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MEMORANDUM

Date: March 30, 2012

To: File: Laguna de Santa Rosa; TMDL Development and Planning

From: Steve Butkus

Subject: Assessment of Nutrients Limiting Algal Biomass Production in the Laguna de Santa Rosa

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In 1995, a TMDL addressing nitrogen, ammonia, and dissolved oxygen in the Laguna was completed by the North Coast Regional Water Quality Control Board (Regional Water Board) (Morris, 1995). The TMDL took the form of the *Waste Reduction Strategy for the Laguna de Santa Rosa* (Waste Reduction Strategy) and it addressed the reduction of nitrogen loading from point and nonpoint sources. The 1995 TMDL established both concentration-based and mass-based goals for both total nitrogen (TN) and total ammonia-N (NH_3-N).

The 1995 TMDL nitrogen goals were based on the criterion for acute ammonia-N toxicity, and not algal productivity related to eutrophication. However, the TMDL describes that the expected reductions in total nitrogen would also result in reductions of ammonia-N, phosphorus, and organic matter. By focusing efforts to reduce nitrogen, the expectation was that the coincident reductions in other pollutants, such as phosphorus and organic matter, would reduce algal productivity and reduce the frequency of exceeding water quality objectives for dissolved oxygen. The TMDL presumed that the low daily dissolved oxygen concentrations were caused by excessive algal respiration during the night.

BACKGROUND

Limitation of algal productivity is considered to follow Liebig's Law of the Minimum which states that the yield of plant production is limited by the nutrient that is in shortest supply (Hutchinson 1957). The limitation of nutrients on biomass yield can be measured using algal growth potential tests (Skulberg 1965; Hutchinson 1957). Nitrogen was the nutrient of focused pollutant reductions in the 1995 TMDL due to algal growth potential tests that showed nitrogen was potentially the nutrient limiting algal productivity (Roth and Smith 1994).

The ratio of Carbon:Nitrogen:Phosphorus (C:N:P) in biomass is often used to assess nutrient limitation. The Redfield ratio is the empirically developed stoichiometric ratio of C:N:P (Redfield 1934). In natural waters, nitrogen and phosphorus are far more scarce than carbon and are usually the nutrients limiting the growth of algae. Carbon limits algal growth only in waters that are heavily fertilized with phosphorus and nitrogen, like sewage lagoons (Welch and Lindell 1980). The N:P limitation ratio by weight is 7:1. Nitrogen is considered to limit algal growth at N:P ratios below 7:1 and phosphorus limits growth at ratios above 7:1 (Smith 1979).

MEASURED TOTAL NITROGEN TO TOTAL PHOSPHORUS RATIOS IN THE LAGUNA WATERSHED

Water quality data from the following studies were collected over time from numerous agencies and compiled for analysis: Otis (1990), NCRWQCB (1992), Church and Zabinsky (2005), Sloop et al. (2007), and NCRQWCB (2008). The concentration data were compiled from 1989 through 2008. Figure 1 showes the value of N:P for samples collected at the four (4) TMDL attainment locations. Most of the N:P ratios are below the Redfield ratio (i.e., N:P = 7) indicating possible nitrogen limitation. No apparent visible trend is observed in N:P ratios over time. Figure 2 shows the value of N:P from samples collected in Santa Rosa Creek at Willowside Road. The N:P ratios are scattered evenly around the Redfield ratio with 46% below the line indicating possible co-limitation. The N:P ratio appears to be higher for the period of time that the TMDL was being implemented (i.e. 1995-2000).

The distribution of N:P ratios in lentic reaches of the Laguna watershed is shown in Figure 3. All of the locations presented were well below the Redfield ratio indicating possible nitrogen limitation. The percent of samples collected in lentic reaches that were below the Redfield ratio ranged from 79% to 95% (Table 1). The distribution of N:P ratios in lotic reaches of the Laguna watershed is shown in Figure 4. The location in Santa Rosa Creek at Willowside Road appears to show co-limitation between nitrogen and phosphorus with about 46% below the Redfield ratio (Table 1). However, the Laguna watershed tributaries sampled during 2008 showed a similar distribution of N:P ratios as those observed in the lentic reaches. Eighty-five percent (85%) of these samples were below the Redfield ratio indicating possible nitrogen limitation.

SCIENTIFIC LITERATURE ON NUTRIENT LIMITATION

Algal Growth Potential (AGP) studies were used widely in the 1980s to determine which nutrient limited biomass production. The rationale presented by the 1995 TMDL for the focus on nitrogen as the limiting nutrient in the Laguna was based on AGP studies (Morris 1995). However, these tests used the standard green algal species, *Selenastrum capricornutum,* which may not represent the same nutrient limitation as the

Laguna algal community. In addition, laboratory-measured nutrient limitation affects only short-term algal growth and nutrient uptake rates and does not indicate the total availability of the nutrient for algal biomass formation (Welch and Lindell 1980). The use of laboratory AGP tests to assess nutrient limitations in the aquatic environment ignores many external sources of nitrogen, such as nitrogen fixation discussed below (Wickham and Rawson 2000)

In 1972, the U.S. Environmental Protection Agency (USEPA) determined that for freshwater systems the control of phosphorus is required to control algal biomass. The USEPA (Bartsch 1972, as reported in Wickham and Rawson 2000) stated that "phosphorus availability is the single, most important and necessary step to be taken in eutrophication control. The most effective way to control eutrophication is to reduce phosphorus inputs. Phosphorus contributions should be reduced in every feasible way."

The declaration that algal biomass was most often limited by phosphorus concentration was challenged by the detergent industry, which claimed that carbon and nitrogen were the limiting nutrients (Cooke et al. 1986). Considerable research was conducted in the 1960s and 1970s to assess nutrient limitation which resulted in confirmation that phosphorus controls the production of algal biomass, and that nitrogen and carbon become limiting nutrients for only short periods of time (Sakamoto 1966; Vollenweider 1968; Dillon and Rigler 1974; Schindler 1974; Jones and Bachman 1976; Canfield and Bachman 1981; OCED 1982).

Cooke et al. (1986) describes a review of numerous studies where nutrient loads to lakes were reduced by diversion or advanced waste treatment of wastewater. The researchers found that although the N:P ratios were very low indicating nitrogen-limitation to algal growth, phosphorus was quickly established as the limiting nutrient after treatment. The conclusion of the literature review was that reductions in phosphorus alone resulted in the observed reduced algal biomass in these lakes.

Schindler et al. (2008) studied the fertilization of a small lake for 37 years. The study applied constant annual inputs of phosphorus and decreasing inputs of nitrogen to test the theory that controlling nitrogen inputs can control eutrophication. For the final 16 years (1990–2005), the lake was fertilized with phosphorus alone. Reducing nitrogen inputs increasingly favored nitrogen-fixing cyanobacteria as a response by the phytoplankton community to extreme seasonal nitrogen limitation. Nitrogen fixation was sufficient to allow biomass to continue to be produced in proportion to phosphorus, and the lake remained highly eutrophic, despite showing indications of extreme nitrogen limitation seasonally. The authors concluded that to reduce eutrophication, the focus of management must be on decreasing inputs of phosphorus.

Wickham and Rawson (2000) conducted a study examining the impact of phosphorus on Laguna eutrophication. Analysis of historical data indicated that phosphorus is the nutrient controlling Laguna productivity. The analysis showed a highly significant correlation (p=0.001) between total phosphorus concentrations and phytoplankton cell density. Similar correlations were not observed with concentrations of nitrogen forms.

The report concludes that phosphorus loads should be reduced in the Laguna for management of eutrophication, instead of nitrogen loads.

Nitrogen Fixation in the Laguna

Nitrogen may be expected to limit algal production in highly eutrophic surface waters due to the low N:P ratio. However, given sufficient time, phosphorus will end up limiting the algal biomass. Numerous studies have shown that the addition of phosphorus will stimulate nitrogen fixation and the biomass increases to match already available or increased phosphorus loading (Welch and Lindell 1980, Carpenter 2008). As a freshwater body becomes more eutrophic, algal species compositions shift to become more dominated by cyanobacteria. Many species of cyanobacteria can convert or “fix” atmospheric nitrogen to dissolved ammonia-N. The dissolved ammonia-N is then oxidized to nitrate-N and becomes available for algal growth. Cyanobacteria blooms are common in the Laguna (Wickham and Rawson 2000)

Azolla filiculoides (water fern) is a macrophyte that is native and widespread in the Laguna watershed. The water fern is a small (1-2 cm) floating plant that is capable of spreading quickly and completely over open water areas. After the removal of the macrophyte *Ludwigia hexapetala* in some areas of the Laguna, *Azolla filliculoides* was found to infest 88% of area restored, with one-third of the restored area completely covered with the plant (Meisler 2008). The water fern forms a symbiotic relationship with the cyanobacterium *Anabaena azollae*, which fixes atmospheric nitrogen to the dissolved form. Therefore, the widespread presence of the native water fern severely limits the effectiveness of eutrophication control by reducing nitrogen loads.

FINDINGS

To reduce the adverse effects of biostimulatory substances, one must determine which nutrient, if reduced, will reduce biomass most efficiently and over the long term. Eutrophication of lakes naturally leads to lower N:P ratios, such that short term bioassays will show N to be most limiting to growth rate. However, given the potential for nitrogen fixation in the Laguna, reductions of phosphorus loading are needed to control the amount of algal biomass production and reverse the adverse effects of eutrophication.

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TABLES

Table 1. Percent of Samples collected that are below the Redfield Ratio of 7

Waterbody Type	Location	Percent of Samples below Redfield Ratio
Lentic	Stony Point	87%
	Occidental Road	93%
	Guerneville Road	95%
	Trenton-Healdsburg Road	79%
	Other Laguna Locations	82%
Lotic	Santa Rosa Creek	46%
	Other Laguna Tributaries	85%

FIGURES

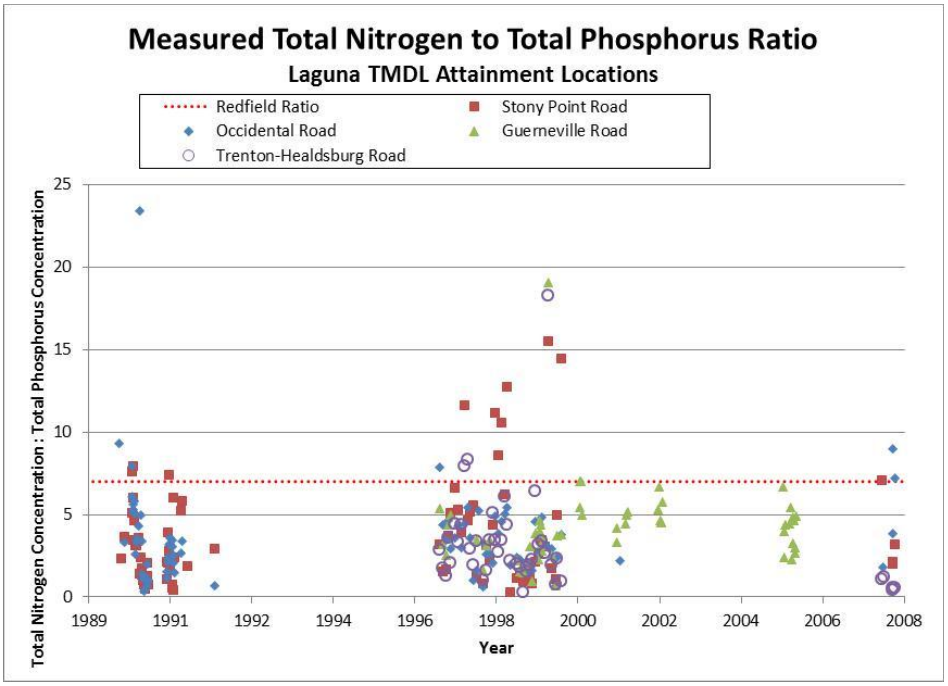

Figure 1. Measured Total Nitrogen to Total Phosphorus Concentration Ratios at the Laguna TMDL Attainment Locations Over Time

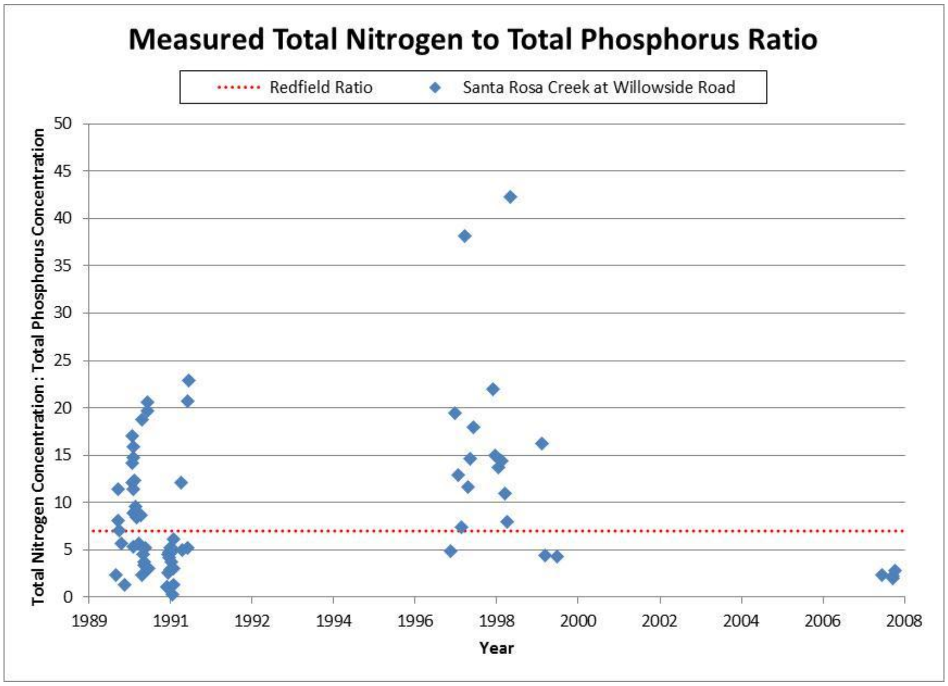

Figure 2. Measured Total Nitrogen to Total Phosphorus Concentration Ratios in Santa Rosa Creek at Willowside Road Over Time

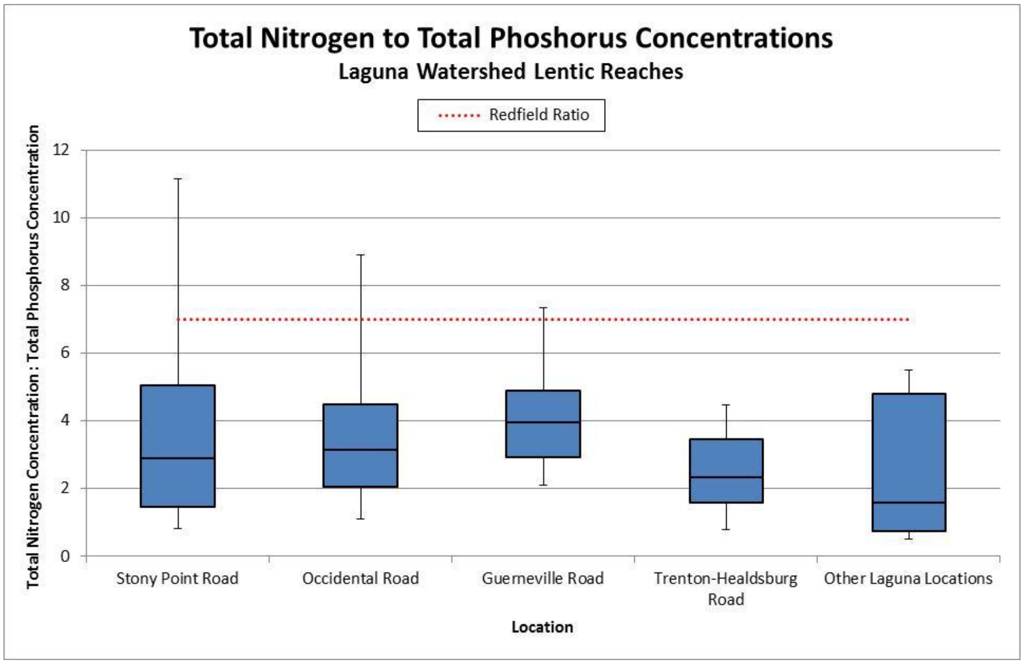

Figure 3. Distribution of Measured Total Nitrogen to Total Phosphorus Concentration Ratios in the Laguna Lentic Reach Areas

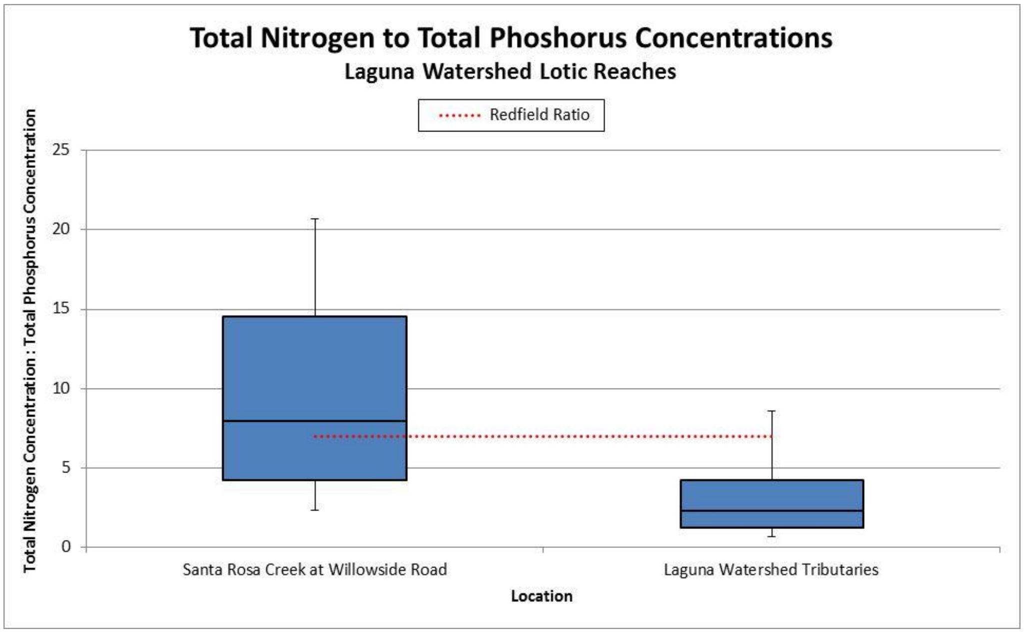

Figure 4. Distribution of Measured Total Nitrogen to Total Phosphorus Concentration Ratios in the Laguna Lotic Reach Areas