Memorandum

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TO: Karen Cowan, County of Orange

SUBJECT: Relationships Between Nutrients and Algae in Newport Bay and the Newport Bay Watershed (Task 1.4)

Cc: Karen Ashby, LWA

1.0 INTRODUCTION AND PROBLEM STATEMENT

Nitrogen, an essential nutrient for algal growth and aquatic life, can cause excessive algal growth and harm aquatic life when present in high abundance. Large mats of macroalgae were common in Lower and Upper Newport Bay during the 1980's and 1990's, and anecdotal reports of algal blooms exist for the streams in the watershed. Algal blooms threaten beneficial uses by impeding wading and boating, and by harming aquatic life through reductions in dissolved oxygen. During the peak bloom in Newport Bay of 1985-1986, dissolved oxygen levels in some areas of the Bay dropped to 0 mg/L, resulting in a fish kill (USEPA 1998).

As a result of these impacts, a nutrient Total Maximum Daily Load (TMDL) was established in 1998 that established nutrient load allocations and waste load allocations. Although the extent of algal growth has declined in the past several years and nitrogen loads have decreased, summer blooms continue to occur both in San Diego Creek and portions of Upper Newport Bay.

Concentrations of nitrogen in the water column exceed Basin Plan numeric objectives in the upper portion (Reach 2) of San Diego Creek, and has been shown to promote excessive growth of algae in Newport Bay, although there is evidence that impacts on beneficial uses related to freshwater and estuarine habitats, recreation, and navigation have declined in recent years due to reductions in nitrogen loads (Hauptly and Moore, 2005)

The Nitrogen and Selenium Management Program (NSMP) includes a series of tasks that will assist the NSMP Working Group in assessing the impacts of nitrogen (Task 1.4) as well as evaluating the nutrient TMDL (Task 4). The primary objective, however, of the nitrogen-related tasks is to assist the Working Group with making management decisions based on a quantitative assessment of the available data.

The objective of Task 1.4 is to identify the locations in the Newport Bay Watershed and Newport Bay where excessive algal growth is occurring and, to the extent possible, develop a quantitative relationship between nitrogen levels, algal growth, and beneficial use impairment, and use this relationship to assess the relative risk of nitrogen impacts in the bay and the watershed.

This task consists of:

- Sub-task 1.4.1 Describe the extent of excessive algal growth; and
- Sub-task 1.4.2 Assess linkages between nitrogen and algal growth.

Two technical memoranda addressed sub-task 1.4.1 (Indicators for Detecting Algae-Related Aquatic Life Use Impairments in the Newport Bay Watershed and Newport Bay, May 30, 2007, and Results of Algal Survey in the Newport Bay Watershed, May 30, 2007).

The purpose of this memo is to explore the relationships between nitrogen and algal biomass in the Newport Bay Watershed. It is important to note that this memo does not promote specific numeric targets for adoption as water quality objectives, but strictly to provide technical support to the Working Group in evaluating the relationships between nitrogen and algal biomass. The development of such water quality objectives would include an analysis pursuant to California Water Code 13241, which is beyond the scope of this task. In addition, the investigations reported here must be considered exploratory due to the limited amount of data available, the very high between- and within-year variation in nutrients and algae in southern California streams and estuaries, and the inherent complexity of nutrient-algal relationships in any aquatic system.

This technical memo builds on the earlier memoranda for sub-task 1.4.1 and addresses sub-task 1.4.2 by using the best available science (both theoretical and empirical) to determine the nature of the relationship between nitrogen and algal growth. Sub-task 1.4.2 includes the directive to develop a modeling approach to describe the linkages between nitrogen and algal growth, incorporating a range of realistic environmental conditions. This sub-task also requires coordination with the joint EPA/State Water Resources Control Board Regional Technical Advisory Group (RTAG), which has developed modeling tools for assessing the likelihood of nutrient impacts on freshwater systems, and published guidelines for use of those tools (Tetra Tech 2006). Defining the functional linkage between nitrogen and algal growth will be critical in determining the role of nitrogen in impacts on beneficial uses, planning and evaluating best management practices (BMPs), and developing recommendations regarding any needed revisions to the water quality objective and the nutrient TMDL.

The modeling tools developed by the RTAG for freshwater systems, while still new, are fully operational at this time. At the request of EPA Region IX, researchers at the Southern California Coastal Water Research Project (SCCWRP) and Regional Board staff, in conjunction with Tetra Tech Inc., are currently developing an approach for setting water quality objectives for nutrients for California estuaries. Although a conceptual framework for the approach to estuarine objectives has been established (Sutula et al. 2006a), useable models are not yet in place for assessing potential nutrient targets for Newport Bay. Therefore, while the working group will continue to collaborate with SCCWRP and the Regional Board to address nutrient-algae relationships in the Bay, this memo focuses primarily on nutrient-algae relationships in the watershed.

This memo is divided into the following sections:

- Section 2 – Methods and Approach to Problem
    - 2.1 – Upper Newport Bay
    - 2.2 – San Diego Creek and the Newport Bay Watershed
- Section 3 – Results
    - 3.1 – Performance and Calibration of Stream Models
    - 3.2 – Using the Models to Predict Protective Nitrogen Concentrations
- Section 4 – Discussion
    - 4.1 – Factors Affecting Algal Growth Not Accounted for in Modeling Approach
    - 4.2 – Difficulties in Assessing Relationships Between Nutrient Concentrations and Algal Biomass
    - 4.3 – Importance of Considering Site-Specific Conditions
    - 4.4 – Feasibility of Achieving Projected Nitrogen Levels
- Section 5 – Next Steps
- Section 6 – References

2.0 METHODS AND APPROACH TO ASSESSING NUTRIENT-ALGAE RELATIONSHIPS

Different methods are required to assess nutrient-algae relationships in the watershed and the bay because of the difference in physical, chemical, and biological conditions between the two habitat types. The watershed is a freshwater system with unidirectional flow, typically shallow waters resulting in frequent high water temperatures, and because many of the water conveyance channels are concrete-lined they have very high light availability and are largely free of sediment. In contrast, the bay has variable salinity, multi-directional tidal flushing, greater attenuation of light through the water column, and importantly, natural sediments throughout which provide year-round processing, sequestration, and releases of nutrients such as nitrogen and phosphorus which fuel algal growth.

This section describes the separate considerations and methods which are or will be used to assess nutrient-algal relationships in both the bay and the watershed.

2.1 Upper Newport Bay

As stated above, researchers at the Southern California Coastal Water Research Project (SCCWRP), in conjunction with Tetra Tech Inc., are currently developing an approach for setting water quality objectives for nutrients for California estuaries (Sutula et al. 2006a). Their proposed approach includes developing modeling tools which will quantitatively link nutrient loads and concentrations to biological response indicators. These modeling tools will use available data on algal biomass, percent cover and estimated nutrient loading to the estuary to develop correlations between nutrients and algal blooms. Although nuisance algal growth primarily occurs during the warm, dry summer months, nutrient loading during both dry and wet seasons will need to be considered separately. Nutrients deposited in the sediments of the Bay during winter storms can be released slowly throughout the course of the subsequent dry season, fueling algal growth (Sutula et al. 2006b).

The modeling effort for developing water quality objectives for nutrients in estuaries is still under development, and cannot yet be applied to Newport Bay; therefore no data are presented in this technical memorandum. However, the Working Group will continue to work closely with SCCWRP in both the development of these modeling tools and their implementation in Newport Bay.

2.2 *Newport Bay Watershed*

The assessment of linkages between nitrogen and algal growth and biomass accumulation in the Newport Bay watershed is addressed here through a multi-pronged approach including:

1) Analyzing available data on algae and nutrient concentrations in the watershed;
2) Comparison of those data with information from other, similar watersheds in southern California and elsewhere; and
3) Making predictions based on models which can be calibrated specifically to the Newport Bay watershed using the available data.

This approach is described in further detail below.

2.2.1 Data Availability

Ideally, multiple years' worth of quantitative information on both water column nutrient concentrations and algal biomass would be compared in order to identify long-term patterns in the nutrient-algae relationship. This relationship can change from year to year, and may be highly variable in response to changes in climate (e.g., winter rainfall amounts and summer temperatures). Algal biomass, including benthically attached and floating mats of micro- and macroalgae, exhibits two natural peaks, one in late spring/early summer, and a second in late summer/early autumn. These natural peaks occur in pristine, non-urbanized streams as well as those more heavily anthropogenically influenced; the causes of these natural peaks are not fully understood but likely include some combination of changes in light and nutrient availability, water temperatures, and changes in grazing pressure by invertebrates. Because algal biomass in streams can vary greatly in space and time (i.e., from site to site within a watershed, and across seasons within a year), biomass data should be collected at least three times over the course of each year. These data can then be combined to represent an annual average amount of biomass for any given site (see *Indicators for Detecting Algae-Related Aquatic Life Use Impairments in the Newport Bay Watershed and Newport Bay*, May 30, 2007, for a more thorough discussion of this).

Data on nutrient concentrations (nitrogen and phosphorus) in the watershed are readily available since the County of Orange regularly collects this information at multiple sites and some of these sites have been monitored for several decades. However, data on algal abundance (percent cover and biomass) are limited and have only been collected in the spring, summer, and fall of 2006. This study was completed as a part of the Working Group's efforts to characterize algal growth and impacts within the watershed. The details of the study and the results are presented in a technical memorandum (Results of Algal Survey in the Newport Bay Watershed (Task 1.4.1), dated

May 30, 2007; hereafter, "Algal Survey"). Because the large year-to-year differences in rainfall in southern California's Mediterranean climate can cause similarly large difference in patterns of algal biomass in streams, these data gathered within a single year must be used with caution; ideally, multiple years' worth of both nutrient concentrations and algal biomass would be used to more robustly assess nutrient-algal relationships.

2.2.2 Comparison with Other Stream Systems

Comparison of the results of the watershed algae study with similar results for streams outside of southern California is difficult, as the long, dry summers of the Mediterranean climate in the southern California region produce very different algal communities than are found in other temperate-climate regions with regular flood disturbance (e.g. every six weeks). Regular rainfall and flooding events tend to scour algae from a streambed and "reset" the community; in contrast, the six-month dry season of southern California can be expected to produce streams with naturally higher amounts of standing algal biomass (Simpson 2006). An additional complication is the fact that many of the streams in the Newport Bay watershed have been heavily channelized for flood control purposes, removing the natural substrate complexity and much of the biogeochemical processing of nutrients which occurs in unchannelized streams.

Instead of a broad literature survey, the results from the 2006 Algal Survey were compared to the results from a 2001-2002 study conducted in the Malibu Creek watershed (Busse et al. 2006), another southern California stream system which undergoes long dry summers, and which has many channelized flood control structures. Although the nutrient concentrations in the streams surveyed in the Malibu Creek study were generally much lower than those in the Newport Bay watershed, the two studies were conducted with very similar methods, and the results can be compared for greater insight into the specifics of nutrient-algal relationships in southern California streams. This is described further in section 4.0.

2.2.3 Watershed Modeling Tools

EPA Region IX, working with Tetra Tech Inc. has developed a Nutrient Numeric Endpoint (NNE) tool to assist in assessing nutrient-algal relationships in California streams, for the purposes of developing nutrient criteria. This project arose out of the efforts of the EPA-convened Regional Technical Advisory Group (RTAG), which included representatives from state, federal, and tribal agencies, in addition to representatives from environmental groups and industries, and thus enjoyed broad stakeholder support. The modeling tool was developed in summer of 2006 and has not yet been widely tested or applied. However, it is a very useful tool, and it represents the best available scientific method for assessing nutrient-algae relationships in the Newport Bay watershed.

The NNE tool uses water column nutrient concentrations and some site-specific factors (e.g., canopy cover, stream velocity, days since last scouring flood event) to predict algal biomass and resulting water quality impacts such as depressed dissolved oxygen concentrations. To do so, the tool presents results from two general models, one mechanistic and the other statistical.

- The QUAL2K model is a mechanistic model that calculates abundance of algae based on laboratory studies of growth rates in response to resource availability (primarily light and nutrients). Three versions of the model are available, including the "Standard" Qual2K and two revised versions which have been adjusted to be more applicable to California streams where disturbance by major flooding events is rarer than in regions with year-round rainfall. The model predicts **maximum** (peak) algal biomass in streams.
- Two versions of the statistical model were developed by Dodds and others (Dodds et al. 1998, Dodds et al. 2002) from a database containing surveys of nutrient concentrations and algal abundance in hundreds of streams throughout North America and New Zealand. The statistical model simply draws correlations between the nutrient and algae data. While there is a large amount of variation in the data, statistically significant correlations do arise because of the large number of samples. The Dodds models predict both **maximum** and **average** algal biomass in streams.

Tetra Tech's NNE modeling tool is an important and very useful development in the field of stream ecology and water quality management. However, as is explicitly acknowledged in the published materials supporting the NNE tool, the model results cannot simply be applied rigidly to derive numeric nutrient criteria (Tetra Tech 2006). Rather, the results are meant to be used as one of multiple lines of evidence in developing nutrient criteria. It is also explicitly acknowledged in the supporting documents for the NNE tool that nutrient-algae relationships are extremely complicated and modified by many site-specific conditions, and that these conditions must be taken into account in developing nutrient criteria, or even in designating impairment of water bodies. Factors such as temperature, flow conditions, and availability of other key resources (e.g., light and phosphorus) also exert strong influence on algal growth and accumulation of biomass. In addition, these other factors can either mitigate or intensify the impacts of algal biomass on aquatic life and recreational uses of streams.

Both types of models were tested using data collected in the Algal Survey in Newport Bay watershed in 2006. All of the models make predictions of algal biomass resulting from either solely inputs of nutrient concentrations, or inputs of nutrient concentrations plus estimates of other important factors for algal growth such as light availability, temperature, and time since last flooding or scouring event. Results from all three versions of the Qual2K (the mechanistic models) and both Dodds 1998 and 2002 (the statistical models) were compared to actual data collected in the Newport Bay watershed. The versions of these models that had the most accurate output (i.e., closest to the empirical data collected in the watershed) were then used to estimate a range of nitrogen concentrations that may be protective of aquatic life in the watershed.

The Dodds models made predictions of both annual average (i.e., average of multiple measurements over the course of a year) and maximum (i.e., a single measurement) algal biomass. The levels of algal biomass developed to protect aquatic life in the Newport Bay watershed are based on averages, not maxima; therefore results of the 2006 Algal Survey were used to estimate the actual relationship between maximum and average biomass in the watershed, and this ratio was used to calibrate the output of the Qual2K model.

3.0 RESULTS[1]

3.1 Performance and Calibration of Stream Models

Reasonably consistent results were obtained in calibrating both the Dodds 2002 and the standard Qual2K models to the results of the Algal Survey in the Newport Bay watershed. Both the statistical and mechanistic models were more likely to overpredict algal biomass at sites with concrete-lined channels (CICF25, CMCG02, MIRF07, WYLSED) and underpredict biomass at sites with soft sediments (ACWF18, BARSED, LANF08). These results are summarized in **Table 1** and discussed in further detail below. The locations of all sites surveyed are shown in **Figure 1**.

These calibrations were then used to back-calculate a range of nitrogen concentrations predicted to be protective of the algal biomass threshold specified in the technical memo *Indicators for Detecting Algae-Related Aquatic Life Use Impairments in the Newport Bay Watershed and Newport Bay* dated May 30, 2007 (average 150 mg m^{-2} chlorophyll a; Larry Walker Associates). The standard Qual2K model predicted algal biomass much more accurately than either of the two revised versions, and therefore only the standard version was used for predicting protective nitrogen concentrations.

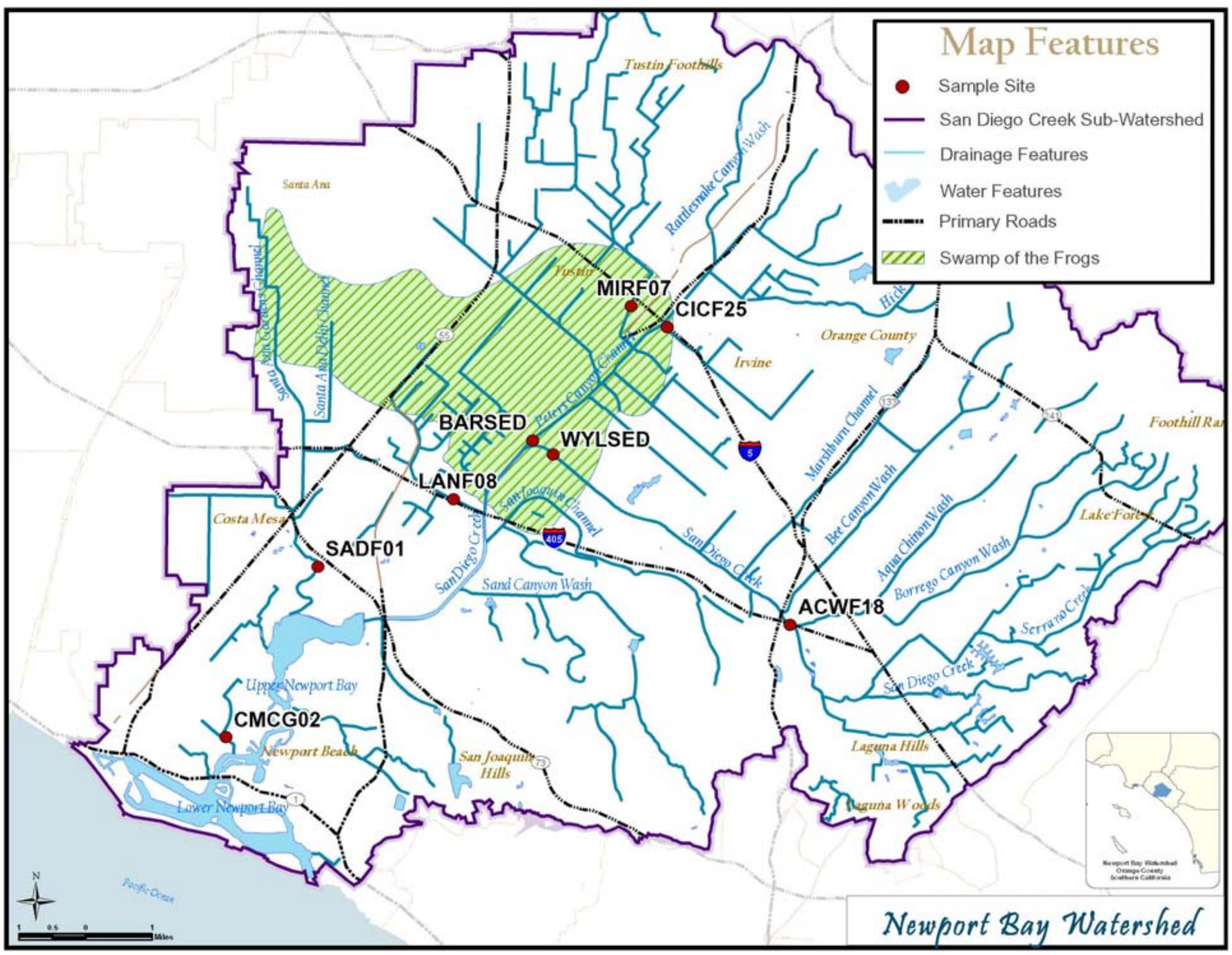
[1] The Results and Discussion sections of this Memorandum include some new information and references which have become available since the July 24 draft. Of particular importance is the use of a revised version of the Tetra Tech NNE modeling tool, which has changed some of the results (specifically, the N-algal relationships predicted by the Dodds 2002 statistical model); see esp. **Table 1** and **Figures 2, 4a** and **4b**.

Table 1. Summary of Results Comparing Predicted Algal Biomass with Measured Biomass in the Newport Bay Watershed in 2006 (percent of biomass predicted by model shown in parentheses under the actual value).

Site Code	Creek Name	Substrate type	Maximum Chl a (mg m^{-2})			Average Chl a (mg m^{-2})	
			Measured	Predicted: Dodds 2002	Predicted: Standard Qual2K	Measured	Predicted: Dodds 2002
ACWF18	Agua Chinon	soft sediments (sandy)	742	551 (74%)	474 (64%)	477	253 (53%)
BARSED	Peters Canyon Wash	soft sediments (sandy, silty)	2658	359 (14%)	414 (16%)	1300	189 (15%)
LANF08	Lane Channel	soft sediments (silty, clayey)	790	271 (34%)	434 (55%)	743	115 (16%)
MIRF07	El Modena-Irvine Channel	concrete-lined	327	319 (98%)	424 (130%)	152	133 (87.3%)
CICF25	Central Irvine Channel	concrete-lined	230	465 (203%)	459 (200%)	149	204 (137%)
WYLSED	San Diego Creek	concrete-lined	249	525 (211%)	450 (181%)	114	312 (273.2%)
SADF01	Santa Ana Delhi	concrete-lined	2917	273 (9%)	361 (12%)	1141	135 (12%)
CMCG02	Costa Mesa Channel	concrete-lined	347	351 (101%)	372 (107%)	241	139 (58%)

It is important to note here that the performance of both the Qual2K and the Dodds models was assessed using only one year's worth of data on algal biomass. As mentioned in Section 2.2.1, relationships between nutrients and algae can change dramatically from year to year, particularly in southern California. Annual rainfall amounts can vary over an order of magnitude in this region, with concomitant variation in the frequency and severity of flooding/algal scouring events, the relative contribution of anthropogenic vs. natural runoff generating streamflows, and the composition of biological communities which respond to these physical and chemical changes. Rainfall in the 2006 water year represented about 87% of the 129-year average for southern California (source: National Weather Service, Los Angeles Civic Center station). However, "average" rainfall years are relatively rare, with precipitation totals commonly ranging from less than 30% to over 150% of average. Because the nutrient-algae relationships presented here have been developed based on data from only one year, they should be interpreted with caution. Testing the models against data gathered in multiple years with different climatological conditions would greatly improve the reliability of the results.

Figure 1. Map of Sites Sampled in the Newport Bay Watershed in 2006.



3.1.1 Statistical Models, Average Biomass

With few exceptions, average algal biomass was consistently underpredicted by both Dodds models. Predictions using Dodds 2002 averaged 81% of measured algal biomass, while predictions from Dodds 1997 averaged only 29% of measured (**Figure 2, Table 1**).

Figure 2. Comparison of Modeled Average Algal Biomass with Measured Average Algal Biomass.
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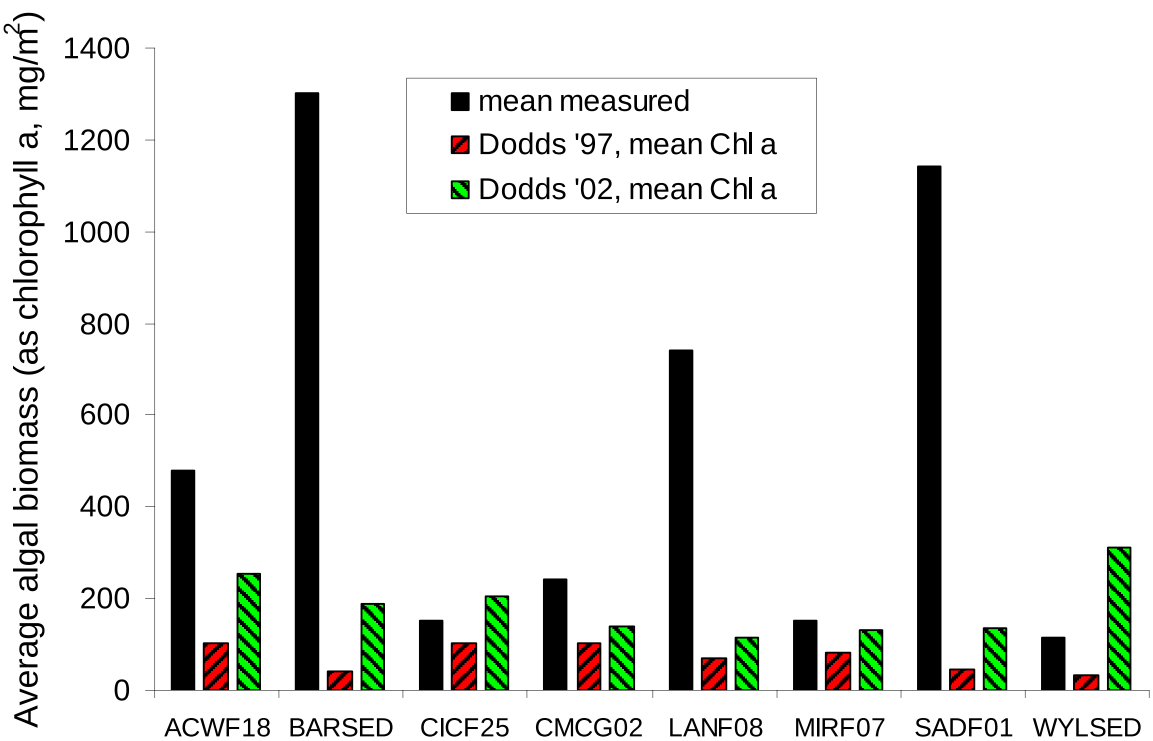
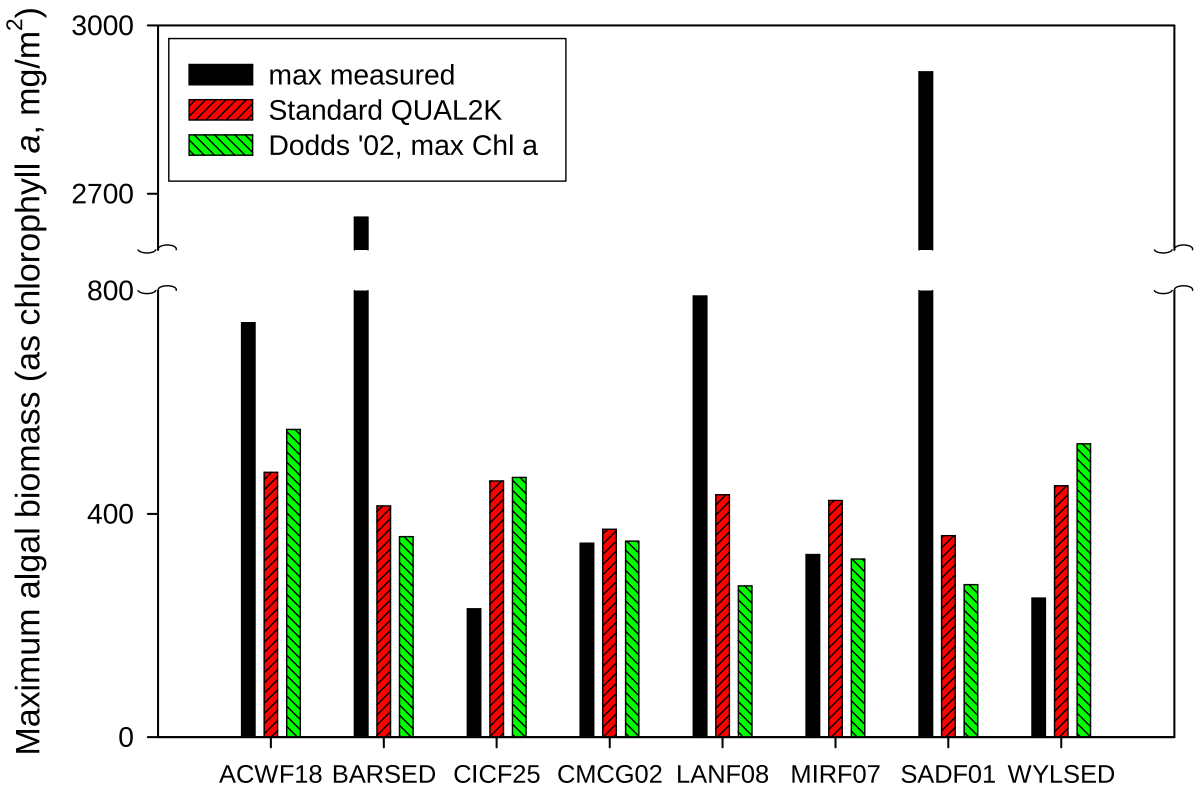


3.1.2 Mechanistic vs. Statistical models, Maximum Biomass

Maximum algal biomass was better predicted by both the mechanistic and statistical models (**Figure 3, Table 1**). Of the mechanistic models, the Standard QUAL2K was the most accurate at predicting real biomass, predicting on average 96% of actual measured maximum biomass. It tended to overpredict biomass at sites with concrete-lined channels (by up to 200%) and underpredict biomass at sites with soft sediments (as low as 16% of actual biomass). The predictions of the Dodds 2002 statistical model averaged 93%, and showed the same bias of underpredicting biomass at sites with soft sediments (down to 14% of measured) and overpredicting biomass in concrete-lined channels (up to 211%).

Figure 3: Comparison of Modeled Maximum Algal Biomass with Measured Maximum Algal Biomass.



These results are qualitatively similar to results reported when the NNE tool was applied to the Malibu Creek watershed, one of the few other southern California watersheds in which algal biomass has been rigorously measured over multiple seasons (Tetra Tech, 2007a). In that study the Standard QUAL2K model predicted maximum biomass at 115% of what was actually measured, with a range of 32% - 186%. The Dodds 2002 statistical model predicted actual biomass at an average of 110%, with a range of 13% - 303%. However, there was no bias evident with regards to substrate type present at any of the sites analyzed from that watershed.

3.1.3 Performance-based Choice of Models for the Newport Bay Watershed

The information gathered in the previous section can be used to apply both the Dodds 2002 statistical model and the standard Qual2K mechanistic model specifically to the Newport Bay watershed. Since these two models demonstrated the best performance when compared to empirical data, they can be used to project a range of nitrogen concentrations which may be protective of the proposed 150 mg m^{-2} chlorophyll a algal biomass threshold.

3.2 Using the Models to Predict Protective Nitrogen Concentrations

The standard Qual2K and the Dodds 2002 models performed the most accurately when ground-truthed against measured conditions in the Newport Bay watershed. Therefore these two models are the most appropriate to use for predicting a range of upper thresholds for nitrogen concentrations which may maintain algal biomass at or under the proposed 150 mg m^{-2} average chlorophyll a threshold.

However, other factors besides nitrogen affect and support algal growth. In particular, phosphorus and light availability must be taken into account when deriving nitrogen thresholds. Both nitrogen and phosphorus are necessary for algal growth, and the ratio between these two nutrients can affect growth rates of algae (Redfield 1934). N:P ratios vary widely across different sites in the Newport Bay watershed (see **Table 2**), so the effects of nitrogen on algal growth was modeled at multiple N:P ratios. These included N:P ratios (by mass) of 250, 100, 50, and 10, representing the range of ratios found at the sites sampled. The N:P ratio representing the Redfield ratio of 7.2 was included, as this is widely considered to be an ideal N:P ratio for algal growth (Redfield, 1934).

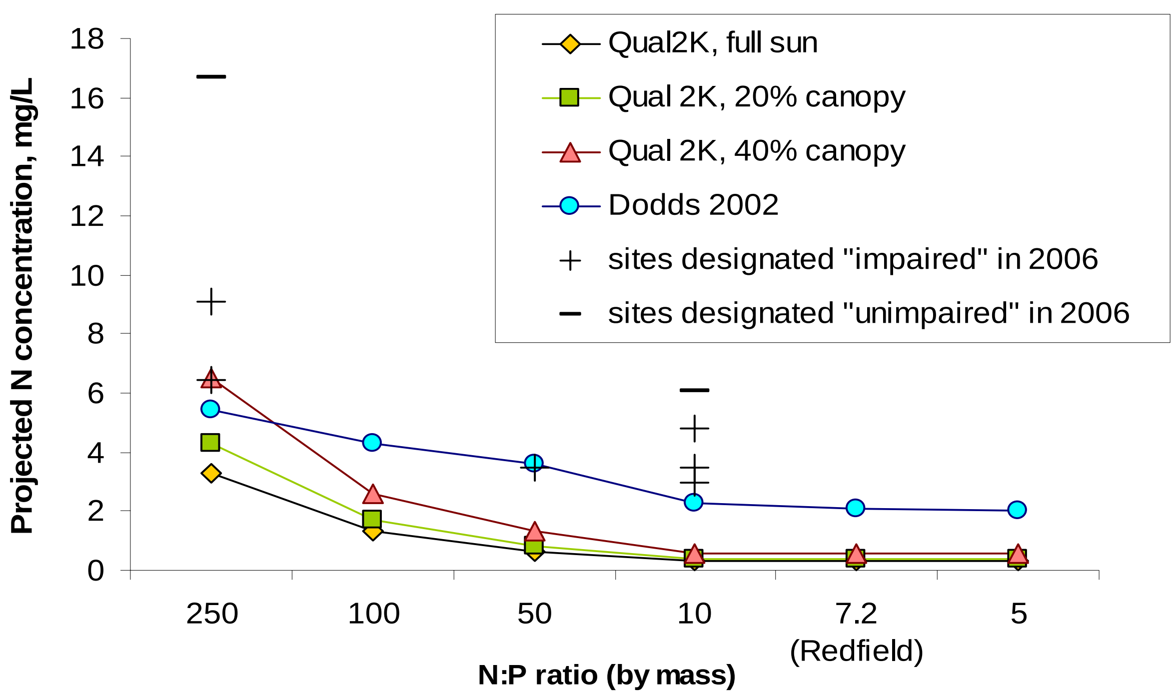
Table 2. Average Dry-season (March – September) N and P Concentrations and Molar N:P Ratios at Sites Sampled in the Newport Bay Watershed in 2006.

Site Code	Creek Name	Average Total N (mg/L)	Average Total P (mg/L)	Average N:P Ratio (by mass)
ACWF18	Agua Chinon	6.0	0.61	10
MIRF07	El Modena-Irvine Channel	3.5	0.13	26
CICF25	Central Irvine Channel	4.8	0.42	12
BARSED	Peters Canyon Wash	9.1	0.05	202
WYLSED	San Diego Creek	16.7	0.09	185
LANF08	Lane Channel	3.5	0.06	55
SADF01	Santa Ana Delhi	6.4	0.02	275
CMCG02	Costa Mesa Channel	3.0	0.26	11

Sunlight is also a major factor controlling algal growth, as algal photosynthesis is often limited by light availability. The Qual2K model provides for predictions of algal growth at different light levels, and so the biomass/N relationship was also modeled at three levels of light availability: full sun, 20% canopy cover, and 40% canopy cover. Although all the sites sampled in the Newport Bay watershed during the Algal Survey are channelized and have virtually no canopy cover, other sites within the watershed do still retain a riparian canopy. Therefore, on a watershed-wide scale it is important to consider the effects of shading on nutrient-algae relationships.

The standard Qual2K model for sites with full sunlight availability produced the lowest nitrogen thresholds, from 3.3 mg/L total N for a site with an N:P ratio of 250, to 0.3 mg/L for a site with an N:P of 5. The Dodds 2002 statistical model produced the highest thresholds at most N:P ratios, from 5.4 mg/L total N for the high N:P sites, to 2.0 mg/L at the sites with the lowest N:P ratios; however, the highest N threshold was predicted by the Qual2K model for a site with 40% canopy cover, at 6.5 mg/L total N. **Figure 4a** presents protective nitrogen concentrations predicted by the different models under different N:P ratios (within the range of those actually measured in the Newport Bay watershed). N concentrations for sites measured in the 2006 Algal Survey are included for reference, with sites that exceeded the proposed algal thresholds marked +, and sites which did not exceed the impairment criteria marked -.

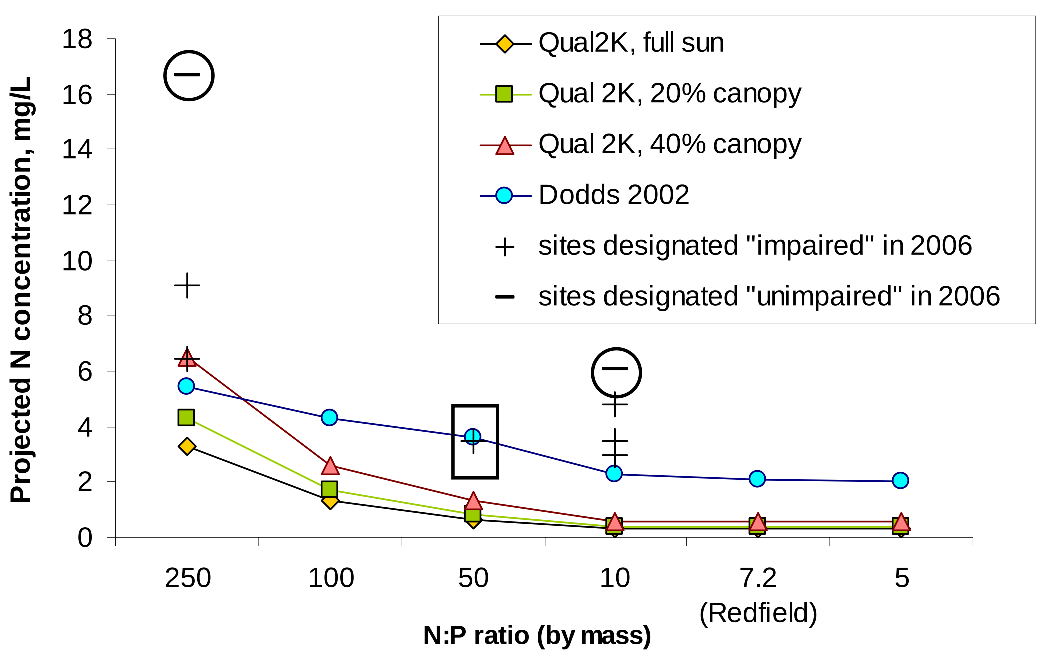
Figure 4a. Nitrogen Concentrations Projected to be Protective of Aquatic Life Under Different Modeling Scenarios.



Predictions derived using the standard Qual2K model appear to be generally more protective than those derived from the Dodds 2002 model, except at the highest N:P ratio. For instance, the Dodds model predicts that at a site with an N:P ratio in the water column of 50, values under 3.6 mg/L of nitrogen should not produce algal biomass greater than the proposed algae threshold (enclosed by rectangle in **Figure 4b** below). However, one site monitored during the Algal Survey had an N:P ratio near 50 (LANF08; see **Table 2**) and average nitrogen concentrations less than 3.6 mg/L, yet had levels of algal biomass above the proposed threshold (site marked by + symbol enclosed within rectangle in **Figure 4b** below). Conversely, two sites had high total N concentrations (CICF25 and WYLSED, enclosed in circles in **Figure 4b** below) which all the models predicted would have very high algal biomass as well; however, they had very low amounts of algae. Algal biomass at these sites was probably much more strongly influenced by some other site-specific factors such as unknown toxicity or water temperature (both sites had very shallow water).

The Dodds 2002 empirical model is likely to be less applicable than the Qual2K model to the streams in the Newport Bay watershed for a number of reasons. First, only a very small number of the data used to generate the Dodds model came from streams in Mediterranean-type climates, with the long flood-free summers typical of southern California. Second, few of the streams in Dodds' database had levels of algal biomass comparable to those measured here (most were lower), which reduces the reliability of the model in the range of interest here. And third, despite having a large amount of input data, Dodds' model had a rather low coefficient of determination (as evidenced by an R^2 value of 0.40; Dodds et al. 2002), and the authors stated that the predictive power of the model for specific streams was likely to be low.

Figure 4b. Nitrogen Concentrations Projected to be Protective of Aquatic Life Under Different Modeling Scenarios, with Highlighted Examples of Sites Exceeding Proposed Thresholds.



4.0 DISCUSSION

Nitrogen water quality objectives designed to protect aquatic life should be developed and applied on a site-specific basis, and should take into account the other primary resources that can stimulate algal growth (phosphorus and light availability). The range of nitrogen concentrations predicted by the models was between 0.3 and 6.5 mg/L total N, with higher levels projected for areas where light and phosphorus concentrations are low, and, conversely, lower levels of nitrogen projected where light and phosphorus are in greater supply (see **Table 2** and **Figure 4**). Although this technical memo discusses the science of nutrient-algal relationships, it does not discuss the practical and economic aspects of the development of and compliance with nutrient criteria. Some of the factors that should be considered with regards to these initial model runs are outlined in greater detail below.

4.1 Factors Affecting Algal Growth Not Accounted for in Modeling Approach

Predicting algal biomass in streams from nutrient concentrations in the stream water can be very difficult. Multiple factors interact to control algal biomass in streams; nitrogen and phosphorus concentrations are two important factors, but others such as light availability, current speed, substrate type (e.g., concrete vs. sand vs. cobbles vs. bedrock), and consumption of algae by fish and invertebrate grazers are also crucial, and must be taken into account in any attempts to predict algal biomass in a stream. In addition, in streams influenced by urban runoff or wastewater effluent, the stimulatory effects of nutrients on algal growth can be counteracted by the negative effects of other dissolved substances such as metals, herbicides, or pharmaceutical by-products (Brooks et al. 2006). Some of these other factors (light availability and current speed) are accounted for in the QUAL2K model, but not in either of the Dodds statistical models. Further, some of the potentially important factors (substrate type, grazing pressure, toxicity) are not addressed by either type of model.

4.2 Difficulties in Assessing Relationships Between Nutrient Concentrations and Algal Biomass

The difficulties in relating algal biomass to nutrient concentrations are evident in the data from the 2006 Newport Bay Watershed survey. Although the sites with higher average nitrogen concentrations often had higher average and maximum algal biomass, higher nitrogen concentrations did not necessarily result in high algal biomass at any given site, and nitrogen was not significantly statistically correlated with algal biomass. The site with the highest nitrate concentrations (WYLSED, with mean nitrate of 15.9 mg/L) actually had some of the lowest measurements of algal biomass, which were typically well under the proposed impairment criterion (average 114 mg m^{-2} chlorophyll a).

The lack of close correlation between nutrient concentrations and algal biomass can also be observed in a recent study by Busse et al. (2006) in the Malibu Creek watershed, one of the few other stream surveys conducted in southern California that collected simultaneous data on both nutrient concentrations and algal biomass. For instance, four of the streams in the Malibu Creek study had similar average total nitrogen concentrations, within the low end of the range measured from the Newport watershed (TN between 1.0 – 1.6 mg/L). However, algal biomass in those streams ranged over an order of magnitude; biomass in two of the streams exceeded the proposed 150 mg m^{-2} chlorophyll a criterion, but in the other two biomass was well under 150 mg m^{-2}.

4.3 Importance of Considering Site-Specific Conditions

Nitrogen thresholds thus can be most effective when developed and applied on a site-specific basis, and should take into account (at the very least) the availability of phosphorus and light at each site or reach. For instance, in a shaded reach with an intact riparian canopy, higher levels of nitrogen may be allowed because algal growth will be limited by light. However, in an unshaded concrete channel, lower nitrogen levels will be required to limit algal growth. Similarly, when phosphorus concentrations are high, lower levels of nitrogen will be required, but when phosphorus levels are very low, phosphorus availability may limit algal growth and higher levels of nitrogen may be permitted without increasing algal biomass.

Physical conditions in the individual stream reach should also be taken into account. The 2006 survey results showed that algal biomass is typically much higher at sites with soft sediments than at sites with concrete-lined channels, probably because soft sediments offer greatly increased surface area for microalgal attachment and growth. While colonies of microalgae are less visible than the more obvious clumps of bright green macroalgae, they can reach very high levels of biomass on soft sediments, and can similarly affect dissolved oxygen, pH, and aquatic life in the stream. In order to reduce biomass of all types of algae, lower levels of N may be required to limit algal biomass at sites with soft sediments, but higher levels of N may be permitted in concrete-lined channels.

In addition, some evidence suggests that in concrete-lined channels in southern California, the presence of algae can actually enhance the ecology of the stream (Tetra Tech 2007b). In their natural condition streams provide a wide diversity of habitat (e.g. fast-moving, shallow riffles, slow, deep pools, boulders, cobbles, pebbles, and sand, and a range of shade vs. sunny conditions) which supports biological diversity. The extreme habitat simplification in a concrete channel nearly eliminates both physical and biological diversity. In this condition the presence of algal biomass, up to a point which may be above the level of 150 mg m^{-2} chlorophyll a, likely increases the range of physical habitat and food source types available for benthic macroinvertebrates, thus increasing the diversity and sheer number of invertebrates present at a site. This effect has been recently documented in the San Gabriel River, another heavily channelized, urban-influenced stream system in southern California (Tetra Tech 2007b).

Historical conditions should also be considered when assessing nutrient-algal relationships. Given the long, disturbance-free summers common to southern California, it is likely that even in the absence of human influence, streams which had persistent, year-round surface flow might have had unusually high levels of algal biomass occurring with low N and P concentrations (as compared to streams in regions with year-round precipitation, and therefore more frequent disturbance and scouring floods) (Simpson, 2006). Unfortunately it is difficult to impossible to know what the condition of streams in Orange County might have been prior to human influence, as most areas that might provide reference streams have been developed, and are subject to intense human activity.

Finally, it is important to note that reducing nitrogen levels down to even the lowest levels discussed in this report would likely not eliminate either natural or nuisance algal blooms. Spring algal blooms are a natural feature of all streams, whether affected by human activities or not (Simpson 2006), and algal blooms can occur even under extremely low nutrient conditions when other resources, such as light, are abundant. This is particularly important in this system as light is reliably abundant in the Newport Bay Watershed because many of the streams are channelized, with minimal to no shading or riparian canopy.

4.4 Feasibility of Achieving Projected Nitrogen Levels

This memo deals primarily with the science of nutrient-algal relationships in the Newport Bay Watershed, and the nitrogen concentrations discussed herein should not be taken as recommendations for thresholds to be used in the revised TMDL. Practical concerns will need to be addressed regarding the feasibility of achieving any proposed nitrogen threshold.

Despite reductions in nutrient concentrations at some sites in the Newport Bay watershed (Hauptly and Moore 2005), nitrate concentrations at some sites continue to be very high, largely as a result of uncontrollable sources such as rising groundwater which is high in nitrate (Hibbs 2000, Meixner et al. 2004). Atmospheric deposition may also be a significant source of nitrogen to the watershed (Meixner et al. 2004). Because these persistent sources are for the most part not controllable, best management practices will likely be important in reducing algal blooms in both the watershed and the bay. In addition, economic concerns must be addressed in determining water quality objectives (California Water Code, Section 13241)

5.0 NEXT STEPS

Although this technical memo identifies a modeling approach to describe the linkages between nitrogen and algal growth, there is additional data and information that will be necessary in order to ensure that the relationship is accurately defined for both Newport Bay and the watershed. This includes the following:

- A larger data set is needed for algal biomass in the Newport Bay watershed so that the models can be tested against data gathered in multiple years with different climatological conditions. This would greatly improve the reliability of the results.
- The Working Group needs to continue to work closely with SCCWRP and Tetra Tech in applying their approach for developing water quality objectives for nutrients in estuaries to Upper Newport Bay.
- The Working Group will need to continue to collaborate with the Regional Water Board in assessing all available information in order to determine whether or not the present water quality objectives need to be revised.

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