Nutrient Numeric Endpoint Analysis for the Klamath River, CA

Prepared for:

U.S. EPA Region IX

and

North Coast Regional Water Quality Control Board

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1 Introduction: The California NNE Approach

The Klamath River in California is listed as impaired for temperature, nutrients, and low DO/organic enrichment. The North Coast Regional Board is developing TMDLs in collaboration with Oregon and USEPA to address these impairments. For TMDL development, Tetra Tech is applying a set of linked simulation models consisting of CE-QUAL-W2 (for reservoirs) and RMA (for free-flowing reaches). The TMDL runs have primarily addressed numeric criteria for DO and temperature.

Tetra Tech, under contract to EPA Region IX and the California State Water Resources Control Board also developed an approach for calculating nutrient numeric endpoints (NNE) for use in California Water Quality Programs (Tetra Tech, 2006). The "Technical Approach to Develop Nutrient Numeric Endpoints for California," referred to as the California NNE approach, is 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 but effective spreadsheet tools for application in lake/reservoir or riverine systems to assist in evaluating the translation between response indicators and nutrient concentrations or loads.

One important use of the NNE is for setting initial nutrient endpoints for waterbodies requiring nutrient TMDLs. Tetra Tech (2007), under contract with USEPA, conducted a case study of potential NNE endpoints on the Klamath River. That study, "Nutrient Numeric Endpoints for TMDL Development: Klamath River Case Study", addressed only periphyton in the riverine portion of the watershed and used water quality data for 2000-2003, coupled with periphyton observations from 2004. Since that time, significantly more data have become available, and corrections have been made to earlier data. At the request of the North Coast Regional Water Quality Control Board, USEPA has funded this follow-on study. The two major purposes are (1) to extend the NNE analysis to the two reservoirs (Iron Gate and Copco) on the California portion of the Klamath system, and (2) to update the stream periphyton analysis to reflect more recent and corrected data.

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2 Iron Gate and Copco Reservoirs

2.1 USES AND IMPAIRMENTS

Beneficial uses of Copco and Iron Gate reservoirs are defined in the Water Quality Control Plan (NCRWQCB, 2007) and are summarized in Table 1. Both existing and potential uses are protected. Uses related to the protection of endangered salmonid fish species (COLD, RARE, MIGR, SPWN) are of particular interest to many stakeholders in the Klamath River system.

Table 1. Beneficial Uses of Copco and Iron Gate Reservoirs

Code	Use	Copco	Iron Gate
MUN	Municipal and Domestic Supply	E	P
AGR	Agricultural Supply	E	P
IND	Industrial Service Supply	E	P
PRO	Industrial Process Supply	P	P
FRSH	Freshwater Replenishment	E	E
NAV	Navigation	E	E
POW	Hydropower Generation	E	E
REC1	Water Contact Recreation	E	E
REC2	Non-Contact Water Recreation	E	E
COMM	Commercial and Sport Fishing	E	E
WARM	Warm Freshwater Habitat	E	E
COLD	Cold Freshwater Habitat	E	E
WILD	Wildlife Habitat	E	E
RARE	Rare, Threatened, or Endangered Species	E	E
MIGR	Migration of Aquatic Organisms	E	E
SPWN	Spawning, Reproduction, and/or Early Development	E	E
SHELL	Shellfish Harvesting	NA	E
AQUA	Aquaculture	E	E

Notes: E - Existing Use; P - Potential Use; NA - Use not applicable.

California's 2006 Section 303(d) list identified the Klamath River hydrologic unit from the Oregon border to Iron Gate (including both Iron Gate and Copco reservoirs) as impaired due to nutrients, organic enrichment/low dissolved oxygen, and temperature.

By letter of 13 March 2008, Alexis Strauss, Director, Water Division, USEPA Region IX determined that, in addition to this listing, "one Klamath River segment is impaired due to the presence of elevated concentrations of microcystin toxins, specifically the Oregon to Iron Gate segment which includes the Copco and Iron Gate reservoirs." EPA's decision came in response to a suit filed by the Klamath

Riverkeeper on 30 July 2007 (*Klamath Riverkeeper v. USEPA,* Docket No. C 07-3908 (SBA) (N.D. Cal.)). Microcystins are a class of toxic chemicals produced by some strains of the cyanobacteria *Microcystis aeruginosa* that are released into waters when cyanobacterial cells die or cell membranes degrade. These chemicals are a human health risk, capable of inducing skin rashes, sore throat, oral blistering, nausea, gastroenteritis, fever, and liver toxicity (USEPA Region IX, 2008). Microcystin toxins have also been shown to produce effects on animals including acute livestock poisoning and tumor production in fish guts and liver. Microcystin can thus potentially impair a number of beneficial uses of a waterbody. While California has not established numeric water quality objectives for microcystin toxins, EPA based its decision on observations that exceed the World Health Organization guidelines for moderate probability of adverse health effects of microcystin concentrations above 20 µg/L in recreational waters (WHO, 2003), resulting in impairment of the REC-1 beneficial use and the narrative toxicity objective for Iron Gate and Copco reservoirs.

2.2 POTENTIAL NNE TARGETS

Nutrient concentrations in Iron Gate and Copco reservoirs, along with associated physical conditions, are associated with the formation of summer algal blooms, including the formation of extensive blooms of the cyanobacteria *Microcystis aeruginosa*. Algal blooms in the Klamath reservoirs potentially impact designated beneficial uses in a number of ways, including the following linkages between algal growth and beneficial use impairment:

1. The presence of visible algal blooms can directly impact contact and non-contact recreational uses (REC1, REC2) by creating unaesthetic conditions and unpleasant conditions for contact recreation. This is foremost a function of the total algal biomass present during blooms, but a given biomass of cyanobacteria that form visible scums or mats may present a greater problem than a comparable biomass of planktonic algae.
2. Microcystin toxins, produced by blooms of *Microcystis aeruginosa*, have been determined by EPA to cause impairment in the reservoirs. The beneficial uses threatened by elevated microcystin levels include MUN, AGR, REC1, REC2, COMM, WARM, COLD, WILD, RARE, MIGR, SPWN, AQUA and SHELL.
3. Excess algal growth disrupts the dissolved oxygen (DO) balance, leading to super-saturation during daylight periods of high productivity, and depletion of DO during nighttime respiration and as a result of the decay of dead biomass in the water column. Excess productivity typically results in an increase in organic matter loading to the bottom (hypolimnetic) waters of a reservoir, resulting in rapid DO depletion during stratified conditions. In addition, there can be a self-reinforcing feedback loop, as oxygen depletion at the sediment-water interface can promote the release of phosphorus and ammonium from the sediment, which in turn can support additional algal growth. High algal densities can also disrupt pH, as CO_2 is consumed during the day (at depths with sufficient light for photosynthesis) and released during nighttime respiration. Algal-induced changes to the DO balance can thus impair REC1, REC2, COMM, WARM, COLD, WILD, RARE, SPWN, and AQUA beneficial uses.
4. Excess algal growth results in an increase in the export of organic matter from the reservoirs, which in turn can exert an oxygen demand and potentially impair the DO balance and associated beneficial uses in the stretches of the Klamath River downstream from the reservoirs. On the other hand, algal uptake and settling may reduce the transport of inorganic nutrients downstream during the growing season, potentially mitigating impacts in the reaches below the reservoirs.
5. Conditions that lead to dominance by cyanobacteria in the plankton community can have adverse effects on the fishery (other than direct toxicity), as cyanobacteria generally support a much less rich population of planktonic invertebrates, which in turn support forage and juvenile game fish

populations. This potentially affects REC2, COMM, WARM, COLD, WILD, RARE, and SPWN uses.

Of these five impact linkages, the current TMDL effort, driven by the Consent Decree schedule, focuses on numbers 3 and 4, specifically addressing the need to meet DO (as well as temperature) numeric criteria. For these impacts, the target is already established in the numeric water quality criteria.

The required reductions in nutrient and organic matter loads to meet DO criteria will also reduce impacts associated with the other three impact linkages, but are not developed to specifically address these issues. These three risk hypotheses involve narrative, rather than numeric criteria. The Basin Plan contains the following statements of objectives relevant to nutrients in the Klamath:

> ***Biostimulatory Substances***
>
> *Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.*
>
> ***Toxicity***
>
> *All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life. Compliance with this objective will be determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, bioassays of appropriate duration, or other appropriate methods as specified by the Regional Water Board.*

EPA, in establishing the 303(d) listing for microcystin toxins, cites WHO guidance on microcystin targets. However, the scientific understanding does not seem to be sufficiently advanced to translate microcystin levels into quantitative target levels of *Microcystis* biomass or biovolume. As stated in the 2008 EPA staff report

> “WHO used a number of studies to estimate an approximate microcystin concentration that would be expected from a given cell density of *Microcystis aeruginosa*. However, WHO acknowledges that the cyanobacterial cell density may not be a reliable proxy for microcystin toxin concentrations, because different cyanobacterial strains may be present and their genetic capacity may not produce toxins. In fact, some blooms of *Microcystis aeruginosa* may produce little to no microcystin toxins… For Section 303(d) purposes, EPA considered the cyanobacterial cell density results as part of our assessment but we did not rely on this ancillary information as definitive evidence of corresponding ambient concentrations of microcystin toxins.”

Further, quantitative prediction of *Microcystis* cell density as a function of nutrient loading is exceedingly difficult, as it involves a combination of the total potential algal growth supported by nutrient loads, the factors that may promote cyanobacterial dominance within the planktonic algal community, and the factors that may enable *Microcystis* to out-compete other cyanobacteria. To achieve narrative standards and protect beneficial uses, linkage (1) requires an appropriate limit on total algal biomass, linkage (5) requires control of cyanobacterial dominance within blooms, and linkage (2) requires control of toxin-producing strains of *Microcystis* within cyanobacterial blooms. Notably, the risks associated with impact linkages (2) and (5) would also be controlled if the general risk of algal blooms was reduced.

Proposed nutrient numeric endpoints developed for the draft CA NNE framework are expressed as two numbers: the boundary between BURC I/II, indicating a concentration below which impacts are unlikely, and the boundary between BURC II/III, indicating a concentration above which impacts are likely. Table 3-2 in Tetra Tech (2006) recommended algal density targets for summer average chlorophyll *a*. These proposed targets were selected by Regional and State Board staff, based on input from Tetra Tech, at the State Water Board Nutrient Numeric Training Workshop held on May 18-19, 2005 in Sacramento, CA, as shown in Table 2.

Table 2. Proposed CA NNE Planktonic Algal Biomass Targets in Lakes and Reservoirs (as µg/L chlorophyll *a* expressed as a summer mean)

Risk Category Boundary	Beneficial Use				
	COLD	WARM	REC1	REC2	MUN
I/II	5	10	10	10	5
II/III	10	25	20	25	10

The most restrictive recommendations are for the COLD and MUN beneficial uses, both of which apply to Copco and Iron Gate reservoirs. Therefore, the BURC II/III boundary of 10 µg/L summer average chlorophyll *a* provides one potential target for managing these reservoirs. It should be noted, however, that the CA NNE targets are still in draft form, and have not been adopted by the State Board or incorporated into the North Coast Water Quality Control Plan at this time.

The CA NNE document (Tetra Tech, 2006) also considered cyanobacterial density as a potential target, but did not propose specific BURC boundary values. One potential target for cyanobacteria would be to reduce the frequency of cyanobacterial dominance. For example, British Columbia states that waters classified for primary recreation and aquatic life uses should have planktonic populations consisting of less than 50 percent of cyanobacterial cells by volume (MELP, 1992). Volumetric predictions are difficult with simple models, and Downing et al. (2001) instead recommend a target of less than 50 percent of total algal biomass for cyanobacteria. Their work demonstrated that there is typically a rapid phase change between low cyanobacteria densities (less than 20 percent of biomass) to cyanobacterial dominance (> 80 percent of biomass) as nutrient concentrations and total phytoplankton biomass increase. Cyanobacterial dominance is also conveniently expressed using the BG index (BGI), where BGI = ln(%BG/(100 - %BG)), in which %BG is the cyanobacterial biomass expressed as a percentage of the total algal biomass (Trimbee and Prepas, 1987). The 50 percent breakpoint is equivalent to BGI = 0, while values greater than zero indicate increasing cyanobacterial dominance. Downing et al. also found that the risk of greater than 50% cyanobacteria in individual lakes increased proportionately with the BGI.

Downing et al. also undertook regression analysis for prediction of BGI, using data from 99 lakes around the world. Contrary to expectation, they found that TN/TP ratio was not a good predictor of BGI (R^2=26%). The best predictors were phytoplankton biomass, total chlorophyll *a*, and total nitrogen, with R^2 value of 42-43 percent. Total phosphorus was also a better predictor of BGI than TN/TP (R^2 = 34%). The authors argue that "the most potentially useful of these relationships is that with total P, because total P predicts phytoplankton biomass…and discriminates incisively the lakes dominated by Cyanobacteria…," although the correlation coefficient is decreased by a few outliers and a nonlinear asymptote. The equations for predicting BGI from TN and TP are given as follows:

$$\mathrm{BGI} = -10.0 + 3.03 \log_{10} \mathrm{TN}$$

$$\mathrm{BGI} = -4.16 + 1.88 \log_{10} \mathrm{TP}$$

In sum, management of Iron Gate and Copco reservoirs to achieve designated beneficial uses appears to require some or all of the following: controls on total algal biomass, the percent of cyanobacteria within total algal biomass, and the dominance of *Microcystis* within the cyanobacterial population.

2.3 APPLICATION OF NNE SCOPING TOOLS

The NNE BATHTUB scoping tool was applied to Copco and Iron Gate reservoirs for the two years of 2002 and 2005, selected because these are the years for which extensive monitoring data are available.

After documenting a reasonable agreement with observations, the tool was then applied to the 2000 TMDL model year.

2.3.1 BATHTUB Tool

In support of the CA NNE approach, Tetra Tech developed a spreadsheet application of the U.S. Army Corps of Engineers BATHTUB model (Walker, 1996) to establish screening level nutrient loading targets for lakes and reservoirs by estimating algal response to nutrient loading. BATHTUB is a steady-state model that calculates nutrient concentrations, chlorophyll *a* concentrations (or algal densities), turbidity, and hypolimnetic oxygen depletion based on nutrient loadings, hydrology, lake morphometry, and internal nutrient cycling processes. It explicitly addresses conditions in run-of-river, and short residence time reservoirs. BATHTUB uses a steady-state mass balance model approach that estimates the distribution of external and internal nutrient loads between the water column, outflows, and sediments. External loads can be specified from various sources including stream inflows, nonpoint source runoff, atmospheric deposition, groundwater inflows, and point sources. Internal nutrient loads from cycling processes may include sediment release and macrophyte decomposition. Since BATHTUB is a steady-state model, it focuses on long-term average conditions rather than day-to-day or seasonal variations in water quality. Algal concentrations are predicted for the summer growing season when water quality problems are most severe. Annual differences in water quality, or differences resulting from different loading or hydrologic conditions (e.g., wet vs. dry years), can be evaluated by running the model separately for each scenario.

BATHTUB first calculates steady-state phosphorus and nitrogen balances based on nutrient loads, nutrient sedimentation, and transport processes (lake flushing, transport between segments). Several options are provided to allow first-order, second-order, and other loss rate formulations for nutrient sedimentation that have been proposed from various nutrient loading models in the literature. The resulting nutrient levels are then used in a series of empirical relationships to calculate chlorophyll *a*, oxygen depletion, and turbidity. Phytoplankton concentrations are estimated from mechanistically based steady-state relationships that include processes such as photosynthesis, settling, respiration, grazing mortality, and flushing. Both nitrogen and phosphorus can be considered as limiting nutrients, at the option of the user. Several options are also provided to account for variations in nutrient availability for phytoplankton growth based on the nutrient speciation in the inflows. The empirical relationships used in BATHTUB were derived from field data from many different lakes, including those in EPA's National Eutrophication Survey and lakes operated by the Army Corps of Engineers. Default values are provided for most of the model parameters based on extensive statistical analyses of these data.

It is important to emphasize that the model is a simple screening tool for prediction of average conditions, and that more informative results can be obtained from more detailed, calibrated models. However, BATHTUB's ease of use makes it ideal for rapid evaluation of potential nutrient-algal interactions.

2.3.2 Data Assembly

BATHTUB application to Copco and Iron Gate reservoirs addressed conditions observed near the dams, representing each reservoir as a single longitudinal segment with a stratified water column. Relatively intensive monitoring data for the two reservoirs exists for 2002 and 2005. These data, along with an analysis of mass balances, are presented in Kann and Asarian (2005), and Kann and Asarian (2007). Due to very short residence times in the winter high-flow season, summer algal concentrations in these reservoirs are most strongly affected by loading in and shortly prior to the growing season, consistent with the recommendations of Walker (1996). Flows and loads were therefore calculated for April to September in 2002 and May to September in 2005 (data are not available for April 2005), based on the results calculated by Kann and Asarian, as shown in Table 3.

Table 3. Flow and Nutrient Data for BATHTUB Application

	Copco		Iron Gate	
	2002 (Apr-Sep)	**2005 (May-Sep)**	**2002 (Apr-Sep)**	**2005 (May-Sep)**
Inflow (hm^3)	434	379	532	402
TP Load (kg)	119,380	59,000	122,300	53,700
TN Load (kg)	480,710	545,100	511,500	421,400
TIP Load (kg)	71,489	35,331	79,925	35,094
TIN Load (kg)	182,031	206,414	130,586	107,583
Summer TP (mg/L)	0.24	0.15	0.19	0.13
Summer TN (mg/L)	1.14	1.23	1.19	1.01
Summer Chlorophyll *a* (µg/L)	8.3	12.2	19.5	19.2

2.3.3 BATHTUB Application

Both Copco and Iron Gate reservoirs are known to have low net trap efficiency for nutrients, due to a combination of short residence times and apparent nutrient regeneration from the sediments under stratified conditions (Butcher, 2008). Kann and Asarian (2007) estimated that Copco Reservoir (for 2004-2005 conditions) retained about 9 percent of influent TN and TP, while Iron Gate retained about 3 percent of influent TP and 10 percent of influent TN. The TMDL model estimated (for 2000 conditions) that Copco retained about 1 percent of TP and 4 percent of TN, while Iron Gate retained about 6 percent of TP and 18 percent of TN. The low net retention rates suggest that net sedimentation rates should be lower than the defaults specified for the BATHTUB scoping tool. Accordingly, the TN and TP sedimentation calibration factors were set to 0.1.

With the revised sedimentation factors, the BATHTUB scoping tool provides a good representation of summer average TN and TP observed in the epilimnion near the dam in both reservoirs (Figure 1 and Figure 2). The model also captures the spatial gradient from Copco to Iron Gate and the relative temporal change between 2002 and 2005 conditions for TP.

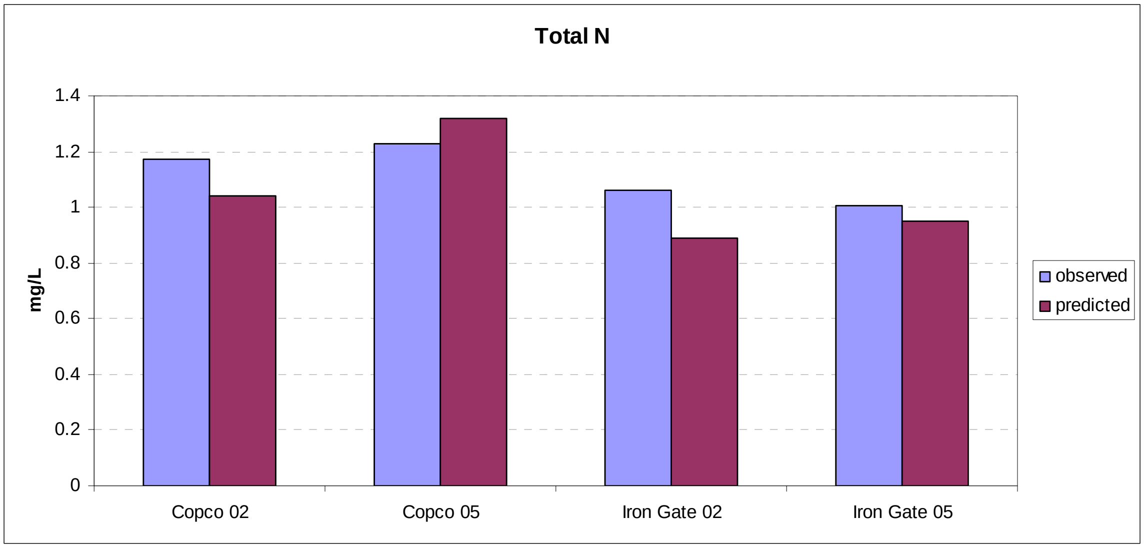


Figure 1. Observed and Predicted Total Nitrogen Concentrations in Copco and Iron Gate Reservoirs

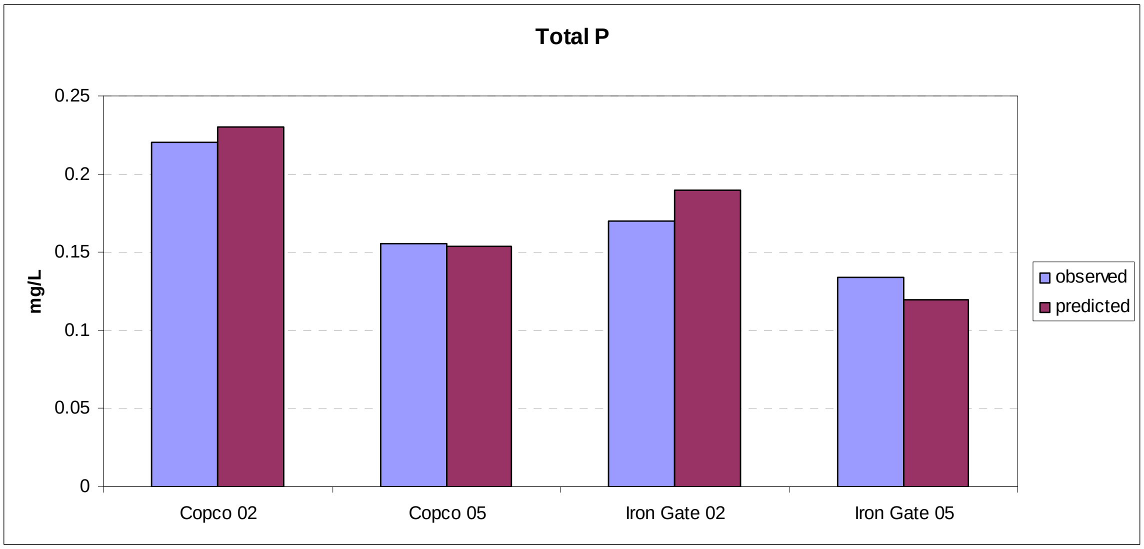


Figure 2. Observed and Predicted Total Phosphorus Concentrations in Copco and Iron Gate Reservoirs

Chlorophyll *a* results were generated without any changes to the default calibration factor of 1.0, and provide a reasonable match to observations (Figure 3). Given that chlorophyll *a* concentrations are highly variable in space and time, as well as the fact that chlorophyll *a* measurements may provide an imprecise measure of cyanobacterial density, these results are considered reasonable. In particular, small samples from right-skewed distributions, such as is typically observed for chlorophyll *a*, are prone to under-estimate the true mean concentration. Predictions for Copco could be brought closer in line with observations by decreasing the chlorophyll *a* calibration factor; however, the quantity and precision of available data do not appear to be sufficient to warrant such fine-scale adjustments.

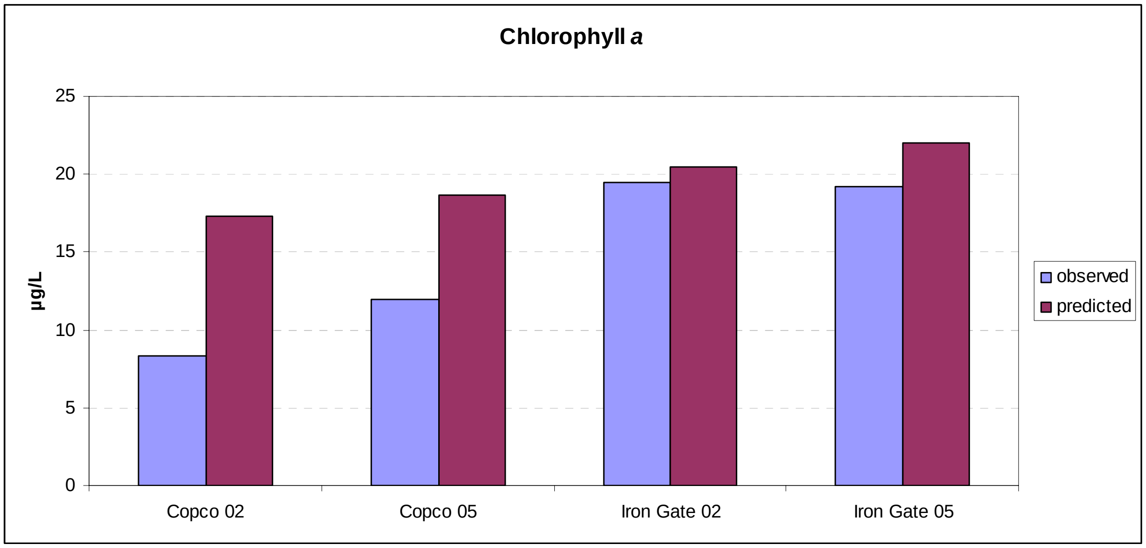


Figure 3. **Observed and Predicted Chlorophyll *a* Concentrations in Copco and Iron Gate Reservoirs**

The scoping model also predicts the exceedance probability for different concentration levels, based on the coefficient of variation (CV, standard deviation normalized to the mean) of concentrations. Results using the BATHTUB default CV (in natural log space) of 0.42 are shown in Figure 4, suggesting that occasional blooms in excess of 100 µg/L are consistent with the predicted summer average concentrations in Iron Gate, as well as in Copco Reservoir.

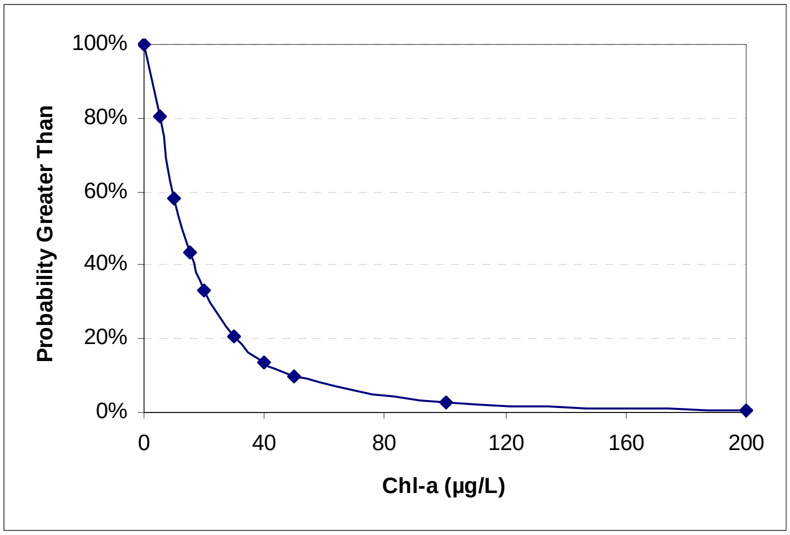


Figure 4. **Predicted Distribution Curve for Chlorophyll *a* in Iron Gate Reservoir, 2005**

Downing et al.'s (2001) regression equations for BGI as a function of TN and TP concentrations were applied to the predicted nutrient concentrations, and suggest that the algal community is likely to include a significant fraction of cyanobacteria on average (Table 4). The percentage of cyanobacteria predicted from TN concentrations is consistently lower than that predicted from TP concentrations, but both relationships indicate a potential for episodic cyanobacterial blooms, increasing the risk for microcystin toxin production.

Table 4. Cyanobacterial Dominance Predicted for Copco and Iron Gate Reservoirs

	Copco 2002	Copco 2005	Iron Gate 2002	Iron Gate 2005
BGI-P	0.27	-0.15	0.14	-0.27
Cyanobacteria % from BGI-P	56.7%	46.3%	53.5%	43.2%
BGI-N	-0.85	-0.54	-1.06	-0.98
Cyanobacteria % from BGI-N	29.8%	36.7%	25.7%	27.3%

Note: The "Blue Green Index" (BGI) is calculated using the regression relationships presented by Downing et al. (2001).

Application of the spreadsheet tool for year 2000 based on flows and nutrient loads predicted by the Klamath TMDL model yield similar results, with growing season average chlorophyll *a* estimated at 19.7 µg/L for Copco and 23.2 µg/L for Iron Gate. The cyanobacterial fractions of algal biomass are estimated at 64.0 and 59.9 percent using BGI-P, and 39.2 and 30.2 percent using BGI-N.

2.3.4 Potential Nutrient Numeric Endpoints

The BATHTUB scoping tool solves for combinations of TN and TP loading that are consistent with achieving a target growing season average concentration of chlorophyll *a*. Results consistent with achieving the CA NNE recommended BURC II/III boundary of 10 µg/L chlorophyll *a* as a growing season average concentration are shown in Figure 5 for the three years of model application.

The scoping tool predicts that the desired chlorophyll *a* target can be met by reducing phosphorus loading *or* nitrogen loading. The percentage reductions needed to achieve the 10 µg/L target are shown in Table 5. In terms of total algal biomass, it is not necessary to reduce loads of both nutrients to meet the target, as the growth will be controlled by the availability of the most limiting nutrient. These suggest that beneficial uses can be attained by reducing the TP load by approximately 90 percent or by reducing the TN load by approximately 65 percent. However, control by reducing only one nutrient would alter the N:P ratio, and changing the N:P ratio may well have other consequences for algal dynamics in the reservoir, as is discussed further in Section 2.4.

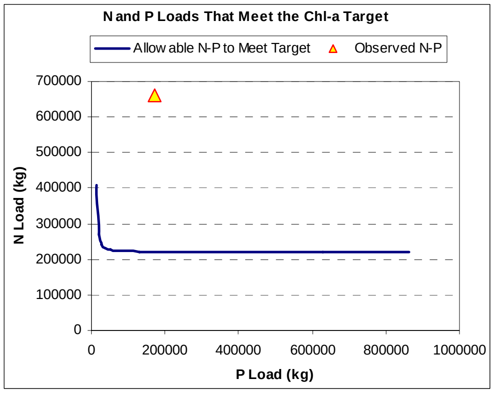
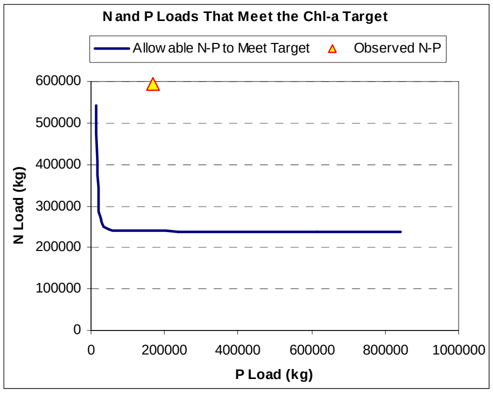
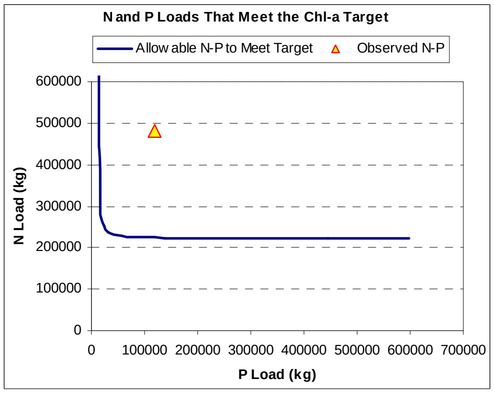
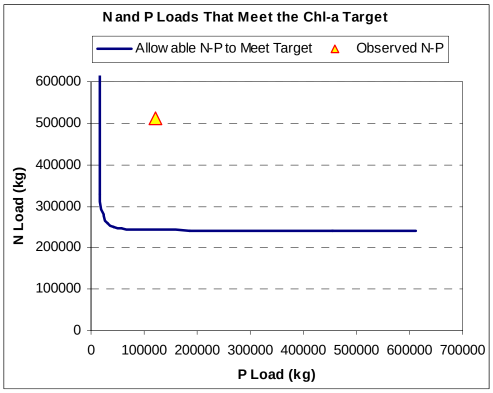
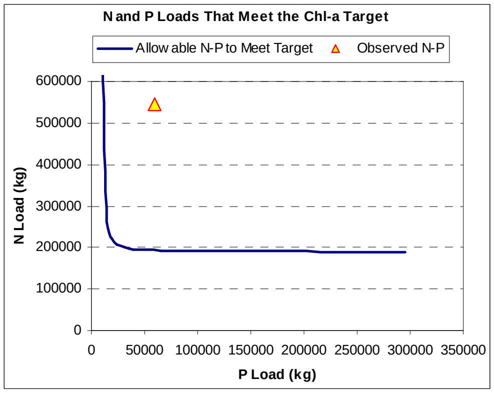
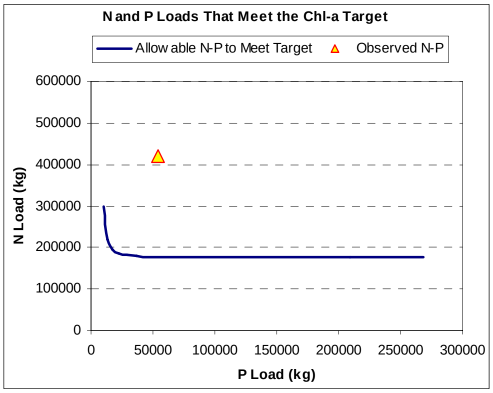
Year	Copco	Iron Gate
2000		
2002		
2005		

Figure 5. Allowable Load Curves to Achieve a 10 µg/L Summer Average Chlorophyll *a* Target

Table 5. Single Component Nutrient Reductions to Achieve a 10 µg/L Summer Average Chlorophyll *a* Target (April-September Loads)

Year	Total Phosphorus		Total Nitrogen	
	Copco	Iron Gate	Copco	Iron Gate
2000	89%	92%	67%	60%
2002	85%	89%	54%	53%
2005	81%	80%	65%	58%

The TMDL model is already calling for significant nutrient reductions to meet DO criteria. Under the dams-in water quality compliance scenario (T4BS1), the April-September 2000 phosphorus loads to Copco are reduced by 89 percent while the nitrogen loads are reduced 73 percent; the reductions in loads to Iron Gate are 88 percent and 74 percent, respectively. Notably, the proposed phosphorus reductions are very similar to those suggested in Table 5, while the proposed total nitrogen reductions in the compliance scenario are greater. Therefore, the T4BS1 scenario developed for dissolved oxygen management would also be expected to meet the algal density target, as developed in this document, to support the COLD and other beneficial uses in Iron Gate and Copco reservoirs.

In addition to reducing the total nitrogen and phosphorus loads, the T4BS1 scenario results in a change in the inorganic fraction of incoming nutrients, with a smaller inorganic fraction, which should also help damp algal response. Application of the BATHTUB tool for 2000 conditions with the T4BS1 nitrogen and phosphorus loads results in a predicted growing season average concentration of 6.6 µg/L in Copco and 4.1 µg/L in Iron Gate. Using Walker's default coefficient of variation for the natural log of chlorophyll *a* of 0.42 suggests that concentrations would be greater than 10 µg/L on 17.4 percent of growing season days in Copco and 2.8 percent of growing season days in Iron Gate.

The T4BS1 scenario also predicts reductions in cyanobacterial populations. With the reduced nutrient and algal settling rates used for BATHTUB application to existing conditions, calculations of the BGI from TN are low (10.8 and 7.2 percent of biomass as cyanobacteria in Copco and Iron Gate, respectively), while the BGI based on TP is reduced to near 25 percent (24.9 and 22.9 percent, respectively).

These results should be considered conservative (that is, including an implicit margin of safety) because the low net sedimentation rates of nutrients assumed for the application to existing conditions have not been altered. In fact, the T4BS1 scenario should result in greater dissolved oxygen concentrations at the sediment-water interface, resulting in lower rates of recycling of nutrients from the sediments, in turn causing higher net sedimentation rates for nutrients. If it is assumed that the effective net sedimentation rates increase to the default values given by Walker, the predicted summer average chlorophyll *a* concentrations in Copco and Iron Gate would decline to 5.0 and 3.0 µg/L, while the predicted cyanobacterial fractions of algal biomass would be 21 and 20 percent, respectively.

Predicted summer average nutrient concentrations in Iron Gate from the BATHTUB scoping tool – relevant to the analysis of downstream effects – are summarized in Table 6 for year 2000 conditions.

Table 6. Summer Average Nutrient Concentrations Predicted for Iron Gate Reservoir (Year 2000 Conditions)

	Existing Loads	T4BS1 Loads with Existing Sedimentation	T4BS1 Loads with Default Sedimentation	Change
TN (mg/L)	1.057	0.288	0.255	-76%
TP (mg/L)	0.267	0.037	0.030	-89%

These BATHTUB results are in good agreement with the CE-QUAL-W2 simulation of concentrations in Iron Gate outflow for the June-September 2000 period. The T4BS1 simulation (without benthic nutrient flux) shows a change relative to existing conditions of -73 percent for TN concentrations and -88.5 percent for TP concentrations.

2.4 MANAGEMENT TO REDUCE *MICROCYSTIS* BLOOMS IN RESERVOIRS

Conditions in Iron Gate and Copco reservoirs, including the risk of microcystin toxins, can clearly be mitigated by a general decrease in eutrophication potential, which would in turn reduce the frequency of cyanobacterial blooms, including *Microcystis* blooms. Other potential strategies to address microcystin levels include control of cyanobacterial dominance within blooms, and control of toxin-producing strains of *Microcystis* within cyanobacterial blooms. As demonstrated by Downing et al. (2001), the risk of cyanobacterial dominance increases with increasing levels of TN, TP, and algal biomass, and is also best addressed through a general reduction in eutrophication potential.

Many Cyanobacteria are able to control buoyancy, enabling them to alternate between light-rich (but nutrient poor) surface waters and nutrient rich (but light poor) waters lower in the water column, yielding a competitive advantage against passively floating algal species (Hyenstrand et al., 1998). Many bloom-forming Cyanobacteria are also able to tolerate higher temperatures than true algae. Lake management strategies that increase vertical mixing (counteracting the cyanobacterial buoyancy advantage) and decrease surface water temperatures may thus be useful pieces of an overall control strategy.

Earlier authors (e.g., Smith, 1983) had theorized that a key factor in promoting cyanobacterial dominance was a low N:P ratio, as many bloom-forming Cyanobacteria can fix atmospheric N_2 (although not *Microcystis aeruginosa*). Downing et al. demonstrate that this ratio is not a good predictor of cyanobacterial dominance.

While the N:P ratio is not a good predictor of general cyanobacterial dominance, it may play an important role in competition between different species of Cyanobacteria. Significantly, *Microcystis aeruginosa* does not fix atmospheric nitrogen, but the competing cyanobacterium *Aphanizomenon* does – suggesting that manipulation of nutrient ratios could cause a shift within cyanobacterial blooms from the toxin-producing *Microcystis* to non-toxin producing *Aphanizomenon*. Moisander et al. (2008) recently reported results of ongoing nitrogen and phosphorus fertilization experiments in Iron Gate and Copco using in-lake incubation chambers. Addition of inorganic nitrogen resulted in an increase in total phytoplankton biomass, *Microcystis* abundance, and microcystin concentrations under both high and low light conditions. Phosphorus additions increased *Microcystis* abundance only under low light conditions, whereas the addition of nitrogen or phosphorus decreased the relative abundance of *Aphanizomenon* by promoting growth of *Microcystis*. Based on this research, Moisander concluded that inputs of dissolved inorganic nitrogen to the reservoirs during the summer season are maintaining and increasing toxic blooms of *Microcystis*, and that reduction of nitrogen inputs to the reservoirs would reduce blooms of *Microcystis*. This suggests that management by reduction of nitrogen loads would yield dual benefits by both reducing the total algal biomass and shifting the cyanobacterial population away from *Microcystis* toward *Aphanizomenon*. The work is ongoing, and may yield valuable insights into optimal management of the reservoirs.

In sum, the proposed nutrient reductions appear to have good potential to address all five of the linkages between algal growth and beneficial use impairment discussed in Section 2.2.

1. Frequency of visible algal blooms will be reduced as average algal biomass decreases.
2. Production of microcystin toxins should decline as total algal biomass decreases and cyanobacterial dominance within the algal population is reduced.
3. Algal effects on the DO balance will be mitigated, as demonstrated in the existing TMDL model.

4. Export of organic matter downstream will be reduced as algal growth is reduced.
5. Reduction in cyanobacterial dominance will potentially result in a healthier aquatic ecosystem that supports an improved fishery.

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3 Klamath River below Iron Gate

The Klamath River watershed encompasses 15,722 square miles in the states of Oregon and California, flowing from the Cascades in Oregon westerly and southerly to the Pacific Ocean in Del Norte Co., CA (see Figure 6). The analysis in this section addresses the major part of the flowing, freshwater portions of the mainstem Klamath River in California, running from the outlet of Iron Gate Reservoir near the Oregon border in Siskiyou County, CA to the confluence with the Trinity River in Humboldt County, CA and represents a major update to the analysis presented in Tetra Tech (2007).

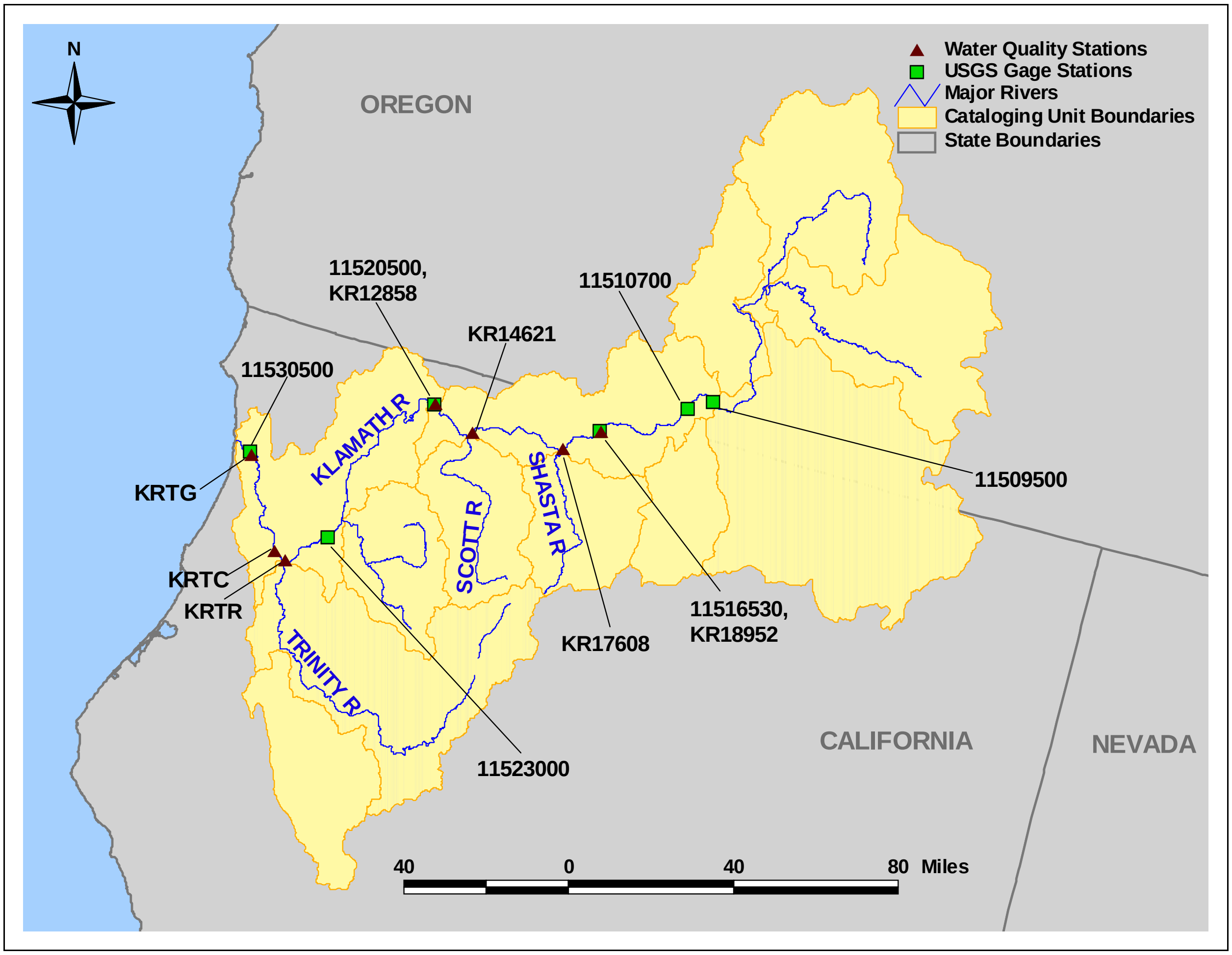

Figure 6. The Klamath River, Showing Selected Water Quality Sampling Stations and Flow Gages on the Lower Klamath River

3.1 USES AND IMPAIRMENTS

The Water Quality Control Plan (NCRWQCB, 2007) establishes multiple beneficial uses for the Klamath River below Iron Gate Reservoir (Table 7). A small portion of the river just upstream of the confluence with Trinity River is under the jurisdiction of the Hoopa Valley Tribe, while much of the Klamath River downstream of the Trinity River is under jurisdiction of the Yurok Tribe.

Table 7. Beneficial Uses of Klamath River below Iron Gate Reservoir

Code	Use	Status
MUN	Municipal and Domestic Supply	E
AGR	Agricultural Supply	E
IND	Industrial Service Supply	E
PRO	Industrial Process Supply	E
FRSH	Freshwater Replenishment	E
NAV	Navigation	E
POW	Hydropower Generation	E
REC1	Water Contact Recreation	E
REC2	Non-Contact Water Recreation	E
COMM	Commercial and Sport Fishing	E
WARM	Warm Freshwater Habitat	E
COLD	Cold Freshwater Habitat	E
WILD	Wildlife Habitat	E
RARE	Rare, Threatened, or Endangered Species	E
MIGR	Migration of Aquatic Organisms	E
SPWN	Spawning, Reproduction, and/or Early Development	E
AQUA	Aquaculture	P
CUL	Native American Culture	E

Notes: E - Existing Use; P - Potential Use; NA - Use not applicable.

California's North Coast Regional Water Quality Control Board has included the free-flowing portion of Klamath River down to the Trinity River on its Clean Water Act Section 303(d) list of impaired waters. Identified impairments include excursions of criteria for nutrients, temperature, and organic enrichment/low DO for segments of the river in California, which are classified for COLD and SPWN beneficial uses.

3.2 POTENTIAL NNE TARGETS

Nutrient loading in the Klamath River produces high levels of periphytic algae. The Hoopa Valley Tribal Environmental Protection Agency has adopted periphyton criteria for the reach of the Klamath River within the Hoopa Valley Indian Reservation. To date, the North Coast Regional Board has not established targets for this endpoint.

While periphyton is included in the Klamath River TMDL models, limited periphyton data were available for model calibration during the years of interest. Calibration focused largely on DO concentrations and diurnal variability in DO, which implicitly include the effects of periphyton and other aquatic vegetation, rather than calibrating directly to periphyton density.

It is important to evaluate periphyton as a response endpoint for several reasons. First, periphyton affects the balance of DO and pH in the river. Second, excess periphyton growth can directly impair COLD, SPWN, and REC designated uses. Finally, in the Klamath River excess periphyton growth (particularly development of *Cladophora* beds) may present an additional important source of risk for maintenance of a healthy salmonid population. This risk hypothesis is summarized in Kier Associates (2005) as follows:

> …*Ceratomyxa shasta* is a myxozoan parasite that causes major problems for the health of juvenile salmonids in the Klamath River. Infection rates are extremely high and in many years results in the death of significant portion of the juvenile salmonids in the Klamath River. Nichols and Foott (2005) estimated that in 2004, 45% of juvenile fall-run Chinook salmon were infected with *C. Shasta* and that the majority of those fish would not survive, and that impact of a loss of that many fish could rival the 2002 adult fish-kill where over 33,000 adult salmon died.
>
> High nutrient levels may be stimulating luxuriant growth of *Cladophora*, a filamentous green algal species. *Cladophora* beds are a favored habitat for polychaete worms that are a host for *C. Shasta* (Stocking and Bartholomew, 2004). The high incidence of *C. Shasta* in the Klamath River may be due to an increase in polychaete populations caused by an increase in polychaete habitat (Stocking and Bartholomew, 2004)… To reduce the incidence of *C. Shasta* infection in the Klamath River, it may be insufficient to improve pH and D.O. alone to reduce fish stress. It also may require reduction in parasite loads by reducing nutrients to reduce the prevalence of *Cladophora* and hence *C. Shasta*'s polychaete host.

Water quality objectives for DO and pH are defined in basin plans, and the relationship between these endpoints, planktonic algal growth, and nutrients is well addressed in the existing calibrated TMDL model. Where a site-specific calibrated nutrient response model exists, this provides the best means of developing appropriate site-specific nutrient numeric endpoints. The North Coast Regional Water Quality Control Board, however, has not yet proposed criteria for periphyton in this river (although the Hoopa have), and this aspect of nutrient response was not the primary focus of the existing TMDL modeling effort.

The Hoopa Valley Tribal Environmental Protection Agency (Kier Associates, 2005; Hoopa Valley TEPA, 2008) recently adopted periphyton standards for the short section of the lower Klamath River on the Hoopa Valley Reservation at Saints Bar just upstream of Trinity River. In addition to DO and pH, they selected periphyton density as an endpoint for criteria development, and initially recommended a maximum annual periphyton biomass of 100 mg/m^2 of periphyton chlorophyll *a*. The criterion was subsequently revised to read as follows (Hoopa Valley TEPA, 2008):

> *Periphyton -For the Klamath River only (Trinity River standards yet to be developed), the maximum annual periphyton biomass shall not exceed 150 mg chlorophyll* a*/m^2 of streambed area.*

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 and SPWN beneficial uses, the recommended BURC I/II boundary is 100 mg/m^2, while the BURC II/III boundary is 150 mg/m^2. Existing conditions in the Klamath are clearly often above the BURC II/III boundary, indicating impairment of these uses.

Of particular interest for the Klamath, the risk of *Cladophora* (a filamentous green algae) prevalence (and corresponding large polychaete populations) 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. These findings support the use of the BURC boundaries in establishing targets for the Klamath River. The Klamath River was historically mesotrophic (Kier Associates, 2005), and water quality conditions in the lower river are exacerbated by large blooms of nitrogen-fixing cyanobacteria (blue-green algae) in Upper Klamath Lake and in the Klamath reservoirs. This suggests that the BURC II/III boundary of 150 mg/m^2 maximum benthic chlorophyll *a* may be most appropriate for the Klamath. The CA NNE approach, however, also recognizes that nutrients occur naturally, and vary in relationship to soils, geology, and land cover, in some cases potentially resulting in benthic chlorophyll *a* concentrations in excess of 150 mg/m^2 under natural conditions. Where this is the case, the natural condition would supersede the proposed target.

3.3 APPLICATION OF NNE SCOPING TOOLS

The CA NNE approach proposes a numeric target for benthic chlorophyll *a*, which is a secondary or response indicator relative to nutrients. To achieve the target, an analysis is required to link nutrient concentrations or load to benthic algal response. Under a previous Work Assignment, Tetra Tech (2007) developed an analysis of potential nutrient numeric endpoints for the lower Klamath downstream of Iron Gate. That analysis relied on a compilation of nutrient monitoring data through 2004. Since that time, data have become available for 2005-2007, and a detailed review of the monitoring data has resulted in modifications of the data through 2004. The sections that follow thus represent an update, revision, and extension of the previous analysis for the free-flowing reaches of the Klamath River below Iron Gate Dam.

3.3.1 Benthic Biomass Tool

The CA NNE *Technical Approach to Develop Nutrient Numeric Endpoints for California* (Tetra Tech, 2006) includes (Appendix 3) the development of a simplified scoping tool of maximum periphyton density in streams. This NNE Benthic Biomass spreadsheet tool is distributed as an Excel spreadsheet. The tool calculates both algal density under average conditions and benthic chlorophyll *a*. Both are estimated using a variety of methods:

- Dodds (1997) method (both mean and maximum)
- Dodds (2002) method (both mean and maximum, using corrected parameters from 2006 erratum[1])
- Standard QUAL2K Model method (maximum)
- Revised QUAL2K Model method (maximum)
- Revised QUAL2K, with adjustment for days of biomass accrual (maximum)

The maximum algal contribution to dissolved oxygen deficit is also calculated, using the Revised QUAL2K Model method. Lastly, the tool allows the user to supply a target (either algal density or benthic chlorophyll *a*), select a calculation method, and the tool will display a graph of allowable TN and TP to meet the target.

The QUAL2K approach is based on the steady-state limit approximation of the benthic algae simulation contained in version 1 of the QUAL2K model (Chapra and Pelletier, 2003). This simulates benthic algal response to nutrient concentrations and light availability. An estimate of the maximum (spatially averaged) response to a given set of forcing functions is obtained as the steady-state asymptote of the model. Because detailed validation data were not available for California, parameters of the model were

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[1] The original equations appeared in Dodds, W.K., V.H. Smith, and K. Lohman, 2002, Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams (*Can. J. Fish. Aquat. Sci.*, 59:865-874). The equations were corrected in a 2006 erratum (*Can. J. Fish. Aquat. Sci.*, 63: 1190-1191). The Algal Biomass Spreadsheet beginning with v. 13 (2/28/07) incorporates the corrected coefficients provided in the erratum.

adjusted to obtain approximate agreement with the Dodds (2002) empirical model when applied to California EMAP and Regional Board 6 periphyton data (see Tetra Tech, 2006). It should be noted that this approach introduces considerable uncertainty into predictions for individual streams, and development of a calibrated, site-specific model would be preferable when sufficient data are available. Version 2 of QUAL2K (Chapra et al., 2006) contains significant modifications to the simulation of benthic algae, including an evaluation of nutrient limitation based on the Droop model of changes in intracellular nutrient quotas. Our analysis shows, however, that the changes to Version 2 result in only minor changes to the shape of the steady-state solution, and do not improve the ability of the model to match the Dodds predictions.

Tetra Tech (2006) also developed a “revised QUAL2K” method for predicting maximum periphyton biomass – also tuned to the Dodds (2002) results for the California data set. This approach uses the QUAL2K v.1 solution, but assumes that the “available” fraction of total nutrient used in the model varies as a function of concentration:

$$Availability\ Fraction\ (AF) = 1 - \frac{\gamma}{1 + \exp(\alpha - \beta \log_{10} C)}$$

in which α, β, and γ are parameters from a logistic regression model fit to data, as described in Tetra Tech (2006), and *C* is the total nutrient concentration. Availability here represents more than just the inorganic fraction of nutrients, as it may also reflect factors such as mat thickness, vertical gradients in the water column, and temporal variability in the inorganic fraction.

Interestingly, the total effect on the Monod growth limitation can be equivalently expressed as an effect on nutrient availability or as an inverse effect on the half-saturation constant:

$$\phi = \frac{AF \cdot C}{k_s + AF \cdot C} = \frac{C}{k_s / AF + C},$$

in which *AF*, the available fraction, is a function of total nutrient concentration, *C*, and k_s is the constant Monod half-saturation constant used in the standard QUAL2K model.

The NNE Benthic Biomass spreadsheet tool provides a simple, but robust method for relating nutrient concentrations to benthic algal density. Specifically, the maximum spatially averaged periphyton density is predicted as a function of summer nutrient concentrations and other hydrologic and physical characteristics. A variety of established prediction methods are included. These yield results that are generally similar but differ from one another, reflecting the uncertainty that is present in such predictions.

It is important to provide some clarification on the “maximum” density that is predicted by the tool. What the model predicts is the spatially averaged maximal supported response to a given set of forcing conditions, without reductions by grazing or intermittent die off. In other words, it is the average concentration expected under optimal growth conditions for a given set of nutrient concentrations. It is not the maximum point density that can be observed on a single rock, which can be considerably higher. In addition, it should not be considered as the maximum response to average nutrient conditions: if nutrient concentrations fluctuate above average conditions for a sufficient length of time, additional algal growth will likely occur. Finally, it should be noted that the maximum is difficult to observe. Even if accurate spatially averaged densities are measured, they will often be less than the model-predicted maximum. When performing correctly, the tool should provide an approximate upper-bound envelope on spatially averaged observations.

Because the NNE tools provide only a scoping-level analysis of nutrient targets, they may be superseded by a site-specific calibrated nutrient response model where available. The existing Klamath River TMDL models include, but are not calibrated to periphyton. Instead, calibration focused on DO because of concerns regarding the representativeness of the periphyton data that are available from the Klamath, due to small sample size and lack of replication. As noted above, accurate prediction of DO implicitly requires a reasonable representation of periphyton and other aquatic vegetation. Continued and improved periphyton sampling would further strengthen the TMDL model application and allow its extension to quantitative analysis of impacts other than DO.

3.3.2 Data

Data have been collected at many sites on the Klamath River, but few stations have consistent long runs of data. For the purpose of this analysis, seven sites on the mainstem Lower Klamath River in California were selected that had reasonable amounts of water quality and periphyton data. These sites are (see also Figure 6 above):

Table 8. Selected Water Quality Monitoring Stations on the Lower Klamath River

Station Number	Station Name	River Mile
KR18952	Klamath River below Iron Gate Dam	189.52
KR17608	Klamath River above Shasta River	176.08
KR14261	Klamath River above Scott River	142.61
KR12858	Klamath River at Seiad Valley	128.59
KRWE	Klamath River above Trinity River (Weitchpec)	43
KRTC	Klamath River below Trinity River above Tulley Creek	35.5-39.2
KRTG	Klamath River at Turwar	5.79

3.3.2.1 Algal Response Data

USEPA and cooperators undertook four rounds of periphyton sampling in the river in 2004 (Eilers, 2005). The published report describes the results of only one of these sampling rounds; results for the remainder were provided by the North Coast Regional Water Quality Control Board. All four sampling rounds followed the same sampling and analytical methodology.

Results of the periphyton sampling include benthic chlorophyll *a*, percent coverage, wet weight, and ash-free dry weight (AFDW). Unfortunately, the information on periphyton density (benthic chlorophyll *a* and AFDW) was obtained from relatively small and separate samples. Specifically, as described in Eilers (2005), determinations of benthic chlorophyll *a* and AFDW were each made by scraping an area of 25 mm x 75 mm from a single rock. The two measurements were made on separate samples, from separate rocks. Because there is not information from multiple points on multiple transects, the measurements may reflect a considerable amount of local variability, and may not be assumed to be representative of average densities in the reach sampled. Further, as the chlorophyll *a* and AFDW estimates come from separate rocks they are not necessarily paired samples, and inferences regarding the ratio of chlorophyll *a* and AFDW are suspect.

Results of the 2004 sampling are summarized for selected stations in Table 9.

Table 9. Summer 2004 Periphyton Sampling in the Klamath River

Station	Average Periphyton Chlorophyll *a* (mg/m^2)	Maximum Periphyton Chlorophyll *a* (mg/m^2)	Average Ash-Free Dry Weight (g/m^2)	Maximum Ash-Free Dry Weight (g/m^2)	Autotrophic Index (Average)
KR18952 – Klamath River below Iron Gate Dam	304.1	462.0	20.9	33.9	606.3
KR17608 – Klamath River above Shasta River	706.1	186.0	44.8	150.9	528.0
KR14261 – Klamath River above Scott River	120.4	353.0	68.7	141.3	684.6
KR12858 – Klamath River at Seiad Valley	65.5	122.0	25.6	54.4	1,982.2
KRWE – Klamath River above Trinity River	126.4	312.5	84.7	202.0	2,420.9
KRTC – Klamath River below Trinity	8.0	10.6	47.6	106.1	6,283.0
KRTG – Klamath River at Turwar	15.1	15.1	71.4	122.5	1,596.5

Notes: Samples at KR14261 combined with nearby samples from Walker Bridge Rd. Samples at KR17608 combined with nearby samples at Colliers Rest and Cottonwood Creek.

As noted above, the chlorophyll *a* and ash-free dry weight (AFDW) results are obtained from separate samples. Nonetheless, the autotrophic index (AI; ratio of AFDW to chlorophyll *a*) values are generally high, and appear to increase downstream. Collins and Weber (1978) suggest that an AI value greater than 400 is generally representative of "polluted" conditions in which the periphyton contains a high percentage of heterotrophs. In the lower Klamath, the AI values may reflect high levels of input of organic matter from eutrophic reservoirs upstream. The 2004 samples at KRTC and KRTG have very low chlorophyll *a* densities, but moderately high AFDW, suggesting largely heterotrophic communities.

Unfortunately, this sampling effort does not appear to provide a firm basis for calculating the ratio of chlorophyll *a* to AFDW (as mg/g), which is a key parameter for application of the QUAL2K-based prediction methods. The ratios from individual sample events reported by Eilers range from 0.1 to 96 mg/g, well outside of the range expected from algal stoichiometry, with a median of 1.1 and average of 7.1 (Figure 7) – probably due to the fact that the analyses are not from the same samples.

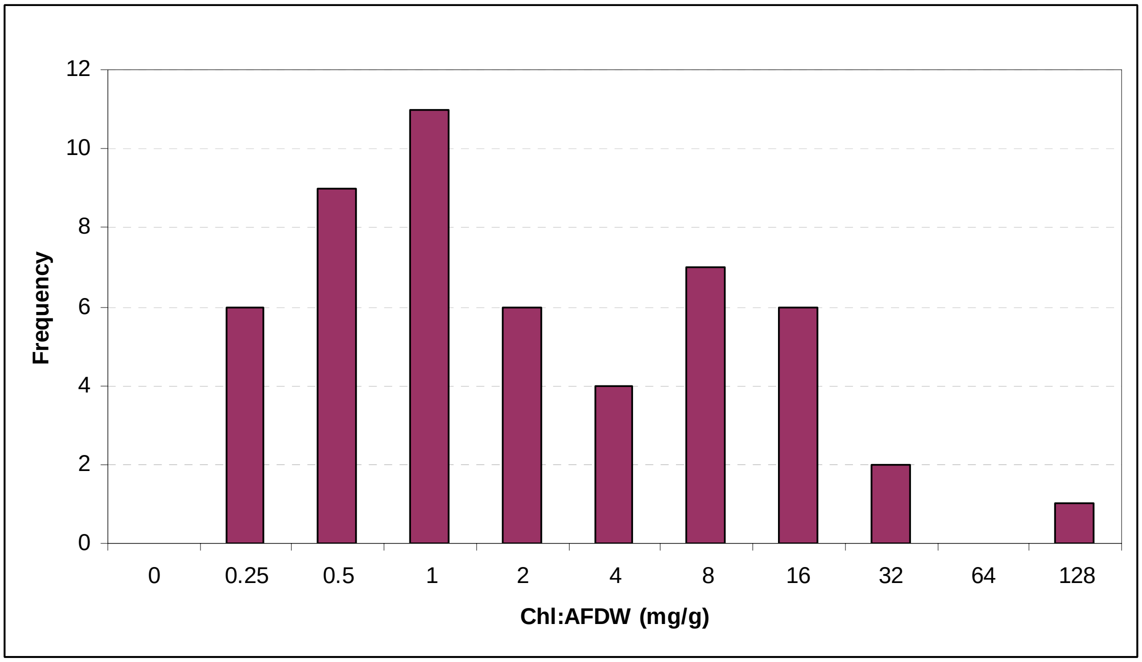

Figure 7. Histogram of Apparent Chlorophyll *a* to AFDW Ratios in 2004 Periphyton Data

Additional periphyton samples were collected by the Yurok Tribe in 2004 and 2006-2007 at KRWE (Weitchpec) and KRTG (Turwar). The 2004 results contain species composition data and AFDW, but not chlorophyll *a*. At KRWE, the average AFDW was 87.2, the maximum 122.5. At KRTG, the average AFDW was 108.2, the maximum 134.5. The 2006-2007 chlorophyll *a* results are shown in Table 10, reflecting revisions to the 2007 laboratory results reported to Tetra Tech by the Regional Board on April 7, 2008. AFDW was not reported for these data. The 2006 chlorophyll *a* results appear anomalously high, for unknown reasons. Communities at these stations were usually dominated by diatoms.

Table 10. Yurok Periphyton Sampling Results for 2006-2007

Station	Year	Average Periphyton Chlorophyll *a* (mg/m^2)	Maximum Periphyton Chlorophyll *a* (mg/m^2)
KRWE (Weitchpec)	2006	609.3	1086.2
	2007	123.6	326.0
KRTG (Turwar)	2006	325.8	651.7
	2007	73.4	163.0

It should be emphasized that it is very difficult to obtain reach average chlorophyll *a* densities in the Klamath, due to its size, depth, and velocity. It appears that all samples taken to date do not qualify as spatially averaged values, but are more representative of point concentrations. As a result, some of the observed maximum values are likely to be greater than the model predictions, which represent spatially averaged algal response under optimal growth conditions, not the maximum point density.

3.3.2.2 Chemical Water Quality

In contrast to periphyton, an extensive database of chemical water quality exists collected by multiple agencies. Earlier data were compiled into an Access database in 2004. Some of the earlier data have since been corrected and substantial amounts of additional data have been collected since 2004. Accordingly, Tetra Tech worked with the Regional Board to develop a comprehensive tabulation of nutrient monitoring data in the Klamath.

The river data were separated into three time periods, 1996-2001, 2002-2004, and 2005-2007, which correspond approximately to the periods for which the reservoir BATHTUB scoping tools have been developed (2000, 2002, and 2005), and the periods during which periphyton samples are available (2004 and 2006-2007).

Statistics were calculated for the summer season (June – September). 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 11). To account for the influence of fluctuations in nutrient concentration on maximum algal response, predictions are made at the 75th percentile value. The ratio of total N to total P at these stations is typically less than the Redfield ratio of 7.2 (representing the typical cellular composition of algae), suggesting that nitrogen may frequently be the nutrient that is most limiting on algal growth.

3.3.2.3 Physical Data

Flow gaging data, and associated measurements, are available from five USGS gages between Iron Gate Dam and the Klamath estuary. Additional information on stream geometry, velocity, and stage is available from the calibrated hydrodynamic model of the Lower Klamath (PacifiCorp, 2005).

Table 11. Summer Nutrient Water Quality at Klamath River Stations below Iron Gate

		1996-2001				2002-2004				2005-2007			
	Station	Count (days)	Mean	25%^{le}	75%^{le}	Count (days)	Mean	25%^{le}	75%^{le}	Count (days)	Mean	25%^{le}	75%^{le}
PO_4-P (mg/L)	KR18952	42	0.152	0.110	0.173	32	0.120	0.100	0.143	32	0.105	0.088	0.130
	KR17608	6	0.198	0.150	0.240	16	0.131	0.113	0.160	21	0.105	0.080	0.133
	KR14261	6	0.204	0.140	0.250	14	0.117	0.091	0.140	19	0.103	0.088	0.120
	KR12858	41	0.124	0.083	0.150	24	0.084	0.060	0.110	8	0.067	0.049	0.075
	KRWE	0	ND	ND	ND	24	0.039	0.027	0.053	5	0.041	0.021	0.062
	KRTC	11	0.041	0.031	0.051	19	0.027	0.015	0.036	4	0.035	0.033	0.044
	KRTG	9	0.025	0.020	0.032	29	0.022	0.014	0.031	4	0.024	0.022	0.029
Org-P (mg/L)	KR18952	42	0.046	0.009	0.053	32	0.069	0.040	0.080	32	0.039	0.010	0.053
	KR17608	6	0.026	0.000	0.040	14	0.076	0.030	0.110	19	0.032	0.000	0.035
	KR14261	6	0.022	0.000	0.028	14	0.085	0.051	0.086	19	0.055	0.013	0.056
	KR12858	41	0.106	0.009	0.040	22	0.050	0.028	0.071	8	0.024	0.016	0.030
	KRWE	0	ND	ND	ND	24	0.051	0.029	0.060	5	0.015	0.013	0.017
	KRTC	11	0.036	0.013	0.059	19	0.054	0.032	0.080	4	0.015	0.014	0.016
	KRTG	9	0.068	0.035	0.081	29	0.050	0.020	0.071	4	0.017	0.015	0.019

		1996-2001				2002-2004				2005-2007			
	Station	**Count (days)**	**Mean**	**25%^{le}**	**75%^{le}**	**Count (days)**	**Mean**	**25%^{le}**	**75%^{le}**	**Count (days)**	**Mean**	**25%^{le}**	**75%^{le}**
NO_2+NO_3-N (mg/L)	KR18952	50	0.296	0.110	0.421	31	0.161	0.110	0.205	43	0.169	0.097	0.238
	KR17608	6	0.166	0.064	0.260	25	0.122	0.070	0.160	20	0.187	0.118	0.263
	KR14261	6	0.117	0.050	0.167	13	0.094	0.050	0.130	17	0.129	0.096	0.120
	KR12858	37	0.172	0.050	0.260	16	0.079	0.040	0.110	16	0.069	0.005	0.107
	KRWE	0	ND	ND	ND	26	0.042	0.033	0.040	4	0.005	0.005	0.005
	KRTC	8	0.084	0.040	0.100	26	0.071	0.020	0.040	4	0.006	0.005	0.006
	KRTG	8	0.076	0.040	0.100	22	0.039	0.040	0.040	4	0.026	0.023	0.028
NH_3-N (mg/L)	KR18952	50	0.091	0.043	0.085	29	0.059	0.050	0.050	43	0.024	0.005	0.039
	KR17608	6	0.043	0.024	0.047	25	0.067	0.020	0.060	20	0.020	0.005	0.034
	KR14261	6	0.041	0.028	0.044	12	0.031	0.000	0.050	19	0.011	0.005	0.005
	KR12858	37	0.032	0.000	0.040	17	0.065	0.050	0.050	16	0.008	0.005	0.011
	KRWE	0	ND	ND	ND	21	0.042	0.050	0.050	4	0.004	0.005	0.005
	KRTC	8	0.058	0.050	0.050	25	0.087	0.010	0.050	4	0.005	0.005	0.005
	KRTG	8	0.061	0.050	0.050	15	0.075	0.050	0.050	4	0.005	0.005	0.005
Org-N (mg/L)	KR18952	42	0.816	0.488	0.727	23	0.761	0.488	1.027	32	0.898	0.675	1.072
	KR17608	6	0.641	0.560	0.680	14	0.756	0.505	0.964	19	0.944	0.760	1.034
	KR14261	6	0.670	0.661	0.724	6	0.834	0.558	1.036	19	0.796	0.575	0.936
	KR12858	37	0.577	0.380	0.650	10	0.434	0.355	0.469	8	0.492	0.384	0.600
	KRWE	0	ND	ND	ND	12	0.432	0.225	0.502	5	0.257	0.213	0.291
	KRTC	8	0.289	0.150	0.388	23	0.306	0.120	0.335	4	0.200	0.175	0.221
	KRTG	8	0.356	0.146	0.375	10	0.212	0.138	0.238	4	0.205	0.191	0.244
Total N (mg/L)	KR18952	42	1.210	0.758	1.150	27	0.942	0.630	1.118	41	1.083	0.866	1.260
	KR17608	6	0.849	0.720	0.971	18	0.878	0.615	1.108	18	1.051	0.889	1.185
	KR14261	6	0.828	0.758	0.872	6	0.949	0.673	1.176	17	0.937	0.693	1.125
	KR12858	37	0.781	0.500	1.000	16	0.566	0.540	0.600	17	0.559	0.479	0.648
	KRWE	0	ND	ND	ND	14	0.480	0.265	0.530	5	0.235	0.180	0.272
	KRTC	8	0.431	0.240	0.538	23	0.386	0.190	0.440	4	0.211	0.189	0.231
	KRTG	8	0.493	0.296	0.538	14	0.305	0.240	0.328	4	0.231	0.212	0.272

Notes: Total Nitrogen calculated as some of Total Kjeldahl Nitrogen (TKN) plus NO_3-N plus NO_2-N where available. Non-detects treated as one-half the detection limit. Organic N calculated as TKN minus NH_3-N. Organic P calculated as Total P minus PO_4-P.

3.3.3 NNE Tool Application

The California NNE benthic biomass scoping tool was applied to the Klamath River in California to provide a scoping-level estimate of nutrient targets. Details on the development and use of this tool are available in Tetra Tech (2006).

Physical parameters for the scoping tool are summarized in Table 12 and explained further below.

Table 12. Parameters Specified for the NNE Tool Application

Station	Typical Summer Velocity (m/s)	Summer Depth for Analysis (m)	Unshaded Summer Solar Radiation (cal/cm^2/d)	Light Extinction Coefficient (m^{-1})	Days of Accrual	Chlorophyll *a* to AFDW Ratio
KR18952	0.65	0.45	528	0.725	185.7	5
KR17608	0.65	0.45	584	0.725	185.7	4
KR14261	0.69	0.45	527	0.725	122.8	4
KR12858	0.61	0.45	527	0.725	122.8	4
KRWE	0.69	0.45	524	0.760	81.9	4
KRTC	0.69	0.45	524	0.760	81.9	4
KRTG	0.69	0.45	526	0.760	69.1	4

Velocity

Stream velocity at each site was input as the "typical" summer value shown in the output of the RMA model of the Klamath River.

Depth

The RMA model output provides information on stage (or maximum depth) at each station, and average depth can be inferred from flow and cross-sectional area. However, the Klamath is a relatively wide river, and much of the potential benthic algal problem is believed to be associated with shallower water. It is therefore appropriate to evaluate impact at shallower depths, where light extinction in the water column is less of a factor. The 2004 periphyton samples were all collected in shallow water at a depth of approximately 0.45 m. Therefore, this depth was used in the scoping model applications.

Solar Radiation

Unshaded solar radiation for the summer period (June-August) was estimated based on latitude using the routine incorporated in the Benthic Biomass spreadsheet. The spreadsheet incorporates an approximation for shading effects on light availability as well. No data on local canopy and topographic shading were available; however, the majority of the Lower Klamath channel appears to be relatively open, so no shading was assumed, except at Seiad Valley. In that reach, the river flows in a N-S direction, whereas other sampled reaches have an approximately E-W orientation. Therefore, there is likely to be more topographic and canopy shading at Seiad Valley, and a value of 40 percent shading was selected.

Light Extinction Coefficient

Light extinction 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. The extinction coefficient was then estimated based on median summer turbidity, which ranged from 2.5 to 3.2 NTU.

Accrual

The scoping model provides an option to evaluate effects on expected maximum algal density based on days of accrual, using the relationship of Biggs (2000), where accrual time is defined as the number of days between events three-times the median flow. Accrual time was analyzed at each of the USGS gages. Because the Klamath is a large river with a multi-day response time, the number of events per year was estimated based on the count of times the hydrograph crossed the three-times-median threshold, rather than the number of individual days above the threshold. Resulting estimates (Table 13) were extrapolated to the nearest water quality monitoring station. The system shows a pattern of decreasing time between scouring events with distance downstream as additional major tributaries join.

Table 13. Estimated Days of Accrual (1985-2005 Data)

USGS Gage	Average Days of Accrual
11516530: Klamath River below Iron Gate	185.7
11520500: Klamath River near Seiad Valley	122.8
11523000: Klamath River at Orleans	81.9
11530500: Klamath River at Klamath	69.1

Half-Saturation Constants

Lacking site-specific data, half-saturation constants for nutrients are set at the levels described in Tetra Tech (2006). For the standard QUAL2K model, the optimized half-saturation constants were 0.206 mg/L for inorganic N and 0.00853 mg/L for inorganic P (Table 4 in Appendix 3 of Tetra Tech, 2006). For the revised QUAL2K model, the half-saturation constants are defined in relation to total nutrient concentrations, and vary from 0.0260 to 2.83 mg/L for total N, and from 0.0205 to 0.0470 mg/L for total P following the logistic regression model (Table 6 in Appendix 3 of Tetra Tech, 2006).

Chlorophyll *a* to AFDW Ratio

One of the most problematic parameters is the chlorophyll *a* to AFDW ratio (mg/g), where AFDW represents the fixed carbon biomass. The need for this parameter arises when the model formulation predicts biomass (as is done in the QUAL2K-based approach), while the target is specified as chlorophyll *a*. The ratio translates between the two, but can be highly variable. As noted above, only the 2004 sampling examined both AFDW and benthic chlorophyll *a*, but analyses were from small samples and the chlorophyll *a* and AFDW measures were obtained from scrapings from different rocks. These data do not provide a reliable basis for estimating the ratio in the Klamath.

Selection of an appropriate ratio is complicated by the fact that periphytic communities contain a mix of photosynthesizing autotrophs and heterotrophs, including bacteria and fungi, whose growth is based on allochthonous carbon sources. The models are supposed to predict only photosynthetic biomass, but heterotrophs can also take up nutrients from the water column, so the predicted response of biomass as a function of nutrient concentrations likely includes both heterotrophic and autotrophic biomass. Further complications arise because (1) some algae exhibit mixotrophy, in which they are able to assimilate energy from fixed carbon compounds as well as by photosynthesis, and (2) exudates of benthic phototrophic algae may support bacterial and fungal heterotrophic populations, thus tying the heterotroph density to photosynthetic production.

In the development of the QUAL2K method (Tetra Tech, 2006), parameters of QUAL2K were "tuned" to provide a match to the predictions of Dodds' (2002) empirical model of maximum algal density when a chlorophyll *a* to AFDW ratio of 2.5 was assumed. Selection of this value was an appropriate compromise for a cross-sectional dataset, as the ratio of 2.5 corresponds to an autotrophic index of 400, generally presented as the upper limit of clean water conditions.

The CA NNE document (Tetra Tech, 2006) also noted that "alternate, site-specific ratios may be appropriate in specific waterbodies where appropriate information is available." For the Klamath, the Dodds method appears to underpredict maximum observed chlorophyll *a*, which also introduces a tendency for the QUAL2K-based methods, which are tuned to the Dodds method, to underpredict the maxima. Therefore, the chlorophyll *a* to AFDW ratio was increased from 2.5 to 4.0 at all stations except the station below Iron Gate, where a value of 5.0 was used.

3.3.4 Exploratory Data Analysis

Before applying the spreadsheet tool, an exploratory analysis was undertaken to examine the correlation between benthic chlorophyll *a* and nutrient concentrations. Both the average and the maximum benthic chlorophyll *a* from the 2004 sampling are plotted against the 75th percentile of summer average TN and TP concentrations from 2002-2004 water quality monitoring data in Figure 8. This suggests that observed periphyton density is indeed correlated to nutrient concentrations, with the strongest correlation (shown by higher R^2 value) between the observed maximum chlorophyll *a* and TN concentrations.

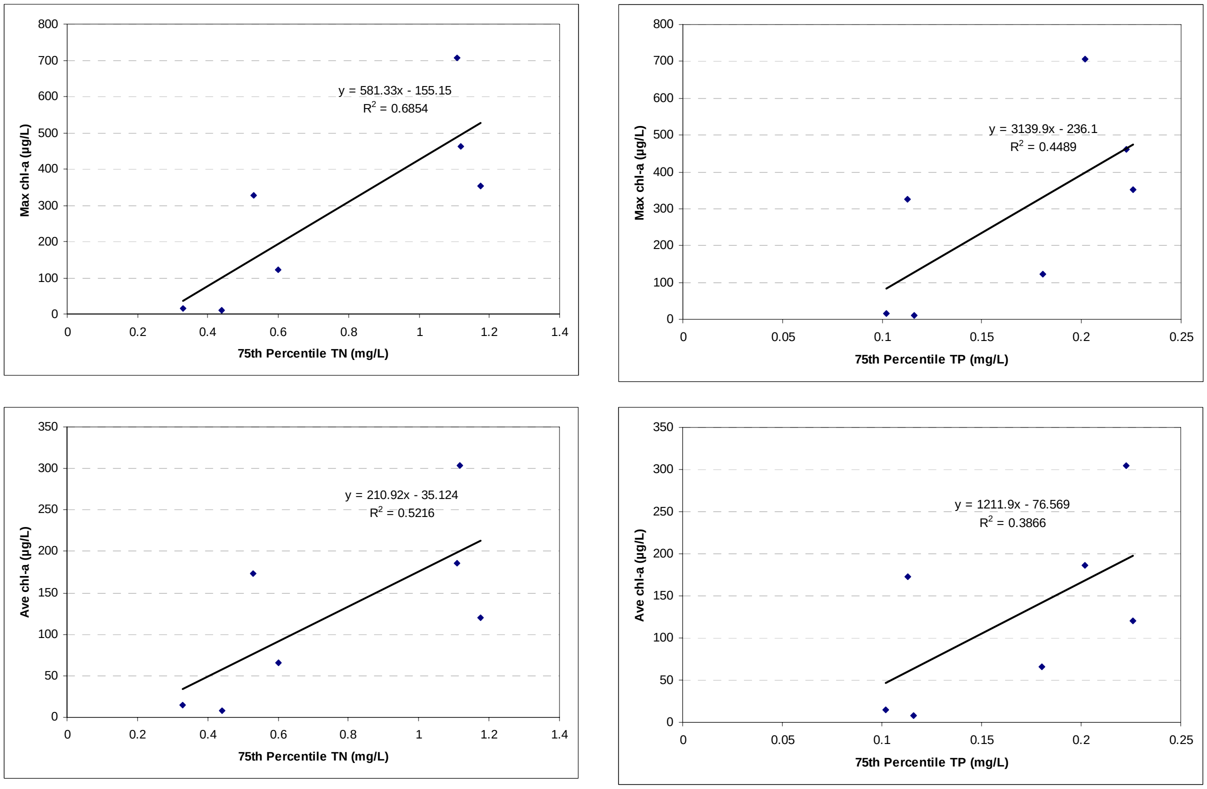

Figure 8. Relationship of Observed Periphyton Chlorophyll *a* to Nutrient Concentrations, 2004 Klamath Sampling

3.3.5 NNE 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. For this application, 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 the upper-bound estimate that describes maximum benthic algal density. The tool provides access to multiple predictions, but only three are presented here, all calculated at the 75th percentile summer nutrient concentration, as described above in Section 3.3.2. Of the empirical approaches, results are shown for the latest version of the Dodds model (Dodds, 2002), while for parametric approaches the results for both the standard QUAL2K and revised QUAL2K models (which are tuned to correspond to the Dodds' results on small streams) are shown, the latter both with and without an accrual adjustment (Table 14). The accrual adjustment has little effect on the upstream stations (where the estimated days of accrual are large), but does have a noticeable effect from station KRWE downstream. Of the other available methods, the 1997 version of the Dodds model has been superseded by the more detailed analysis of Dodds (2002). The Dodds method is of particular interest for comparison because results do not depend on the chlorophyll *a* to AFDW ratio.

Table 14. Predicted and Observed Maximum Benthic Chlorophyll *a* (mg/m^2)

Station	Period	Standard QUAL2K	Revised QUAL2K	Revised QUAL2K with Accrual Adjustment	Dodds 2002	Observed Maximum	Observed Average
KR18952 (below Iron Gate)	1996-2001	547	478	477	245		
	2002-2004	426	489	488	248	462	304.1
	2005-2007	441	504	503	241		
KR17608 (above Shasta)	1996-2001	399	363	362	236		
	2002-2004	344	404	403	251	706	186
	2005-2007	398	433	432	236		
KR14261 (above Scott)	1996-2001	333	347	314	231		
	2002-2004	307	406	368	244	353	120.4
	2005-2007	249	375	339	214		
KR12858 (Seiad Valley)	1996-2001	294	264	238	214		
	2002-2004	217	204	185	181	122	65.5
	2005-2007	181	222	201	169		
KRWE (above Trinity)	1996-2001	ND	ND	ND	ND		
	2002-2004	200	261	188	160	312.5	126.4
	2005-2007	30	172	124	115	1086 (2006) 326 (2007)	609 (2006) 124 (2007)
KRTC (below Trinity)	1996-2001	281	250	180	153		
	2002-2004	200	212	153	142	10.6	8
	2005-2007	34	147	105	98		
KRTG (Turwar)	1996-2001	281	246	155	153		
	2002-2004	200	181	114	125	15.1	15.1
	2005-2007	91	163	103	99	652 (2006) 163 (2007)	326 (2006) 73 (2007)

Model predictions of maximum benthic chlorophyll *a* concentrations for 2002-2004 are plotted against the 2004 observations of maximum and average concentrations in Figure 9.

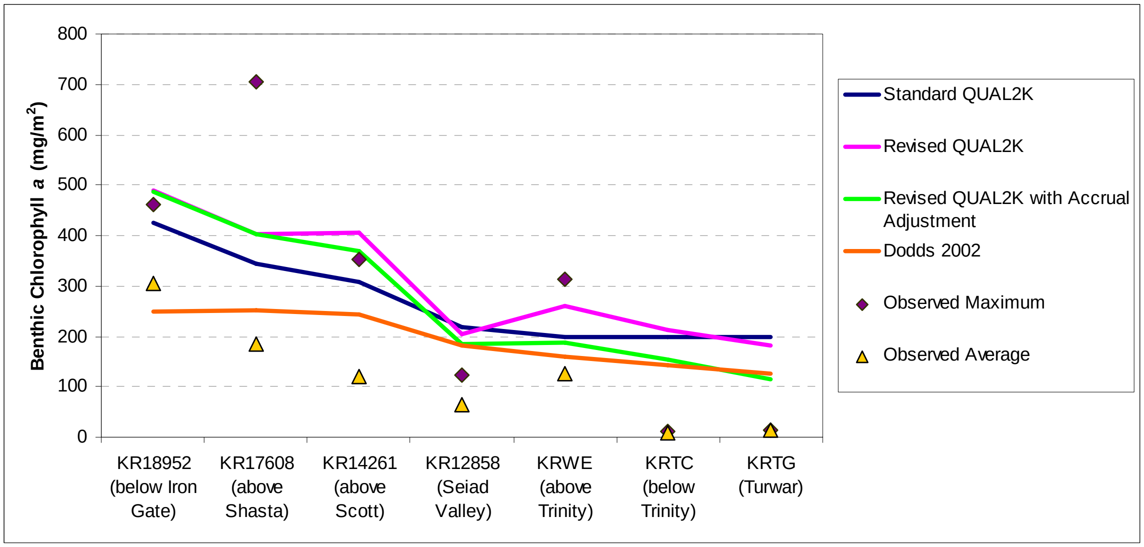

Figure 9. Model Predictions of Maximum Benthic Chlorophyll *a* for 2002-2004 and Observed Densities for 2004

None of the methods provide a perfect match to observations. Indeed, only general qualitative comparisons can be made, as the model predicts spatially averaged responses, whereas the observations reflect point data. In general, the revised QUAL2K approaches appear to do a reasonable job of replicating the spatial trend in observed maxima, while the Dodds results tend to be low. At three of seven stations, the predicted maximum using the QUAL2K approach is greater than the observed – which may only mean that the maximum was not sampled. At two other stations, the QUAL2K predictions are well less than the observed maximum. This may reflect the fact that the observed data are obtained from very small samples, without replication, that may not be representative of spatially averaged conditions in the reach.

Additional comments are warranted regarding several of the stations. For the station above Shasta, the plotted maximum of 706.1 mg/m^2 is for a sample taken at the mouth of Cottonwood Creek, a few miles upstream of station KR17608. Two samples taken at KR17608 had a maximum of only 81.5 mg/m^2. Reported maxima at the downstream stations of KRTC and KRTG were very low in 2004 (less than 20 mg/m^2); however, the Yurok samples from 2006 had a maximum of 652 mg/m^2 at KRTG. The 2004 results at these stations may be biased low relative to the seasonal maximum because they do not include samples from late summer, when periphyton densities are typically at their peak.

Both the data and the model representation of the data are subject to considerable uncertainty. Conditional on the suitability of the model, the tool can then be used to predict nutrient concentration targets needed to achieve a specified maximum algal density. As noted above, for the COLD and SPWN uses present in the Klamath, Tetra Tech (2006) recommends that the target 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 these designated uses.

For the Klamath, the models generally suggest that smaller reductions in total nitrogen than in total phosphorus are needed to reach the target range, and further that total phosphorus concentrations would need to be reduced to very low levels to achieve control of benthic algal growth by phosphorus alone. (Achieving the 100 mg/m^2 target by limiting phosphorus alone would require a total P goal of 2 µg/L.) This is consistent with the low observed total N to total P ratios, which suggest nitrogen limitation on algal growth. Therefore, nutrient limitations to achieve the maximum chlorophyll *a* targets are best expressed in terms of total nitrogen goals (from which corresponding total phosphorus goals may be inferred through use of the Redfield ratio of 7.2, as in Dodds et al., 1997). The resulting total nitrogen goals for a maximum benthic chlorophyll *a* concentration target of 150 mg/m^2 are shown in Table 15, while Table 16 shows the corresponding estimates for a target of 100 mg/m^2 maximum benthic chlorophyll *a*.

Table 15. Total Nitrogen and Phosphorus Goals (mg/L) for Target of 150 mg/m^2 Maximum Benthic Chlorophyll *a* (TP values based on using Redfield ratio of 7.2)

Station	Revised QUAL2K	Revised QUAL2K with Accrual Adjustment	Dodds 2002
KR18952	0.18/0.025	0.18/0.025	0.34/0.047
KR17608	0.23/0.032	0.23/0.032	0.30/0.042
KR14261	0.23/0.032	0.28/0.039	0.33/0.046
KR12858	0.38/0.053	0.44/0.061	0.38/0.053
KRWE	0.24/0.033	0.41/0.057	0.50/0.069
KRTC	0.24/0.033	0.41/0.057	0.49/0.068
KRTG	0.24/0.033	0.51/0.071	0.53/0.074

Table 16. Total Nitrogen and Phosphorus Goals (mg/L) for Target of 100 mg/m^2 Maximum Benthic Chlorophyll *a* (TP values based on using Redfield ratio of 7.2)

Station	Revised QUAL2K	Revised QUAL2K with Accrual Adjustment	Dodds 2002
KR18952	0.08/0.011	0.08/0.011	0.11/0.015
KR17608	0.11/0.015	0.11/0.015	0.10/0.014
KR14261	0.11/0.015	0.14/0.019	0.11/0.015
KR12858	0.19/0.026	0.23/0.032	0.13/0.018
KRWE	0.11/0.015	0.21/0.029	0.17/0.024
KRTC	0.11/0.015	0.21/0.029	0.17/0.024
KRTG	0.11/0.015	0.26/0.036	0.18/0.025

Results for the 150 mg/m^2 target are re-expressed as reductions in TN concentration relative to observed summer average concentrations for the 2005-2007 period based on the revised QUAL2K with accrual adjustment analysis in Table 17. Concentrations observed in the 1996-2001 period are somewhat different, but suggest a similar spatial pattern of needed reductions (Table 18).

Table 17. Reductions in TN Concentrations Relative to 2005-2007 Observations to Achieve the 150 mg/m^2 Target

Station	Percent Reduction in Summer TN Concentration	TN/TP 2005-2007 Summer Average Concentration (mg/L)	Revised QUAL2K with Accrual Adjustment TN/TP Goal (mg/L)
KR18952	83%	1.08/0.14	0.18/0.025
KR17608	78%	1.05/0.14	0.23/0.032
KR14261	70%	0.94/0.16	0.28/0.039
KR12858	21%	0.56/0.091	0.44/0.061
KRWE	0%	0.24/0.056	0.41/0.057
KRTC	0%	0.21/0.050	0.41/0.057
KRTG	0%	0.23/0.041	0.51/0.071

Table 18. Reductions in TN Concentrations Relative to 1996-2001 Observations to Achieve the 150 mg/m^2 Target

Station	Percent Reduction in Summer TN Concentration	TN/TP 2005-2007 Summer Average Concentration (mg/L)	TN/TP Goal (mg/L)
KR18952	85%	1.21/0.20	0.18/0.025
KR17608	73%	0.85/0.22	0.23/0.032
KR14261	66%	0.83/0.23	0.28/0.039
KR12858	44%	0.78/0.23	0.44/0.061
KRWE	No data	No data	0.41/0.057
KRTC	5%	0.43/0.077	0.41/0.057
KRTG	0%	0.49/0.093	0.51/0.071

Table 17 and Table 18 suggest that to achieve the desired reductions in benthic algal density at all stations would require reductions in summer TN concentrations of up to 85 percent. (Achieving targets by controlling TP directly would require reductions of approximately 98 percent at stations through Seiad Valley.) The results for the T4BS1 allocation scenario in Iron Gate Reservoir (see Section 3.3) indicate that this scenario, which is predicted to achieve lake targets, would result in reductions of about 73 percent in summer TN concentrations and about 89 percent in summer TP concentrations for the 2000 simulation. Thus, load reductions in excess of those needed to meet DO criteria and achieve lake planktonic chlorophyll *a* targets may be needed to meet maximum periphyton chlorophyll *a* targets in the Klamath below Iron Gate.

Application of the benthic biomass tool using the 75th percentile summer concentrations in the outflow from Iron Gate predicted by the T4BS1 scenario with benthic flux off results in a prediction of maximum benthic algal chlorophyll *a* at Station KR18952 below Iron Gate of 164 mg/m^2 – slightly in excess of the target – using the revised QUAL2K-based methods. For the same conditions, the Dodds (2002) approach yields a prediction of 84 mg/m^2, well below the target.

3.3.6 Natural Conditions Analysis

The draft CA NNE document (Tetra Tech, 2006) recommended an upper limit of 150 mg/m^2 chlorophyll *a* to support uses in waters of the State of California, yet also recommends that the target should not be set lower than the value expected under natural conditions. This target of 150 mg/m^2 has not been adopted by the State Board and remains open for further evaluation. [The Hoopa Valley Tribe has a regulatory target of 150 mg/m^2 that has been adopted and approved, and applies to the small section of the Klamath River that passes through the Hoopa Valley Tribal lands.]

To examine potential natural conditions in the Klamath River, concentration results from the TMDL Model T1BS natural conditions run were summarized for summer (June-September) conditions. This model run has point sources eliminated and dams out. Current flow leaving Upper Klamath Lake and Klamath Straits Drain in Oregon is continued, but with concentrations reduced to be compliant with the Upper Klamath Lake TMDL. The T1BS run uses 2000 meteorological conditions.

In the dams out simulation, nutrient retention and processing by the Klamath reservoirs is eliminated. This results in changes in the magnitude, timing, and speciation of nutrient loads reaching the lower Klamath River.

Output from the T1BS natural conditions was used to provide input to the NNE benthic biomass tool. Evaluation was made at four locations: below Iron Gate (KR18952), Seiad Valley (KR12858), above Trinity (KRWE), and at Turwar (KRTG). The range of summer average water quality for the natural conditions run is summarized at the 75th percentile level (as was done with the NNE tool to predict maximum benthic chlorophyll *a* in previous sections) and compared to recent observed water quality in Table 19.

Table 19. 75th Percentile of Natural Condition Water Quality (Model Run T1BS) Compared to Observed Water Quality in the Klamath River

	Station	T1BS	1996-2001 Observed	2002-2004 Observed	2005-2007 Observed
PO_4-P (mg/L)	KR18952 – Klamath River below Iron Gate	0.0190	0.173	0.143	0.130
	KR12858 – Klamath River at Seiad Valley	0.0515	0.150	0.110	0.075
	KRWE – Klamath River above Trinity River	0.0601	No Data	0.053	0.062
	KRTG – Klamath River at Turwar	0.0768	0.032	0.031	0.029
Org-P (mg/L)	KR18952	0.0216	0.053	0.080	0.053
	KR12858	0.0220	0.040	0.071	0.030
	KRWE	0.0184	No Data	0.060	0.017
	KRTG	0.0161	0.081	0.071	0.019
Total P (mg/L)	KR18952	0.0406	0.226	0.223	0.183
	KR12858	0.0735	0.190	0.181	0.105
	KRWE	0.0785	No Data	0.113	0.079
	KRTG	0.0929	0.113	0.102	0.108
NO_2+NO_3-N (mg/L)	KR18952	0.0777	0.421	0.205	0.238
	KR12858	0.0957	0.260	0.110	0.107
	KRWE	0.1093	No Data	0.040	0.005
	KRTG	0.1298	0.100	0.040	0.006
NH_3-N (mg/L)	KR18952	0.0831	0.085	0.050	0.039
	KR12858	0.1077	0.040	0.050	0.011
	KRWE	0.1256	No Data	0.050	0.011
	KRTG	0.1467	0.050	0.050	0.005
Org-N (mg/L)	KR18952	0.2671	0.727	1.027	1.072
	KR12858	0.2838	0.650	0.469	0.600
	KRWE	0.2502	No Data	0.502	0.291
	KRTG	0.2598	0.538	0.328	0.244
Total N (mg/L)	KR18952	0.4279	1.150	1.118	1.260
	KR12858	0.4872	1.000	0.600	0.648
	KRWE	0.4851	No Data	0.530	0.272
	KRTG	0.5364	0.538	0.328	0.272

Unlike monitoring results for existing (dams-in) conditions (see above, Table 11), the 75th percentile total nutrient concentrations during the summer tend to increase downstream under the TMDL Model T1BS run. This seems to occur because concentrations in most of the downstream tributaries were kept at existing levels for the T1BS scenario, while upstream concentrations leaving Iron Gate Dam decreased significantly. In addition, the model output reflects continuous subhourly simulation, while the observations are discrete day time grab samples, which may confound direct comparison.

Table 19 also shows that the 75th percentile summer total nitrogen concentrations under natural conditions appear to be greater than the concentrations estimated as needed to meet the 150 mg/m^2 maximum benthic chlorophyll *a* target in the analysis of existing conditions provided above in Table 15. This suggests that natural conditions may result in a tendency for elevated benthic algal densities in the Klamath River.

The dams-out condition will also result in more frequent scouring flows and less days of accrual (time between potential scouring events), which may tend to reduce maximum benthic algal growth. However, data were not available for a long-term analysis of the frequency of scouring flows for the T1BS model conditions. To approximate this effect, the days of accrual for the Revised QUAL2K application with accrual adjustment was set at 69.1 days – the value currently used for the Turwar gage, which is furthest downstream and least affected by the dams on the upper Klamath.

Results of applying the benthic biomass spreadsheet tool to the TMDL Model T1BS conditions are summarized in Table 20. Consistent with the predicted nutrient concentrations, there is no longer a strong spatial gradient in predicted maximum benthic chlorophyll *a* concentrations under the T1BS natural conditions scenario. The standard QUAL2K predictions are much higher than the other approaches due to the increased fraction of inorganic nutrients, which enter directly into the solution for this model, but not the other approaches. The Revised QUAL2K model with accrual adjustment suggests maxima right around the 150 mg/m^2 target, while the QUAL2K approaches without accrual adjustment predict higher densities. The Dodds (2002) approach also predicts maximum densities less than 150 mg/m^2, but results from this model were generally much lower than that obtained for other approaches in the analysis of existing conditions.

The predicted ability to meet the 150 mg/m^2 target using the Revised QUAL2K approach (with accrual adjustment) only occurs due to the assumption of reduced days of accrual. For example, if days of accrual at KRWE are assumed to be 81.9, as in the existing conditions (dams-in) application, the resulting predicted maximum benthic chlorophyll *a* density would be 166, rather than 145 mg/m^2. It is thus not clear from the benthic biomass spreadsheet analysis that the 150 mg/m^2 target could be met under natural conditions A more detailed analysis of the frequency of scouring flows expected under the dams-out natural conditions may be advisable to ascertain the extent to which this phenomenon is likely to limit excess benthic algal density.

Table 20. Predicted Maximum Benthic Chlorophyll *a* (mg/m2) Under TMDL Model Run T1BS Natural Conditions (Dams Out) for Year 2000

Station	Standard QUAL2K	Revised QUAL2K	Revised QUAL2K with Accrual Adjustment	Dodds 2002
KR 18952 (below Iron Gate)	338	250	157	113
KR12858 (Seiad Valley)	246	174	109	135
KRWE (above Trinity)	350	231	145	137
KRTG (Turwar)	377	246	154	147

3.4 DISCUSSION OF KLAMATH RIVER NNE RESULTS

Prediction of periphyton biomass is inherently difficult. This problem is compounded by several factors, including the weak relationship between periphyton biomass and benthic chlorophyll *a* and the sparse and uncertain data available for the Klamath River. The biomass to chlorophyll *a* relationship is expressed through the chlorophyll *a* to AFDW ratio, which is clearly a major source of uncertainty in the QUAL2K-based applications. The observed data are limited, and have been obtained from small samples that may not accurately reflect the reach-averaged conditions predicted by the tool.

Due to the uncertainties in predicting benthic chlorophyll *a*, it may be preferable to define periphyton targets for the Klamath River in terms of AFDW, although more data are needed to establish such a target.

As a result of these caveats, the main value of the benthic biomass tool is in predicting relative changes in benthic chlorophyll *a*, rather than precise estimates. It is clear that significant reductions in summer nutrient concentrations would be needed to meet a target of 150 mg/m^2 maximum benthic chlorophyll *a*; however, the predicted magnitude of the needed reductions is highly uncertain. The reductions that would occur as a result of the T4BS allocation scenario to achieve DO criteria will certainly result in improvements in periphyton density in the Klamath River, but may or may not be sufficient to achieve the BURC II/III target of 150 mg/m^2 maximum benthic chlorophyll *a*. Due to the considerable uncertainty in the NNE analysis. additional data should continue to be collected to build a better understanding of the relationship between nutrient concentrations and periphyton density and support the development of more sophisticated, site-specific models. The RMA model application for Klamath River TMDL development already provides a potential framework for evaluating the benthic algal target in the river; however, the model predictions need to be refined with more data to better assess impacts on beneficial uses in addition to effects on DO, including the formation of periphyton mats that may impair recreational uses, alter the benthic community, and potentially increase the detrimental effects of parasites on salmonid populations.

Finally, although the draft CA NNE document (Tetra Tech, 2006) recommends an upper limit of 150 mg/m^2 chlorophyll *a* to support uses, this target has not been adopted by the State or Regional Board and remains open for further evaluation. As mentioned previously, this target does apply to the small section of the Klamath River that passes through the Hoopa Valley Tribal lands, where a criterion of 150 mg/m^2 has been adopted and approved.

Targets should not be set lower than a value expected under natural conditions. As discussed in Section 3.3.6, the natural condition maximum benthic chlorophyll *a* concentration on Hoopa Valley lands is likely to be near 150 mg/m^2, but may be somewhat higher, depending on the assumptions regarding frequency of scour.

Perhaps more importantly, it would be consistent with the CA NNE approach to develop a site-specific target based on a risk analysis to support beneficial uses in the system. A key here may be establishing the periphyton conditions (and relevant indicator metrics) that are consistent with managing the parasite *Ceratomyxa shasta* at levels that are consistent with maintaining a healthy salmonid population; however, research has not yet advanced to the point where a quantitative target can be set on this basis.

4 References

Biggs, B. J. 2000. Eutrophication of streams and rivers: Dissolved nutrient-chlorophyll relationships for benthic algae. *J. N. Am. Benthol. Soc.*, 19:17-31.

Butcher, J.B. 2008. Nutrient Dynamics in the Klamath. Memorandum to Klamath TMDL Technical Team, February 12, 2008. Tetra Tech, Inc., Research Triangle Park, NC.

Chapra, S. and G. Pelletier. 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Collins, G.B. and C.I. Weber. 1978. Phycoperiphyton (algae) as indicators of water quality. *Trans. Am. Microscop. Soc.*, 97: 36-43.

Dodds, W. K., V.H. Smith, and B. Zander. 1997. Developing nutrient targets to control benthic chlorophyll-a levels in streams: a case study of the Clark Fork River. *Water Research*, 31(7): 1738-1750.

Dodds, W.K., V.H. Smith, and K. Lohman. 2002. Nitrogen and phosphorus relationships to benthic algal biomass in temperature streams. *Canadian Journal of Fisheries and Aquatic Science*, 59: 865-874. Errata published 2006, *Canadian Journal of Fisheries and Aquatic Science*, 63: 1190-1191.

Downing, J.A., S.B. Watson, and E. McCauley. 2001. Predicting cyanobacteria dominance in lakes. *Canadian Journal of Fisheries and Aquatic Science*, 58: 1905-1908.

Effler, S.W., R.K. Gelda, M.G. Perkins, and D.M. O'Donnell. 2005. Modeling light attenuation, Secchi disk, and effects of tripton in Seneca River, New York, USA. *Journal of the American Water Resources Association*, 41(4): 971-984.

Eilers, J.M. 2005. Periphyton in Selected Sites of the Klamath River, California. MaxDepth Aquatics, Bend, OR.

Gallegos, C.L. 1994. Refining habitat requirements of submersed aquatic vegetation: Role of optical models. *Estuaries*, 17: 198-219.

Hoopa Valley TEPA. 2008. Hoopa Valley Indian Reservation Water Quality Control Plan. Hoopa Valley Tribal Environmental Protection Agency, Hoopa Valley Tribe. February 14, 2008. http://www.hoopa-nsn.gov/documents/WQCP.pdf .

Horner, R.R., E.B. Welch, and R.B. Veenstra. 1983. Development of nuisance periphytic algae in laboratory streams in relation to enrichment and velocity, *Dev. Hydrobiol.*, 17: 121-134.

Hyenstrand, P., P. Blomqvist, and A. Petterson. 1998. Factors determining cyanobacterial success in aquatic systems – a literature review. *Arch. Hydrobiol. Spec. Issues Adv. Limnol.*, 15: 41-62.

Kann, J., and E. Asarian. 2005. 2002 Nutrient and Hydrologic Loading to Iron Gate and Copco Reservoirs, California. Kier Associates Final Technical Report to the Karuk Tribe Department of Natural Resources, Orleans, CA.

Kann, J. and E. Asarian. 2007. Nutrient Budgets and Phytoplankton Trends in Iron Gate and Copco Reservoirs, California, May 2005 - May 2006. Submitted to the State Water Resources Control Board, Sacramento, CA by the Karuk Tribe of California, Department of Natural Resources, Orleans, CA.

Kier Associates. 2005. Draft Nutrient Criteria for the Klamath River on the Hoopa Valley Indian Reservation. Prepared for the Hoopa Valley Tribal Environmental Protection Agency by Kier Associates, Mill Valley, CA, Nov. 2005.

Kirk, J.T.O. 1985. Effects of suspensoids (turbidity) on penetration of solar radiation in aquatic ecosystems. *Hydrobiologia*, 125: 195-208.

MELP. 1992. Ambient Water Quality Assessment and Objectives for Elk and Beaver Lakes, Saanich Peninsula, Water Management Branch, Environment and Resource Division, Ministry of Environment Lands and Parks, British Columbia, Canada.

Moisander, P.H., M. Ochiai, A. Lincoff, and S. Corum. 2008. Growth and toxin production of the cyanobacterium *Microcystis aeruginosa* in Klamath River reservoirs. Poster presented at Klamath Basin Water Quality Monitoring Coordination Group Spring Meeting, Yreka, CA, April 2008.

NCRWQCB. 2007. Water Quality Control Plan for the North Coast Region. North Coast Regional Water Quality Control Board, Santa Rosa, CA.

Nichols, K. and J.S. Foott. 2005. FY2004 Investigational Report: Health Monitoring of Juvenile Klamath River Chinook Salmon. U.S. Fish and Wildlife Service California-Nevada Fish Health Center, Anderson, CA.

PacifiCorp. 2005. Klamath Hydroelectric Project (FERC Project No. 2082), Response to November 10, 2005, FERC AIR GN-2, Klamath River Water Quality Model Implementation, Calibration, and Validation. PacifiCorp, Bend, OR.

Smith, V.H. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. *Science*, 221: 669-671.

Stocking, R.W. and J.L. Bartholomew. 2004. Assessing Links between Water Quality, River Health and Ceratomyxosis of Salmonids in the Klamath River System. Oregon State University, Corvallis, OR.

Tetra Tech. 2006. Technical Approach to Develop Nutrient Numeric Endpoints for California. Prepared for U.S. EPA Region IX and California State Water Resource Control Board by Tetra Tech, Inc., Lafayette, CA.

Tetra Tech. 2007. Nutrient Numeric Endpoints for TMDL Development: Klamath River Case Study. Submitted to USEPA Region IX by Tetra Tech, Inc., Research Triangle Park, NC

Trimbee, A.M. and E.E. Prepas. 1987. Evaluation of total phosphorus as a predictor of the relative biomass of blue-green algae with emphasis on Alberta lakes. *Canadian Journal of Fisheries and Aquatic Science*, 44: 1337-1342.

USEPA Region IX. 2008. Staff Report, Reconsideration of California's 2006 Section 303(d) List Omission of Microcystin Toxin Listings for Three Klamath River Segments and Determination to Add Microcystin Toxin Listing for Klamath River Hydrologic Unit (HU), Middle HA Hydrologic Area (HA), Oregon to Iron Gate. U.S. EPA Region IX, San Francisco, CA.

Walker, W.W. 1996. Simplified Procedures for Eutrophication Assessment and Prediction: User's Manual. Instruction Report W-96-2. U.S. Army Corps of Engineers. Water Operations Technical Support Program, Vicksburg, MS.

Walmsley, R.D., M. Butty, H. Van Der Piepen, and D. Grobler. 1980. Light penetration and the interrelationships between optical parameters in a turbid subtropical impoundment. *Hydrobiologia*, 70: 145-157.

Welch, E.B., J.M. Jacoby, R.R. Horner, and M.R. Seeley. 1988. Nuisance biomass levels of periphytic algae in streams. *Hydrobiologia*, 157: 161-168.

WHO. 2003. Guidelines for Safe Recreational Waters, Volume I – Coastal and Fresh Waters, Chapter 8: Algae and Cyanobacteria in Fresh Water. World Health Organization, Geneva.