

Memorandum



DATE: May 30, 2007

TO: Karen Cowan, County of Orange

SUBJECT: Results of Algal Survey in the Newport Bay Watershed (Task 1.4.1)

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I. Background and Purpose

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 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 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.

This technical memorandum summarizes the results of a survey of stream algae conducted in the Newport Bay watershed in 2006. Although algal biomass and occurrence of blooms within Newport Bay have been monitored for several years, no measurements of algal biomass have been made within the freshwater portion of the watershed. Casual observations and anecdotal reports suggest that freshwater algal biomass may be very high, but at present there are no quantitative data to assess the amount of algae present, their relationship to nutrient concentrations, or their resulting impacts, if any, on beneficial uses. The *Nitrogen Sources and Loads Report* (May 29, 2006) identified the lack of information about the extent and magnitude of algae in the Newport Bay watershed, and its impacts on beneficial uses, as a data gap which should be filled in order to determine the effects of nitrogen in the watershed.

As a result, an algae survey was conducted to measure the extent, magnitude, and types of algal biomass present in the Newport Bay Watershed during 2006, and to measure parameters potentially affected by nuisance levels of algae (pH and dissolved oxygen). Results from this study can be used to establish a quantitative baseline for the extent and magnitude of algae in the Watershed, and to begin to define relationships between nitrogen and algal biomass.

This analysis uses the indicator thresholds that have been proposed for protecting aquatic life in the watershed (Section II), and presents the sampling plan for the study (Section III) and the results and conclusions of the study (Sections IV and V, respectively).

II. Indicator Thresholds

The Water Quality Control Plan for the Santa Ana Region (Basin Plan) contains two applicable narrative Water Quality Objectives (WQOs) for nutrient impairment in San Diego Creek (Newport Bay Watershed):

- 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). 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;

Based on these narrative objectives, indicator thresholds for protecting aquatic life in streams in the Newport Bay Watershed have been proposed (*Indicators for Detecting Algae Impairments in the Newport Bay Watershed and Newport Bay (Task 1.4), memo to Karen Cowan dated Jan.3, 2007*). Since elevated pH and depressed dissolved oxygen concentrations (DO) are two of the most common mechanisms by which excessive algal growth may impair aquatic life, these measurements are proposed to be used in conjunction with measures of algal biomass (percent cover of algae and chlorophyll a concentrations) to determine impairment.

Algae can engender conditions of low dissolved oxygen through two mechanisms; (1) Algal respiration, in which living algae directly remove oxygen from the water column, and (2) algal decay, in which the bacterial breakdown of dead algal tissues creates a strong demand for dissolved oxygen. Low dissolved oxygen is most often a problem at night when photosynthesis is not occurring, as during daylight hours oxygen in the water column can be rapidly replaced through algal photosynthesis.

Algae and associated bacteria also influence pH through daily cycles of photosynthesis and respiration. During daylight hours, photosynthesis consumes dissolved inorganic carbon, driving the pH up, while at night, respiration adds carbon dioxide to the water, forming carbonic acid and driving the pH down. Elevated pH levels negatively affect aquatic organisms by dramatically increasing ammonia toxicity (USEPA, 1999).

The thresholds outlined in **Table 1** were developed to explicitly define “excessive algal growth”, and to define amounts of algae which can cause levels of pH and DO which may be harmful to aquatic life. Because DO and pH can also be affected by factors other than high algal biomass, impairment will only be indicated at a site if both high algal biomass and a pH or DO problem are found. Using a multiple lines of evidence approach in this way protects against erroneous designations of impairment by algae. These proposed thresholds will be used when analyzing the data from this study in the results section to determine if there was nitrogen impairment in the streams.

Table 1. Thresholds for Identifying Potential Nitrogen Impairments in Streams

Indicator	Threshold Indicating Potential Impairment	Rationale
Dissolved Oxygen	<p>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.</p> <p style="text-align: center;">AND</p>	<p>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.</p>
	<p>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)</p> <p style="text-align: center;">OR</p>	<p>Five exceedances out of 26 samples are required by the SWRCB Policy¹ 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.</p>
	<p>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)</p> <p style="text-align: center;">OR</p>	
	<p>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)</p> <p style="text-align: center;">OR</p>	<p>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).</p>
	<p>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)</p>	
pH	<p>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.</p> <p style="text-align: center;">AND</p>	<p>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.</p>
	<p>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)</p> <p style="text-align: center;">OR</p>	<p>Five exceedances out of 26 samples are required by the SWRCB Policy¹ 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.</p>
	<p>a rolling annual average of >30% floating algal cover (average at least three measurements from three different seasons when scouring flows are not present)</p> <p style="text-align: center;">OR</p>	
	<p>> 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)</p>	<p>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).</p>

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

III. Sampling Plan

The specific questions addressed in this study were:

- Is excessive algal growth occurring in the Newport Bay watershed?
- If so, what is the spatial extent and temporal variability? What types of algae are present – e.g., biofilms of benthic microalgae, benthically attached green macroalgae, or floating mats of green macroalgae?

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). In southern California algae are usually scoured from the stream bed in winter during storm flows, and reach the highest levels of biomass during the long dry season (typically April – October). Algal biomass exhibits two natural peaks, one in late spring/early summer, and a second in late summer/early autumn. The timing of these peaks can vary somewhat from year to year, so in order to observe any nuisance algal blooms that might occur, the algae survey was performed three times during the 2006 growing season (May 30-31, July 25-26, and September 13-14) at eight sites within the Newport Bay watershed. The sites surveyed are listed in **Table 2** and their locations shown in **Figure 1**.

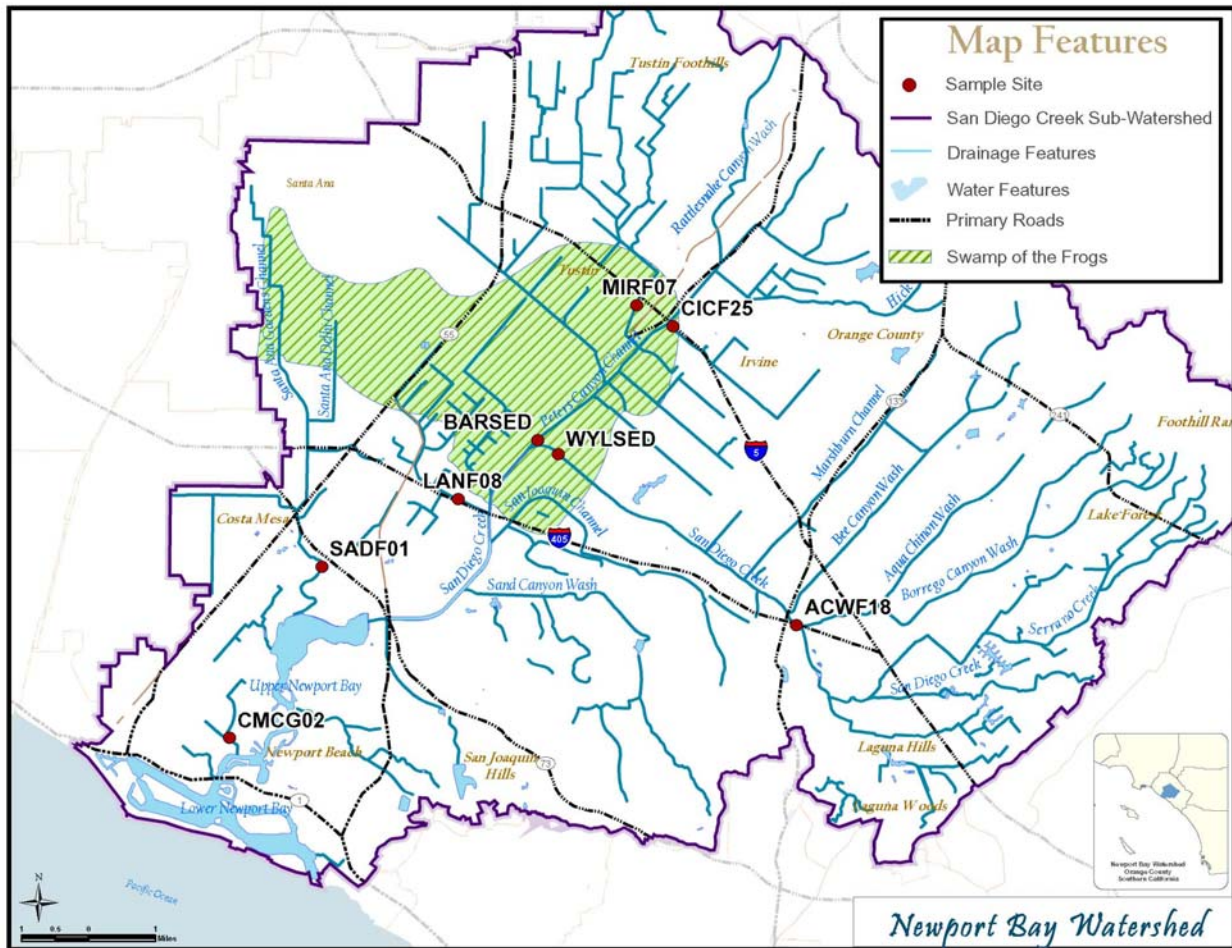
Table 2. Names, Locations, and Sub-Watersheds of Sites Sampled in the Newport Bay Watershed

Site Code	Creek Name	Location	Sub-Watershed
ACWF18	Agua Chinon	Irvine Center Drive	Upper San Diego Creek
MIRF07	El Modena-Irvine Channel	Michelle	Peters Canyon Wash
CICF25	Central Irvine Channel	Trabuco	Peters Canyon Wash
BARSED	Peters Canyon Wash	Barranca Road	Peters Canyon Wash
WYLSSED	San Diego Creek	Culver Drive	Lower San Diego Creek
LANF08	Lane Channel	McCabe Way	Lower San Diego Creek
SADF01	Santa Ana Delhi	Irvine Avenue	Santa Ana Delhi
CMCG02	Costa Mesa Channel	Westcliff Drive	Newport Bay

At each site, percent cover of algae was measured in five cross-stream transects, and the results of these transects were averaged to represent the entire site. Algae were classified by color (brown or green), morphology (filamentous or single-celled), size (length or mat thickness), and habit (benthic or floating) and identified to genus where possible. Composite samples were taken from three of the five transects at each site and sent to Associated Labs, Inc. for analysis of chlorophyll a as an indicator of total biomass.

Daytime pH and DO were measured concurrently with algae at each site. To determine if low concentrations of DO were occurring in the early morning, early morning DO was measured on September 15 (immediately after the September algae sampling) between 05:25 and 06:44 a.m.; these data were supplied by the County of Orange. As part of their regular water quality sampling program, the County had also sampled daytime pH on a year-round basis at each site, and their data from the period Sept. 2005 – Sept. 2006 were used to determine pH effects.

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



IV. Results

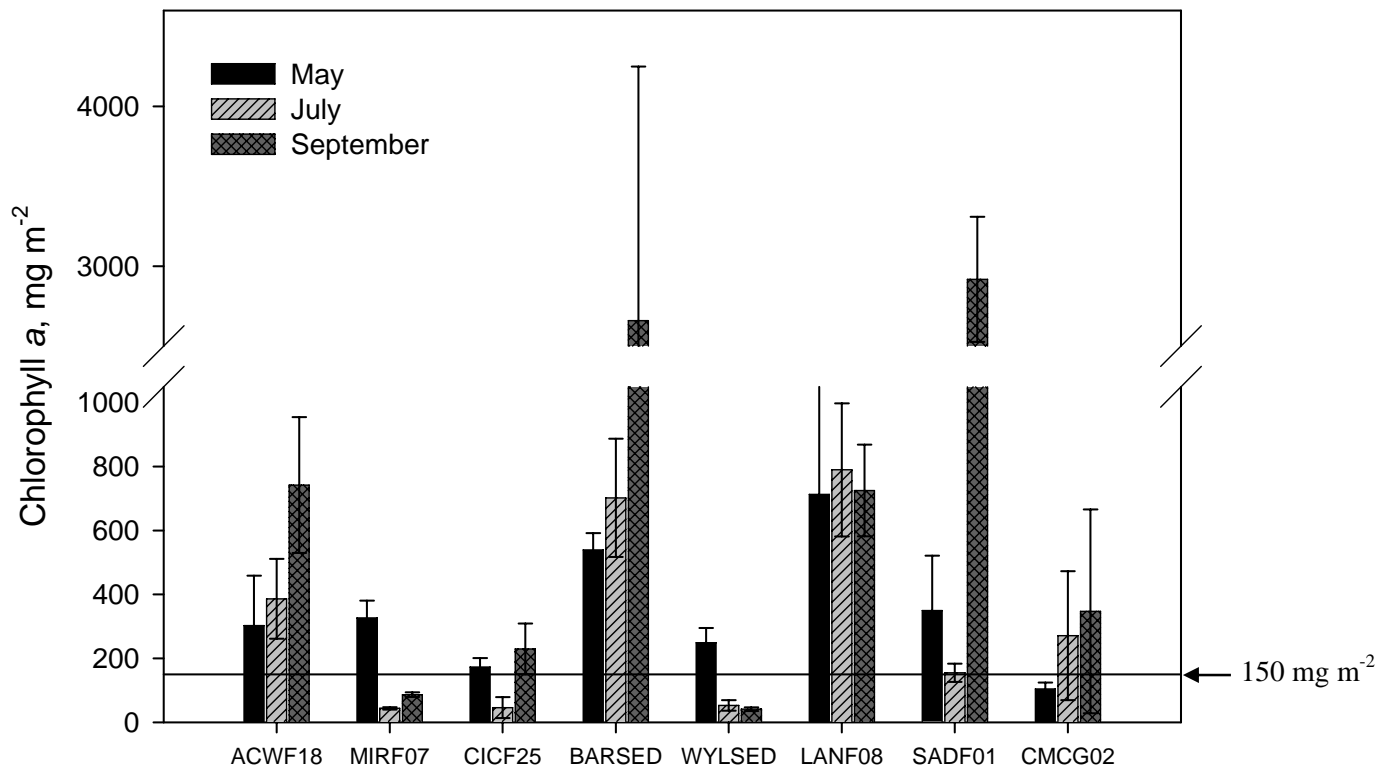
This section presents the results of the study including the algae biomass, percent cover of algae, dissolved oxygen, pH and a determination of impairment of aquatic life in the Newport Bay Watershed based on the proposed thresholds.

Algae: Biomass

The proposed thresholds for determining impairment of aquatic life in Newport Bay Watershed include measurements of chlorophyll a as an indicator of biomass. The threshold is a rolling annual average of $> 150 \text{ mg m}^{-2}$ chlorophyll a (average of at least three measurements from three different seasons when scouring flows are not present).

Annual average algal biomass exceeded the 150 mg m^{-2} threshold at six out of the eight sites (all except WYLSSED and CICF25). Overall, BARSED, SADF01, and LANF08 had the highest average biomass; WYLSSED and CICF25 had the lowest (see pictures of a high biomass site [BARSED] and a low biomass site [WYLSSED] in **Appendix B**). Although biomass was highest at most sites in September, there were some exceptions to this. **Figure 2** shows algal biomass (measured as chlorophyll a) at each site on each sampling date, with a reference line marking the 150 mg m^{-2} threshold.

Figure 2. Algal Biomass in the Newport Bay Watershed



Note: error bars represent +/- one standard error. Also note break in y-axis and reference line at 150 mg m^{-2} .

Algae: Percent Cover

The proposed thresholds for determining impairment of aquatic life in Newport Bay Watershed include measurements of percent cover of algae. The thresholds are:

- *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)*

Percent cover of “nuisance” algae only exceeded the threshold for aquatic life once, at the BARSED site in September. However, the annual average percent cover threshold was never exceeded at any site. **Figures 3a, 3b, and 3c** show percent cover of algae at each site in May, July, and September, respectively.

High percent cover of a submerged vascular plant was noted at one site in September (Horned Pondweed or *Zannichellia palustris* at LANF08). This plant is similar to algae in that it photosynthesizes and respire entirely under water, and it is likely contributing to night time oxygen demand. However, this does not appear to be a problem in most of the Newport Bay watershed; *Zannichellia* was rare or absent at all the other sites sampled.

Figure 3a. Percent cover of algae in May, 2006. Algae in the “nuisance” category are represented by dark gray background; non-nuisance algae are indicated by white background.

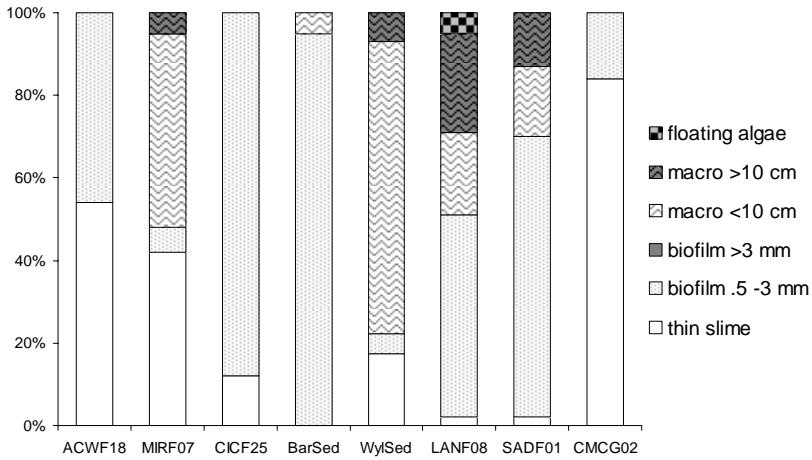


Figure 3b. Percent cover of algae in July, 2006.

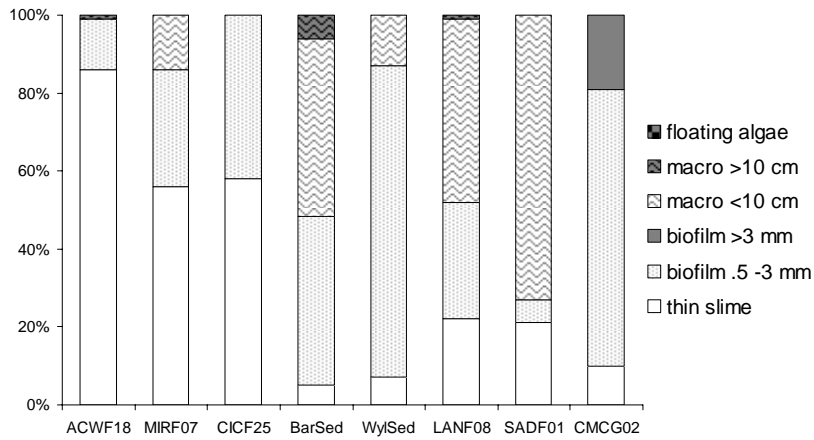
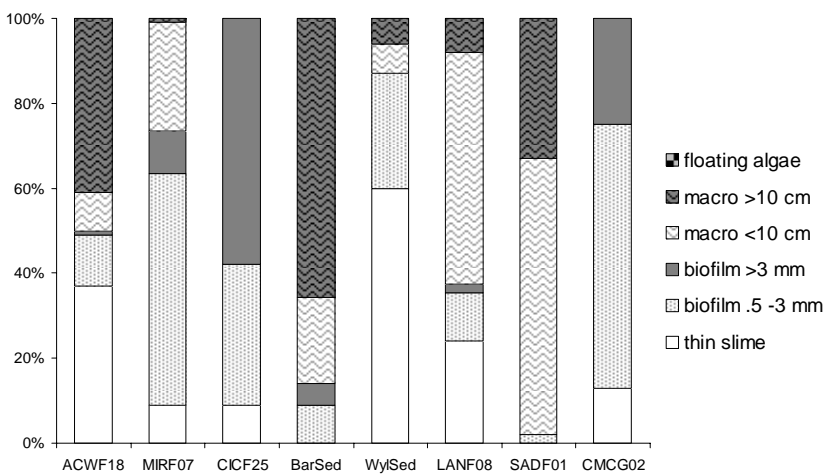


Figure 3c. Percent cover of algae in September, 2006.



Dissolved Oxygen

The proposed thresholds for determining impairment of aquatic life in Newport Bay Watershed include measurements of dissolved oxygen. The threshold is *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.*

Multiple early morning DO measurements were not available for the year preceding the algae surveys. Therefore the one available measurement from September 15, 2006 will be used here to provisionally indicate impairment. Sites which exceeded the DO threshold on this single date should be monitored more frequently in the coming year (i.e., at least 26 times) to determine if DO impairment actually exists. If fewer than five out of 26 measurements at any site over the coming year exceed the DO threshold, then the provisional impairment determination of that site should be modified.

Early morning DO was below 5 mg/L at five out of the eight sites sampled in September. DO and algal biomass generally showed an inverse relationship, with the lowest early morning DO measurements occurring at the sites with the highest algal biomass (e.g., BARSED and SADF01), and the highest DO occurring at sites with lowest algal biomass (e.g., WYLSED and CICF25). See **Table 3** for numerical, site-by-site results.

Table 3. Quantitative Results for Dissolved Oxygen

Site	Early Morning DO (mg/L) September
ACWF18	4.57
MIRF07	7.14
CICF25	7.82
BARSED	2.97
WYLSED	7.94
LANF08	4.75
SADF01	4.2
CMCG02	3.5

Note: Results exceeding thresholds are represented in bold type.

pH

The proposed thresholds for determining impairment of aquatic life in Newport Bay Watershed include measurements of pH. The threshold is *above 8.5 during daytime at least five times out of a minimum of 26 measurements, evenly distributed throughout the calendar year*. In cases where fewer than 26 samples were available for the past year, five was maintained as the number of exceedences indicating impairment, as the SWRCB's Water Quality Control Policy states that "*The number of exceedences required using the binomial test at a sample size of 26 is extended to smaller sample sizes*" (see **Appendix A**).

Daytime pH was not well correlated with algal biomass. In fact the sites with the greatest number of pH measurements above 8.5 were the sites with comparatively low algal biomass (e.g., CICF25, MIRF07, and CMCG02). These instances of high daytime pH may be the result of some influence other than algal biomass and associated physiological activity. See **Table 4** for numerical, site-by-site results.

Table 4. Quantitative Results for pH

Site	Total number of samples	# samples where pH > 8.5
ACWF18	9	2
MIRF07	18	13
CICF25	33	22
BARSED	44	7
WYLSSED	54	6
LANF08	16	3
SADF01	42	6
CMCG02	89	55

Note: Results exceeding thresholds are represented in bold type.

Summary of Results: Indicated Impairments

Based on the indicators of impairment, six out of the eight sites exceeded one or more of the aquatic life thresholds for excessive algae (**Tables 5 and 6**).

Table 5. Quantitative Results for Each Indicator - DO

Site	Early Morning DO (mg/L)		Annual Average Chl a (mg m ⁻²)		Annual average of > 60% cover of nuisance algae		Annual average of >30% floating algal cover		Annual average of >60% nuisance benthic and floating algal cover combined
ACWF18	4.57	AND	477.0	OR	14%	OR	0%	OR	14%
MIRF07	7.14		152.3		5%		0%		5%
CICF25	7.82		149.5		19%		0%		19%
BARSED	2.97		1299.9		26%		0%		26%
WYLSSED	7.94		114.2		4%		0%		4%
LANF08	4.75		742.7		12%		2%		13%
SADF01	4.2		1140.6		15%		0%		15%
CMCG02	3.5		240.7		15%		0%		15%

Note: Results exceeding thresholds are represented in bold type.

Table 6. Quantitative Results for Each Indicator - pH

Site	Total number of samples	# samples where pH > 8.5		Annual Average Chl a (mg m ⁻²)		Annual average of > 60% cover of nuisance algae		Annual average of >30% floating algal cover
ACWF18	9	2	AND	477.0	OR	14%	OR	0%
MIRF07	18	13		152.3		5%		0%
CICF25	33	22		149.5		19%		0%
BARSED	44	7		1299.9		26%		0%
WYLSSED	54	6		114.2		4%		0%
LANF08	16	3		742.7		12%		2%
SADF01	42	6		1140.6		15%		0%
CMCG02	89	55		240.7		15%		0%

Note: Results exceeding thresholds are represented in bold type.

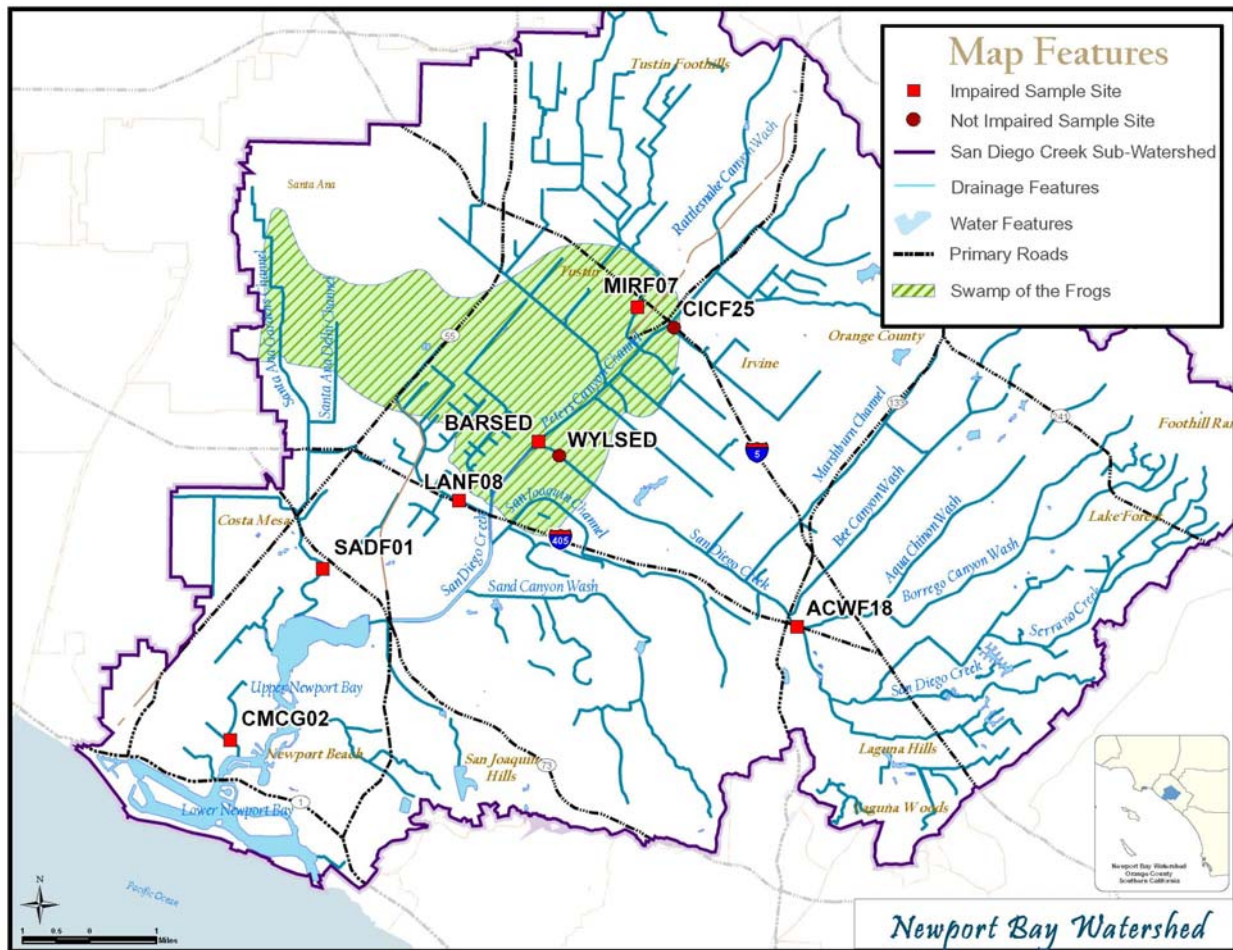
Based on the above results CICF25 and WYLSSED were not impaired by excessive algae; CICF25 exceeded the threshold for pH but not for any other indicator, and WYLSSED did not exceed any thresholds. On the other hand, ACWF18, BARSED, LANSF08, and SADF01 can be considered impaired having exceeded both the average annual chlorophyll and the DO threshold. MIRF07 can be considered impaired having exceeded both the average annual chlorophyll and the pH threshold. CMCG02 could be considered the most impaired, having exceeded the chlorophyll, DO, and pH thresholds. Results for each indicator considered in determining impairment of aquatic life are summarized in **Table 7** and sites considered to be impaired are indicated by square markers in **Figure 4**.

Table 7. Results for Indicators of Impairment for Aquatic Life

Site	Aquatic life threshold exceeded?	DO < 5 mg/L in early am?		pH threshold exceeded?		Annual average chl a > 150 mg m ⁻² ?		Annual average of > 60% cover of nuisance algae?		Annual average of >30% floating algal cover?		Annual average of >60% nuisance benthic and floating algal cover combined?
ACWF18	Y	Y	OR	N	AND	Y	OR	N	OR	N	OR	N
MIRF07	Y	N		Y		Y		N		N		
CICF25	N	N		Y		N		N		N		
BARSED	Y	Y		N		Y		N		Y		
WYLSSED	N	N		N		N		N		N		
LANF08	Y	Y		N		Y		N		N		
SADF01	Y	Y		N		Y		N		N		
CMCG02	Y	Y		Y		Y		N		N		

Note: Results exceeding thresholds are represented in bold type.

Figure 4. Map of the Newport Bay watershed; sites exceeding the algae threshold are designated with squares, those not exceeding thresholds designated with circles.



V. Conclusions

The specific questions addressed in this study were:

- Is excessive algal growth occurring in the Newport Bay watershed?
- If so, where, and what is the spatial extent and temporal variability? What types of algae are present – e.g., biofilms of benthic microalgae, benthically attached green macroalgae, or floating mats of green macroalgae?

Six out of eight of the sites sampled in the Newport Bay watershed exceeded the aquatic life thresholds in 2006. Early morning hypoxia (DO concentrations > 5 mg/L) occurred at least once at the sites with the highest average algal biomass, provisionally indicating that nuisance levels of algae are causing DO impairments at these sites. In contrast, pH impairments (pH > 8.5 during the day) did not appear to be related to algal biomass, as the highest daytime pH was recorded at sites with relatively low algal biomass.

There was an apparent seasonal pattern to algal growth, with the highest biomass recorded in September at all but three sites. Nuisance types of algae (i.e., green macroalgae greater than 10 cm in length and benthic biofilms greater than 3 mm in thickness) were also more common throughout the watershed in September than in May or July.

Implications for future work

These results can now be compared to nutrient data collected from each of the sites surveyed in order to assess linkages between nitrogen and algal growth (Task 1.4.2). Coarse relationships between nitrogen concentrations and algal biomass have been developed at a nation-wide scale (Dodds 2006, Tetra Tech 2006). These relationships can be refined and adopted to the conditions specific to the Newport Bay watershed by bringing in nutrient/algal relationships from studies done in the immediate region (e.g. the Malibu Creek watershed; Busse et al. 2006).

It is important to note that while nitrogen is an important nutrient supporting algal growth, the relationship between algal biomass and nitrogen concentrations is frequently complicated by other physical and chemical factors which can stimulate or inhibit algal growth, such as light availability, water temperature, availability of growth substrate, or concentrations of other nutrients (e.g., phosphorus). Light is particularly likely to be important in stimulating algal growth in the Newport Bay watershed, as all of the sites we sampled had channelized banks with little to no riparian canopy, and therefore very high light availability. At sites determined to be impaired by excessive algal growth, algae might be most effectively reduced by a combination of measures, for instance reducing nutrient concentrations and light availability simultaneously (e.g. by restoring riparian habitat).

VI. References Cited

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APPENDIX A

Table of permissible number of exceedences under different sampling regimes, assuming an unacceptable exceedence 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 exceedences 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 exceedences required using the binomial test at a sample size of 26 is extended to smaller sample sizes.

APPENDIX B

1. Photos of BARSED, one of the more impaired sites, in A) May, B) July, and C) September. Note mats of green macroalgae (circled in (A) and (C)).



Results of Algal Survey

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2. Photos of WYLSSED, a site unimpaired by algae, in A) May, B) July, and C) September.

