Memorandum

L A R R Y
W A L K E R

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DATE: May 14, 2007

TO: Karen Cowan, County of Orange

SUBJECT: Indicators for Detecting Algae-Related Aquatic Life Use Impairments in the Newport Bay Watershed and Newport Bay (Task 1.4)

Cc: Karen Ashby, LWA

The Nitrogen and Selenium Management Program (NSMP) includes a series of tasks that will assist the Working Group in assessing the impacts of nitrogen (Task 1.4) as well as evaluating the nutrient TMDL (Task 4). The objectives of Task 1.4 are to identify the locations in the Newport Bay Watershed and Newport Bay where excessive algal growth is occurring, 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 watershed. This task consists of:

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

Prior to determining the extent of excessive algal growth in Sub-task 1.4.1, indicators of beneficial use impairment must be developed for both the watershed and the bay. Without these indicators, there is no framework for analyzing algae data and categorizing areas as having or not having excessive algae. While the Basin Plan contains narrative water quality objectives stating that excessive algae are not permissible (as identified below), quantitative endpoints and thresholds must be developed to clearly show where algal-related impairments exist.

The Water Quality Control Plan for the Santa Ana Region (Basin Plan) contains three applicable narrative Water Quality Objectives (WQOs) for enclosed bays and estuaries that relate to the nutrient impairment in *Newport Bay*:

- Algae - "Waste discharges shall not contribute to excessive algal growth in receiving waters"; and

- Dissolved Oxygen - "The dissolved oxygen content of enclosed bays and estuaries shall not be depressed to levels that adversely affect beneficial uses as result of controllable water quality factors."

- "Enclosed bay and estuarine communities and populations, including vertebrate, invertebrate, and plant species, shall not be degraded as a result of the discharge of waste.

> Degradation is damage to an aquatic community or population with the result that a balanced community no longer exists. A balanced community is one that... is not dominated by pollution-tolerant species, unless that domination is caused by physical habitat limitations."

The narrative WQOs for nutrient impairment in *San Diego Creek* (Newport Bay Watershed) are:

- Waste discharges shall not contribute to excessive algal growth in inland surface receiving waters;

- The dissolved oxygen content of surface waters shall not be depressed below 5 milligrams per liter (mg/L) as a result of controllable water quality factors. In addition, waste discharges shall not cause the median dissolved oxygen concentration to fall below 85% of saturation or the 95th percentile concentration to fall below 75% of saturation within a 30-day period;

- "Inland surface water communities and populations, including vertebrate, invertebrate, and plant species, shall not be degraded as a result of the discharge of waste. Degradation is damage to an aquatic community or population with the result that a balanced community no longer exists. A balanced community is one that... is not dominated by pollution-tolerant species, unless that domination is caused by physical habitat limitations."

This memo proposes indicators of aquatic life impairment due to algae in the Newport Bay Watershed and Newport Bay. Water quality criteria for nutrients are currently under development, and indicators of recreational use impairment will be addressed at a later date. The indicators for aquatic life are based on existing scientific information, have been developed to reflect conditions in the Watershed and Bay, and include separate thresholds for freshwater and saltwater. Additional guidance was taken from the State Water Resources Control Board's Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List adopted September 30, 2004 (SWRCB Policy). The thresholds used to indicate impairment in the watershed are also very similar to those developed for portions of the Los Angeles River watershed, which have been approved by the Regional Board[1].

A more comprehensive discussion of nitrogen, nutrient-related issues and their effects on beneficial uses in the Newport Bay and Watershed is included in the Conceptual Model for Nitrogen, San Diego Creek/Newport Bay Watershed (NSMP Working Group, Draft Final January 2, 2006). Further discussion of the sources, loads, and distribution of nitrogen in the watershed can be found in the Nitrogen Sources and Loads Report (NSMP Working Group, Interim Report May 29, 2006).

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[1] Letter from Jonathan Bishop to Rodney Andersen dated April 18, 2005, Subject: Workplan for the evaluation of the effectiveness of nitrogen loading reductions in removing algae-related impairments in the Los Angeles River watershed

Proposed Indicators for Detecting Potential Algae Impairments

Multiple lines of evidence will be used to determine potential impairments. These will include both direct measures of algae and measures of chemical changes which can be caused by excessive algae.

Nitrogen (ammonia, nitrate, or total nitrogen) will not be used as an indicator because the TMDL considers high levels of algae to be a better indicator of nutrient problems than nutrient concentrations themselves. It is frequently not possible to determine the instantaneous concentration of nitrogen associated with a particular level of algae. Several processes can interact to complicate the relationship between nitrogen and algae, including luxury uptake of nitrogen by the algae (resulting in high algal biomass with low dissolved nitrogen), or the presence of other factors which can inhibit or support nuisance algal growth (e.g., toxicity to algae from elements of urban runoff, resulting in low algal biomass even with high nitrogen). In addition, in areas of fast currents algal blooms can occur even when nutrient concentrations are low, because the fast-flowing water delivers what nutrients are available at a higher rate. And finally, high amounts of algal biomass can reduce ambient nutrient concentrations by drawing nutrients out of the water at a rapid rate, but can also increase dissolved nitrogen concentrations by influencing flux rates of nutrients from sediments to the water column (Sutula et al. 2006). Because of these complicating factors, algal biomass is a much more reliable indicator of eutrophication than nitrogen concentration itself. If any problems associated with algae are found, the relationships between nitrogen and algae and any potential nitrogen impairment will be evaluated at each site, taking all relevant information (including but not limited to the factors described above) into account.

Algal biomass can be estimated either by measuring percent cover, or by taking samples and measuring dry weight or chlorophyll concentration (chlorophyll is a common measure of algal biomass). The proposed chemical indicators for the protection of aquatic life will be:

- Dissolved oxygen (DO); and
- pH

Each indicator, and its relationship to algae, is discussed briefly below.

Indicators for Aquatic Life

Dissolved Oxygen

Algae can engender low dissolved oxygen through two mechanisms:

- Algal decay - Algal decay fuels bacterial colonies, which often have very high rates of respiration, creating a strong demand for dissolved oxygen.

- Algal respiration - Living algae also respire, increasing the oxygen demand in proportion to the amount of algal biomass present at a site.

Since algal decay and respiration occur at night when photosynthetic oxygen additions are shut off and when wind mixing is often reduced, these mechanisms and conditions can lead to low dissolved oxygen levels. Conversely, oxygen levels in aquatic systems may be high during the day (sometimes super-saturating when algal biomass is high) as a result of algal photosynthesis. The diurnal swing between low dissolved oxygen at night and high dissolved oxygen during daylight can be an indicator of high algae levels that are stressing an ecosystem.

Low dissolved oxygen has been detected in Newport Bay since the 1970s (Kamer and Stein 2003). A more recent study has found it to be most prevalent during nighttime low tides in the summer, and likely to be associated with blooms of macroalgae (Nezlin et al. 2006). A recent study in the Newport Bay watershed found DO at supersaturated levels in some streams during daylight hours, suggesting that hypoxia may be occurring at night in those streams (Orange County, unpub. data).

pH

pH of aquatic ecosystems changes on a diel basis in proportion to the amount of algal biomass present.
- During the day - algal photosynthesis consumes dissolved inorganic carbon, driving pH up.
- At night - respiration by algae, bacteria, and other stream organisms adds carbon dioxide to the water, driving the pH down.

Elevated pH levels negatively affect aquatic organisms by dramatically increasing ammonia toxicity (USEPA, 1999). The diurnal swing between low pH at night and high pH in the afternoon can be an indicator of high algae levels that are stressing an ecosystem. While a large diurnal variation in pH is common in freshwaters where algal biomass is high, it is much less likely to occur in the bay, as the salts in ocean water act as buffers against pH change. Since pH has not been identified as problem related to algae in Newport Bay, pH will only be used as an indicator in streams.

pH levels > 8.5 have rarely been detected in Newport Bay. There were a few occurrences recorded during SCCWRP's recent study which may have been associated with blooms of macroalgae, but they were infrequent and brief, and typically only exceeded the 8.5 threshold by a marginal amount (Nezlin et al. 2006). A recent study in the Newport Bay watershed found very high pH in some streams during daylight hours, suggesting that strong diurnal fluctuations may be occurring in those streams (County of Orange, unpublished data).

Thresholds Indicating Potential Impairments

A threshold of impairment was developed for each indicator presented above. The thresholds are presented in **Tables 1** and **2**. The frequencies of threshold exceedance given are per annum. For example, **Table 1** indicates that, if at any stream site pH is measured above 8.5 on at least five days within a year, AND the average of all chlorophyll a measurements made at that site over the year prior to those measurements was greater than 150 mg m^{-2}, aquatic life at that site would be considered impaired. Similarly, if at any point during a year the average of DO measurements in the bay on seven consecutive days falls below 4 mg/L AND there was greater than 50% cover of macroalgae during the month prior to those seven days, aquatic life in the bay would be considered impaired by algae. Using multiple metrics in this way protects against erroneous designations of impairment, since instances of low DO or high pH could occur without the presence of high algal biomass. In this case alternative causes for the DO or pH excursions could be investigated.

Newport Bay Watershed Indicators (Fresh Water)

Table 1. Thresholds for Identifying Potential Nitrogen Impairments in Streams

Indicator	Threshold Indicating Potential Impairment	Rationale
Dissolved Oxygen	Below 5 mg/L in the early morning (before sunrise) at least five times out of a minimum of 26 measurements, evenly distributed throughout the calendar year. If more than 30 measurements are made within a year, the number of samples < 5 mg/L necessary to indicate impairment will increase according to the table in Appendix A. **AND** a rolling annual average of > 60% cover of nuisance algae, defined here as benthic biofilm > 3 mm or benthic filamentous > 10 cm (average of at least three measurements from three different seasons when scouring flows are not present) **OR** a rolling annual average of >30% floating algal cover (average of at least three measurements from three different seasons when scouring flows are not present) **OR** a rolling annual average of >60% nuisance benthic and floating algal cover combined (average of at least three measurements from three different seasons when scouring flows are not present) **OR** a rolling annual average of > 150 mg m^{-2} chlorophyll a (average of at least three measurements from three different seasons when scouring flows are not present)	5 mg/L is the Basin Plan objective for DO, and DO levels are typically at their lowest in early morning. Algal growth and decay can occur rapidly, and resulting impacts on water chemistry can change within the span of weeks (Simpson 2006). Therefore, to adequately characterize early morning DO conditions in the watershed, measurements should be made on at least a bi-weekly basis. Five exceedances out of 26 samples are required by the SWRCB Policy[1] to establish impairment of water quality, and 26 is the minimum sample size required by their statistical technique (binomial distribution). The number of exceedances required to establish impairment increases with total sample size; sample sizes and numbers of permissible exceedances are listed in Appendix A. The algae thresholds are based upon data collected in other southern California creeks (Simpson 2006) and on a survey of data from several hundred temperate-climate streams by Dodds et al. (1998), which specifies the use of chlorophyll values representing the annual mean of multiple sampling dates. 150 mg chlorophyll a is the threshold recommended by EPA's Nutrient Criteria Technical Guidance Manual for Rivers and Streams (EPA 2000, Chapter 7).
pH	Above 8.5 during daytime at least five times out of a minimum of 26 measurements, evenly distributed throughout the calendar year. If more than 30 measurements are made within a year, the number of samples > 8.5 necessary to indicate impairment will increase according to the table in Appendix A. **AND** a rolling annual average of > 60% cover of nuisance algae, defined here as benthic biofilm > 3 mm or benthic filamentous > 10 cm (average at least three measurements from three different seasons when scouring flows are not present) **OR** a rolling annual average of >30% floating algal cover (average at least three measurements from three different seasons when scouring flows are not present) **OR** > a rolling annual average of 150 mg m^{-2} chlorophyll a (average at least three measurements from three different seasons when scouring flows are not present)	The Basin Plan states that pH should remain between 6.5 and 8.5. Algal growth and decay can occur rapidly, and resulting impacts on water chemistry can change within the span of weeks (Simpson 2006). Therefore, to adequately characterize pH conditions in the watershed, measurements should be made on at least a bi-weekly basis. Five exceedances out of 26 samples are required by the SWRCB Policy[1] to establish impairment of water quality, and 26 is the minimum sample size required by their statistical technique (binomial distribution). The number of exceedances required to establish impairment increases with total sample size; sample sizes and numbers of permissible exceedances are listed in Appendix A. This threshold of % algal cover was based on comparisons between data from other southern California streams (Simpson 2006) and data from a study conducted on the White River in Washington (Stuart 2002).

1. SWRCB's Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List, September 30, 2004.

Newport Bay Indicators (Salt/Brackish Water)

Table 2. Thresholds for Identifying Potential Nitrogen Impairments in the Bay

Indicator	Threshold Indicating Potential Impairment	Rationale
Dissolved Oxygen	> 50% cover of macroalgae at any site in the Bay within the previous month **AND**	Based on criteria developed for Chesapeake Bay (Virginia State Water Control Board 2005), which contains many of the same species present in Newport Bay (Nezlin et al. 2006). The Chesapeake Bay criteria were established after extensive lab and field observations on the effects of low DO on larval, juvenile, and adult life history stages of multiple estuarine species. A recent study by SCCWRP found that while blooms of macroalgae were a likely cause of hypoxic events in Newport Bay, there was a time lag between the beginning of the bloom and the onset of hypoxic conditions. No hypoxic events occurred when algal cover was less than 50% (Nezlin et al. 2006).
	Instantaneous DO levels below 3.2 mg/L in early morning (before sunrise) at any depth in the water column at that site **OR**	
	A seven-day DO average below 4 mg/L in early morning at any depth at that site **OR**	
	A 30-day DO average below 5 mg/L in early morning at any depth at that site	

Assessment of Impacts

Once the extent and magnitude of impairments have been identified using the indicators developed above, the cause of elevated levels of algae will be evaluated. This investigation should include analyzing available data for relationships between nitrogen, algae, and other related parameters such as temperature, pH, and light availability. Other nutrients, particularly phosphorus (P) should be considered as well.

If another nutrient or resource such as P or light availability is limiting algal growth, reducing nitrogen alone may not result in reduced algal levels, and management measures should take other limiting resources into account. Approaches for assessing nutrient limitation include calculating N:P ratios in the water column and experimentally manipulating N and P concentrations in field-based experiments. If relationships between N and P and algal levels are not evident, regression analyses can be used to determine if other physical or chemical factors may be either limiting or contributing to algal growth. Data should be collected throughout the year, as relationships between nutrients and algae can vary seasonally (Busse et al. 2006).

It is important to note that in streams draining highly urbanized area such as the Newport Bay watershed, nutrient inputs from non-point sources are unpredictable and highly variable over time scales of days to weeks (County of Orange 2005). As a consequence, the nature and magnitude of nutrient limitation of algal growth can change daily or weekly, and nutrient concentrations can reach levels high enough to saturate algal growth. Because of these complications, targeting a single nutrient for reduction may not be the best strategy for reducing nuisance algal biomass in streams. Greater success may be achieved by management activities which simultaneously reduce both N and P, or which incorporate reductions in other resources which can limit algal growth (e.g., replanting riparian areas, where feasible, to reduce light availability to the stream).

Even if nitrogen is not found to be the sole resource limiting algal growth, it is still likely an important factor in promoting nuisance algal blooms. Reductions in nitrogen have already been correlated with reductions in algal blooms in the Bay (Hauptly and Moore 2005), and the analyses outlined here will support evaluation of the efficacy of current regulatory and management measures in reducing algae in Newport Bay and the surrounding watershed.

References cited

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APPENDIX A

Table of permissible number of exceedances under different sampling regimes, assuming an unacceptable exceedance level of 25%. Adapted from the State Water Resources Control Board's Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List, adopted September 30, 2004.

Number of samples	Number of exceedances required to indicate impairment
5 – 30	5*
31 – 36	6
37 – 42	7
43 – 48	8
49 – 54	9
55 – 60	10
61 – 66	11
67 – 72	12
73 – 78	13
79 – 84	14
85 – 91	15
92 – 97	16
98 – 103	17
104 – 109	18
110 – 115	19
116 – 121	20

*Application of the binomial test requires a minimum sample size of 26. The number of exceeedances required using the binomial test at a sample size of 26 is extended to smaller sample sizes.