Nutrient Numeric Endpoints for TMDL Development: Santa Margarita River Case Study

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1 Introduction

Tetra Tech, Inc. under contract to EPA Region 9 and the California State Water Resources Control Board developed an approach for calculating nutrient numeric endpoints (NNE) for use in California Water Quality Programs (Tetra Tech, 2006). California is taking a risk-based approach in which targets are developed for response variables (or secondary indicators) such as algal density. These response targets can then be converted to site-specific nutrient targets through use of modeling tools.

The California NNE approach recognizes that there is no clear scientific consensus on precise levels of nutrient concentrations or response variables that result in impairment of a designated use. To address this problem, waterbodies are classified in three categories, termed Beneficial Use Risk Categories (BURCs). BURC I waterbodies are not expected to exhibit impairment due to nutrients, while BURC III waterbodies have a high probability of impairment due to nutrients. BURC II waterbodies are in an intermediate range, where additional information and analysis may be needed to determine if a use is supported, threatened, or impaired. Tetra Tech (2006) lists consensus targets for response indicators defining the boundaries between BURC I/II and BURC II/III.

Tetra Tech (2006) also documents a set of relatively simple spreadsheet tools to assist in evaluating the translation between response indicators and nutrient concentrations or loads. These simplified tools provide a starting place, and should be superseded by calibrated site-specific models where available.

One important use of the NNE is for setting initial nutrient endpoints for waterbodies requiring nutrient TMDLs. Accordingly, USEPA under Contract GS-10F00268k issued a task order to Tetra Tech to apply the NNE method to develop nutrient endpoints for a selected set of California waterbodies requiring nutrient TMDLs. These case studies are intended to demonstrate the NNE process and to test and refine the accompanying tools. The second case study reported under this task order is for the Santa Margarita River.

1.1 SITE

The lower Santa Margarita River Watershed provides the greatest remaining expanse of largely undisturbed riparian corridor in coastal southern California. The lower 27 miles of the watershed, comprised of the main river channel and its estuary, is dominated by federal and state land ownership. At least partly for that reason, it has largely escaped significant development, channelization, and impoundment. Consequently, this watershed serves as valuable habitat, providing a home for 1,000 known species, including seven federal or state listed endangered or threatened species, and more than 60 other species listed by the state and other groups as having special concern. Thus, not only is the lower watershed an environment of high local ecological and economic importance, it is also of high statewide and national interest. Of increasing concern, however, the lower watershed is vulnerable to impacts accompanying development and large-scale land use changes upstream. The upper watershed, drained by Temecula and Murrieta Creeks, includes some of the fastest urbanizing areas in the state. This development pressure increases the potential for additional point and nonpoint pollutant loading to the river.

The Santa Margarita River originates with the confluence of Temecula Creek and Murrieta Creek. Being one of the largest river basins on the southern California coastal plain, its watershed covers about 740 square miles. Temecula Creek rises on the eastern slope of the Palomar Mountains and flows first generally northwest and then southwest through a series of valleys around the northeastern slope of these mountains until it meets Murrieta Creek near Temecula, California. Murrieta Creek begins in the northern slope of the Santa Rosa Plateau and flows generally southeast through a wide valley, until it joins with Temecula Creek. Elevations of the upper basin range from 960 feet at the confluence of Temecula and Murrieta Creeks to 6,812 feet at Thomas Mountain and 6,138 feet at Mount Palomar. Most of the upper watershed includes valley and mesa lands ranging between 1,000 and 1,500 feet elevation. The combined drainage area of the upper basin of Murrieta and Temecula Creeks is 588 square miles.

Downstream from this confluence, the Santa Margarita River flows 27 miles to the Pacific Ocean. The river first descends through a twisting course for about 6 miles in the bottom of Temecula Canyon, a steep-walled gorge cut through the Santa Margarita Mountains that narrows, in places, to 100 feet at the bottom. Some faces of the canyon wall tower more than 300 feet over the river. Near the downstream mouth of the canyon, Rainbow Creek joins the river from the southeast and, about two miles downstream, Sandia Creek joins from the northeast. Further downstream, DeLuz Creek also flows into the Santa Margarita from the northeast. The river then pours from the foothills area, flowing onto an alluvial valley and coastal plain before passing through the Ysidora Narrows, a bottleneck of coastal bluffs formed from sedimentary rock and more resistant marine deposits, which constrict the river course for nearly a mile. Lower basin elevations range from sea level up to near 2,500 feet and include 152 square miles. The U.S. Marine Corps' Camp Pendleton and the Fallbrook Naval Weapons Station comprise approximately 61 square miles or 40% of the lower basin.

The Santa Margarita River Watershed lies within the Humid Temperate Domain, the Mediterranean Division, and the California Chaparral Province. The Humid Temperate Domain is an area predominated by mid-latitude forests containing broad-leafed and coniferous trees. In the United States, the Mediterranean Division, which characteristically has hot, dry summers and mild, wet winters, is situated along the Pacific coast between latitudes 30º and 45º N. Trees and shrubs within this division typically must withstand severe summer drought and evaporation over 2 to 4 months (Bailey, 1978).

The California Chaparral Province occupies the central part of the California Coast Ranges and other mountains of southern California (Bailey, 1978). Throughout this province, the Coast Ranges are gently to steeply sloping low mountains, underlain by shale, sandstone, igneous, and volcanic rocks. Its coastal plains are generally narrow and discontinuous, but sometimes large, with narrow and wide-spaced stream valleys. Precipitation volumes range from 12 to 40 inches annually, distributed relatively evenly between fall, winter, and spring. This generally includes little snow. (Note, however, that the "wet" season in the Santa Margarita River Watershed occurs for most years predominantly during January and February.)

1.2 Beneficial Uses and Impairment

The Upper Santa Margarita River (Hydrologic Unit Basin Number 2.21), including the mainstem of the perennial Santa Margarita, has multiple assigned beneficial uses (CRWQCBSD, 1994):

MUN: Domestic and municipal water supply

AGR: Agricultural supply

IND: Industrial service supply

REC1: Water contact recreation

REC2: Non-contact water recreation

WARM: Warm freshwater habitat

COLD: Cold freshwater habitat

WILD: Wildlife habitat

RARE: Preservation of rare and endangered species.

The Upper Santa Margarita River from its start at the confluence of Temecula and Murrieta Creeks down to De Luz Creek was listed as impaired by phosphorus on California's 2002 CWA 303(d) List of Water Quality Limited Segments (State List ID CAR9022200020011001141050). The listing is based on general nutrient criteria specified in the Basin Plan (CRWQCBSD, 1994, Table 3-2, Endnote a): "Concentrations of nitrogen and phosphorus, by themselves or in combination with other nutrients, shall be maintained at levels below those which stimulate algae and emergent plant growth. Threshold total Phosphorus (P) concentrations shall not exceed 0.05 mg/L in any stream at the point where it enters any standing body of water, nor 0.025 mg/L in any standing body of water. A desired goal in order to prevent plant nuisances in streams and other flowing waters appears to be 0.1 mg/L total P. These values are not to be exceeded more than 10% of the time unless studies of the specific body in question clearly show that water quality objective changes are permissible and changes are approved by the Regional Board. Analogous threshold values have not been set for nitrogen compounds; however, natural ratios of nitrogen to phosphorus are to be determined by surveillance and monitoring and upheld. If data are lacking, a ratio of N:P = 10:1 shall be used…"

A separate nutrient TMDL was completed for Rainbow Creek, a tributary of the Santa Margarita, and approved 22 March 2006 (CRWQCBSD, 2006).

1.3 SUMMARY OF EXISTING ANALYSES

Marcus et al. (1994) undertook a thorough study of water quality in the Santa Margarita. At that time, they reported "Recent nutrient concentration measurements in the Santa Margarita River exceed the basin plan objectives…and are high enough to promote undesirable growth of nuisance algae….Concentrations in Murrieta and Temecula Creek are slightly elevated above goals (average phosphorus concentration around 0.2 mg/L). However, both nitrogen and phosphorus concentrations increase sharply below the confluence with Rainbow Creek…"

Despite these observations, very little quantitative data on benthic algal density have been collected in the Santa Margarita. Hunsaker (1992), Marcus et al. (1994), and San Diego County (2006) have all reported formation of dense growths of the filamentous green algae *Cladophora* in the Santa Margarita during the summer. *Cladophora* is typically regarded as a nuisance algae that is indicative of eutrophication. Monitoring of dissolved oxygen and pH in the river also suggests that excessive algal growth is occurring in the system.

In recent years, the Bureau of Reclamation (CDM, 2003) has sponsored the development of a WARMF model of the Santa Margarita River. This model has been calibrated for hydrology; however, water quality calibration has not yet been reported.

1.4 SCOPE OF THIS EFFORT

Targets have not been specified for benthic algal density in the basin plan for the Santa Margarita River, and benthic algae has rarely been monitored. High concentrations are expected, based on ambient nutrient concentrations and their existence is supported by qualitative observations on nuisance algae and secondary information on dissolved oxygen (DO) and pH. The expected periphyton density in the Santa Margarita River exceeds the density proposed as an upper bound on acceptable conditions (BURC II/III boundary) for the beneficial uses assigned to the Santa Margarita River (Tetra Tech, 2006). These boundaries are 150 mg-chl-a/m^2 for the COLD beneficial use and 200 mg-chl-a/m^2 for the WARM beneficial use, as proposed at State Water Board Nutrient Numeric Training Workshop. Significant reductions in existing nutrient concentrations under low flow conditions in the Santa Margarita River would be needed to achieve these targets. Nonetheless, benthic biological conditions in the Santa Margarita River, although generally rated as Fair to Poor, are better than observed in most other streams of San Diego County (San Diego County, 2006).

A primary focus of this report is determining the nutrient limits that would need to be met to achieve the proposed BURC II/III boundaries during summer low flow conditions. It appears, however, that achieving even the WARM BURC II/III boundary of 200 mg-chl-a/m^2 will pose a considerable challenge for the Santa Margarita River

A major question is whether the NNE targets proposed by the consensus group are appropriate to effluent-dominated streams in Southern California. In these streams, summer flow is largely supported by permitted discharges, irrigation return flow of imported water, and urban runoff. Attaining oligotrophic or mesotrophic status may not be a reasonable option for these streams. The COLD use, in particular, may be appropriate only on a seasonal basis. For the WARM use, it may be appropriate to develop sub-region specific targets. The CA NNE approach contains a provision that endpoints should not be less than natural background. However, few unimpacted reference sites exist for Southern California, and the applicability of reference sites to streams where summer flow might be essentially non-existent without anthropogenic inputs is unclear.

2 Data

The most extensive set of historical data on the Santa Margarita River is that collected by the USMC Camp Pendleton Natural Resources Office (NRO), starting in 1961. Other data have been collected by the U.S. Geological Survey and the San Diego Regional Water Quality Board. In 1991-92 Eastern Municipal Water District and Rancho California Water District sponsored an intensive data collection effort in accordance with proposed river management requirements (Hunsaker, 1992). Earlier data are summarized in Marcus et al. (1994).

A database of all monitoring through 2001 was compiled by CDM in conjunction with the development of a model of the river for the Bureau of Reclamation (CDM, 2003). This database was supplied to Tetra Tech by Nicole Rowan of CDM and forms the basis for the discussion that follows.

Additional monitoring began in November 2001 as part of the San Diego County Urban Runoff Monitoring Program (San Diego County, 2005, 2006). Approximately two flow-weighted storm event samples per year are collected at the Santa Margarita River mass loading station (under the Basilone Road Bridge on Camp Pendleton). These samples are typically taken in February. Dry weather samples are collected at a few sites once or more per year, only one of which is on the mainstem, while biological metrics are reported from the mainstem at Willow Glen Road and on Camp Pendleton near the military base hospital. These limited data are not included in the CDM database, were not available electronically, and are not included in this analysis.

Figure 1 shows the location of the historic monitoring sites as well as the USGS gages in the area with field measurements of hydraulic parameters.

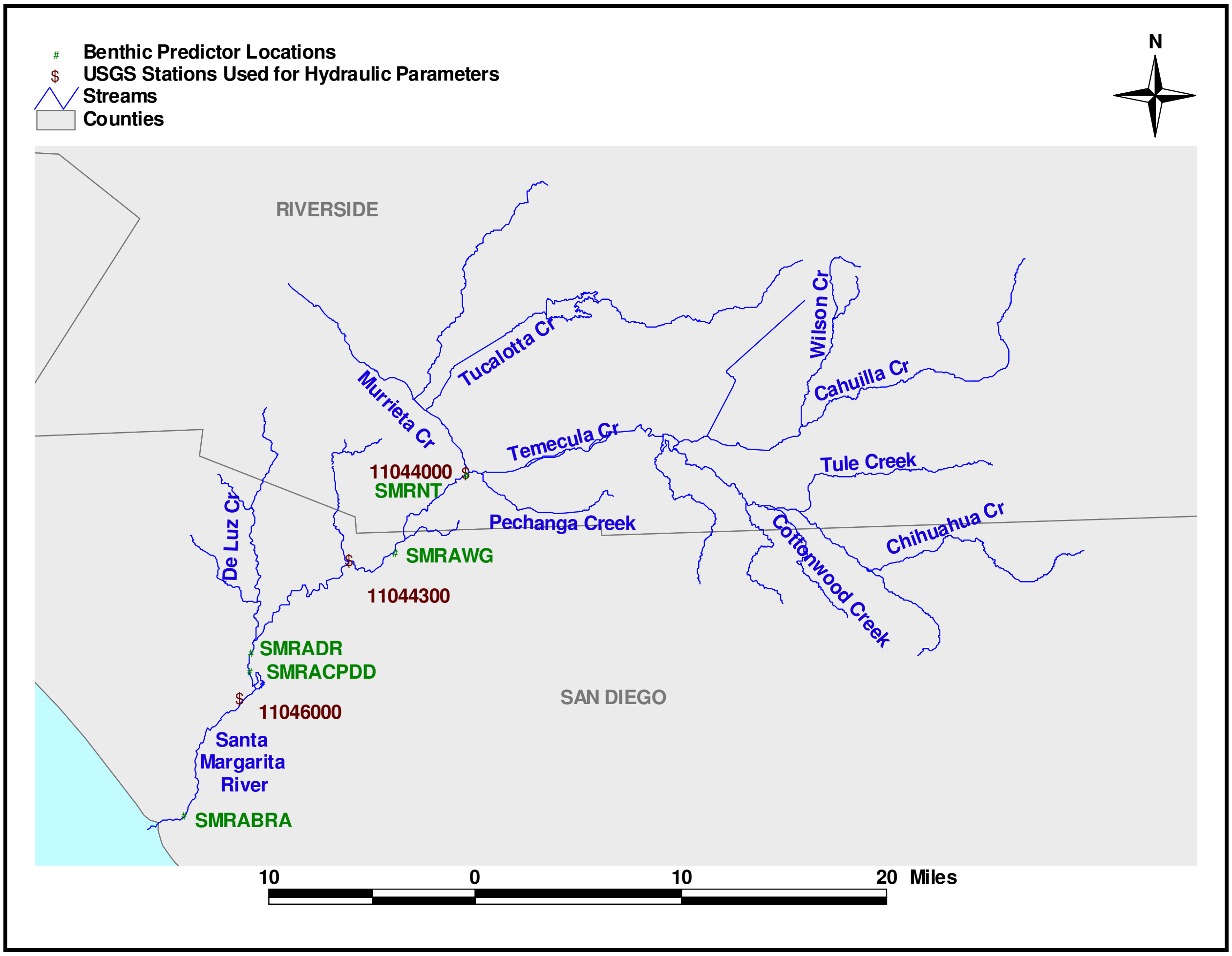

Figure 1. Water Quality Stations and USGS Gages on the Santa Margarita River Used for NNE Tool Application

2.1 Benthic Algal Response Data

Only very limited sampling of benthic algae has been conducted in the Santa Margarita River. In 1991, Hunsaker (1992) undertook extensive study of the system for the upstream water districts. For April 1991, his monitoring report states "…the average water temperature rose by 5.34 ºC and the rainfall was low (0.15"). Algae was able to attach and grow into mats." During the April 1991 monitoring, about 10-12.5 percent of the stream bottom was covered with filamentous algal growth. Hunsaker's report for May 1991 states, "Algal mats and benthic algae increased, …" with up to 25 percent of the bottom covered with filamentous algae. The report for June notes that "…there was an increase in the amount of benthic algae. The floating mats continue to increase." Up to 55 percent of the bottom was covered with filamentous algae at this time.

Also in 1992, Ball and Associates reported longitudinal trends in attached green filamentous algae in the system. Along Temecula Creek populations were dominated by *Spirogyra*. In Temecula Gorge, *Spirogyra* intermingled with two other filamentous green species, *Cladophora* and *Rhizonclonium*, with *Cladophora* becoming the dominant species nearer the estuary. During field work by the Cadmus Group in April-August 1992, dense algal mats (up to 100 percent cover) were reported in Murrieta Creek, with up to 50 percent cover by algal mats in the Santa Margarita River just downstream of the confluence of Murrieta and Temecula Creeks (Marcus et al., 1994).

No subsequent studies of benthic algal density appear to have been undertaken. There is, however, substantial indirect evidence of eutrophication provided by daily cycles of dissolved oxygen and pH. Strong diurnal variation in temperature (which controls DO saturation concentration) are typical in the arid climate of the Santa Margarita, so it is more informative to examine DO deficit – the difference between saturation and actual concentration of oxygen at ambient temperature and chlorinity conditions (Butcher and Covington, 1995). During summer 1994, Cadmus observed DO deficits around 2 mg/L in the morning, with supersaturation in the afternoon. For the last several years (since 2002), the Santa Margarita Ecological Reserve (SMER) program has maintained continuous water quality monitoring at their gorge site, reporting results at 15-minute intervals. Typical results for the late summer of 2005 are shown in Figure 2. DO depletions (positive DO deficit) are typically in the range of 2 to 3 mg/L each morning. Further, strongly negative DO deficits (supersaturation), up to 4 mg/L, are seen during the day (this will vary depending on available sunlight). This diurnal cycle indicates the presence of extensive algal growth. Actual DO concentrations frequently fall briefly below 5 mg/L near the minimum.

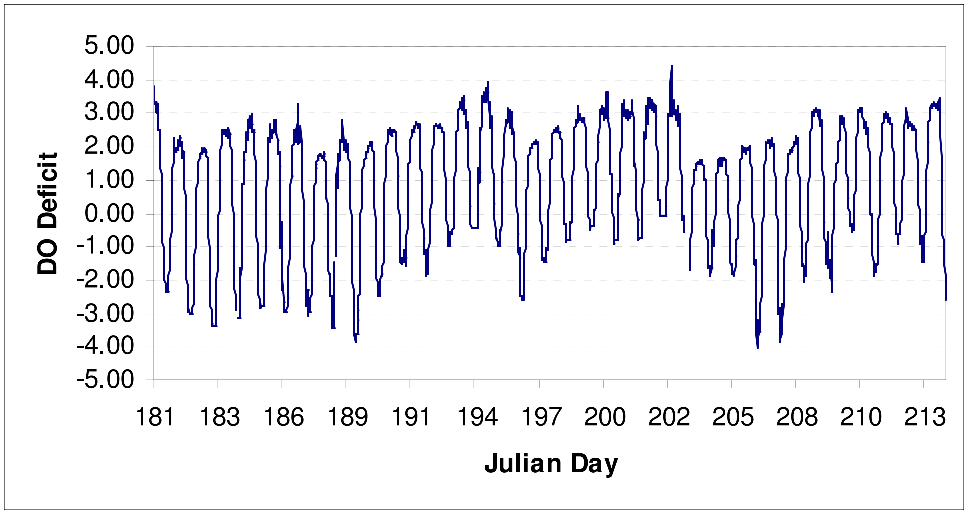

Figure 2. Dissolved Oxygen Deficit, Santa Margarita River at Gorge (SMER), 2005

A similar result is seen for pH (Figure 3), with nighttime values typically around 7.5 and daytime maxima above 8.5. This indicates strong depletion of inorganic carbon by photosynthesis.

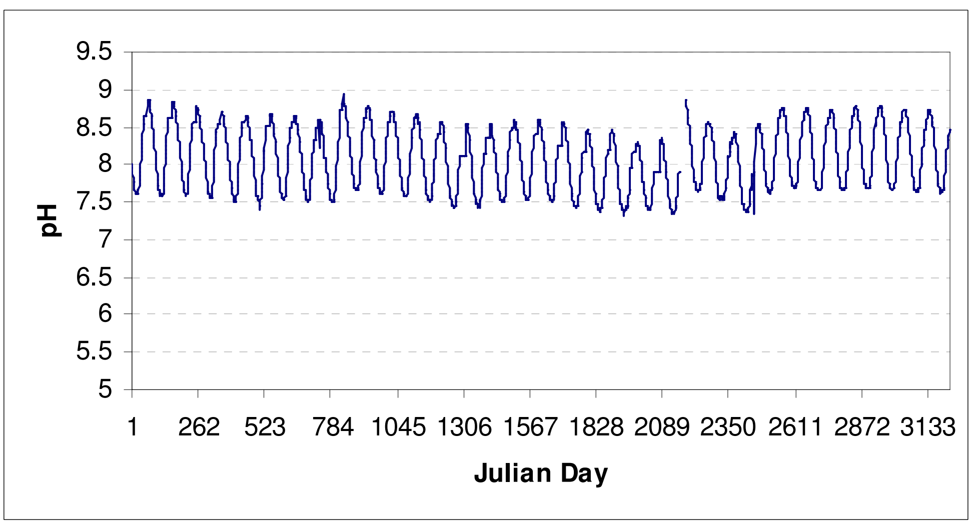

Figure 3. pH Profile, Santa Margarita River at Gorge (SMER), 2005

Some additional qualitative evidence is available from recent bioassessment surveys (San Diego County, 2006). At the Willow Glen Road station, Index of Biotic Integrity (IB) qualitative rankings were fair in October 2003 and poor in May 2004, October 2005 and May 2006. At the downstream bioassessment station on Camp Pendleton, the IBI rankings were fair in 2003-2004 and poor in 2005. For May 2005, the Bioassessment Survey notes "dense growths of filamentous green algae (probably *Cladophora* sp.)" at the Willow Glen monitoring site.

2.2 CHEMICAL WATER QUALITY

In contrast to the limited data on periphyton, an extensive database of chemical water quality exists, collected by multiple agencies as described above.

Statistics for summer season results (June – September) for 1986 through 2001were extracted from the CDM database. As periphyton is expected to have a moderately long response time to ambient nutrient concentrations, extreme values may not be particularly relevant. Therefore, the central tendency and range of the ambient data were described by the mean, median, 25th percentile, and 75th percentile (Table 1). It should be noted that these data are not necessarily representative of current conditions, for which monitoring appears to be sparse. They are, however, useful in context of the NNE scoping to evaluate appropriate nutrient endpoints for the system.

Table 1. Santa Margarita River Water Quality Data, 1986-2001 Summer (June-September)

Parameter	Count	Mean	Median	25th Percentile	75th Percentile
SMRNT: Santa Margarita River Near Temecula					
PO4-P (mg/L)	36	0.76	0.10	0.10	0.40
ORG-P (mg/L)	4	0.15	0.09	0.04	0.20
TP (mg/L)	122	0.18	0.13	0.07	0.22
NO3-N (mg/L)	429	0.9	0.9	0.5	1.3
NH3-N (mg/L)	4	0.3	0.2	0.2	0.3
ORG-N (mg/L)	4	0.6	0.5	0.4	0.7
TKN (mg/L)	75	0.7	0.5	0.4	0.8
TN (mg/L)	107	1.2	1.0	0.8	1.6
Turbidity (NTU)	2	73.3	73.3	40.0	106.7
SMRAWG: Santa Margarita River Above Willow Glenn					
PO4-P (mg/L)	7	0.07	0.05	0.05	0.10
ORG-P (mg/L)	7	0.07	0.00[a]	0.00[a]	0.03
TP (mg/L)	31	0.04	0.00[a]	0.00[a]	0.05
NO3-N (mg/L)	31	0.6	0.4	0.2	1.0
NH3-N (mg/L)	9	0.2	0.1	0.1	0.5
ORG-N (mg/L)	8	0.7	0.5	0.3	0.9
TKN (mg/L)	21	0.7	0.6	0.5	0.8
TN (mg/L)	30	1.2	1.1	0.8	1.6
Turbidity (NTU)	3	6.6	6.5	6.5	6.8

Parameter	Count	Mean	Median	25th Percentile	75th Percentile
SMRADR: Santa Margarita River At De Luz Road					
PO4-P (mg/L)	11	0.34	0.20	0.20	0.25
ORG-P (mg/L)	10	0.19	0.01	0.00 [a]	0.14
TP (mg/L)	26	0.22	0.15	0.08	0.20
NO3-N (mg/L)	37	1.2	0.2	0.0	2.1
NH3-N (mg/L)	10	0.2	0.1	0.1	0.3
ORG-N (mg/L)	10	0.6	0.4	0.2	0.8
TKN (mg/L)	23	0.6	0.5	0.4	0.8
TN (mg/L)	23	1.6	1.0	0.6	2.9
Turbidity (NTU)	3	4.9	5.0	4.3	5.6
SMRACPDD: Santa Margarita River at Camp Pendleton Diversion					
PO4-P (mg/L)	5	0.17	0.20	0.10	0.20
ORG-P (mg/L)	4	0.16	0.13	0.08	0.21
TP (mg/L)	10	0.26	0.20	0.18	0.20
NO3-N (mg/L)	10	0.3	0.0	0.0	0.5
NH3-N (mg/L)	6	0.2	0.1	0.1	0.4
ORG-N (mg/L)	6	0.8	0.3	0.1	0.5
TKN (mg/L)	8	0.8	0.4	0.2	0.9
TN (mg/L)	8	1.1	1.0	0.2	1.5
Turbidity (NTU)	0				
SMRABRA: Santa Margarita River at Brackish					
PO4-P (mg/L)	9	0.38	0.40	0.20	0.60
ORG-P (mg/L)	7	0.53	0.10	0.00 [a]	0.73
TP (mg/L)	12	0.61	0.45	0.20	0.66
NO3-N (mg/L)	9	0.1	0.1	0.1	0.1
NH3-N (mg/L)	9	0.2	0.1	0.1	0.2
ORG-N (mg/L)	9	2.2	0.6	0.1	1.5
TKN (mg/L)	9	2.4	0.8	0.3	1.8
TN (mg/L)	10	1.0	0.7	0.3	1.6
Turbidity (NTU)	3	10.6	10.0	10.0	11.0

[a] Values of zero (in addition to blank cells) were included in the dataset. This value includes all data points, including zeros.

2.3 PHYSICAL DATA

The USGS collects field measurements of velocity, area, width, and flow at select sites where daily stream flow estimates are recorded. Field measurements occur intermittently throughout the year. Three gages on the Santa Margarita River are currently measured. Table 2 summarizes the average summer (June – September) hydraulic characteristics at each gage. Measurements at gage 11044000 have been collected since 1969. Gages 11044300 and 11046000 have been measured since 1989 and 1982, respectively.

Table 2. Average Summer Hydraulic Characteristics of Three USGS Gages on the Santa Margarita River Used for NNE Tool at Five Water Quality Stations

Gage	Flow (cfs)	Velocity (ft/s)	Average Depth (ft)	Width (ft)
11044000	4.62	1.17	0.54	9.3
11044300	6.30	1.12	0.54	15.2
11046000	9.42	1.03	0.36	27.8

Tetra Tech hoped to obtain additional information on hydraulic characteristics from the calibrated WARMF model (CDM, 2003) however, the output from this model was not made available for this analysis.

3 NNE Tools Application

Four water quality stations on the mainstem Santa Margarita River were selected for application of the CA NNE method. Only sites with adequate nutrient data, including at least two phosphorus parameters and three nitrogen parameters, were selected. The required estimates of velocity and depth were taken from the nearest USGS field measurement site that drained the same number of tributaries as the NNE site.

3.1 PARAMETER SPECIFICATION

Field measurements collected by the USGS at three locations along the Santa Margarita River were used to estimate the average summer depths and velocities at the four water quality stations where the NNE tool was used.

Velocity

USGS reports the mean velocity during field measurements as flow rate divided by cross sectional area. Table 3 summarizes the velocities assigned to each NNE site based on the average summer measurements recorded at the three USGS gages.

Table 3. Average Summer Velocities Assumed for NNE Sites

NNE Site	Mean Summer Velocity (fps)
SMRNT: Santa Margarita River near Temecula	1.17
SMRAWG: Santa Margarita River above Willow Glenn	1.12
SMRADR: Santa Margarita River at De Luz Road	1.03
SMRACPDD: Santa Margarita River at Camp Pendleton Diversion	1.03

Depth

USGS does not report average depth in its field measurements, but the parameter can be calculated from the cross sectional area divided by the width. Table 4 summarizes the average summer depths assigned to each NNE site based on the USGS field measurements.

Table 4. Average Summer Depths Assumed for NNE Sites

NNE Site	Mean Summer Depth (ft)
SMRNT: Santa Margarita River near Temecula	0.54
SMRAWG: Santa Margarita River above Willow Glenn	0.54
SMRADR: Santa Margarita River at De Luz Road	0.36
SMRACPDD: Santa Margarita River at Camp Pendleton Diversion	0.36

Solar Radiation

Unshaded solar radiation estimates were generated based on latitude for the period June to September, when nuisance algal blooms are most likely to occur.

Shading

Throughout much of the Santa Margarita River, the stimulatory effect of abundant sunshine is mitigated by the presence of dense riparian cover of willows and emergent macrophytes. In the canyon area, light input is also limited by topographic shading. This shading reduces the amount of solar radiation available to support algal growth, and thus the resulting benthic algal density. Unfortunately, quantitative information was not available on the extent of shading present at the four NNE sites. Results are therefore presented under conditions of zero percent cover and 80 percent cover.

Light Extinction Coefficient

Light extinction in the water column was estimated from turbidity. In general, light extinction is a function of water itself, dissolved colored organic material, phytoplankton, and inanimate particulate matter (Effler et al., 2005), and occurs through a combination of adsorption and scattering. In flowing streams, scattering by inorganic particulates is usually the dominant factor in light extinction, while scattering in the water column is directly measured by a nephelometric turbidity meter as NTU (Gallegos, 1994). Therefore, an approximately linear relationship of light extinction to turbidity is expected in streams. Rather than implementing a complete optics model, we therefore rely on the simple empirical relationship of Walmsley et al. (1980), who established a regression relationship $K_e(PAR) = 0.1\ T + 0.44$, where $K_e(PAR)$ is the extinction rate of photosynthetically active radiation (PAR, per meter) and T is nephelometric turbidity (NTU). The relationship will vary according to the nature of suspensoids (Kirk, 1985), but is similar to results of other authors who suggest slopes of K_e relative to turbidity in the range of 0.06 to 0.12. Because turbidity has only a small effect on available light at the depths analyzed, the Walmsley relationship appears acceptable and was used to estimate the extinction coefficient from the turbidity values shown in Table 1.

Chlorophyll *a* to AFDW Ratio

The QUAL2K approaches predict benthic biomass as ash-free dry weight (AFDW). Prediction of benthic chlorophyll *a* then depends on assumptions of the chlorophyll *a* to AFDW ratio. No site-specific information on this ratio was available for the Santa Margarita, so the default value of 2.5 recommended in Tetra Tech (2006) was used. As noted in that document, this ratio is lower than is expected for autotrophic algae, and reflects the presence of significant amounts of heterotrophic biomass in the training data set. Such an assumption is likely appropriate for the Santa Margarita; however, site-specific information is desirable to assure reasonable predictions. Increasing the ratio to 4.5, which is more typical of autotrophic algal populations, would increase predictions by a factor of 1.8.

Days of Accrual

The scoping model provides an option to evaluate effects on expected maximum algal density based on days of accrual (d_a), using the relationship of Biggs (2000), where accrual time is defined as the number of days between events three-times the median flow. This approach was developed on New Zealand streams, and does not necessarily work well as designed on California streams. In particular, we pointed out that the median flow on the Santa Margarita River is only 2.5 cfs, and, if three times this value is used directly in the calculation of d_a a value of only about 8 days is obtained, which would result in a prediction of highly suppressed benthic algal biomass. (The 2.5 cfs value was based on flow data for water years 1970 through 1996; flow data through 2006 yield a median flow of 3 cfs; see Figure 4).

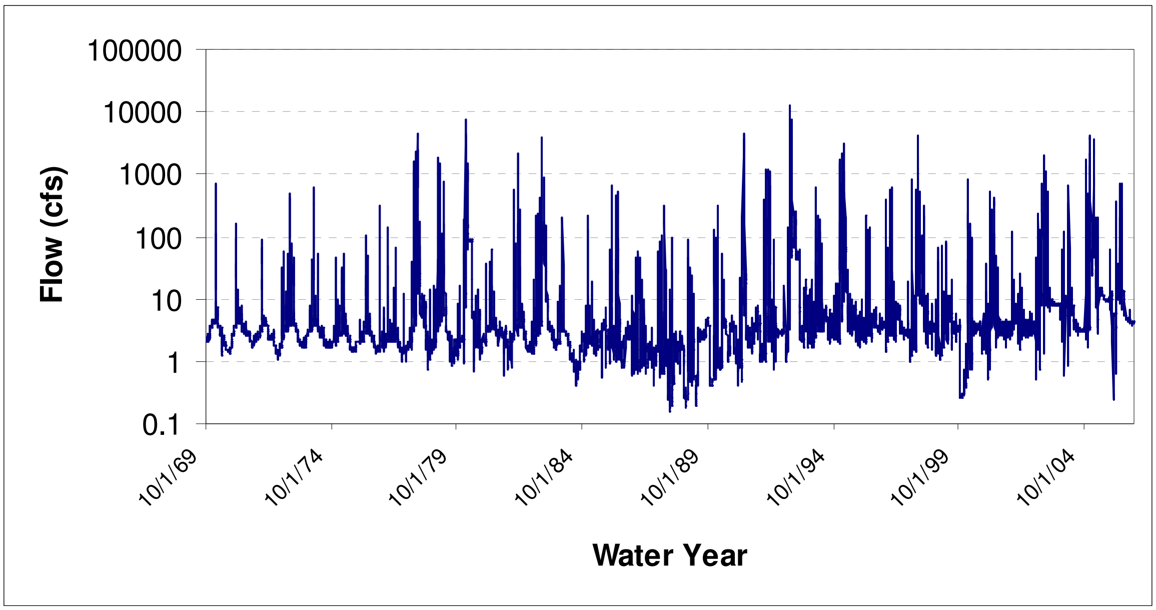

Figure 4. Daily Average Flow, Santa Margarita River at Temecula (USGS Gage 18070302)

Obviously, an estimate of d_a of 8 days is not appropriate – as a flow of 7.5 cfs is unlikely to produce significant scour. Two modifications to Biggs' method were developed to address this problem. The first is a modification in the method of counting "events," and the second is institution of a minimum scour threshold.

First, counting should be on the basis of events, not individual days above the threshold. For example, if the flow went over the scour threshold in spring, stayed there for 20 days (as would be typical in a snowmelt-dominated system), then remained below the threshold for the remainder of the year, only a single event – and not 20 events – should be counted. This is addressed by counting a day as an event only if it is greater than the threshold *and* the previous day was not counted as an event. This modification has a major effect on calculation of d_a for snowmelt-dominated systems and systems that are highly regulated.

Regardless of the method of counting, if three times the median flow is a flow lower than needed to induce scour, the counting process would yield unrealistic results. Research summarized in Welch and Jacoby (2004, p. 284) shows that the true relationship between periphyton density and scour potential is complex, varying with algal species and substrate type. Indeed, increasing velocity may enhance biomass production, up to a point, by providing better mixing of nutrients in the water column. Further, periphyton may adjust to high-scour environments, and thus may be more susceptible to sudden changes in flow than to its absolute magnitude. Ideally, site-specific observations could be used to define the approximate breakpoint in flow at which significant scouring of periphyton occurs, then use this breakpoint in the calculation of days of accrual. As such data are typically lacking, a more general approach is needed for most sites. Welch and Jacoby note that significant scour usually does not begin until flow velocities reach about 70 cm/s (2.3 ft/s). USGS flow measurements on the Santa Margarita at Temecula suggest that a velocity of 2.3 ft/s is not reached until flow exceeds at least 50 cfs (Figure 5).

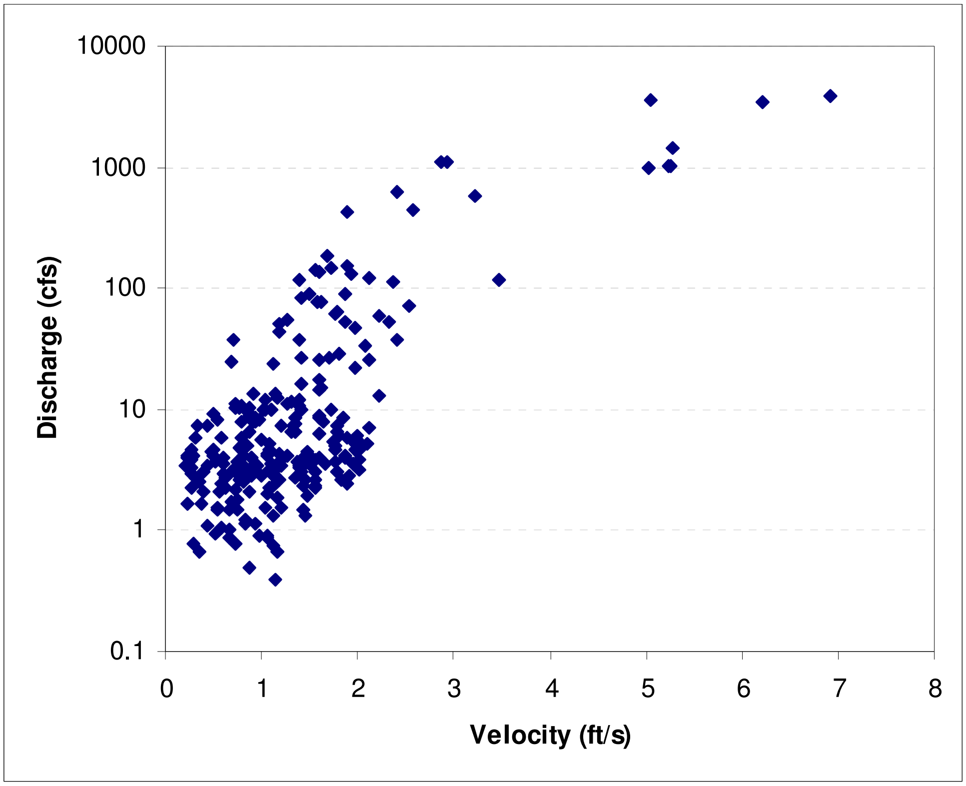

Figure 5. Relationship between Discharge and Velocity, Santa Margarita River at Temecula, CA (USGS Gage 18070302, Water Years 1970-2006)

For use of the Biggs approach on the Santa Margarita, the days of accrual were calculated, on an event basis, using the greater of 3 times the median flow and the flow corresponding to the lower envelope on a velocity of 2.3 ft/s. The value of d_a calculated for the Santa Margarita at Temecula is 132.4 days – rather than the 8.3 days calculated with unadjusted application of the Biggs method. This is in qualitative agreement with observations that little scouring occurs during the summer dry period. The resulting reduction in the potential maximum density is then only about 7 percent.

3.2 MODEL RESULTS

The NNE Benthic Biomass Predictor tool provides a variety of empirical and simplified parametric model approaches to predicting benthic algal response to ambient physical and chemical conditions. The tool was first used to predict maximum benthic chlorophyll *a* at each of the sites. As discussed in Tetra Tech (2006), benthic algal density is highly variable in time and space, and simplified models generally seem to do a better job of predicting maximum benthic algal density. The tool provides access to multiple predictions, but only three are presented here. Of the empirical approaches, we present the revised version of the Dodds model (Dodds, 2002), and, of the parametric approaches, we present the standard and revised QUAL2K models (which are tuned to correspond to the Dodds' results on small streams).

Results, shown in Table 5 in upstream to downstream order, are given for both 80 percent canopy closure and no canopy closure. The two QUAL2K methods are approximately consistent, while the Dodds results (which do not depend on light availability) tend to fall between the QUAL2K predictions with 80 percent and 0 percent canopy closure. No measured data are available to validate these predictions; however, the relatively high predicted maxima are in qualitative agreement with observations of *Cladophora* mats and strong diurnal cycles in DO and pH.

Table 5. Predicted Maximum Benthic Chlorophyll *a* (mg/m^2)

Station	80 % Canopy Closure			0 % Canopy Closure		
	Standard QUAL2K	Revised QUAL2K	Dodds (2002)	Standard QUAL2K	Revised QUAL2K	Dodds (2002)
SMRNT	204	170	343	364	304	343
SMRAWG	185	151	220	334	272	220
SMRADR	209	180	300	370	319	300
SMRACPDD	170	120	244	300	213	244

Note: Revised QUAL2K results are calculated with a days-of-accrual adjustment.

The tool can then be used to predict nutrient concentration targets needed to achieve a specified maximum algal density. For the COLD uses assigned to the Santa Margarita, Tetra Tech (2006) recommends that the target for maximum benthic chlorophyll *a* should generally be between 100 mg/m^2 (BURC I/II boundary below which conditions may be deemed acceptable) and 150 mg/m^2 (BURC II/III boundary above which conditions are deemed unacceptable). For the WARM uses, Tetra Tech (2006) recommends a BURC I/II boundary of 150 mg/m^2 and a BURC II/III boundary of 200 mg/m^2.

Given that predicted maxima are far above the recommended range, analysis was made at the BURC II/III boundaries. In addition, 40 percent canopy closure was assumed for evaluating target values, consistent with the presence of fairly good riparian cover along most of the Santa Margarita River mainstem.

Results for the 200 mg/m^2 WARM target and the 150 mg/m^2 COLD target for maximum benthic chlorophyll *a* are shown in Table 6 and Table 7. In these tables, the Revised QUAL2K method directly predicts total nutrient concentrations for N and P, either of which will achieve the target. The Standard QUAL2K method is based on inorganic nutrient concentrations, and the total nutrient limits shown in the tables are those that would be required at the existing average inorganic fraction of nutrient concentrations. The Dodds (2002) method is based on total nutrient concentrations but always yields co-limitation, such that the target may be obtained by any point along a frontier of Total N and Total P concentrations (see Figure 6). The results shown in the tables are the required concentrations of Total N at the existing average Total P concentration and the required concentration of Total P at the existing average Total N concentration. As the inorganic fraction of nutrients tends to decrease downstream in the Santa Margarita from station SMRNT to SMRAWG, the Standard QUAL2K approach allows higher total nutrient concentrations at SMRAWG, while the Revised QUAL2K method does not.

Table 6. Summer Nutrient Concentrations to Meet WARM Use Maximum Benthic Chlorophyll *a* Target of 200 mg/m² (40% Canopy Closure)

Station	Standard QUAL2K		Revised QUAL2K		Dodds (2002)	
	Total N (mg/L)	Total P (mg/L)	Total N (mg/L)	Total P (mg/L)	Total N (mg/L)	Total P (mg/L)
SMRNT	0.53	0.020	1.2	0.022	0.40	0.05
SMRAWG	0.71	0.021	1.2	0.022	1.2	0.065
SMRADR	0.51	0.015	1.2	0.022	0.68	0.041
SMRACPDD	0.58	0.024	1.1	0.019	0.58	0.12

Table 7. Summer Nutrient Concentrations to Meet COLD Use Maximum Benthic Chlorophyll *a* Target of 150 mg/m² (40% Canopy Closure)

Station	Standard QUAL2K		Revised QUAL2K		Dodds (2002)	
	Total N (mg/L)	Total P (mg/L)	Total N (mg/L)	Total P (mg/L)	Total N (mg/L)	Total P (mg/L)
SMRNT	0.28	0.011	0.79	0.015	0.20	0.013
SMRAWG	0.37	0.011	0.80	0.015	0.52	0.019
SMRADR	0.23	0.0071	0.78	0.014	0.30	0.012
SMRACPDD	0.32	0.013	0.78	0.014	0.22	0.036

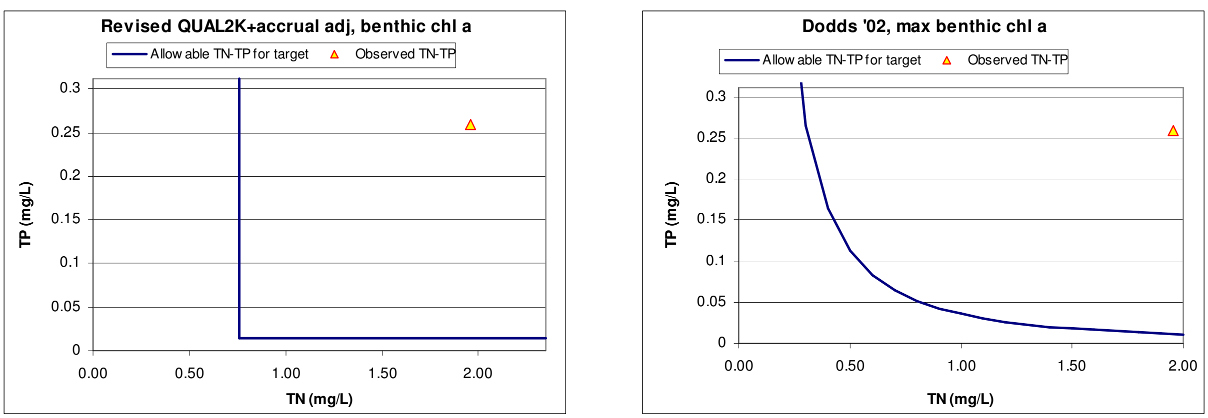

Figure 6. Revised QUAL2K and Dodds 2002 Tool Results for a Target Maximum of 150 mg/m²-Chlorophyll *a* at Station SMRADR

Comparison of Table 6, Table 7, and Table 1 reveals that current conditions in the Santa Margarita are close to the BURC II/III boundary for the WARM use, but that significant reductions in existing nutrient concentrations would be required to meet the COLD BURC II/III target of 150 mg/m² (Table 7). For example, at station SMRNT, the target total N concentration ranges from 0.20 to 0.79 mg/L, while the existing summer average is 1.2 mg/L. The target total P concentration ranges from 0.011 to 0.019, while the existing summer average is 0.18. The predicted targets needed to obtain either the COLD or WARM uses are generally less than the general basin plan objectives of 1 mg/L total N and 0.1 mg/L total P.

While the targets are lower than the basin plan objectives, they are consistent with results from other sites. Chetelat et al. (1999) found that *Cladophora* became dominant at total P concentrations above 20 µg/L (0.020 mg/L), while Sosiak (2002) recommended TP concentrations less than 18 µg/L (0.018 mg/L) to prevent nuisance periphyton growth. Dodds et al. (1997) recommended a limit of 30 µg/L (0.030 mg/L) for the Clark Fork.

USEPA (2000) suggested ecoregional criteria applicable to this area. Model results are compared to the USEPA criteria and the summary of Region 9 RTAG water quality monitoring data in Table 8. The model results for the Santa Margarita are generally similar to the USEPA ecoregional criteria.

Table 8. Comparison of Model Results to USEPA Ecoregional Nutrient Criteria Recommendations and Region 9 RTAG Water Quality Monitoring Data

Chemical	Stream Type	Proposed USEPA 304(a) Criterion	Region 9 RTAG Water Quality Monitoring Data (Tetra Tech 2004)				
			Median	Average	Lower Quartile	Upper Quartile	No of Data points
TN	Minimally Impacted		0.25	0.31	0.13	1.20	156
(mg/l)	Unimpaired		0.40	1.01	0.20	42.70	1425
	Impaired (nutrient)		0.7	1.06	0.40	11.00	868
	Impaired (other)		0.6	0.97	0.30	33.00	1486
	EPA 401(a) (US EPA 2000)	0.50					10
	CA NNE Scoping Tool	0.23 – 0.80					
TP	Minimally Impacted		0.08	0.08	0.03	0.30	34
(mg/l)	Unimpaired		0.07	0.36	0.01	24.80	633
	Impaired (nutrient)		0.13	0.77	0.05	7.94	525
	Impaired (other)		0.07	0.34	0.03	45.10	1069
	EPA 401(a) (US EPA 2000)	0.03			0.02		23
	CA NNE Scoping Tool	0.0071 – 0.036					

4 Suggested Targets

4.1 RESPONSE TARGETS

The California NNE Approach (Tetra Tech, 2006) recommends setting response targets for benthic algal biomass in streams based on maximum density as mg/m^2 chlorophyll *a*. For the COLD beneficial uses, the recommended BURC I/II boundary is 100 mg/m^2, while the BURC II/III boundary is 150 mg/m^2. While quantitative measures of benthic algal density are not available, existing conditions in the Santa Margarita appear to be above the BURC II/III boundary, suggesting impairment of these uses.

Of particular interest for the Santa Margarita ecosystem, the risk of nuisance growth of *Cladophora* increases with increasing maximum benthic chlorophyll *a*. Welch et al. (1988) found that 20 percent or more cover by filamentous green algae was correlated with maximum benthic chlorophyll *a* greater than 100 mg/m^2, while Horner et al. (1983) concluded that biomass levels greater than 150 mg/m^2 often occurred with enrichment and when filamentous forms were more prevalent.

Another response target relevant to nutrients in the Santa Margarita River is dissolved oxygen (DO). The Water Quality Control Plan (CRWQCBSD, 1994) states the following: "Dissolved oxygen levels shall not be less than 5.0 mg/L in inland surface waters with designated MAR or WARM beneficial uses or less than 6.0 mg/L in waters with designated COLD beneficial uses. The annual mean dissolved oxygen concentration shall not be less than 7 mg/L more than 10% of the time." The continuous monitoring by SMER shows that excursions of both the 5 and 6 mg/L criteria occur frequently in summer at the low point of the daily diurnal cycle in the Santa Margarita. Further, saturation DO concentrations under late summer conditions are around 7.5 mg/L, allowing only 1.5 mg/L of DO deficit to meet the COLD use and 2.5 mg/L to meet the WARM use.

Maximum algal densities predicted by the benthic biomass tool are consistent with contributions to the diurnal DO deficit of 2 – 3 mg/L, while meeting the algal density targets for COLD and WARM uses would reduce the contribution to DO deficit to the appropriate range for the use, according to the simplified DO deficit calculations incorporated in the tool.

Algal response to nutrients in the Santa Margarita Estuary is also a relevant response target. Responses in the estuary are believed to depend more on net loading of nutrients to the estuary than on concentrations in the river (Marcus et al., 1994). Achieving acceptable rates of nutrient loading to the estuary may require further reductions in nutrient concentrations in the river. The NNE approach for estuaries, however, is still under development and targets based on estuarine response are not considered in this case study.

4.2 Nutrient Targets

The NNE Benthic Biomass Predictor spreadsheet can be used to translate the response targets into nutrient concentration goals. The model applications shown in Section 3.2 suggest that reductions in nutrient concentrations beyond the general goals provided in the basin plan may be necessary to meet response targets in the Santa Margarita River. However, the tool application is uncalibrated at this time, and different models and options in the tool lead to different predictions of nutrient targets. Development of quantitative nutrient targets based on benthic algal response in the Santa Margarita River should include the collection of appropriate data on existing benthic algal density to allow examination and calibration of model predictions. Ultimate nutrient concentration targets in the Santa Margarita River may also be constrained by loading limits necessary to support uses in the Santa Margarita Estuary.

5 Summary

The NNE benthic biomass tool was successfully applied to the Santa Margarita River and suggest the need for lowering nutrient concentrations from those present in 1986-2001 to support uses based on benthic algal response. Unfortunately, no monitoring data on benthic chlorophyll *a* in the system has been located; however, qualitative information on *Cladophora* mats and large diurnal swings in DO and pH suggest that uses in the river are indeed threatened by excess benthic algal growth

The California NNE approach is a risk-based approach, with ultimate focus on supporting designated uses. The general NNE guidance and accompanying tools provide initial, scoping-level estimates of nutrient reduction targets that can be used as a *starting* point for a TMDL or nutrient management plan.

More sophisticated site-specific nutrient targets can be derived from the response targets through the use of calibrated, site-specific models. If adequately calibrated, the site specific model can be used to set nutrient targets for the Santa Margarita. Calibration of the benthic algal component of the modeling will require collection of data on periphyton densities.

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