Nutrient Numeric Endpoints for TMDL Development: Klamath River Case Study

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1 Introduction

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

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

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 These simplified tools provide a starting place, and should be superseded by calibrated site-specific models where available.

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

1.1 SITE

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 1 below). This analysis 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.

1.2 IMPAIRMENT

The Oregon Department of Environmental Quality and California's North Coast Regional Water Quality Control Board have both included the Klamath River on their Clean Water Act Section 303(d) lists 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 WARM and SPAWN beneficial uses. Oregon lists various portions of the Klamath River and its tributaries for excursions of criteria for dissolved oxygen, chlorophyll a, temperature, pH, and ammonia. Upper Klamath Lake, in Oregon, has extremely high bloom concentrations of the bluegreen alga *Aphanizomenon flow-aquae*, which is capable of fixing nitrogen from the atmosphere. In general, the hydroelectric projects provide environments that promote algal growth and release large quantities of algal biomass and organic nutrients downstream.

1.3 SUMMARY OF EXISTING ANALYSES

A summary of historical monitoring data on the extent, location, and timing of water quality impairments in the Klamath River is provided by Tetra Tech (2004).

PacifiCorp (Bend, OR) operates hydropower generation stations at a series of dams on the Klamath River. As part of the FERC relicensing process, PacifiCorp (2005) developed a set of linked RMA-2/11 and CE-QUAL-W2 models of the free flowing reaches and impoundments of the mainstem, respectively. The RMA models were modified to make the algal and organic matter simulation more like that in CE-QUAL-W2. Tetra Tech is continuing to refine the PacifiCorp model for the purpose of developing TMDLs to address organic enrichment/low DO, temperature, and other impairments. To date, these analyses have included periphyton as a stressor pathway, but not as an endpoint. The RMA models simulate periphyton, but include a fixed limit on periphyton density of 20 g/m^2. For many model segments, the modeled periphyton density quickly reaches this limit and remains there; thus, the model, which provides a reasonable replication of instream water quality conditions, cannot be considered to provide a calibrated representation of benthic algal growth.

The Hoopa Valley Tribal Environmental Protection Agency (Kier Associates, 2005) recently proposed nutrient standards for the lower Klamath River. In addition to DO and pH, they selected periphyton density as an endpoint for criteria development, and recommended a maximum annual periphyton biomass of 100 mg/m^2 of periphyton chlorophyll *a*. Correlation analysis, relating periphyton biomass observed in 2004 to water quality observations, was then used to recommend standards of 0.20 mg/L total nitrogen and 0.035 mg/L total phosphorus.

1.4 SCOPE OF THIS EFFORT

Targets 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 model. Where site-specific calibrated nutrient response model exists, this provides the best means of developing an 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 does not appear to be well constrained or calibrated in the existing models. Therefore, this case study focuses on the periphyton target and development of nutrient numeric endpoints associated with that target.

2 Data

For the purposes of this case study, five 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 Figure 1):

KR18952	Klamath River below Iron Gate Dam
KR17608	Klamath River above Shasta River

KR14261	Klamath River above Scott Creek
KR12858	Klamath River at Seiad Valley
KRTR	Klamath River above Trinity River

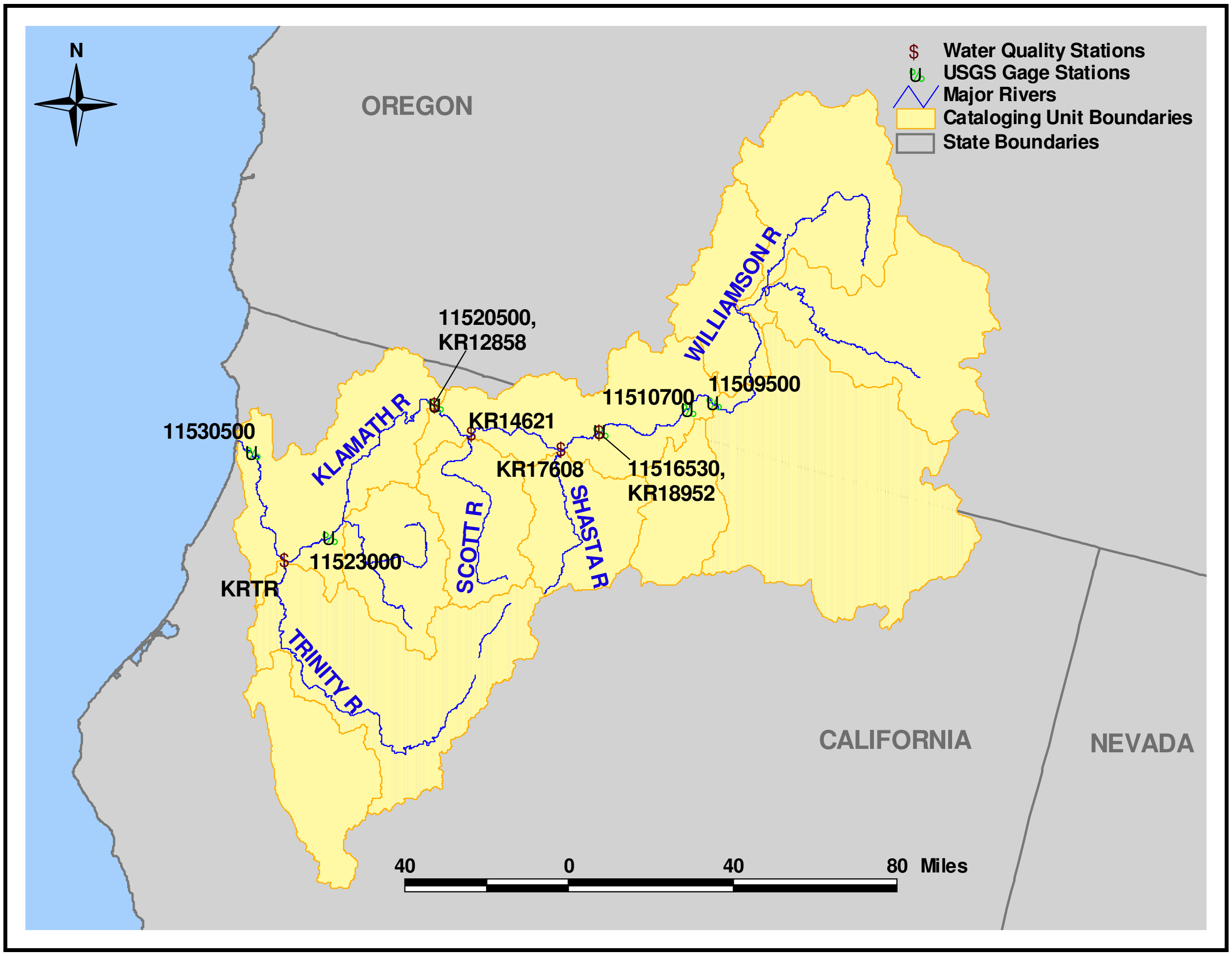

Figure 1. **Selected Water Quality Sampling Stations and Flow Gages on the Lower Klamath River**

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 very small 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 likely reflect a considerable amount of local variability, and cannot 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 1.

Table 1. 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)	Average Ash-Free Dry Weight (g/m^2)	Autotrophic Index (Average)
KRTR – Klamath River above Trinity River	126.4	312.5	84.7	202.0	2415.7
KR12858 – Klamath River at Seiad Valley	65.5	122.0	25.6	54.4	1991.0
KR14261 – Klamath River above Scott Creek	210.5	353.0	100.9	141.3	323.7
KR17608 – Klamath River above Shasta River	52.0	81.5	21.3	38.8	638.9
KR18952 – Klamath River below Iron Gate Dam	304.1	462.0	20.9	33.9	603.9

It should be noted that 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. 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.

2.2 CHEMICAL WATER QUALITY

In contrast to periphyton, an extensive database of chemical water quality exists collected by multiple agencies and described in Tetra Tech (2004). The North Coast Regional Water Quality Control Board supplied a database of these results. Statistics for summer season results (June – September) were extracted from this database. As periphyton is expected to have a moderately long response time to ambient nutrient concentrations, extreme values may not be particularly relevant. Therefore, the central tendency and range of the ambient data were described by the mean, median, 25th percentile, and 75th percentile (Table 2).

Table 2. Klamath River Water Quality Data, 2000-2003 Summer (June-September)

	Station	Count	Mean	Median	25th Percentile	75th Percentile
PO_4-P (mg/L)	KR12858	12	0.174	0.145	0.137	0.198
	KR14261	10	0.141667	0.14	0.2225	0.223
	KR17608	6	0.188333	0.1475	0.234167	0.234
	KR18952	13	0.15	0.13	0.16	0.160
	KRTR	4	0.04	0.0375	0.0425	0.043
ORG-P (mg/L)	KR12858	12	0.052	0.002	0.000	0.023
	KR14261	9	0.054	0.000	0.000	0.033
	KR17608	6	0.063	0.017	0.001	0.053
	KR18952	10	0.055	0.032	0.003	0.040
	KRTR	3	0.023	0.020	0.015	0.030
NO_3+NO_2-N (mg/L)	KR12858	12	0.135	0.095	0.050	0.111
	KR14261	10	0.127	0.143	0.063	0.170
	KR17608	6	0.165	0.153	0.062	0.260
	KR18952	13	0.164	0.140	0.073	0.214
	KRTR	4	0.036	0.034	0.030	0.039
NH_3-N (mg/L)	KR12858	12	0.125	0.080	0.067	0.190
	KR14261	10	0.111	0.095	0.073	0.100
	KR17608	6	0.109	0.092	0.069	0.122
	KR18952	13	0.075	0.087	0.050	0.100
	KRTR	4	0.125	0.100	0.100	0.125
ORG-N (mg/L)	KR12858	12	0.659	0.558	0.343	0.893
	KR14261	9	0.739	0.717	0.617	0.850
	KR17608	6	0.574	0.553	0.503	0.636
	KR18952	12	0.717	0.677	0.519	0.859
	KRTR	2	0.730	0.730	0.645	0.815
Turbidity (NTU)	KR12858	0	no data	no data	no data	no data
	KR14261	4	3.050	2.850	2.775	3.125
	KR17608	0	no data	no data	no data	no data
	KR18952	7	2.384	2.500	1.950	2.595
	KRTR	4	3.875	3.200	3.150	3.925

Note: Organic N calculated as TKN minus NO_3+NO_2-N; Organic P calculated as Total P minus PO_4-P

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).

3 NNE Tools Application

3.1 PARAMETER SPECIFICATION

Velocity

Stream velocity at each site was input as the "typical" summer value shown in the output of the PacifiCorp (2005) RMA model of the Klamath.

Depth

The PacifiCorp 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

Solar radiation was estimated for the summer period (June-August) was estimated based on latitude using the routine incorporated in the Benthic Biomass spreadsheet. No data on canopy or topographic shading were available; however, the majority of the Lower Klamath channel appears to be relatively open, so no shading was assumed.

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 3) 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 3. 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 above Shasta River	81.9
11530500 Klamath River at Klamath	69.1

3.2 MODEL RESULTS

The NNE Benthic Biomass Predictor tool provides a variety of empirical and simplified parametric model approaches to predicting benthic algal response to ambient conditions. The tool was first used to predict maximum benthic chlorophyll *a* at each of the sites. As discussed in Tetra Tech (2006), benthic algal density is highly variable in time and space, and simplified models generally seem to do a better job of predicting maximum benthic algal density. The tool provides access to multiple predictions, but only three are presented here. Of the empirical approaches, we present the latest revision of the Dodds model (Dodds 2002), while for a parametric approach we present the revised QUAL2K model (which is tuned to correspond to the Dodds' results on small streams), both with and without an accrual adjustment (Table 4). The accrual adjustment has little effect on the upstream stations (where the estimated days of accrual are large), but does have a noticeable effect at the downstream station KRTR.

Table 4. Predicted and Observed Maximum Benthic Chlorophyll *a* (mg/m^2)

Station	Revised QUAL2K	Revised QUAL2K with Accrual Adjustment	Dodds 2002	Observed Maximum
KRTR	404	290	163	312
KR12858	358	324	214	122
KR14261	294	266	208	353
KR17608	207	206	210	81.5
KR18952	411	410	211	462

In general, the revised QUAL2K approaches appear to do a reasonable job of replicating observed maxima. At three of five stations, the predicted maximum is greater than the observed – which may only mean that the maximum was not sampled. At two other stations, the QUAL2K predictions are less than the observed maximum by around 20 percent. This is likely within the error of the model, but also 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.

The tool can then be used to predict nutrient targets consistent with achieving a specified maximum algal density. For the COLD and SPAWN 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. Therefore, results are most conveniently presented 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 algal concentration target of 150 mg/m^2 are shown in Table 5, while Table 6 shows the corresponding estimates for a target of 100 mg/m^2 maximum benthic chlorophyll *a*.

Table 5. Total Nitrogen Goal (mg/L) for Target of 150 mg/m^2 Maximum Chlorophyll *a*

Station	Revised QUAL2K	Revised QUAL2K with Accrual Adjustment	Dodds 2002
KRTR	0.17	0.30	0.59
KR12858	0.22	0.26	0.33
KR14261	0.32	0.38	0.33
KR17608	0.50	0.50	0.31
KR18952	0.57	0.57	0.35

Table 6. Total Nitrogen Goal (mg/L) for Target of 100 mg/m^2 Maximum Chlorophyll *a*

Station	Revised QUAL2K	Revised QUAL2K with Accrual Adjustment	Dodds 2002
KRTR	0.08	0.15	0.19
KR12858	0.10	0.13	0.11
KR14261	0.16	0.19	0.11
KR17608	0.26	0.26	0.10
KR18952	0.29	0.29	0.11

Results of the two model types are rather different because the QUAL2K approach is based on the most limiting nutrient, while the Dodds et al. (1997, 2002) approach assumes co-limitation, and the N:P ratio for the Klamath differs from the typical values found in the development data set used by Dodds. A comparison of the two approaches is shown for downstream station KRTR – where the difference between approaches is greatest – in Figure 2.

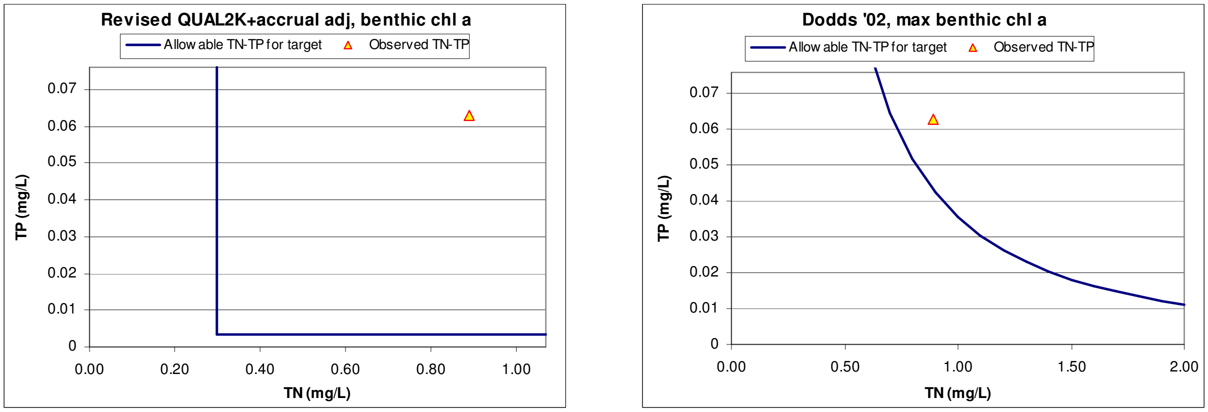

Figure 2. **Revised QUAL2K and Dodds 2002 Tool Results for a Target Maximum of 150 mg/m^2-Chlorophyll *a***

4 Suggested Targets

The California NNE approach is a risk-based approach, with ultimate focus on supporting designated uses. The general NNE guidance and accompanying tools provide initial, scoping-level estimates of nutrient reduction targets that can be used as a starting point for a TMDL. It should be noted, however, that the general targets can potentially be replaced by appropriate site-specific targets. Site-specific targets for response endpoints might arise from a site-specific risk analysis. More sophisticated site-specific nutrient endpoints can be derived from the response targets through the use of calibrated, site-specific models.

To date, TMDL and modeling efforts on the Klamath have focused on instream response endpoints of DO and pH, which are strongly affected by planktonic algal productivity in the Klamath reservoirs. Numeric DO criteria are already available, and a calibrated model has been developed to address these issues. Therefore, the DO and impoundment planktonic algae endpoints are not addressed further here.

Nutrient loading in the Klamath also produces high levels of periphytic algae. To date, targets have not been established for this endpoint (although the Hoopa Valley Tribal Environmental Protection Agency has proposed periphyton targets). Further, while periphyton is included in the Klamath River models, these have not been rigorously calibrated for periphyton prediction. Therefore, periphyton in the Klamath mainstem is an appropriate case study for the NNE approach to setting targets.

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, SPAWN, and REC designated uses. Finally, in the Klamath 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.

4.1 RESPONSE TARGETS

The California NNE Approach (Tetra Tech, 2006) recommends setting response targets for benthic algal biomass in streams based on maximum density as mg/m^2 chlorophyll *a*. For the COLD 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 prevalence 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.

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 cyanophytes in the upper 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 Hoopa, however, have proposed a target maximum density of 100 mg/m^2, coincident with the BURC I/II boundary. Setting a final response endpoint target within this range may require additional ecological work to evaluate the risk posed by maximum concentrations between 100 and 150 mg/m$^{2.}$

4.2 NUTRIENT TARGETS

The NNE Benthic Biomass Predictor spreadsheet can be used to translate the response targets into nutrient concentration goals. As noted above, nitrogen appears to be somewhat more limiting in most of the Klamath segments, and it is thus appropriate to set a nitrogen target together with an approximate phosphorus target based on the Redfield ratio.

Application of the Revised QUAL2K method in the spreadsheet tool at the recommended response variable target of 150 mg/m^2 chlorophyll *a* leads to nitrogen goals that range from 0.57 mg/L below Iron Gate to 0.17 mg/L (without accrual adjustment) to 0.30 mg/L (with accrual adjustment) above Trinity River (Table 5). (The Dodds (2002) is not recommended for targeting in this system as it appears to underestimate observed densities.) Acceptance of an accrual adjustment may require further evidence in this system, and should be evaluated in light of the need for a margin of safety (as the occurrence of scouring flows at the indicated frequency is not guaranteed). Nitrogen concentrations in the Klamath naturally decline downstream of Iron Gate Dam, although not to the extent indicated as needed to meet the goal above Trinity River. Runs of the full calibrated RMA/W2 modeling system for the Klamath should be undertaken to determine whether reductions to meet the target at Iron Gate will result in meeting targets downstream at the Trinity River.

One consideration for evaluating the lower total nitrogen goals predicted to be needed at the station above Trinity River is that the Revised QUAL2K approach works with total nutrient concentrations, and does not consider the inorganic fraction. This fraction tends to become larger as flow proceeds downstream. Use of the Standard QUAL2K model (which does account for nutrient speciation) suggests that a larger total nitrogen concentration of 0.27 mg/L might meet targets at KRTR. Again, this may be an issue to evaluate in a more complex, calibrated model.

Total nitrogen goals to meet a target of 100 mg/m^2 maximum chlorophyll *a* are slightly more than half of those needed to meet the 150 mg/m^2 target (Table 6).

The analysis of nutrient goals conducted by the Hoopa (Kier Associates, 2005) suggested a goal of 0.20 mg/L total nitrogen. This goal is not, however, based on the stated periphyton target of 100 mg/m^2 chlorophyll *a*, bur rather on correlation analysis between summer total nitrogen and other response variables such as daily minimum DO and maximum pH. Our approach suggests similar limits in the downstream portion of the Klamath near Hoopa tribal lands, but suggests that higher concentrations may be acceptable upstream.

5 Summary

The California NNE method and tools were successfully applied to the analysis of periphyton in the Lower Klamath River. The Revised QUAL2K method appears to provide a reasonable fit to observed maximum periphyton density (as chlorophyll *a*). To meet a target maximum density of 150 mg/m^2, total nitrogen concentrations are predicted to need to be reduced to 0.57 mg/L below Iron Gate Dam and to 0.30 mg/L (with accrual adjustment) or 0.17 mg/L (without accrual adjustment) above Trinity River. These correspond to reductions of 40 percent, 66 percent, and 81 percent relative to existing conditions, respectively.

The NNE tools provide only a scoping-level analysis of nutrient targets, and should 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, and further include a fixed maximum cap on periphyton density that is less than observed concentrations. Further refinements may enable use of this model to better evaluate site-specific responses of periphyton. There are, however, concerns regarding the accuracy of the little periphyton data that are available from the Klamath, due to small sample size and lack of replication. Thus, continued and improved periphyton sampling may be needed to calibrate the TMDL model for this component.

6 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.

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. *Can. J. Fish. Aquat. Sci*. 59: 865-874.

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.

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.

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.

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.

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

Tetra Tech. 2004. Data Review and Modeling Approach – Klamath and Lost Rivers TMDL Development. Prepared for U.S. Environmental Protection Agency Region 10, U.S. Environmental Protection Agency Region 9, Oregon Department of Environmental Quality, and North Coast Regional Water Quality Control Board by Tetra Tech, Inc., Fairfax, VA.

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.

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.