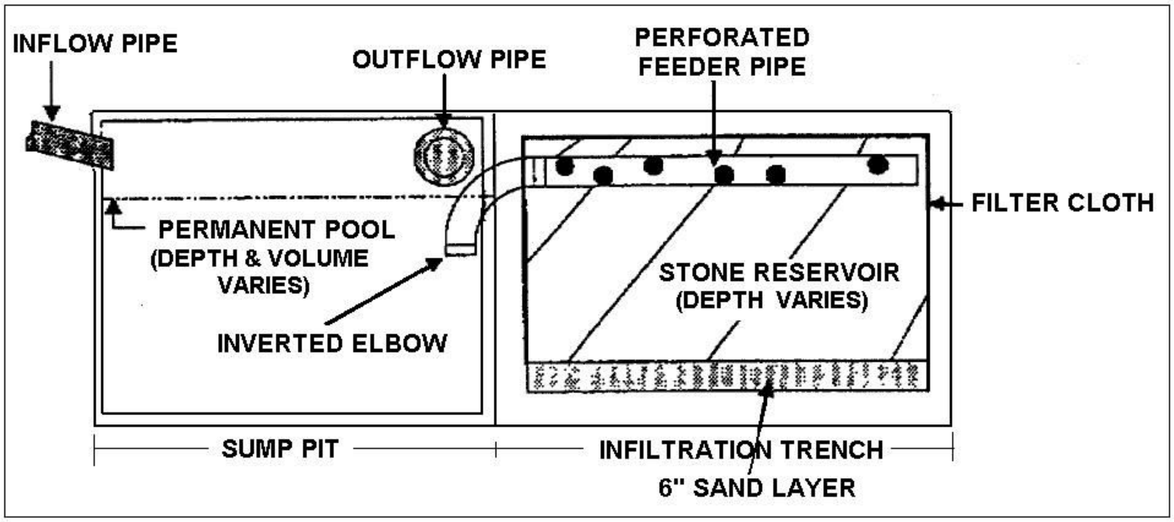
Infiltration - Infiltration systems include infiltration trenches, infiltration basins, grass filter strips, porous pavement, and sump systems. Infiltration systems such as trenches, basins, filter strips, and porous pavement can be rock-filled, typically have no outlet, and receive stormwater runoff that infiltrates through the bottom of the structure and into the soil. Example diagrams of porous pavement and sump pits are shown in Figures 8.23c and 8.23d. Infiltration systems are shown in Table 8.23d to have higher removal rates of stormwater pollutants overall than any of the other stormwater management practices listed here. However, these systems must be maintained to remain effective, are only applicable to certain soil conditions, and cannot be installed in areas with high water tables. A common concern with infiltration systems is that they are susceptible to rapid clogging in areas with high erosion rates and/or marginal infiltration capacities (Schueler et al, 2000).

***Figure 8.23c**: Porous Pavement/Recharge Bed Design.*



(Schueler et al, 2000)

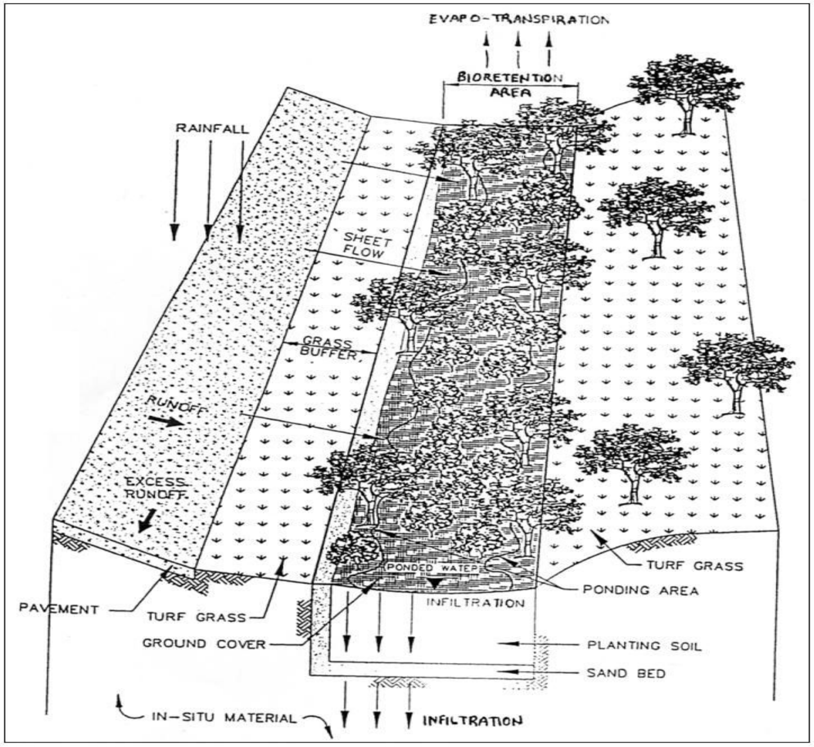
***Figure 23d**: Sump pit used to pretreat runoff before infiltration.*



(Schueler et al, 2000)

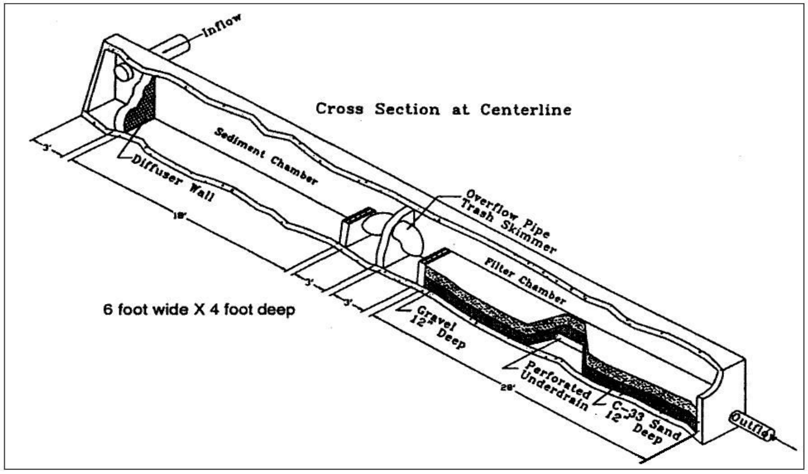
Filtering systems - Filtering systems, such as surface sand filters and bioretention areas may reduce nutrient loading. Filters need to be regularly maintained to keep them working effectively. The filters need to be adequately designed so that they can handle the expected runoff volumes and total suspended solid concentrations. Studies on pollutant removal performance of sand filters reveal they are effective in removing total phosphorus, but may export soluble phosphorus, can leak nitrate, and have high removal rates of suspended sediments (Schueler et al, 2000).

***Figure 8.23f**:* Bio-retention area serving as a parking lot.



(Schueler, 2000)

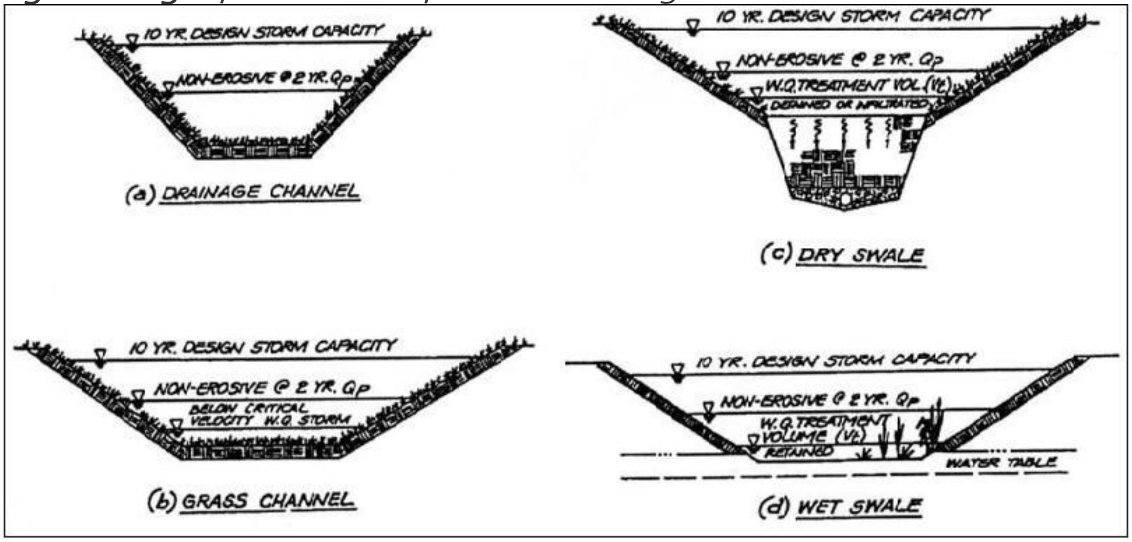
***Figure 8.23e**: Schematic of an underground sand filter*



.
(Schueler, 2000)

Open channels or swales – These systems include drainage swales, grass channels, dry swales, and wet swales, which are intended to act as bio-filters that treat stormwater as it is conveyed. Performance of these systems is related to various factors of the channel or swale such as length, underlying soil type, vegetation type, imperviousness of soil, and depth to groundwater. Studies on pollutant removal performance of swales reveal they have a wide variation in phosphorus removal, high removal rates of suspended sediments, and can actually leak excess bacteria rather than filter it (Schueler et al, 2000).

Figure 8.23g: *Open channel options for treating stormwater.*



(Schueler, 2000)

Table 8.23d below is a comparison of the median pollutant removal efficiencies of some conventional pollutants among the selected categories of stormwater management practices.

Table 8.23d: *Groups of Structural Stormwater Management Practices and Median Removal Rate of Stormwater Pollutants*

Practice Group	Median Removal Rate for Stormwater Pollutants (%)					
	TSS	TP	Sol P	Total N	$NO_x^{\#}$	Bacteria†
Ponds	80	51	66	33	43	70
Wetlands	50-80*	15-45*	36	<30*	67	<30*
Surface Sand Filters	86	59	3	38	(-14)	37
Infiltration	50-80*	15-45*	85	50-80*	82	65-100*

Practice Group	Median Removal Rate for Stormwater Pollutants (%)					
	TSS	TP	Sol P	Total N	NO_x[#]	Bacteria[†]
Trenches						
Infiltration Basins	50-80*	50-80*	NA	50-80*	82	65-100*
Swales	30-65*	15-45*	38	15-45*	31	<30*
Porous Pavement	65-100*	30-65*	NA	65-100*	NA	65-100*
Vegetated Filter Strips	50-80*	50-80*	NA	50-80*	NA	<30*

Notes:
Table adapted from Schueler et al, 2000, unless otherwise noted.
 # - Refers to nitrate-nitrite nitrogen (NO_3^- and NO_2^-)
† - Fecal bacteria
** - Adapted from EPA, August 1999*
TSS – total suspended sediment
TP – Total phosphorus
Sol P – Soluble phosphorus

Notice that sand filters are listed as having a negative reduction capacity, which indicates that more nitrate and nitrite is exported from the filter than comes in. This phenomenon is indicative of the nitrification effect, where microbial bacteria convert ammonia into nitrate. This nitrification effect can be verified if there is an apparent loss of ammonia upon passing through the filter bed, coupled by the excess production of nitrate through the filter bed (Claytor and Schueler, 1996).

Table 8.23e below lists base costs, relative land consumption, and applications for several storm water BMPs. Note that the costs of storm water management exclude the cost of land designated for storm water management and maintenance charges.

***Table 8.23e**: Base costs of typical applications of stormwater BMPs*

BMP Type	Cost per cubic meter of water treated	Annual maintenance cost (% of construction cost)	Application[†]	Relative land consumption (% of impervious area)
Retention basin[1-4]	$100,000	3%-6%	50-acre residential site (Impervious cover = 35%)	2.5%
Wetland[1-5]	$125,000	2%-6%	50-acre residential site (Impervious cover = 35%)	4%

BMP Type	Cost per cubic meter of water treated	Annual maintenance cost (% of construction cost)	Application[†]	Relative land consumption (% of impervious area)
Infiltration trench1[1,2]	$45,000	5%-20%	5-acre commercial site (Impervious cover = 65%)	2.5%
Infiltration basin[2,3]	$15,000	1%-10%	5-acre commercial site (Impervious cover = 65%)	2.5%
Sand filter[1,4]	$35,000-$70,000	11%-13%	5-acre commercial site (Impervious cover = 65%)	1.5%
Bioretention[1,2]	$60,000	5%-7%	5-acre commercial site (Impervious cover = 65%)	5%
Grass swale[2]	$3,500	5%-7%	5-acre residential site (Impervious cover = 35%)	15%
Filter strip[2]	$0-$9,000	$320/acre (maintained)	5-acre residential site (Impervious cover = 35%)	100%
Porous pavement[3]	$124,000/hectare	5%	NA	NA

Notes: Based on EPA, August 1999.
** - Base year for all cost data is 1999; base costs do not include land costs and total capital costs. Cost units refer to cost per meter cubed volume of stormwater treated.*
†- 5-acre and 50-acre sites are approximately 2-hectare and 20-hectare sites, respectively.

Maintenance charges over a 20 to 25 year period can equal initial construction costs. Some of the more effective stormwater management practices can have maintenance costs that are quite high, like infiltration basins, which can cost $500 to $1,000 per year to maintain (Schueler et al, 2002). Land costs in Napa can range from approximately $30,000 per acre to well above $100,000 per acre ($75,000 to $250,000 per hectare), depending on the quality and location of the land. Some storm water practices, such as grassed swales and bioretention areas, can actually be less expensive than standard storm drain systems and can provide better environmental results. The use of ponds, wetlands, grassed swales and bioretention areas may also increase land values through a higher willingness to pay for waterfront property.

8.24 - Agricultural Alternatives

Load reduction for agriculture can be either implemented at the source, through reductions in fertilizer application, eliminating runoff of manure from stables and manure piles, or controls can be implemented off-site with structural and nonstructural BMPs designed to capture and reduce the concentration of nutrients in runoff before it enters waterways.

Methods to reduce nutrient loads consist of on-site managerial measures that involve the changing of farming practices to use less nitrogen or reduce the loss of nitrogen to runoff or leaching to groundwater. Off-site measures consist of structural stormwater treatment practices designed to capture and filter agricultural runoff prior to entry into surface waters. Structural treatment practices were described above in the stormwater alternative section. The application of these structures in an agricultural setting is similar to the urban setting, however, collection and conveyance of agricultural runoff before and after treatment is achieved typically with unpaved gradients and canals or swales, rather than paved gradients, curb and gutter systems, or storm water conveyance systems. Despite these differences and expected higher loads of TSS in an agricultural setting, the descriptions of storm water treatment practices in an urban setting are valid, and the options presented below are limited to only on-site management measures.

The on-site management measures listed below are considered practical and economically feasible BMPs for nutrient and water management, developed by academic researchers, growers, fertilizer retailers, and crop consultants (UCDANR, 1998). These methods consist of site measures that involve the changing of farming practices to ultimately use less nitrogen or reduce the loss of nitrogen to runoff or leaching to groundwater, while at the same time not altering crop value or productivity. The on-site management measures described here deal with managing pollutants from the source before they cause a problem, and may be considered a cheaper, more direct, and a more effective means of protecting water resources from nonpoint sources of pollution than off-site controls.

Reduce fertilizer inputs to sustainable levels - This measure involves reducing fertilizer input to optimum levels. Optimum fertilizer application rates considered here are based on three criteria: a) the reductions in nitrate levels do not affect crop yield; and b) maximum utilization of nitrate; and c) minimum amount of nitrate leached.

Developing a sustainable fertilizer rate for the Napa River Watershed was based on finding instances where low fertilizer rates were reported in a setting that had many similarities to grape production in Napa. Low application rates using a 2:10:15 solution of nitrogen, phosphorus, and potassium in drip irrigation practices for vineyards were demonstrated by AgroTech Supply of Geyserville, California for a 5-year old, full-producing vineyard (McCarthy, 2000). This solution can reportedly be used on any grape variety, and has advantages of bringing younger vines into production sooner. It also can yield higher prices for grapes as a result of improved color and solids content. The application rate was documented at 235 liters per hectare (25 gallons an acre), using four to five applications split evenly about every five weeks between April and August, plus one post-harvest application. Note that this practice was accompanied by tissue testing once a year at bloom. In a younger vineyard, the amount of the 2:10:15 solution would be reduced to 140 liters per hectare (15 gallons an acre) per application.

The Napa County Farm Bureau reported that the most common fertilizers used in Napa County are calcium nitrate and potassium sulfate. To alter fertilizer rates to approximate the 2:10:15 solution (nitrate: phosphorus: potassium), nitrate would be the variable used to achieve the modification. For instance, calcium nitrate contains 15.5% nitrogen, so if calcium nitrate use were maintained while trying to achieve the modified rate, the total amount of nitrogen used in fertilizer in one year should not exceed the total amount of nitrogen used in one year with the modified rate (2% nitrogen at six applications per year with 95 liters (25 gallons) per application).

Agriculture General Management Measures - Common concerns about crop nutrient requirements include nutrient sources, application methods, rates, and timing. Table 8.24a lists several general management measures designed to improve the efficiency of nitrogen use in crops by managing N fertilizer and water efficiently. Management measures are considered the best economically achievable technology or process for limiting movement of nitrogen into ground or surface waters. A more detailed description of the general practices listed below can be found in from the University of California Division of Agriculture and Natural Resources Production Guide: Nitrogen and Water Management for Coastal Cool-Season Vegetables, (UCDANR, 1998).

Table 8.24a: Recommended agricultural practices for improving the efficiency of nitrogen use (UCDANR, 1998).

#	Description of management measure
1	**Evaluate current irrigation and fertilization practices and plan improvements in management.** o Develop and implement a system for keeping long-term records on each field of water and nutrient/soil amendment inputs, cultural operations, pest problems, land leveling or other improvements, and crop yield intensity
2	**Avoid fertilizer material spills during all phases of transport, storage, and application.** o When transporting fertilizer, do not overfill trailers or tanks. o Maintain all fertilizer storage facilities to meet government and industry standards and protect them from the weather o Clean up fertilizer spills promptly o Whenever injecting fertilizer into irrigation water, ensure backflow does not occur o Distribute rinse water from fertilizer application equipment evenly throughout the field.
3	**Base the amount and timing of N fertilizer applied on crop needs and production goals.** o Before applying N early in the growth cycle, assess the amount of nitrate already present by soil (or soil solution) sampling and analysis. o When applying manure shortly before a crop is planted, determine the nutrient condition of the manure and the amount of nitrate already present in the soil. Apply manure at a rate consistent with the crop nutrient requirements. o Split applications of N fertilizer o When possible avoid water-running N fertilizer in the furrows. If fertilizer N must be water-run, maximize irrigation uniformity and inject fertilizer during the last half of the irrigation set. o Use plant tissue sampling for mid- and late-season fertilizer decisions. o Do not apply excessive single amounts of fertilizer N during the rainy season. o For fertilizer application during fall tillage use only low N-containing

#	Description of management measure
	materials such as N:P2O5:K2O equal to 1:3:3. Higher N materials may be appropriate if a crop is to be planted soon. o Measure nitrate levels in the irrigation water and adjust N fertilizer rate accordingly.
4	**Place N fertilizer materials where maximum plant uptake will occur.** o Incorporate N fertilizer into the crop bed by placing fertilizer on the seed row and watering it in, by knifing fertilizer into the bed, or by broadcasting fertilizer and then listing it up into the bed. o Incorporate manures and other organic amendments into soil with consideration of the timing of conversion of manure N to other forms.
5	**Minimize leaching losses of nitrate during non-crop periods.** o If conditions permit, grow a cover crop rather than leaving fields fallow during the rainy season.
6	**Operate irrigation systems to minimize deep percolation and N losses.** o Monitor soil moisture between irrigations and use the information to guide irrigation timing decisions. o Base amount of water applied on crop need. o Know the flow rate and time required to apply the desired inches of water. o Use the minimum leaching fraction that will prevent yield reduction from salinity or stand establishment problems. o When injecting fertilizer into irrigation water, follow all applicable government agency industry guidelines for backflow prevention and regularly check and maintain backflow prevention devices. o If irrigation efficiency remains low after all practical improvements have been made, convert to a more efficient irrigation system.
7	**Improve existing furrow irrigation.** o Convert to surge irrigation. o If fields are more than 1,000 feet long, consider cutting the furrow run length in half with a corresponding decrease in set time. o Use high flow rates initially to get water down the field and then cut back to finish off the irrigation. Avoid doing the opposite. o Prepare fields as uniformly as possible, with no variations in slope. o Use practices to increase uniformity among furrows (e.g. torpedos, extra tractor trip, etc.). o Collect surface runoff for recirculation or reuse elsewhere.
8	**Improve existing sprinkler irrigation.** o Monitor flow and pressure variation throughout the system to detect non-uniform application. o Maintain the irrigation system by repairing leaks, replacing malfunctioning sprinklers, and maintaining adequate water pressure through the entire set. o To the extent possible, operate sprinklers during the least windy periods. o Use offset lateral moves. o When the pressure variation throughout the system is excessive, use flow control nozzles. o Make set times as short as possible for stand establishment. o For very large blocks, consider converting to linear move sprinkler systems.
9	**Improve existing drip irrigation.** o Use appropriate lateral hose lengths to improve uniformity. o Use drip tape that has a small emitter discharge exponent. o Check for clogging potential by conducting water analysis and

#	Description of management measure
	fertilizer/water compatibility tests. o Use filtration, chemical treatments, and flushing as necessary to prevent or correct clogging problems.

Note: Table adapted from University of California Division of Agriculture and Natural Resources Production Guide: Nitrogen and Water Management for Coastal Cool-Season Vegetables, publication number 21581, 1998.

Soil and plant tissue sampling

Soil and plant testing can be performed to accurately determine a crop's fertilizer needs. Establishing a soil and plant tissue testing program can help ensure that a crop receives the amount of nitrate needed for maximum yield and quality, while minimizing the amount of nitrate removed from the root zone through runoff or leaching. Plant sampling and analysis can be performed by either conventional tissue analysis or by quick tests, and should be conducted at mid- to late-season during periods of rapid growth. Soil sampling and analysis typically involves analysis for the following parameters: pH, P, K, and salinity. The results from soil analysis can be used to identify whether or not more applications of N fertilizer are required. Integrated monitoring of soil and plant nitrate status is especially useful for drip-irrigated production, where crop managers can respond quickly to any low levels of nitrate found (UCDANR, 1998).

Cover crops

Cover crops include grasses, clovers, peas, and other small plants that are most frequently used to replenish soil organic matter and reduce soil erosion. Cover crops have also been credited with reducing the need for nitrogen fertilizer through nitrogen fixation, reducing soil compaction leading to increased water filtration capabilities of the soil, and increasing biodiversity which protects beneficial insects, manages weed control, and provides aesthetic beauty. In vineyards cover crops can be planted in between rows and sometimes under the vines themselves (Locke, 2002).

California native grasses can be used to preserve more natural watershed conditions, and are selected for favorable qualities that have been described as hearty and tough, drought tolerant, and effective filtration systems. Table 8.24b lists some California native grasses that are frequently used and some that are still considered experimental.

Table 8.24b: *Frequently used and experimentally used native cover crops*

Frequently used natives	Experimental natives
Meadow barley *Hordeum brachyanterum*	Pine bluegrass *Poa secunda secunda*
California barley *Hordeum brachyanterhum ssp. Californicum*	Various species of *Nassella*
“Molate” red fescue *Festuca idahoensis*	Various species of *Melica*, including California Oniongrass *Melica californica* and the Tory melic *Melica torreyana*
Idaho fescue *Festuca idahoensis*	California oat grass *Danthonia californica*
California brome *Bromus carinatis*	
Blue wildrye *Elymus glaucus*	

Notes: from Locke, 2002

Cover crops types and methods can specifically target erosion control and soil building. Some growers in Napa have made a commitment to no-till cover crops, which are an efficient erosion control measure. Soil building cover crops grow quickly and produce a great deal of biomass, which then is tilled under to add organic matter to the soil ultimately enhancing soil nitrogen. Examples of frequently used no-till and soil building cover crops are listed in Table 8.24c.

Table 8.24c: *Frequently used no-till and soil building cover crops*

Frequently used no-till	Frequently used soil builders
Red oats *Avena sativa*	Red oats *Avena sativa*
Cereal barley *Hordeum vulgare*	Cereal barley *Hordeum vulgare*
Cereal rye	Cereal rye

Frequently used no-till	Frequently used soil builders
Secale cereale	*Secale cereale*
Crimson clover *Trifolium incarnatim*	Crimson clover *Trifolium incarnatim*
"Zorro" annual fescue *Vulpia myruos*	Bell (fava) bean *Vicia faba*
"Blando" brome *Bromus hordeaceus*	Austrian winter pea *Pisum sativum*
Annual rye grass *Lolium multflorum*	Vetch *Vicia sativa*
Rose clover *Trifolium hirtum*	Purple vetch *Vicia benghalensis*
	"Lana" woolypod vetch *Vicia villosa ssp. Dasycarpa*
	Berseem clover *Trifolium alexandrinum*

Notes: from Locke, 2002

Manure Management

Manure contains variable amounts of nitrogen, and can be considered a contributor of nitrogen to groundwater and surface waters if not managed properly. Manure management measures should be implemented for both livestock and for application to agricultural fields.

Implementation measures to consider for livestock include, setting stream setbacks to keep animals away from streams and tributaries, and removing manure more frequently from stables. It is important to ensure that manure from stables is managed properly throughout the year and that animal waste is not allowed to runoff into streams at any time (EPA Region 9, 2003).

Manure management with respect to application on agricultural fields involves the proper timing and handling, and monitoring nitrogen levels in soil and plant tissue. These manure management practices seek to utilize N efficiently on the crops by avoiding N loss through runoff, leaching to groundwater, or volatilization to the atmosphere.

Over-application of manure leads to nitrogen loss from impending runoff or leaching to groundwater. Nitrogen content in manure varies depending on the type, age, and amount of litter present in the manure. Most of the N present in the manure is in organic form and must be mineralized by microbial organisms into the usable inorganic forms- ammonium and nitrate. Microbial N turnover rates can range from a few weeks to a few years, however turnover typically occurs more rapidly within the course of several weeks or months. Excessive N levels can build up when manure is applied periodically to the same field. Since it is difficult to know exactly how much N will be released, an active soil analysis and plant tissue testing program should be used to determine the amount of available N and ensure that the total crop N requirement is not exceeded (UCDANR, 1998). Other manure practices can ensure that its nutrient value is not lost to volatilization or surface runoff.

- Volatilization occurs when moist manure is exposed to the air, and N is lost as volatile ammonia. Spreading manure in a thin layer so that wet manure dries quickly;
- Incorporating manure into the soil within a few hours of application;
- Not applying manure before a prolonged rainy, fallow period. If manure must be applied to a fallow field, grow a cover crop. In California, to avoid the rainy seasons, apply manure during the late spring and fall.
- Apply manure based on efficient use rather than accessibility to manure supply.

More information on manure management can be found in Production Guide: Nitrogen and Water Management for Coastal Cool-Season Vegetables (UCDANR, 1998), and Organic Soil Amendments and Fertilizers (Chaney et al, 1992).

Other Practices dealing with water and nutrient use efficiency

Modern irrigation scheduling and educational programs are available to provide almost real time data, and can be accessed via the internet. The California Irrigation Management Information System (CIMIS) is a free program of the Department of Water Resources that has a network of weather stations that can provide almost real time guidance on crop irrigation levels, has recommendations concerning efficient water use, and provides data to plan irrigation scheduling. This system can be utilized to control erosion and protect water quality, and can be found at http://www.cimis.water.ca.gov/ (CIMIS, 2004). Wateright is another option for modern irrigation scheduling that can be accessed by agricultural users, commercial turf growers, and homeowners. It is sponsored by the Bureau of Reclamation and California Department of Water Resources, and more can be found at http://www.wateright.org/ (Wateright, 2004).

The Central Coast Vineyard Team's Positive Points System is a 1,000-point self-assessment tool for evaluating the extent of sustainable vineyard practices used on the farm. Growers are evaluated on environmental issues commonly associated with production agriculture: protecting surface and ground water quality, minimizing soil erosion, reducing risks associated with pesticides and agricultural chemicals, protecting worker safety, and conserving habitat within the vineyard. The benefits of this free service are that it enables growers to identify areas of management that are weak or need attention, and it can be used as a tool to document implementation of specific management measures in a vineyard. More can be found on the Positive Points System at http://www.vineyardteam.org/pps.html (Central Coast Vineyard Team, 2004).

Data was not available to estimate the degree of N reduction that can be achieved through implementation of CIMIS and the 1,000-point tool for managing vineyard practices. However, the merits of these programs are evident in that they both strive to reduce inputs of water and fertilizer thereby reducing the overall amount of nutrients that are conveyed in run-off and groundwater into open surface waters.

8.25 – Selected load reduction alternatives

Of the alternatives covered for reducing nutrient inputs and/or outputs from WWTPs, septic systems, urban settings, and agricultural operations, those that were considered for modeling and the implementation of a TMDL have available quantified effectiveness and cost estimates available. In addition, the measures considered are those that can be implemented to significantly improve existing conditions in areas where they are not currently in use. Section 10 presents reduction scenarios for the following BMP measures:

WWTPs : Implementation of NDN processes for nutrient removal.

Septic systems : Retrofitting faulty septic systems with Nitrex filters.

Urban setting : Implement a suite of structural BMPs designed to capture urban runoff and effectively filter nutrients, sediments, and pathogens prior to entering the storm drain system.

Agricultural operations :

1) modify fertilizer application to a sustainable rate, which entails a 2% nitrogen solution at five to six applications per year with 25 gallons per application.

2) Custom select a suite of structural BMPs designed to capture agricultural runoff and effectively filter nutrients, sediments, and pathogens prior to entering open surface waters.

9.0 - TMDL DEVELOPMENT

The TMDL development described below presents an estimate of the assimilative or loading capacity of Napa River and its tributaries, and presents an allocation of mass load reductions (kg N/day) in each impaired section of the water body for the sources of concern.

Further growth of a region should be considered in the TMDL development process. Population increase, land use changes, and sometimes even future weather patterns are all factors to be considered during TMDL development. According to information obtained from San Francisco Bay RWQCB, population and land use in the Napa River Watershed are not predicted to change significantly within the TMDL's time horizon. Therefore, variable climate might be the most important factor affecting TMDL development.

All the proposed load reduction scenarios and TDN target levels were applied back to the simulated period and rerun in the models to observe the change in TDN concentration throughout the river. Due to lack of information for predicting future weather patterns, historic measured weather data was used in making assumptions concerning future weather patterns. Here we assume that the weather conditions that have occurred in the past are representative of what will likely occur in the near future. Therefore, model simulations using previous weather data are used to predicate weather patterns that may occur in the near future.

Sources of loads to the Napa River have been determined by the models to be derived from both anthropogenic and natural or background sources. The mechanism of transport from natural and human land uses occurs when mineral nitrogen from the soil transforms into ion solution forms during rainfall. It then gets transported into the river channel with surface runoff, lateral flow and groundwater return flow. Usually high concentrations of TDN can be expected in the river immediately following the first rainstorms after a long period of dry weather. This is because significant amounts of nitrogen are accumulated in and on the land surface from human and nature activities during dry weather and then, given the high solubility of inorganic nitrogen, nitrogen is flushed out of the soil when the first rainstorms. Transient high mineral nitrogen concentrations (>1.0 mg/L) may be observed even in areas where only natural nitrogen sources exist. Our modeling seemed to support this.

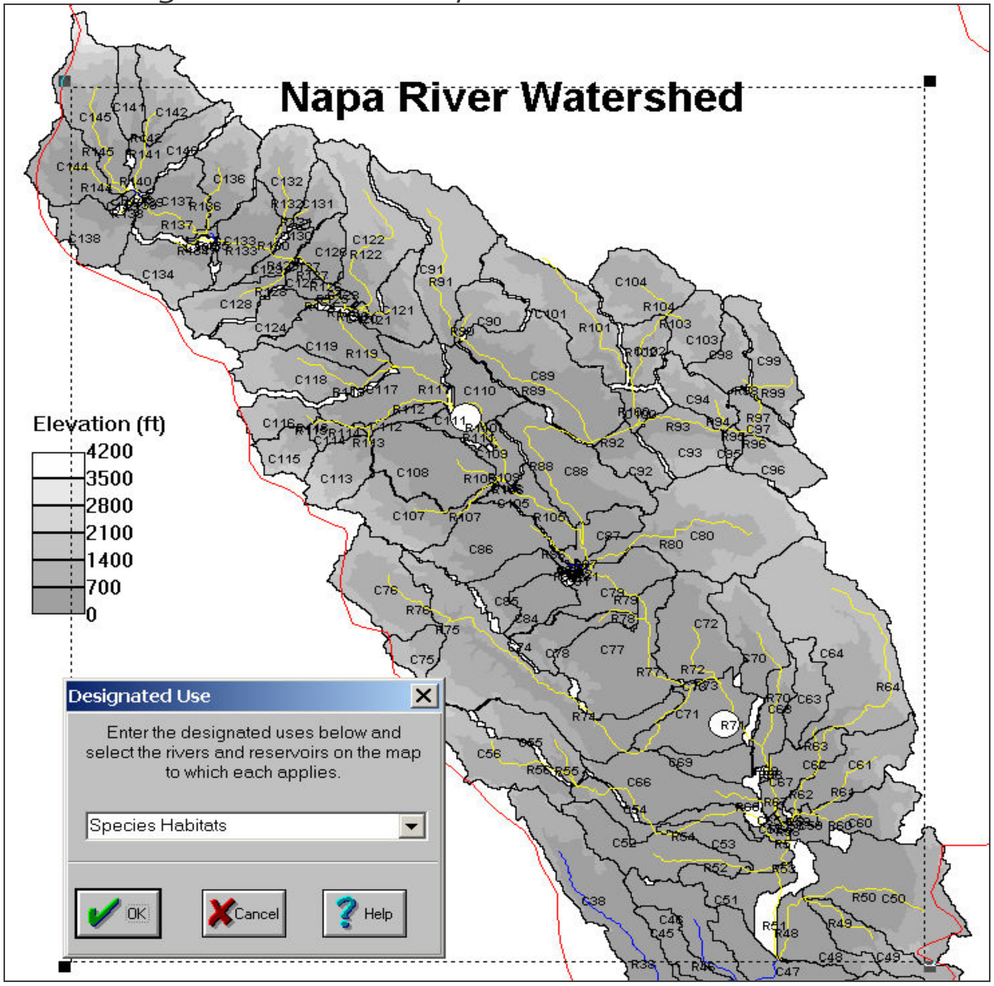
As discussed in the model sensitivity section, background TDN conditions seem to prevent achievement of the dry season water quality goal of 0.2 mg/L TDN. However, there is some uncertainty in our modeling results. First, we were unable to obtain irrigation flow information and thus were unable to make predictions on the effect of irrigation return flow to the TDN level in the river. Irrigation return flow is the major source of flow to the river along with groundwater seepage during the dry season, and thus may be a significant source of nutrient loads during the dry season. Second, according to both model simulations, initial soil nitrate concentrations under agricultural land alone could cause the TDN concentration in the main river channel to exceed the dry season target level of 0.2 mg/L after the simulation period. This result was obtained by setting initial soils concentrations to 1.5 mg/L for agricultural land use and 0.1 mg/L for non-agricultural land. These soil nitrate concentrations contribute to the nitrogen load of groundwater, which cannot easily be prevented from contributing to nitrogen loads in the river. Therefore, the target level of 0.2 mg/L in dry season may be unattainable at this point. Therefore, in this project, we decided not to develop a TDN TMDL for the Napa River Watershed for the dry season. Additional soil nitrate and irrigation return flow studies would be needed to better understand these dry season conditions

Data collection on irrigation management and modeling work on dynamics between initial soil nitrate concentrations and groundwater nutrient content are recommended.

Also, considering TDN at an intermittently high natural background level as described before, the target level of TDN was set to be 1 mg/L for 95% of the time, instead of 100% of the time, for the wet season. Since this TDN level is mostly biostimulatory and related to chronic toxicity, impairments are generated only if levels are high for a long period of time, and not due to daily peaks.

The whole Napa River Watershed was under our consideration for TDML development. The designated use of species habitat was specified and the target level of 1 mg N/l was applied. Figure 9.0a shows the reaches under consideration in yellow and the designated use of them as species habitat.

Figure 9.0b: Designated use of the Napa River

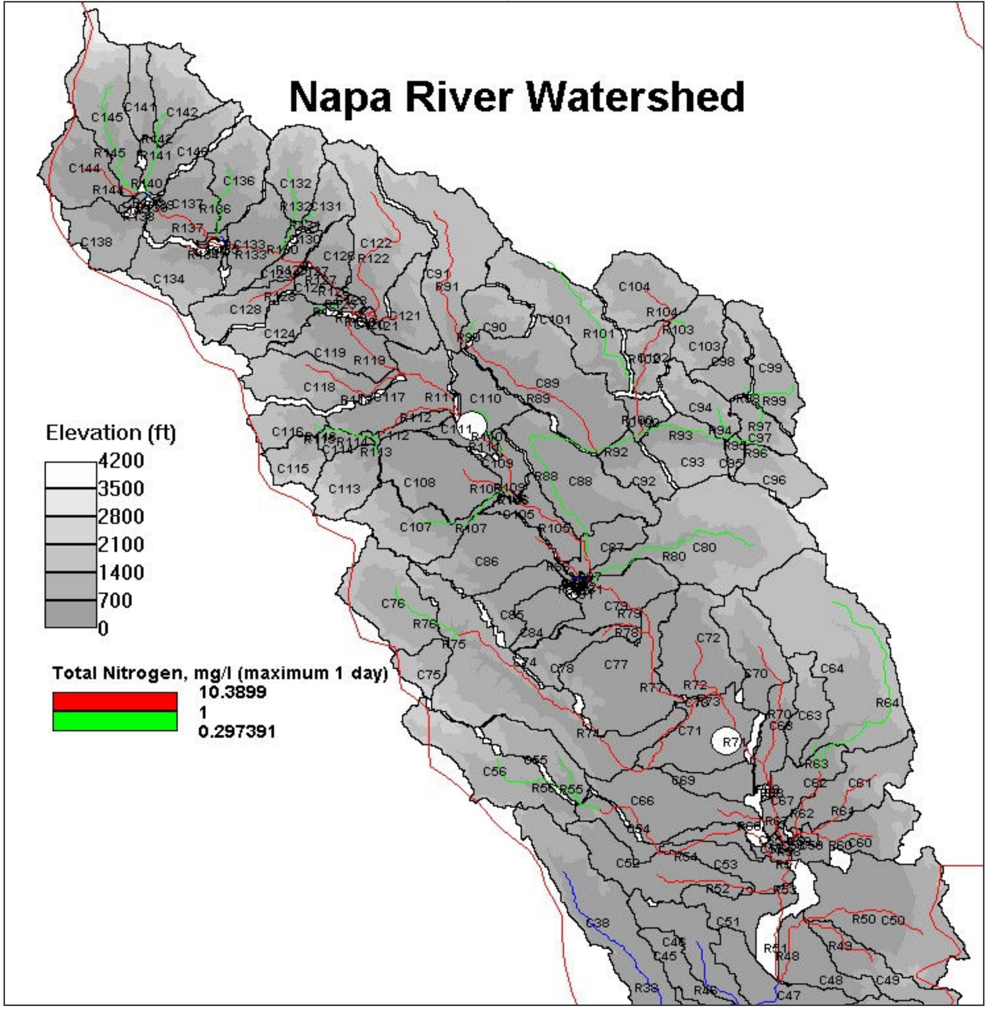


Enter the designated uses below and select the rivers and reservoirs on the map to which each applies.

Species Habitats

9.1 - PROCEDURE TO DEVELOP THE TMDLS

***Figure 9.1a**: Current condition of the Napa River Watershed*



The water quality of NAPA watershed, as simulated by WARMF, under the status quo is presented in Figure 9.1a. Stream segments that exceed the above-mentioned TDN target level appear in red. TMDLs were developed for each impaired river reach. The modeling procedure used for the TMDL development began with the most upstream reach, then moved downstream when the water quality in the upstream reach complied with the objective level. Therefore, all impaired tributaries have priority in TMDL development because the drainage from tributaries significantly affects water quality in the main river channel. Once all impaired tributaries complied with the target, TMDLs for the main river channel were developed from the most upstream to downstream reaches, one by one.

9.2 - TMDL DEVELOPMENT USING WARMF

Since SWAT and WARMF produced similar results in terms of TDN load in the watershed as discussed in the previous section, WARMF and SWAT were run in parallel again to develop TMDLs for each of the impaired river reaches. Again, due to SWAT's inability to present the water quality data spatially, results from WARMF are presented first to demonstrate the process by which the TMDL was developed. SWAT results are presented later for the purpose of comparison.

Table 9.2a and 9.2b present all the potentially impaired tributaries and their TDN sources and percentage contribution from each source under the status quo. See Figure 9.0b for a map of locations of the listed tributaries. This information is helpful in determining which reduction strategy we should use to bring the water quality down to the target level. Usually, excluding background contributions, the most controllable source has the biggest reduction percentage, considering it is the biggest contribution to the loading problem. Table 9.1a and 9.1b below are the simulated current nutrient loads as modeled by WARMF, which were subsequently used to construct TMDLs to reduce these loads in order to meet TDN goal levels.

Table 9.2a: Impaired Tributaries and their TDN Sources (kg N/d)

River Reach	Mixed Forest	Orchard	Coniferous	Shrub / Scrub	Grassland	Pasture	Farm	Residential	Septic System	Grand Total
R0048	0	1	1	0	0	4	0	3	4	14
R0049	0	0	0	0	0	2	0	0	1	3
R0050	0	1	0	0	0	2	0	1	2	8
R0052	0	2	0	0	0	1	0	3	1	7
R0054	0	7	2	0	0	6	0	1	3	18
R0060	0	3	0	0	0	0	0	0	1	5
R0061	0	1	0	0	0	1	0	0	1	3
R0062	2	2	1	1	0	2	0	1	4	13

R0066	0	12	0	0	0	0	0	1	2	15
R0070	0	0	2	0	0	0	0	0	1	3
R0072	0	6	1	0	0	0	0	0	0	7
R0074	0	7	8	0	0	3	0	0	5	23
R0089	0	4	5	0	0	1	0	0	2	12
R0091	0	2	2	0	0	1	0	0	0	5
R0100	0	14	8	1	0	0	0	0	3	26
R0102	0	13	6	0	0	0	0	0	1	20
R0104	0	10	5	0	0	0	0	0	0	16
R0108	0	32	0	0	0	0	0	0	1	34
R0112	0	13	6	0	0	0	0	0	2	21
R0118	0	10	2	0	0	0	0	0	2	15
R0121	0	0	1	0	0	0	0	1	0	2
R0122	0	1	2	0	0	0	0	1	3	6
R0128	0	6	2	0	0	0	0	0	1	9
R0134	0	10	2	0	0	0	0	0	1	14
R0138	0	8	1	0	0	0	0	0	0	10
R0143	0	9	2	0	0	2	0	0	2	15
R0144	0	7	1	0	0	1	0	0	1	10
Total	3	182	59	4	1	26	0	14	43	333

***Table 9.2b**: Impaired Tributaries and Percentage Contribution from Sources*

River Reach	Mixed Forest	Orchard	Coniferous	Shrub / Scrub	Grassland	Pasture	Farm	Residential	Septic System	Grand Total
R0048	0%	9%	8%	3%	3%	31%	0%	19%	28%	100%
R0049	0%	0%	12%	0%	1%	56%	0%	2%	29%	100%
R0050	0%	17%	6%	5%	5%	24%	0%	19%	25%	100%
R0052	0%	24%	4%	0%	1%	17%	0%	41%	12%	100%
R0054	0%	38%	10%	0%	0%	33%	0%	4%	15%	100%
R0060	0%	65%	1%	4%	0%	9%	0%	7%	14%	100%
R0061	0%	38%	1%	8%	0%	27%	0%	8%	18%	100%
R0062	18%	12%	10%	7%	2%	14%	1%	5%	31%	100%
R0066	0%	80%	0%	0%	0%	1%	0%	9%	10%	100%
R0070	0%	1%	55%	0%	0%	13%	0%	6%	26%	100%
R0072	0%	83%	13%	0%	0%	2%	1%	0%	1%	100%
R0074	0%	30%	33%	2%	0%	11%	0%	2%	23%	100%
R0089	0%	34%	42%	0%	0%	8%	0%	1%	15%	100%
R0091	0%	38%	39%	0%	0%	20%	0%	3%	0%	100%
R0100	0%	55%	29%	4%	0%	0%	0%	0%	13%	100%
R0102	0%	67%	29%	2%	0%	0%	0%	0%	3%	100%
R0104	0%	66%	30%	2%	0%	0%	0%	0%	2%	100%

R0108	*0%*	*94%*	*1%*	*0%*	*0%*	*0%*	*0%*	*1%*	*4%*	*100%*
R0112	*0%*	*63%*	*27%*	*0%*	*0%*	*0%*	*0%*	*0%*	*10%*	*100%*
R0118	*0%*	*71%*	*13%*	*0%*	*0%*	*0%*	*0%*	*1%*	*15%*	*100%*
R0121	*0%*	*14%*	*60%*	*0%*	*0%*	*0%*	*0%*	*26%*	*0%*	*100%*
R0122	*0%*	*18%*	*24%*	*0%*	*0%*	*1%*	*0%*	*10%*	*47%*	*100%*
R0128	*0%*	*66%*	*26%*	*0%*	*0%*	*0%*	*0%*	*0%*	*8%*	*100%*
R0134	*0%*	*76%*	*15%*	*0%*	*0%*	*0%*	*0%*	*2%*	*7%*	*100%*
R0138	*0%*	*76%*	*12%*	*0%*	*0%*	*4%*	*0%*	*4%*	*4%*	*100%*
R0143	*3%*	*64%*	*11%*	*1%*	*0%*	*10%*	*0%*	*0%*	*11%*	*100%*
R0144	*0%*	*69%*	*10%*	*0%*	*0%*	*11%*	*0%*	*0%*	*10%*	*100%*

SWAT has no explicit method for modeling BMPs whereas WARMF presents limited options for reducing nutrient loads through BMP implementation. WARMF offers a function to reduce fertilization, the ability to apply buffer zones, and the option to increase street sweeping operations for residential areas. Neither model, though, is able to simulate all BMPs. It should be noted that although buffer zones can be introduced, the plant type grown in these zones is not adjustable. Therefore, calculated nitrogen removal efficiency is mostly based on the width of the buffer zone. This may not be true for actual conditions. In our case, TDN can readily move into the shallow groundwater. In many areas, much of the nitrogen enters the vegetative buffer zone through subsurface flow (Wenger 1999). The ability of the buffer zone to reduce nitrogen concentrations in subsurface flow depends a great deal on the pattern of the subsurface flow and the root depth.

In order to bring impaired tributaries into compliance with our objective level, the models run for impaired tributaries considered a combination of the three BMP options (reducing fertilization, applying buffer zones, and increasing the street sweeping) available in the models. Note that these three operations are those operations that the models can simulate and the combination of these operations was set arbitrarily in order to achieve the desired reductions. These operations were effective in illustrating reduction percentages that may achieve reduction levels – regardless of cost, feasibility, and social acceptance considerations.

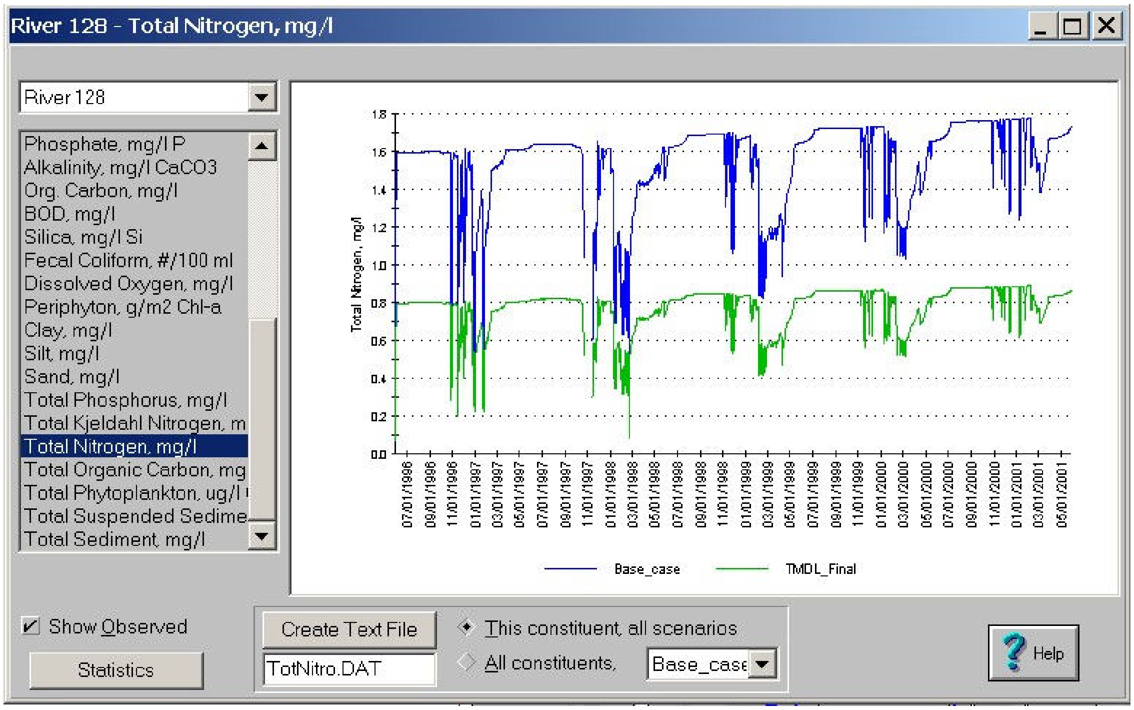
Therefore, permanent load reduction allocations within a specific watershed should consider these factors, as well as site-specific subwatershed conditions.

Table 9.2c: WARMF reduction allocation for each impaired tributary.

River reaches	*Percentage Reduction*	*Load Reduction (kg/d)*
R0048	60%	8
R0049	30%	1
R0050	30%	2
R0052	50%	4
R0054	50%	9
R0060	50%	2
R0061	40%	1
R0062	50%	7
R0066	60%	9
R0070	40%	1
R0072	50%	4
R0074	40%	9
R0089	50%	6
R0091	30%	2
R0100	30%	8
R0102	30%	6
R0104	50%	8
R0108	70%	24
R0112	30%	6
R0118	50%	7
R0121	40%	1
R0122	40%	3
R0128	50%	4
R0134	50%	7
R0138	50%	5
R0143	50%	7
R0144	50%	5

After the TMDLs for tributaries were applied, TDN concentration in all potentially impaired tributaries should be in compliance with the target level. For example, the water quality of Reaches R128 and R144 before and after TMDLs were considered are shown in Figures 9.2a and 9.2b (Refer to Figure 9.0b for the their location).

***Figure 9.2a**: Water Quality of Reach 128 under base case and TMDL case, using WARMF.*


River 128 - Total Nitrogen, mg/l

River 128

Total Nitrogen, mg/l

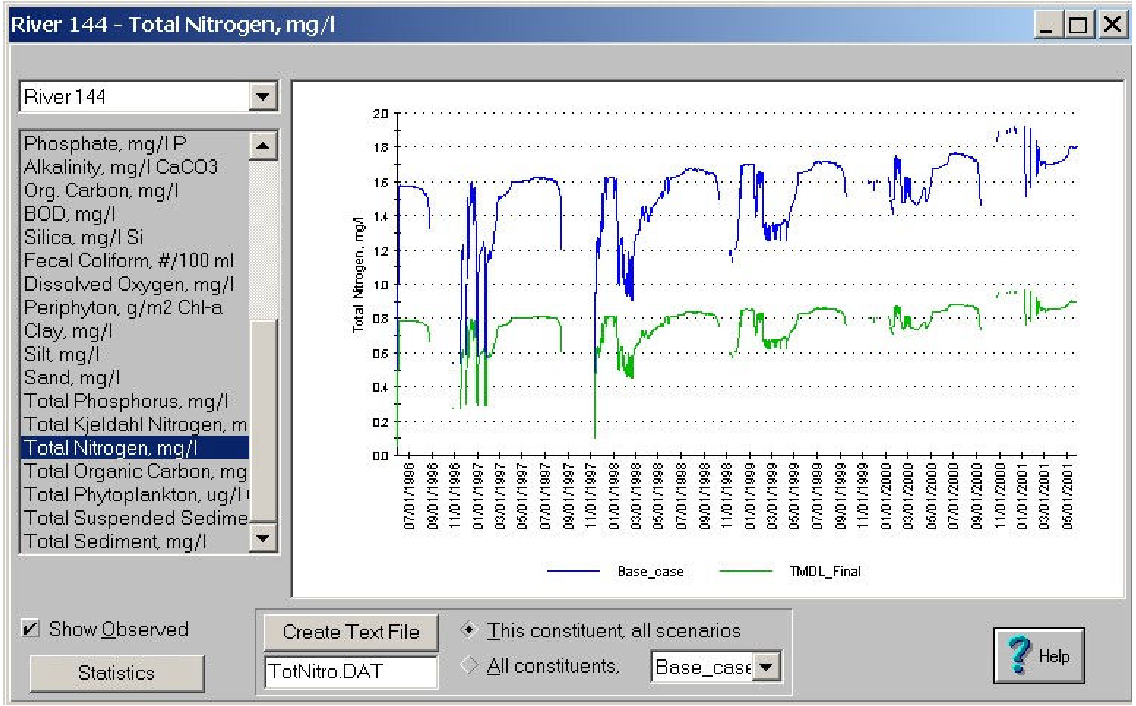
☑ Show Observed

TotNitro.DAT

● This constituent, all scenarios

○ All constituents, Base_case

***Figure 9.2b**: Water Quality of Reach 144 under the base case and TMDL case, using WARMF.*


River 144 - Total Nitrogen, mg/l

River 144

Total Nitrogen, mg/l

☑ Show Observed

TotNitro.DAT

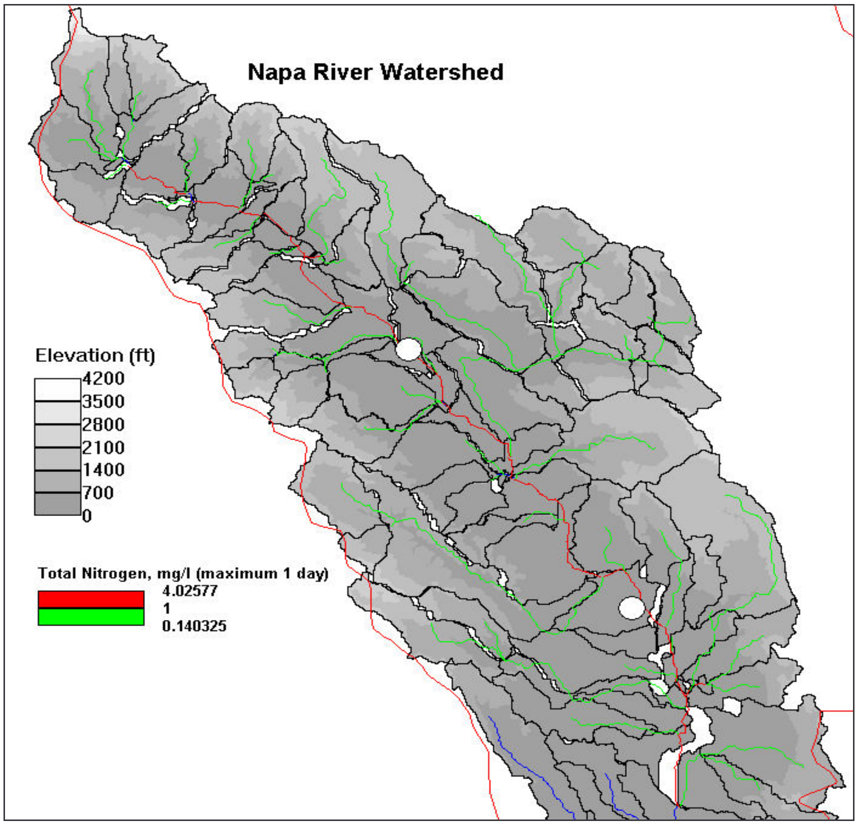
● This constituent, all scenarios

○ All constituents, Base_case

As one can see, the TDN concentrations in both reaches have been brought down to or below the target concentration for the wet season.

Next, TMDLs for reaches of the main river channel were developed. In order to develop loading reductions for each catchment along the main river channel, we first “removed” all point sources in isolate the influence of WWTPs on the water quality of the main river channel. After the removal of all point sources along the main river reaches, water quality was simulated (Figure 9.2c). Since all tributaries are subsequently in compliance with the target level, the impairment of water quality in the main channel was believed to be caused by the TDN load from catchments along the main river channel alone. The nutrient load from these catchments into the rivers appears in Table 9.2d. Therefore, nonpoint TDN load from these catchments needs to be reduced in combination with waste loads from WWTPs.

Figure 9.2c*: Impairment of water quality by TDN load from Catchments along the main channel, without WWTP loads*



Tables 9.2d and 9.2e present the regional TDN load from sources within these catchments under current conditions; including point sources but excluding TDN contribution from upstream.

Table 9.2d Regional TDN Load of Impaired Main River Reaches from their immediate catchment (kg N/d)

River reach	Mixed Forest	Orchard	Coniferous	Shrub / Scrub	Grassland	Pasture	Farm	Residential	Septic System	General Point Sources	Grand Total
R0051	0	1	0	0	0	0	0	3	0	0	5
R0053	0	1	0	0	0	0	0	2	1	125	129
R0057	0	1	0	0	0	0	0	0	0	0	1
R0062	0	2	0	0	0	1	0	1	1	0	4
R0071	0	16	0	0	0	1	0	0	0	0	18
R0077	0	29	1	0	0	1	0	0	1	59	91
R0079	0	8	0	0	0	0	0	0	0	0	8
R0087	0	5	1	0	0	0	0	0	0	0	5
R0105	0	12	0	0	0	0	0	0	0	0	12
R0109	0	5	0	0	0	0	0	0	1	0	6
R0117	0	8	1	0	0	0	0	1	4	29	43
R0119	0	13	1	0	0	1	0	0	2	0	18
R0125	0	4	0	0	0	0	0	0	0	0	5
R0129	0	6	0	0	0	0	0	0	0	0	7
R0133	0	7	1	0	0	0	0	0	1	0	9
R0137	0	7	1	0	0	1	0	1	0	32	41

***Table 9.2e**: Impaired Main River Reaches and Percentage Contribution from Regional Sources*

River reach	Mixed Forest	Orchard	Coniferous	Shrub / Scrub	Grassland	Pasture	Farm	Residential	Septic System	General Point Sources	Grand Total
R0051	0%	16%	1%	0%	0%	9%	0%	68%	7%	0%	100%
R0053	0%	1%	0%	0%	0%	0%	0%	1%	1%	97%	100%
R0057	0%	88%	2%	0%	0%	0%	0%	8%	2%	0%	100%
R0062	1%	43%	0%	2%	0%	13%	3%	19%	19%	0%	100%
R0071	0%	89%	2%	0%	0%	6%	1%	1%	0%	0%	100%
R0077	0%	32%	1%	0%	0%	1%	0%	1%	1%	65%	100%
R0079	0%	95%	3%	0%	0%	0%	0%	0%	2%	0%	100%
R0087	0%	87%	9%	0%	0%	0%	0%	0%	4%	0%	100%
R0105	0%	97%	0%	0%	0%	0%	0%	0%	3%	0%	100%
R0109	0%	80%	1%	0%	0%	0%	0%	0%	19%	0%	100%
R0117	0%	19%	3%	0%	0%	0%	0%	2%	10%	66%	100%
R0119	0%	74%	6%	0%	0%	7%	0%	2%	12%	0%	100%
R0125	0%	97%	3%	0%	0%	0%	0%	0%	0%	0%	100%

River reach	*Mixed Forest*	*Orchard*	*Coniferous*	*Shrub / Scrub*	*Grassland*	*Pasture*	*Farm*	*Residential*	*Septic System*	*General Point Sources*	*Grand Total*
R0129	*0%*	*92%*	*5%*	*0%*	*0%*	*0%*	*0%*	*0%*	*4%*	*0%*	*100%*
R0133	*0%*	*84%*	*9%*	*0%*	*0%*	*0%*	*0%*	*0%*	*7%*	*0%*	*100%*
R0137	*0%*	*17%*	*1%*	*0%*	*0%*	*2%*	*0%*	*2%*	*0%*	*79%*	*100%*

In order to bring the impaired main reaches into compliance, the models were then run to achieve the target level for the impaired main reaches through some combination of the three BMP options (reducing fertilization, applying buffer zones, and increasing the street sweeping). The combination of these operations was set arbitrarily in achieving the desired reductions. Therefore, in allocating the calculated load reduction within a specific watershed, thorough consideration of cost, feasibility and social acceptance, as well as site-specific subwatershed conditions, must be taken into account as well.

Starting at the most upstream, impaired main reach and moving downstream one by one, TMDLs for impaired main river reaches due to loads from immediately adjacent catchments were developed.

Figure 9.2d presents an intermediate step where load reduction has been developed for all main river reaches upstream of Catchment 077, where the Yountville WWTP is situated. All reaches downstream are still above the target level.

Figure 9.2d: *Intermediate step in TMDL development for the Napa River Watershed.*

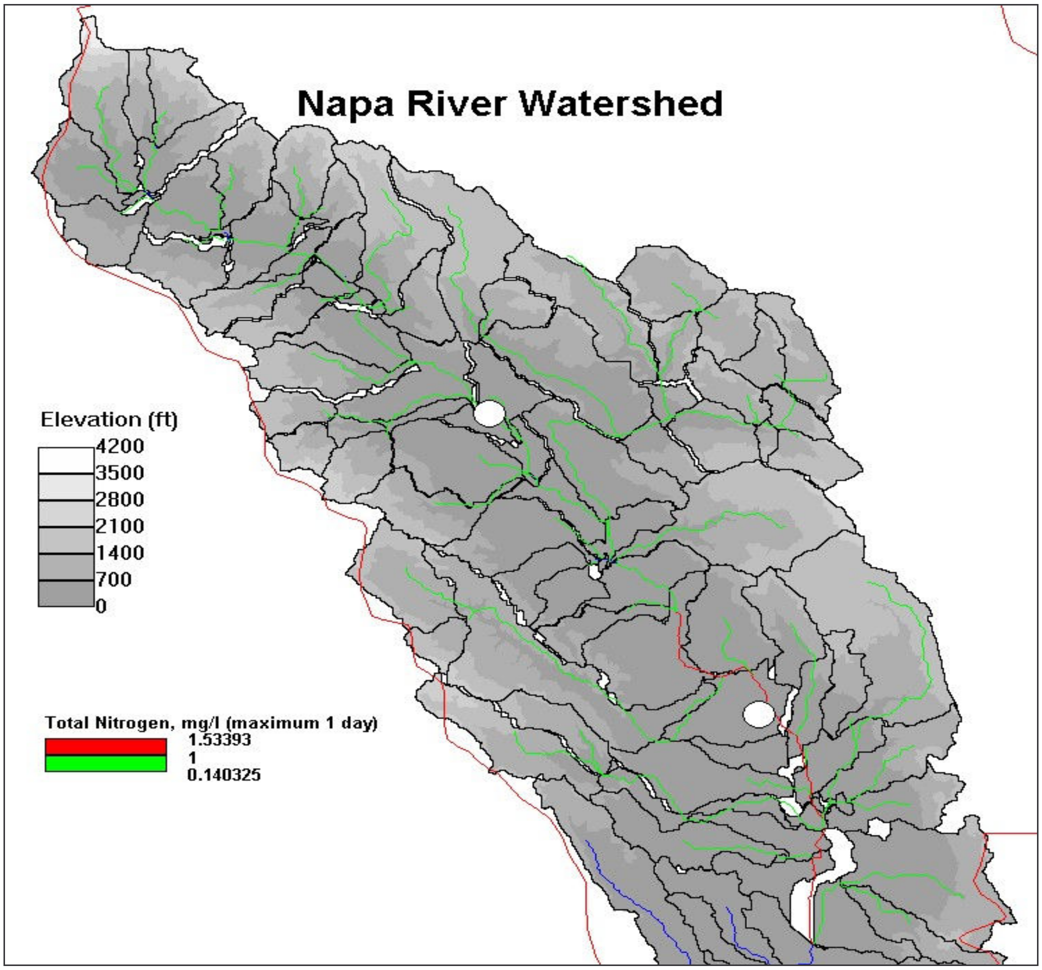


Table 9.2f: *Load Reduction for Main River Catchments, using WARMF.*

River Reaches	*Nonpoint Source Percentage Reduction*	*Point Source Percentage Reduction*	*Load Reduction (kg N/d)*
C0051	*0%*	*0%*	*0*
C0053	*0%*	*70%*	*87*
C0057	*0%*	*0%*	*0*
C0062	*0%*	*0%*	*0*
R0071	*50%*	*0%*	*9*
R0077	*50%*	*65%*	*54*
R0079	*50%*	*0%*	*4*
R0087	*30%*	*0%*	*2*
R0105	*50%*	*0%*	*6*
R0109	*50%*	*0%*	*3*

R0117	*50%*	*50%*	*22*
R0119	*50%*	*0%*	*9*
R0125	*50%*	*0%*	*2*
R0129	*50%*	*0%*	*3*
R0133	*50%*	*0%*	*4*
R0137	*50%*	*88%*	*33*

For the four WWTPs located in the Napa River Watershed, due to their significant contribution of TDN to the main river channel, their load needs to be reduced considerably according to the WARMF simulation. Table 9.2g presents the concentrations of TDN that each WWTP can be allowed to discharge after the TMDLs are applied, assuming no change is made to their current dilution ratios.

***Table 9.2g**: Allowable TDN concentrations and load reduction In the effluent from each WWTPs.*

	Calistoga	St. Helena	Yountville	Napa
Allowable TDN Concentration (mg N/l)	1.1	5.6	7.0	3.0
Load Reduction (kg N/d)	28	14	38	87

As one can see, the allowable TDN concentration in the effluent from both Calistoga and Napa WWTPs need to be quite low. This is the case if both WWTPs continue the dilution ratio of 10:1. Another way to reduce the TDN load from both WWTPs could be to use a higher dilution ratio, which would result in lower in-stream TDN concentrations. In this case, both WWTPs might need to build bigger retention ponds to hold their effluent when the stream flow is not large enough to discharge.

According to the simulation, once all load reductions are applied to the corresponding catchments, the water quality of all the river reaches within the entire Napa River Watershed should be in compliance with the target level. The simulated water quality under this condition is presented in Figure 9.2e and the water quality comparison between the base case and TMDL case are presented in Figure 9.2f through Figure-9.2i.

Figure 9.2e: *Simulated water quality after all TMDLs applied using WARMF.*

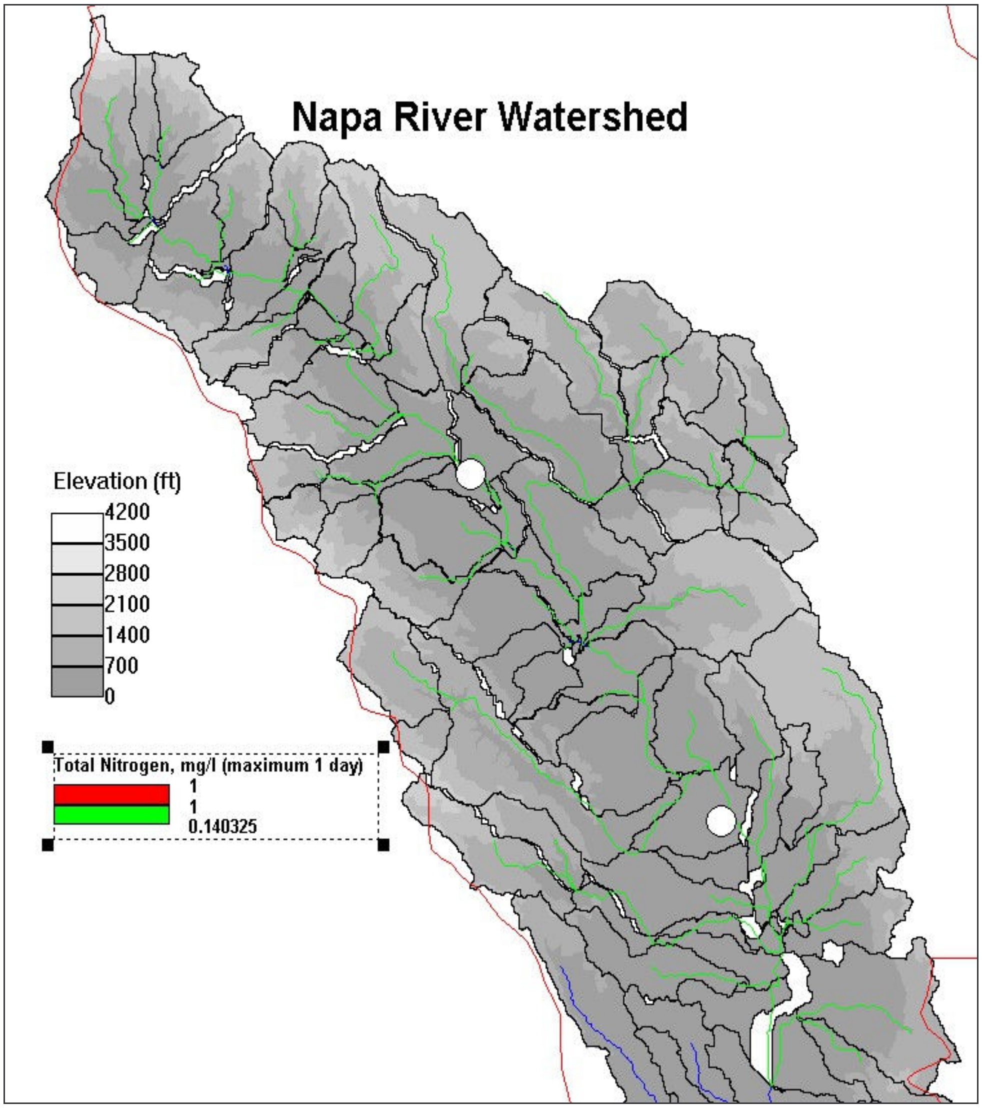


Figure 9.2f: *Water Quality at Calistoga point under base case and TMDL case, using WARMF.*

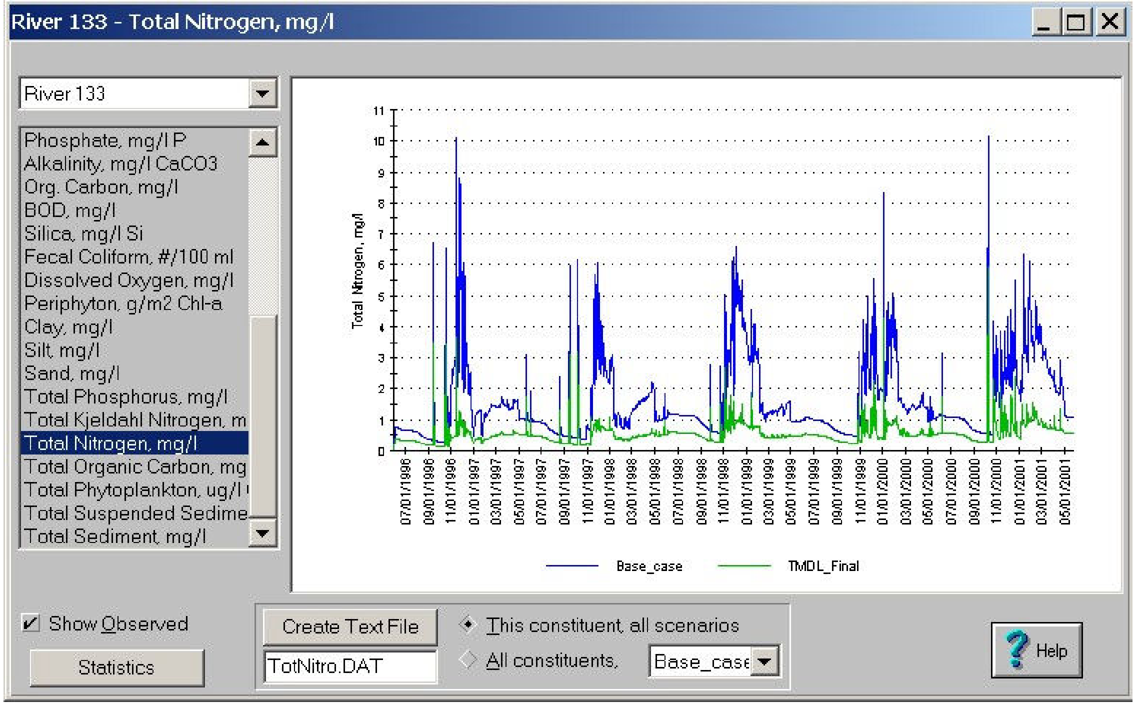


Figure 9.2g: *Water Quality at the St. Helena point under base case and TMDL case, using WARMF*

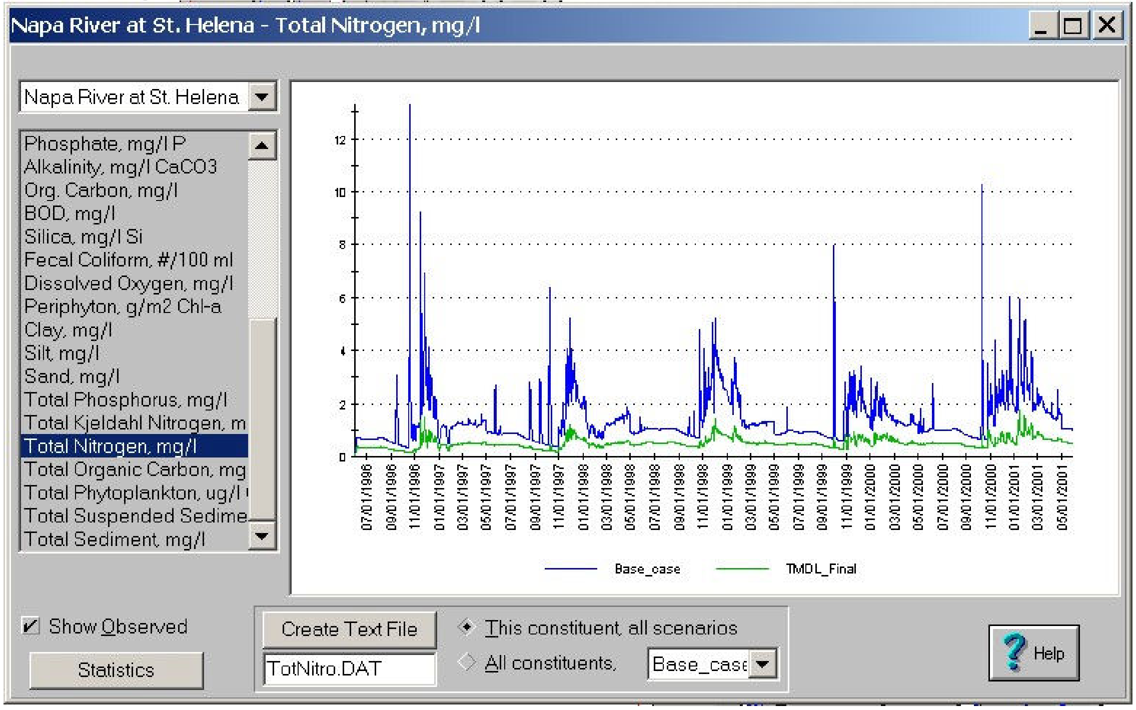


Figure 9.2h: *Water Quality at Yountville point under base case and TMDL case, using WARMF.*

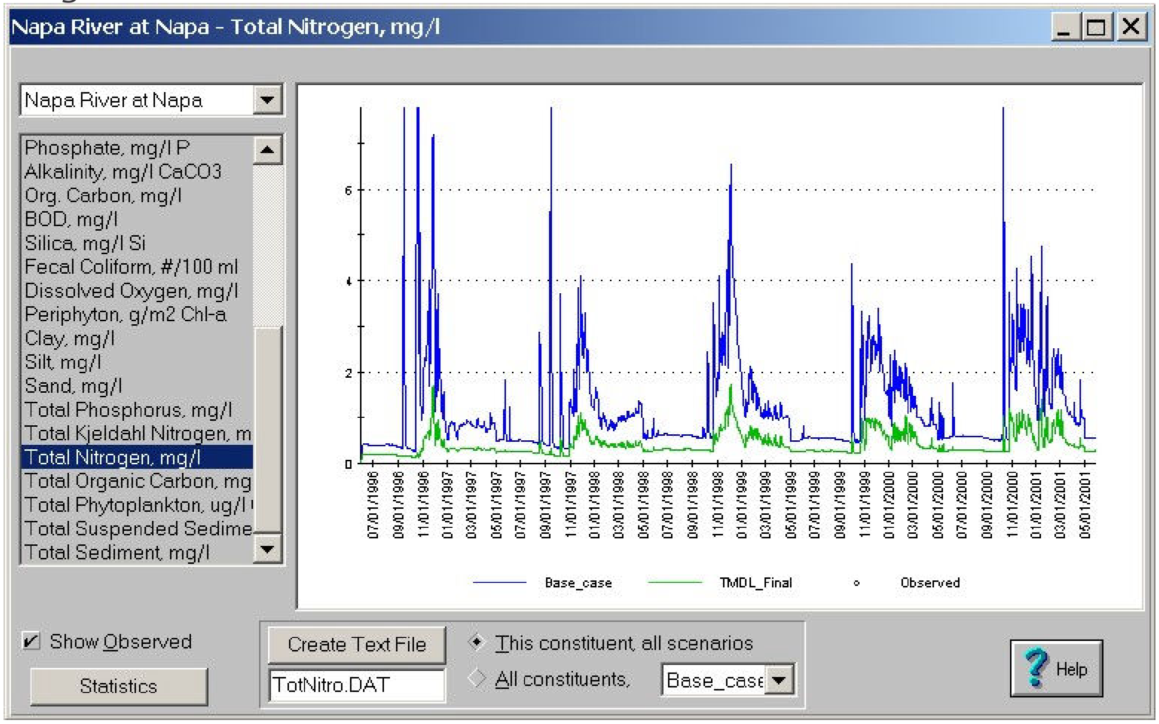
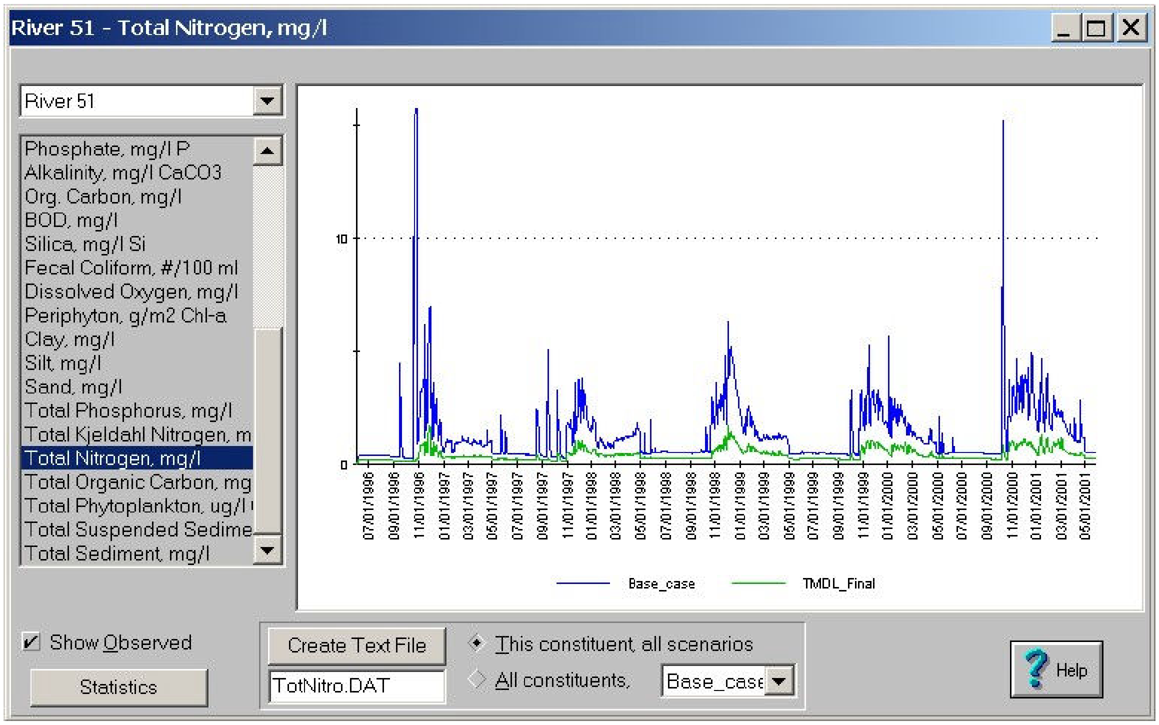


Figure 9.2i: *Water Quality at Napa point under base case and TMDL case, using WARMF.*



9.3 - TMDL Development Using SWAT

Following the same procedure as mentioned before, SWAT was run to develop TMDLs for both impaired tributaries and main reaches. The TDN sources and proposed load reductions are presented below.

Table 9.3a: *Impaired Tributaries and their TDN Sources (kg N/d)*

	Forest-evergreen	Forest-mixed	Forest-deciduous	Range-brush	Range-grasses	Orchard	Pasture	Residential-low density	Commercial	Septic system	Point Sources	Total
R01	2	0	0	0	3	13	0	0	0	1	0	19
R08	4	1	0	0	0	14	0	0	0	0	0	20
R13	3	0	0	0	1	20	0	0	0	1	0	25
R15	1	0	0	1	2	20	0	0	0	0	0	24
R17	0	0	0	0	0	3	0	0	0	0	0	3
R20	10	4	0	0	0	53	0	0	0	2	0	67
R21	0	0	0	0	0	10	8	8	0	2	0	27
R23	0	2	0	3	7	0	16	0	0	2	0	30
R24	0	0	0	2	0	4	25	0	0	2	0	33
R26	0	0	0	0	0	1	0	0	0	0	0	1
R27	3	4	0	0	3	0	0	7	0	2	0	18
R30	1	1	0	1	2	14	0	0	0	2	0	21

Table 9.3b: *Impaired Tributaries and Percentage Contribution from Sources.*

	Forest-evergreen	Forest-mixed	Forest-deciduous	Range-brush	Range-grasses	Orchard	Pasture	Residential-low density	Commercial	Septic system	Point Sources	Total
R01	11%	0%	0%	0%	18%	67%	0%	0%	0%	3%	0%	100%
R08	22%	7%	0%	0%	0%	70%	0%	0%	0%	1%	0%	100%
R13	12%	0%	0%	0%	4%	81%	0%	0%	0%	3%	0%	100%
R15	4%	0%	0%	4%	6%	84%	0%	0%	0%	2%	0%	100%
R17	0%	0%	0%	0%	5%	92%	0%	0%	0%	3%	0%	100%
R20	14%	5%	0%	0%	0%	78%	0%	0%	0%	2%	0%	100%
R21	0%	0%	0%	0%	0%	36%	29%	29%	0%	7%	0%	100%
R23	0%	6%	0%	9%	22%	0%	55%	0%	0%	7%	0%	100%
R24	0%	0%	0%	6%	0%	13%	75%	0%	0%	6%	0%	100%
R26	6%	6%	0%	0%	6%	32%	0%	19%	0%	32%	0%	100%
R27	17%	19%	0%	0%	18%	0%	0%	36%	0%	10%	0%	100%
R30	4%	5%	0%	5%	10%	67%	0%	0%	0%	9%	0%	100%

***Table 9.3c**: Reduction allocation for each impaired tributary.*

River Reaches	*Percentage Reduction*	*Load Reduction (kg N/d)*
R01	*40%*	*8*
R08	*40%*	*8*
R13	*40%*	*10*
R15	*50%*	*12*
R17	*30%*	*1*
R20	*60%*	*40*
R21	*50%*	*13*
R23	*50%*	*15*
R24	*50%*	*16*
R26	*20%*	*0*
R27	*40%*	*7*
R30	*50%*	*10*

***Table 9.3d**: Regional TDN Load of Impaired Main River Reaches from its immediate catchment (kg N/d).*

River Reach	*Forest-evergreen*	*Forest-mixed*	*Forest-deciduous*	*Range-brush*	*Range-grasses*	*Orchard*	*Pasture*	*Residential-low density*	*Commercial*	*Septic system*	*Point Sources*	*Total*
R04	*6*	*0*	*0*	*0*	*3*	*31*	*0*	*0*	*0*	*1*	*32*	*73*
R05	*4*	*0*	*0*	*0*	*1*	*11*	*0*	*0*	*0*	*0*	*0*	*16*
R07	*4*	*0*	*0*	*0*	*1*	*15*	*0*	*0*	*0*	*1*	*0*	*21*
R32	*0*	*0*	*0*	*0*	*1*	*9*	*0*	*0*	*0*	*0*	*28*	*39*
R14	*0*	*0*	*0*	*0*	*0*	*8*	*0*	*0*	*0*	*0*	*0*	*9*
R18	*2*	*0*	*0*	*0*	*0*	*41*	*0*	*0*	*0*	*1*	*0*	*44*
R19	*0*	*0*	*0*	*0*	*3*	*42*	*0*	*0*	*0*	*0*	*59*	*105*
R33	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*2*
R22	*1*	*0*	*1*	*0*	*2*	*16*	*0*	*0*	*0*	*1*	*0*	*21*
R25	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*1*
R28	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*2*	*0*	*0*	*0*	*3*
R29	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*125*	*126*
R31	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*1*

Table 9.3e: Impaired Main River Reaches and Percentage Contribution from Regional Sources.

River Reach	Forest-evergreen	Forest-mixed	Forest-deciduous	Range-brush	Range-grasses	Orchard	Pasture	Residential-low density	Commercial	Septic system	Point Sources	Total
R04	9%	0%	0%	0%	4%	42%	0%	0%	0%	1%	44%	100%
R05	25%	0%	0%	0%	6%	67%	0%	0%	0%	3%	0%	100%
R07	19%	0%	0%	0%	5%	72%	0%	0%	0%	5%	0%	100%
R32	1%	0%	0%	0%	2%	22%	0%	0%	0%	1%	73%	100%
R14	0%	0%	0%	0%	4%	91%	0%	0%	0%	5%	0%	100%
R18	5%	0%	0%	0%	0%	93%	0%	0%	0%	2%	0%	100%
R19	0%	0%	0%	0%	3%	41%	0%	0%	0%	0%	56%	100%
R33	4%	4%	0%	0%	7%	79%	0%	0%	0%	6%	0%	100%
R22	3%	0%	3%	0%	11%	79%	0%	0%	0%	4%	0%	100%
R25	5%	4%	0%	0%	0%	28%	0%	61%	0%	2%	0%	100%
R28	6%	10%	0%	0%	0%	0%	0%	77%	0%	7%	0%	100%
R29	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	99%	100%
R31	5%	7%	0%	0%	12%	0%	0%	67%	0%	9%	0%	100%

Table 9.3f: Load Reduction for Main River subwatersheds.

River Reaches	Nonpoint Source Percentage Reduction	Point Source Percentage Reduction	Total Load Reduction (kg/d)
R04	70%	90%	58
R05	40%	0%	6
R07	40%	0%	8
R32	40%	50%	18
R14	40%	0%	4
R18	80%	0%	35
R19	75%	70%	76
R33	0%	0%	0
R22	60%	0%	13
R25	0%	0%	0
R28	10%	0%	0
R29	0%	75%	94
R31	0%	0%	0

Table 9.3g: Comparison of total load reduction from two models

	WARMF	*SWAT*
Total Load Reduction for the Entire Watershed (kg/d)	*394*	*453*
Total Percentage Reduction	*45%*	*55%*

As one can see, the two models resulted in similar total N load reduction for the Napa River Watershed, with WARMF projecting a 45% reduction in total TDN load and SWAT projecting 55%. Given the limited monitoring data for calibrating the models, this range (45-55%) is very reasonable.

10.0 - PROPOSED LOAD REDUCTION SCENARIOS

10.1 - RECOMMENDED LOAD REDUCTION ALTERNATIVES

Based on the alternative nutrient reduction scenarios presented in Section 8.0, and upon considerations of effectiveness, cost, and the applicability of the various measures presented, several different BMPs are recommended for WWTPs, septic, agriculture, and urban land use settings. Modeling results obtained and discussed previously reveal that substantial reductions may need to be carried out in each of these sources in order to meet the wet season nitrogen objective of 1.0 mg TDN/L. Reaching the dry season goal of 0.2 mg TDN/L was determined to be unattainable by both models, even in the absence of all current anthropogenic point and non-point sources. Further monitoring data should be used to verify soil nitrate concentrations to determine the validity of the un-attainability of the dry season target. Uncertainties in modeling soil denitrification, in modeling nitrogen uptake by riparian vegetation, and in modeling nitrogen uptake by in-stream organisms are also relevant to our results. These and other factors could result in achieving the summer 0.2 mg/L target level assuming no anthropogenic loading.

Point and anthropogenic non-point sources contribute the following in-stream loads to the entire watershed (Table 10.1a). Percentage contributions to the entire watershed were discussed in Sections 7.6 (see Tables 7.61c, 7.61d). Only sources that contributed 1% or more of the TDN load to the entire watershed are presented.

Table 10.1a: Percentage contributions of TDN by land use sectors for the entire watershed, as modeled by SWAT and WARMF

Land use sector	Percentage contribution of TDN for the entire watershed	
	SWAT model	WARMF model
WWTP	28%	28%
Septic	2%	7%
Residential	2%	2%
Orchard	40%	35%
Pasture	6%	4%

The alternatives presented below are limited to those that have measurable reduction percentages and at least rough estimates of cost for comparison purposes. Several of the non-structural BMPs discussed in Section 8 are not considered due to uncertainty in the degree to which they would reduce nutrient loading. However, they are considered important measures in managing pollutants from the source. Presented BMPs are considered cheaper, more direct, and more effective means of protecting water resources from nonpoint sources of pollution than off-site controls.

Translating the load allocations into implementation plans is not covered here. However, an implementation plan was developed that uses load allocations expected to be feasible, cost effective, and designed to achieve water quality targets. This was achieved by developing waste load allocations for point sources, and load allocations for non-point sources, as described in Section 9. The waste load allocations can be established by NPDES permits, and the load allocations are addressed through implementation of BMPs. Implementation of BMPs generally occurs through voluntary and incentive programs, such as government cost-sharing. Nonpoint source load allocations within a TMDL document should show that (1) there is reasonable assurance that nonpoint source controls will be implemented and maintained or (2) nonpoint source reductions are demonstrated through an effective monitoring program (EPA, 1997).

10.11 - WWTP Proposed Waste load reduction scenario

The implementation of the NDN process for nutrient removal is recommended. Where very low effluent nitrogen concentrations (less than 5 mg/L) are desired, a three-stage NDN process (continuous-flow suspended-growth process with alternating aerobic/anoxic/aerobic stages) is recommended. In a comparison of NDN new-plant alternatives performed by Foess et al, the three-stage system was ranked as the most favorable based on its moderate costs, process control flexibility, and ease of operation. This process is suitable for achieving nitrogen effluent quality of 6 mg N/L, and phosphorus effluent quality of 2 mg P/L (Foess et al, 1998).

Total cost of construction of a three-stage system retrofit for each WWTP is projected for a 20-year period of operation and maintenance and was adapted from Table 8.21c. Note that the estimates calculated were based on the unit cost for installing a new-three-stage process plant with a 100,000 gallon per day (gpd) capacity. Included construction costs, annual O & M costs, and uniform annual costs were calculated for a 20-year period with an interest rate of 6 %. The difference between current load and the projected load with a three-stage system was then used to determine the marginal cost per kg of N removed over a 20-year period; this appears in Table 10.1b.

Table 10.1b: Cost to retrofit WWTPs within with a 3-stage system

Treatment plant	Plant capacity [MGD]	Total retrofit cost including 20 years O&M†	Current load [kg N/day]	Projected load with 3-stage [kg N/day]‡	Cost per extra kg N removed over 20 years [$/kg N]
Yountville	2	$49,000,000	59	5	$123
St. Helena	3.2	$79,000,000	29	7	$498
Calistoga	3	$74,000,000	32	7	$403
Napa City	14.7	$360,000,000	125	33	$538
Total	22.9	$562,000,000	245	52	$391*

Notes:
MGD – Million gallons per day.
** - Average value.*
† - Adapted from Foess et al, 1998.
‡ - Based on achievable effluent quality of 6 mg N/L (Foess et al, 1998).

Achieving an effluent level of 6 mg N/L with the three-stage process translates into reductions from current effluent levels from each of the WWTPs, as calculated in Table 10.1b.

10.12 - Septic Tank Proposed Waste load reduction scenario

Retrofitting costs are estimated for the possible 15% failed septic tanks. According to this assumption, approximately 1,413 septic tanks will need to be retrofitted with a Nitrex™ filter at a cost of $2,900 each. The total cost of septic retrofitting is estimated at $4,097,265. Each retrofitted septic tank is expected to last for 5 years and the cost does not include maintenance. Note as well that costs considered here do not include the cost of a septic survey, which would require an extensive survey of existing septic tanks would have to be performed to identify faulty septic tanks. Daily nitrogen load from each septic tank can be calculated by multiplying the nitrogen concentration in effluent with the product of the effluent amount each person contributes per day and the number of people served by the septic tank. To be conservative, we assumed that all of this portion of nitrogen load would have directly formed the nitrogen load in the river. Therefore, the nitrogen load reduction by retrofitting can be calculated by multiplying this load with the nitrogen removal efficiency of the Nitrex™ filter. Therefore, the total nitrogen load reduction over the working period of the filter is calculated as follows:

$$\frac{42.5 \times 50 \times 3.79 \times 4}{10^6} \times 0.97 \times 1413 \times 365 \times 5 = 80581\,(\mathrm{Kg\ N})$$

The estimates of parameters values used were obtained from section 7.3 and section 8.22. The cost per unit nitrogen reduction was calculated to be $51/Kg N reduction.

Additionally, an annual inspection program should be developed in order to check the functional failure and provide periodic maintenance of all the existing septic tanks in the watershed. Also, septic tank maintenance information should be spread through an education campaign.

10.13 – Agricultural Proposed Load Reduction Scenarios

Orchards and pastures currently contribute an average between the two models of approximately 38% and 5% of the TDN load to the Napa River watershed as a whole (Table 10.1a). Proposed recommendations for reducing agricultural loads are:

(1) Modify fertilizer use to a lower sustainable rate that supposedly does not affect crop yield;

(2) Implement a suite of structural BMPs designed to filter run-off passing over agricultural property reducing the concentration of nutrients in waters that would eventually assimilate with inland surface waters.

Agricultural BMPs Option 1: Modify fertilizer application to a sustainable rate

Fertilizer application rates were initially modeled at a rate of 84-kg/hectare year (34 lbs/acre year). A modified application rate of 42-kg/hectare year was derived as a potential best management practice. This modified application rate is based upon proven drip irrigation practices for vineyards performed by AgroTech Supply of Geyserville, California, and is adapted from the nitrogen content portion of the nutrient solution used; a 2-10-15 solution of nitrogen, phosphorus, and potassium (McCarthy, 2000). More details of this measure are discussed in Section 8.24. Assuming that this modified application rate does not affect crop productivity, this reduction would presumably cut costs in half as well. Table 10.13 is an estimate of the total costs spent per year in the Napa River watershed on fertilizer, using calcium nitrate at a cost of $1.15 per kilogram ($2.50 per pound). Note that only sub-watersheds where agricultural land use comprises greater than 10% of the sub-watershed were considered in this estimate.

Table 10.13a: Fertilizer application modifications and cost savings

Hectares of subwatersheds with agriculture	Total hectares of agriculture within those subwatersheds	Estimated fertilizer costs [$/year]	Possible cost savings [$/yr]	Cost per kg N removed [$/kg N]
47,353	17,819	1,400,000	700,000	-$10

Reducing fertilizer application rates by half across all agricultural land uses as modeled by WARMF, has the effect of reducing the total agriculturally derived TDN loads by approximately 44%. On a cost per unit reduction of nitrate scale, implementing this BMP can result in a cost savings of approximately $10 for each kg N reduced in-stream.

Agricultural BMPs Option 2: Custom selected structural stormwater treatment practices

The structural agricultural runoff BMPs we recommend are based on nutrient reduction percentages and costs derived from urban structural stormwater BMPs (Tables 8.23d and 8.23e).

A hypothetical scenario was developed for the agricultural land use sector (orchards and pastures) in an attempt to gauge the costs per unit reduction of N throughout the Napa River Watershed for each structural BMP. The total costs of implementing each structural BMP separately for all agricultural land uses throughout the Napa River Watershed, and costs of design, construction, capital, land, and the first five years of maintenance were all lumped into a total cost for each structural BMP. In addition, cost breakdowns of total cost per kg of N removed throughout the watershed for the five years were determined. These cost estimates are presented in Table 10.13c. The sub-watersheds evaluated are listed below in Table 10.13b.

Table 10.13b: SWAT agricultural sub-watersheds considered for BMP *implementation*

Sub-watershed	Sub-watershed area [hectares]	Agricultural area [hectares]	Percentage of agricultural land use	Impervious area* [hectares]
1	2120	378	18	7
4	4624	1,142	25	22
5	2023	325	16	6
7	2408	590	25	11
8	2288	391	17	7
13	2300	786	34	15
14	784	658	84	12
15	2550	1,279	50	24
17	227	175	77	3
18	3118	2,179	70	41
19	3422	2,462	72	47
20	6231	1,551	25	29
21	1929	1,222	63	23
22	2040	749	37	14
23	4969	916	18	17
24	2217	1,543	70	29
30	2567	745	29	14
32	1136	589	52	11
Total	46,954	17,680	43†	336

Notes:
Areas as modeled by SWAT. Note that sub-watersheds considered meet the following criteria: contribute to In-stream loading; are present in sub-watersheds that have proposed load reductions; and have greater than 10% agricultural land use.
** - based on a fraction of total impervious area for agricultural land of 1.9% (Capiella and Brown, 2001).*
† - Average percent agricultural land use of target sub-watersheds.
To convert from hectares to acres, multiply the number of hectares by 2.47.

The total costs of these BMPs are based on BMP cost, land requirements, and maintenance cost estimates from Table 8.23e, using a price of land estimate of $75,000 per acre. To create a 2004 estimate, the inflation rate is assumed to be 10% from 1999 to 2004. Other assumptions include an impervious area estimation of 1.9 % agricultural land (Cappiella and Brown, 2001), and maintenance costs for the first 5 years of each BMP. Reduction percentages used are from Table 8.23d. In addition, this analysis only considered orchard and pastureland uses that comprised at least 10% of the area of a sub-watershed. Although the cost formulas were taken from estimates intended for use in an urban setting, no adjustments were made to these figures other than those previously mentioned, even though reduction percentages and costs may be different for implementing these BMPs in an agricultural setting. Given the availability of farm equipment to build and maintain these BMPs, it is likely costs will be lower than in an urban setting.

To illustrate, an example is presented in Table 10.13c on how to calculate total costs for implementing one individual structural BMP for all agricultural land use areas throughout the Napa River Watershed. The cost estimate for implementing ponds to capture all run-off coming off all agricultural land in the target sub-watersheds, for instance, is based upon a 1999 cost estimate formula that is intended for 50-acre residential sites with 35% impervious cover (Table 8.23e). The general formula to estimate the total cost of implementing ponds is as follows:

***Table 10.13c**: Calculation of agricultural pond total cost*

Project cost per unit area (C_a)	$100,000 / 20.2 hectare site
Land use area (L_a)	17,680 hectares of agricultural land
Cost of capital factor (C_c)	30% of construction cost
Maintenance factor (M)	4.5% for 5 years = 22.5%
Inflation factor (i)	10% for 1999 to 2004
Rainfall zone factor (R)	1/1.24 for southwest U.S.
Land use fraction (L_c)	2.5% of impervious area
Impervious fraction (I)	1.9% for agricultural land
Cost of land (C_l)	$185,000/hectare
Total BMP cost $(1+(C_c+M+i))*R*C_a*L_a + L_c*L_a*I*C_l$	$120,000,000

Total BMP costs for the other structural BMPs reviewed here are presented below in Table 10.13d, along with the cost per kg N removed over the five years of operation estimated. The costs per kilogram N removed for each BMP not only take into account the previously mentioned costs of capital, land, maintenance, design, and rainfall zone, but are also calculated considering the SWAT modeled source loads of N originating from agricultural land and deriving a cost estimate based on each BMP's reduction capability. For instance, the sum of agricultural loads across the watershed was modeled by SWAT to result in an in-stream loading of 373 kg N/day. The cost per kg N removed considers 5 years of in-stream loading originating from agricultural land (approximately 700,000 kg N) With the removal capability of ponds from Table 8.23e (43%), approximately 300,000 kg N can be removed. The total cost for this period ($120,000,000) divided by the total N removed produces a cost per kilogram N removed estimate of approximately $400.

Table 10.13d: Costs of implementing individual structural BMPs to capture all runoff from agricultural land in the Napa River Watershed, along with unit costs for reduction.

BMP type	Total BMP land requirements [hectares]	Total cost of implementing BMPs	Cost per kg N removed over 5-year period [$/kg N]
Ponds	8	$120,000,000	$396
Wetland	13	$140,000,000	$308
Infiltration trench	8	$780,000,000	$1,390
Infiltration basin	8	$180,000,000	$315
Sand filter	5	$740,000,000	NA*
Bioretention	17	$720,000,000	NA
Grass swale	5	$51,000,000	$243
Filter Strip	336	$155,000,000	NA

Notes:
NA – Results not available.
** - Results available, however, sand filters can have a negative nitrate reduction potential.*

Table 10.13d indicates that the three most cost effective BMPs for reducing nutrients on agricultural land in the Napa River watershed are grass swales, wetlands, and infiltration basins, respectively. Grass swales can be an effective BMP, and can also be implemented as pretreatment to another BMP to increase the overall pollutant removal capacity.

In general, within the agricultural sector, reductions in fertilizer application should not require any costs, in fact, cost savings are expected from lower purchasing requirements. The reductions proposed for a modified fertilizer rate are not intended to cause a lower productivity or yield, however, while this method has been proven in neighboring Sonoma County, results have not been reported for Napa County. Reductions in fertilizer application can achieve a 44% decrease of agricultures loads. Beyond that, structural BMPs such as grass swales, wetlands, and infiltration basins are a cost-effective means to further reduce loads in comparison to some of the other BMPs examined.

10.14 Proposed Urban Load Reduction Scenarios

Urban BMPs Option: Custom selected structural stormwater treatment practices

This option implements a suite of structural BMPs designed to capture urban runoff and effectively reduce nutrients, sediments, and pathogens prior to entering the storm drain system. The structural BMPs would be implemented separately in sub-watersheds where the urban land use sector comprises more than 10% of the area of a sub-watershed.

Each of the structural BMPs presented in Table 8.23d were implemented in the models and subsequently evaluated with respect to effectiveness and costs. Effectiveness of the structural stormwater BMP is based on its nutrient reducing capacity, with secondary considerations made to sediment and pathogen reducing capacity. Costs are based on Tables 8.23e.

Like the agricultural results section above, a hypothetical situation was evaluated that consisted of using each structural BMP separately to reduce all run-off passing over urban land uses. The sub-watersheds evaluated are listed in Table 10.13c. Note that this evaluation was carried out only on SWAT modeled sub-watersheds where the urban sector contributed to in-stream loading, where the sub-watersheds have proposed load reductions per Section 9; and where the urban fraction of land within a sub-watershed exceed 10%. In addition, only low-density urban land uses consisted of more than 10% in any of the sub-watersheds. Thus commercial, medium, and high-density urban land uses are not explicitly considered in this assessment. Therefore, urban land here refers to low-density urban.

10.13d: SWAT urban sub-watersheds considered for BMP implementation.

Sub-watershed	Sub-watershed area [hectares]	Urban area [hectares]	Percentage of urban land use	Impervious area* [hectares]	Impervious fraction of sub-watershed [%]
21	1,929	707	37	85	4
27	4,237	610	14	73	2
29	131	51	39	6	5
Total	6,297	1,368	22	164	3

Notes:
Areas as modeled by SWAT. Note that sub-watersheds considered meet the following criteria: contribute to in-stream loading; are present in sub-watersheds that have proposed load reductions; and have greater than 10% urban land use.
** - based on a fraction of total impervious area for low density residential land of 12%.*
† - Average percent urban land use of target sub-watersheds.
To convert from hectares to acres, multiply the number of hectares by 2.47.

Total costs of implementation were estimated for a structural BMP. For instance, an infiltration trench would be constructed throughout every sub-watershed meeting the 10% area requirement. These estimates attempted to capture costs associated with design, construction, land requirement, the first five years of maintenance, and were adjusted with a 3% inflation rate to reflect a 2004 estimate. Price of land used was the same as for agricultural land use; $185,000 per hectare ($75,000 per acre). Based on typical costs of BMPs (Table 8.23e), estimates of the costs of implementing a certain BMP throughout all urban areas was assessed. These estimates were then converted to a cost for each percentage of nutrient reduction (cost per reduction percent), which are presented in Table 9.13d.

Table 10.13e: Urban structural BMP costs and unit costs for reduction.

BMP type	Total BMP hectares required	Cost of implementing BMPs	Cost per kg N removed over 5-year period [$/kg N]
Ponds	5	$9,600,000	$766
Wetland	8	$12,000,000	$606
Infiltration trench	5	$61,000,000	$2,534
Infiltration basin	5	$14,000,000	$595
Sand filter	3	$58,000,000	NA*
Bioretention	10	$57,000,000	NA
Grass swale	3	$7,800,000	$862
Filter Strip	207	$40, 000,000	NA
Porous pavement	NA	$226, 000,000†	NA

Notes:
NA – Results not available.
** - Results available, however, sand filters have a negative nitrate reduction potential.*
† - Results do not include the cost of land.

Table 10.13e indicates that the three most cost-effective BMPs for an urban setting in the Napa River watershed are infiltration basins, wetlands, and ponds, respectively. In addition, these BMPs do not have large land requirements and costs per acre in comparison to some of the other structural BMPs listed. BMP costs estimated for the urban land use sector differ from the agricultural land use sector based on the total hectares of land implemented with BMPs and amounts of nutrients that enter and are effectively filtered by each BMP. Overall, due to the relatively low loading contribution of the urban sector, the implementation of BMPs in this setting was not found to be cost effective in comparison to BMPs for other sectors. Therefore, no load reductions to current levels are recommended for the urban sector.

10.2 - LOAD REDUCTION ALTERNATIVES RECOMMENDED

The load reduction measures recommended here are based on the efficiency of a BMP to prevent pollutants from entering the river and the total cost of implementation. The recommendations rely on the calculations and assumptions used to estimate nutrient loads, pollutant removal ability and costs of each option. This process was used to derive the cost-effectiveness of each option as applied to the Napa River watershed. The reduction measures presented in Table 10.2a have the best cost-effectiveness of the alternatives considered, and are presented as allocations that will achieve the target levels. Loading by each point or non-point source is as modeled by WARMF.

Table 10.2a: Percentage anthropogenic contributions and reductions of TDN of sources of N for the entire watershed, as modeled by WARMF

Land use sector	Loading to impaired sub-watersheds [kg N/day]	Average contribution of TDN for the entire watershed (%)	BMP	Cost per kg N removed [$/kg N]	Reduction of TDN throughout the entire watershed [kg N/day]
<u>WWTPs</u>			Retrofit with 3-stage NDN process		
Napa	125	14%		$538	87
Yountville	59	7%		$123	38
St. Helena	28	3%		$498	14
Calistoga	32	4%		$403	28
Septic	62	7%	Nitrex^{TM} filter retrofit	$51	8
Residential†	18	2%	Infiltration basin	$595	0
			Wetlands	$606	0
			Ponds	$766	0
Agriculture†‡	427	49%	Fertilizer reduction	-$10	188
			Grass swales	$243	31
			Wetlands	$308	0
			Infiltration basins	$315	0
TOTAL	603	86%		$75,797	394

Notes:
** - Costs here represent the total cost over a 20-year period.*
† - Costs here represent the total cost of the BMP over a 5-year period
‡ - Represents both orchards and pastures.
NA – Estimates not available.
$ - Does not include the cost of maintenance or a septic survey to identify faulty tanks.

The percentage reductions allocated to each land use and BMP measure were assigned using the available source loads from each source. Once an option was fully implemented, the second most cost effective measure was implemented to its reduction capability. The one exception is WWTPs, which relied on a reduction allocation that was predetermined by the WARMF model. Once loads were allocated to WWTPs according to WARMF recommendations, load allocations were assigned to each BMP based on cost-effectiveness. The priority order is as follows: Nitrex^{TM} filter retrofit for faulty septic systems; fertilizer reduction, grass swales, and wetlands for the agricultural land use sector. The remaining load to be allocated was assigned to the agricultural sector using infiltration basins. The combined load reductions from these measures totals 394 kg N/day, which would achieve N concentrations below the wet season target of 1.0 mg N/L. Anthropogenic sources currently account for approximately 86% of the N loads to the Napa River. Implementing the above recommended BMPs to achieve the wet season target would call for a 65% reduction in anthropogenic loads, such that the anthropogenic loads would subsequently account for 45% of total load contributions to the Napa River.

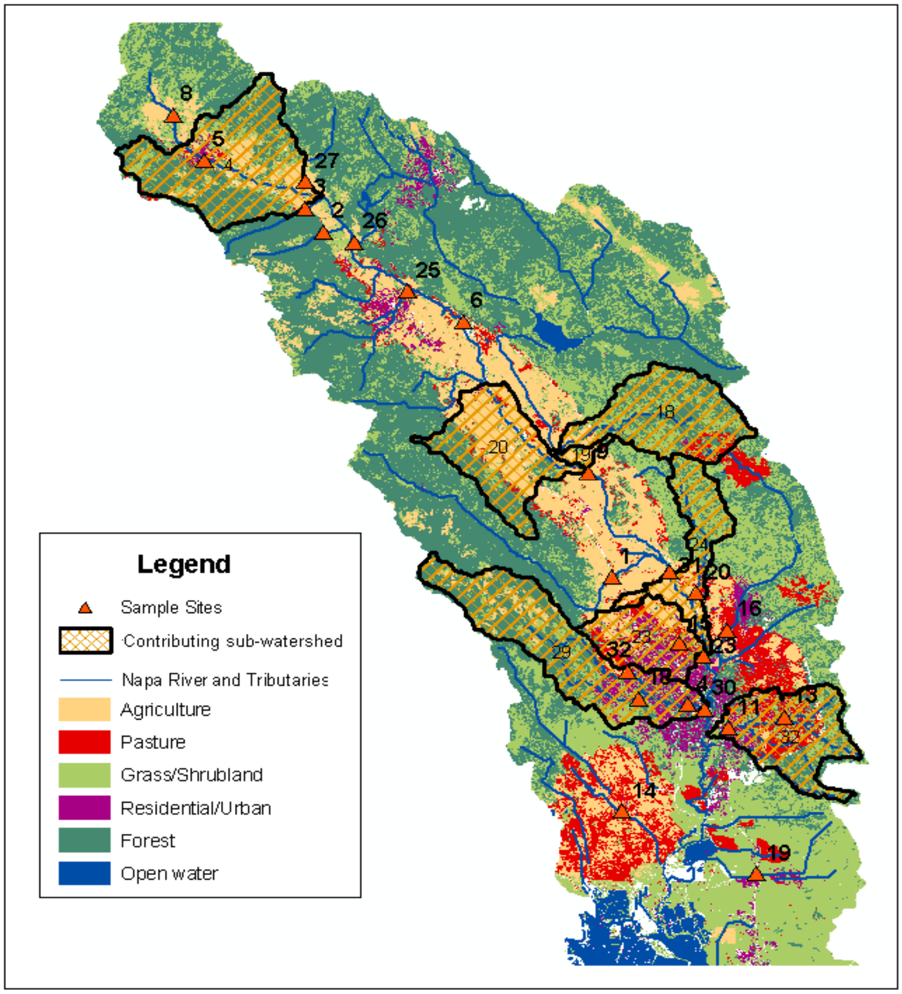
In addition or alternative to the retrofits recommended for the Napa and Calistoga WWTPs, another possible strategy for nutrient load reduction may be to increase the dilution rate of effluent from 10:1 to 50:1. An increase in the dilution rate to 50:1 may require larger retention ponds in order to hold effluent in cases where a low stream flow precludes discharge. The costs for this measure were not determined, however, implementing a 50:1 dilution rate would produce similar results to retrofitting these plants with a 3-stage NDN process.

11.0 - BMP MONITORING PLAN FOR NUTRIENT MANAGEMENT

A monitoring plan was not designed in this study. However, a brief description of the target areas for monitoring is presented.

The major purpose of effluent monitoring for the Napa River Watershed is to test for compliance with the target level of total dissolved nitrogen (TDN). Effluent monitoring will help to establish accurate mass loads of various pollutant sources at certain locations along the river. The monitoring plan should focus on the sub-watersheds (Fig 11.1a) that are hotspots causing excessive nutrient loading.

Figure 11.1b: *Contributing sub-watersheds for nutrient loading*



In order to do so, sampling stations should be installed along these hot spots where the tributaries are entering the main river stream. Comparison of effluent monitoring results to target levels may require weekly or monthly calculations based on the stream condition rather than in the previous time frame intervals in order to efficiently evaluate the management plan, and to see which duration of the year is most significant in terms of TDN loading.

12.0 – SUMMARY AND CONCLUSIONS

The Napa River Watershed has been listed as impaired by sediment, pathogen, and nutrient loading. This project has focused on the impairment of the Napa River from nutrient loading, mainly nitrate and ammonia. These nutrients may cause eutrophication. Eutrophication can damage the habitat for aquatic life, including the endangered Chinook salmon and Steelhead trout, and the aesthetic quality for recreational use of the river. Consequently, a TMDL reduction plan is currently underway. The TMDL reduction plan for sediment has reached completion, due to the high priority listing of sediment. This project has developed a nutrient reduction management plan designed to aid in the development of the Napa River Watershed nutrient TMDL by the San Francisco Bay RWQCB.

The project aimed to develop recommendations for nutrient load reductions, based on the scientific results of field studies and computer modeling, as well as on the economic implications for stakeholders. The extent of nutrient impairment was examined through an analysis of water samples. The San Francisco Bay RWQCB took water samples at 23 sites throughout Napa River and its tributaries in January 2003 and June 2003 to monitor total dissolved nitrogen (TDN). At all sites along the river, except the northernmost, the concentration of TDN exceeded target levels of 1.0 mg N/L in the wet season and of 0.2 mg N/L in the dry season. In this project, two watershed models, SWAT and WARMF, were calibrated against measured hydrological and nutrient data and were then run in parallel to calculate TMDLs for each of the impaired river segments. Based on computer modeling results for the time span of 1996-2001, the models produced similar results of total TDN loading in the Napa River Watershed, with SWAT producing 830 kg N/day and WARMF producing 873 Kg N/day. The modeling results also indicated that the dry season target level may not be attainable, even in the absence of anthropogenic nonpoint sources, due to the current concentration of nitrate in soils under agricultural land near the tributaries and main stem. Based on the simulation results, significant exceedance of TDN target levels exists under the status quo, and in order to reach the wet season target level, a substantial reduction of TDN loading would be required.

The models were run to achieve the target level for impaired river segments through some combination of the models' options. The modeling procedure used for the TMDL development began with the most upstream reach, then moved downstream when the water quality in the upstream reach complied with the target level. Therefore, all impaired tributaries have priority in TMDL development because the drainage from tributaries significantly affects water quality in the main river channel. Once all impaired tributaries complied with the target, TMDLs for the main river channel were developed from the most upstream to downstream reaches, one by one. Point-source load reductions were considered along with nonpoint-source load reductions in developing the TMDLs. The calculated total TDN load reduction for the Napa River Watershed was 395 kg N/day as simulated by WARMF and 453 kg N/day as simulated SWAT.

The project explored various strategies for reducing the loads of point and non-point sources of TDN. The strategies are based on an extensive literature review of TMDL reports, scientific journals, and guidance documents. Reduction of pollutant loads is primarily achieved by waste load reductions of point sources through NPDES permits, which specify discharge limits, and, of non-point sources through BMPs. For BMP's, voluntary and incentive programs may be needed. In a TMDL reduction plan for nutrients, non-point source allocations should indicate a reasonable assurance that controls will be implemented and maintained, and non-point source reductions will occur through monitoring programs.

In order to develop a nutrient reduction management plan, we explored a number of alternatives designed to provide a cost-effective means to reduce excess nutrients. The scenarios provided various options, considering possible point and non-point sources of TDN. Point sources of concern included wastewater treatment plants, and non-point sources of concern included faulty septic systems, fertilizer run-off from agricultural land-uses, and run-off from urban land uses. For wastewater treatment plants, biological nutrient removal processes may be implemented, reducing the concentration of nitrogen to 6 mg/L or less in effluent by utilizing a nitrification-denitrification system. For faulty septic tanks, we recommend retrofitting faulty tanks with Nitrex filters. After identification and modification of these tanks, annual inspection should occur to monitor their condition and maintenance. Information related to septic tank maintenance should also be provided through educational measures. As for agricultural load reductions, fertilizer application may be reduced so that it reaches a sustainable rate. In addition, structural stormwater BMPs may be implemented for the agricultural land use sector in order to filter runoff and to thereby reduce the nutrient concentration. Based on our analysis, grass swales and wetlands would be the most cost-effective agricultural BMPs. For urban runoff, management measures were not found to be cost-effective in comparison to nutrient loads and implementation of BMPs for the other land use sectors.

The type and extent of load reduction measures recommended here are based on the amount of pollutants a BMP prevents from entering the river and the total cost of implementation. The percentage reductions allocated to each land use and the recommended BMP measures were assigned using the available source loads and the reduction potential of that BMP. Once an option was fully implemented, the second most cost effective measure was implemented to its reduction capability. This process was used to derive the most cost-effective allocation of load reductions that will achieve the target levels as applied to the Napa River watershed. The total cost under the most cost-effective allocation was calculated at $75,797 per day in order to reach the calculated total load reduction simulated by WARMF, which has a better calibration than SWAT.

In addition or alternative to the retrofits recommended for the Napa and Calistoga WWTPs, another possible strategy for nutrient load reduction may be to increase the dilution rate of effluent from 10:1 to 50:1. An increase in the dilution rate to 50:1 may require larger retention ponds in order to hold effluent in cases where a low stream flow precludes discharge. The costs for this measure were not determined, however, implementing a 50:1 dilution rate would produce similar results to retrofitting these plants with a 3-stage NDN process.

12.1 - COMPARISON OF THE TWO MODELS

Both models are physically-based, distributed-parameter and continuous time watershed modeling tools. SWAT is developed to predict the impact of land use management practices on water and sediment.

SWAT is a public domain software, supported and incorporated by the USEPA into its BASINS, a watershed management model framework. Most basic SWAT input data for watersheds in the USA is available from EPA's BASINS website for free. In comparison, WARMF is a proprietary model and a fee is charged for the use of the software. In most cases, the developer provides the user with most of the basic input data.

WARMF has strong functionalities in terms of post data processing, and the user has the option to show nearly all results graphically, while SWAT has limited functionalities of showing both the input and output data graphically.

Successful use of both models has been documented in the past, and watershed modelers are increasingly accepting of the models. Yet, several issues complicate the more successful application of the two models in TMDL development.

12.11 - Limitations of WARMF

1. WARMF requires more computer running time than SWAT does for an area of the same size and delineation. This reflects the more complex set of equations and higher spatial resolution used in WARMF.

2. Besides nutrients, WARMF routes many other minerals, such as Al, Na, K, and Ca, whose fate and transport are linked to those of nutrients. Although this feature increases its credibility in simulation fate and transport of pollutants, it increases the data needs and calibration time.

3. WARMF does not clearly separate lateral flow and ground water return flow, which sometimes causes problems when calibrating surface flow and base flow separately.

4. Compared with SWAT, simulated values of a number of parameters are not available to users. These parameters include nitrogen transformation data in soil and biomass growth on the ground. This inadequacy makes it difficult to locate possible errors in setting the values of parameters.

5. The WARMF manual is not as detailed as that of SWAT.

12.12 - Limitations of SWAT

1. The overall complexity of SWAT input means that model development may require significant time, depending on the user's modeling background and knowledge of surface and groundwater systems as well as pollutant fate and transport.

2. As a public domain model, SWAT leaves its users with significant freedom to adapt it to a specific environment, suggesting that the users can access nearly all

of the system parameters. The down side of this flexibility is that the users usually have a difficult time setting up the model because too many parameters need to be adjusted when most of them are actually correlated. The difficulty also occurs when selecting parameters to use in calibrating the model.

3. SWAT uses soil curve numbers in routing surface flow and it is intended to study long-term impacts. Therefore, the simulated peak flow does not always match the measured peak flow well.

4. SWAT has no graphic user interface for post processing of the output data. This significantly increases the time required to develop a TMDL using SWAT.

5. SWAT has no input parameters for septic tanks, so the use of SWAT is not recommended in an area where septic tanks are deemed to be a major nutrient source.

6. SWAT does not accept dynamic air quality input and this limits its application to areas where air deposition is a considerable source of pollutant(s).

7. SWAT is not appropriate for simulating significant urban land since it was originally developed to simulate agricultural land.

8. SWAT has no means for tracing the pollutants to its sources, which limits the analysis.

9. Unlike WARMF, SWAT does not have a scenario manager and it cannot save an ongoing project as a file with different name. This significantly increases the resource requirement, especially time, in developing a TMDL using SWAT. It also increases the risk of losing the work halfway through simulations.

12.2 - RECOMMENDATIONS

- Data collection on irrigation management and modeling work on dynamics between initial soil nitrate concentrations and groundwater nutrient content are recommended. According to both models, current soil nitrate concentrations alone may cause the TDN concentration in the main river channel to exceed the dry season target level of 0.2 mg/L after 10 years of simulation. This result was obtained by setting initial soils concentrations to 1.5 mg/L for agricultural land use and 0.1 mg/L for non-agricultural land. These soil nitrate concentrations contribute to the nutrient load of groundwater, which may not be feasibly prevented from contributing to nutrient loads in the river. Therefore, the target level of 0.2 mg/L in the dry season may be unattainable at this point. Therefore, in this project, we did not develop a TDN TMDL for the Napa River Watershed for the dry season target level.

- Recommendations for achieving waste load reductions for WWTPs consist of retrofitting the plants with 3-stage NDN systems. Load reductions for nonpoint sources are recommended to be achieved with the following BMPs, ordered according to cost-effectiveness: Nitrex^{TM} filter retrofit for faulty septic systems; fertilizer reduction, grass swales, wetlands, and infiltration basins for the agricultural land use sector. The combined load reductions from these measures totals 453 kg N/day, which would achieve stream levels of N below the wet season target of 1.0 mg N/L according to the SWAT model. Note that several other measures were reviewed in this analysis that may be as effective or more effective than those recommended at reducing nutrient loads, however, these measures have not been included in the final analysis due to a lack of data on cost or effectiveness at reducing nutrient loads.

- In addition or alternative to the retrofits recommended for the Napa and Calistoga WWTPs, another possible strategy for nutrient load reduction may be to increase the dilution rate of effluent from 10:1 to 50:1. An increase in the dilution rate to 50:1 may require larger retention ponds in order to hold effluent in cases where a low stream flow precludes discharge. The costs for this measure were not determined, however, implementing a 50:1 dilution rate would produce similar results to retrofitting these plants with 3-stage NDN processes.

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