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DATE: June 14, 2013

SUBJECT: SUMMARY OF TMDL DEVELOPMENT DATA PERTAINING TO NUTRIENT IMPAIRMENTS IN THE LAGUNA DE SANTA ROSA WATERSHED

INTRODUCTION

The purpose of this memorandum is to summarize information and data analyzed by staff to date for the development of the Laguna de Santa Rosa Total Maximum Daily Loads (TMDLs) for phosphorus, nitrogen, dissolved oxygen, temperature and sediment – as such are relevant to the development of National Pollutant Discharge Elimination System (NPDES) permits for the City of Santa Rosa Subregional Water Reclamation System and for the Town of Windsor Wastewater Treatment, Reclamation, and Disposal System.

The greater Laguna de Santa Rosa watershed consists of the Laguna de Santa Rosa, Santa Rosa Creek, and Mark West Creek hydrologic subareas (HSAs), as mapped in the Water Quality Control Plan for the North Coast Region (NCRWQCB 2011), also known as the Basin Plan.

The information and data summarized herein primarily pertain to the nutrient impairments and the nutrient assimilative capacity of the mainstem of the Laguna de Santa Rosa (hereinafter mainstem Laguna, which approximately begins in the City of Cotati and flows north to its confluence with Mark West Creek) and the lower portion of the mainstem of Mark West Creek (hereinafter, lower Mark West Creek, from its confluence with the mainstem Laguna to its confluence with the Russian River).

STATUS OF LISTINGS AND TMDL DEVELOPMENT

On October 11, 2011, the United States Environmental Protection Agency (USEPA) provided final approval of the most current Clean Water Act (CWA) Section 303(d) list of impaired water bodies prepared by the State of California. The list identifies the entire Russian River watershed, including the Laguna de Santa Rosa, Santa Rosa Creek, and Mark West Creek HSAs, as impaired by excess sediment and elevated water temperatures. In addition, Santa Rosa Creek, the Laguna de Santa Rosa, and portions of the Lower Russian River are identified as impaired by pathogenic indicator bacteria, and the Laguna de Santa Rosa is identified as impaired by low dissolved oxygen, nitrogen, phosphorus, and mercury.

TMDLs for nitrogen, ammonia, and dissolved oxygen were approved by the USEPA in 1995 in the form of the Waste Reduction Strategy for the Laguna de Santa Rosa (Morris 1995). The Waste Reduction Strategy called for the reduction of nitrogen loads to address ammonia toxicity concerns along the mainstem Laguna and lower Mark West Creek. The Strategy was implemented via improvements to municipal wastewater treatment facilities and dairy management practices in the greater Laguna watershed. These improvements are the likely cause of observed reductions in nutrient and ammonia concentrations in the mainstem Laguna between the late 1990s and early 2000s (Sloop et al. 2007).

Regional Water Board staff are currently developing new TMDLs for nitrogen, phosphorus, dissolved oxygen, temperature, and sediment in the greater Laguna de Santa Rosa watershed to address continuing water quality impairments. These TMDLs will apply to all water bodies in the Laguna de Santa Rosa, Santa Rosa Creek, and Mark West Creek HSAs. These TMDLs are estimated to be completed in 2016.

Regional Water Board staff are also currently developing a pathogen TMDL to address indicator bacteria impairments in the Russian River, the Laguna de Santa Rosa, and the Santa Rosa Creek watersheds. The pathogen TMDL is estimated to be completed in 2016. Development of a mercury TMDL for the Laguna de Santa Rosa is not yet scheduled.

SUMMARY OF NUTRIENT DYNAMICS AND IMPAIRED CONDITIONS

Nitrogen compounds (ammonia, nitrate, nitrite, and dissolved organic nitrogen) and phosphorus compounds (phosphate, particulate phosphorus, and dissolved phosphorus) in surface waters can stimulate the growth rates of algae and macrophytes, as well as increase the activity rates of bacteria and fungi. The overabundance of nitrogen and phosphorus compounds in surface water systems can result in the excessive growth and decay of these organisms, thus accelerating the process of eutrophication, especially in lake-like waters. This biostimulatory condition leads to the lowering of dissolved oxygen levels below concentrations needed for the survival and health of fish and aquatic life, negatively affects the aesthetic quality of water bodies, and impairs beneficial uses.

While nutrient inputs to an aquatic system significantly contribute to biostimulatory conditions, there are other contributing factors. These include physical factors that influence the mixing and aeration of water, such as wind, temperature, channel geometry, and water flow rates.

Available data and other information suggest that harmful biostimulatory conditions are present in the mainstem Laguna and lower Mark West Creek, including: elevated amounts of nutrients in the water column and in aquatic sediments, elevated levels of chlorophyll *a*, low dissolved oxygen levels, and the extensive presence of benthic macrophytes (including *Ludwigia* sp.) These reaches, as well as other water bodies in the greater Laguna de Santa Rosa watershed, are also facing significant water quality problems due to high levels of instream sedimentation, hydrologic and physical habitat changes, and high water temperatures.

In addition to being a causative agent of an aquatic system's biostimulatory response, excessive amounts of nitrogen can also contribute to instream ammonia toxicity, as described by Butkus (2013). Ammonification is the process by which nitrogen compounds are converted to ammonia, which is toxic to fish and aquatic life in its unionized form. High concentrations of total nitrogen can lead to high levels of ammonia toxicity, especially where instream temperatures and pH levels are high. Available data suggest that conditions present in the mainstem Laguna and lower Mark West Creek do not exceed current standards for acute ammonia toxicity.

SUMMARY OF APPLICABLE WATER QUALITY STANDARDS RELATED TO NUTRIENT IMPAIRED CONDITIONS

Biostimulatory Substances

The Basin Plan contains a narrative water quality objective for biostimulatory substances that states: "Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses." In order to interpret this narrative objective, Regional Water Board staff evaluate several chemical and biological indicators against numeric threshold values. These include numeric criteria for phosphorus, nitrogen, and chlorophyll *a* concentrations, as well as numeric Basin Plan water quality objectives for dissolved oxygen. Regional Water Board staff also use macroyphyte cover as a secondary indicator of impairment.

In the early 2000s, the USEPA proposed new total phosphorus, total nitrogen, and chlorophyll *a* criteria for rivers and streams (USEPA 2000) and for lakes and reservoirs (USEPA 2001) based on aggregate ecoregions. Table 1 shows the applicable criteria proposed for Aggregate Nutrient Ecoregion III, which includes the greater Laguna de Santa Rosa watershed. The criteria were empirically derived to represent reference conditions for surface waters, and are based on 25th percentiles of all nutrient data in Aggregate Nutrient Ecoregion III.

Table 1. USEPA Biostimulatory Substance Criteria

Constituent	(Lentic) Criteria for Lakes & Reservoirs	(Lotic) Criteria for Rivers & Streams
Total Phosphorus	0.017mg/L	0.02188 mg/L
Total Nitrogen	0.40 mg/L	0.38 mg/L
Chlorophyll *a*	0.0034 mg/L	0.00178 mg/L

In addition, the State Water Resources Control Board (State Water Board) developed evaluation guidelines for assessing biostimulatory conditions to identify impaired waters for the CWA Section 303(d) list (SWRCB 2007). For rivers and streams, State Water Board staff reviewed the California Nutrient Numeric Endpoint (California NNE) technical approach (Tetra Tech 2006) and four subsequent California case studies. For lakes and reservoirs, State Water Board staff reviewed published research of pollutant effects in freshwater lakes and reservoirs (Welch & Jacoby 2004, as cited in SWRCB 2007). These efforts resulted in the development of nutrient numeric screening tools for total nitrogen, total phosphorous, and chlorophyll *a* concentrations in California surface waters to interpret narrative Basin Plan water quality objectives, as shown in Table 2.

Table 2. California Biostimulatory Substance Criteria

Constituent	(Lentic) Criteria for Lakes & Reservoirs	(Lotic) Criteria for Rivers & Streams with COLD, REC, MUN, & SPWN Beneficial Uses	(Lotic) Criteria for Rivers & Streams with WARM Beneficial Uses
Total Phosphorus	0.100 mg/L	0.02 mg/L	0.08 mg/L
Total Nitrogen	1.200 mg/L	0.23 mg/L	0.52 mg/L
Chlorophyll *a*	0.005 mg/L	150 mg/m^2	200 mg/m^2

Dissolved Oxygen

The narrative water quality objective for biostimulatory substances is also interpreted by comparing dissolved oxygen concentrations to the numeric water quality objective for dissolved oxygen found in the Basin Plan. The objective states that dissolved oxygen levels shall not fall below 7.0 mg/L at any time, that 90% or more of all annual dissolved oxygen levels shall be equal to or exceed 7.5 mg/L, and that 50% or more of all annual dissolved oxygen levels shall be equal to or exceed 10.0 mg/L.

Ammonia Toxicity

The Basin Plan contains a narrative water quality objective for toxicity that states: "All waters shall be maintained free of toxic substances in concentrations that are toxic to, or that produce detrimental physiological responses in human, plant, animal, or aquatic life."

Water quality criteria for toxicity due to ammonia concentrations in fresh water systems have changed over the last several decades (Butkus 2013). Regional Water Board staff currently rely on USEPA's recommended criteria from the 1999 Update of Ambient Water Quality Criteria for Ammonia (USEPA 1999) to interpret the Basin Plan's narrative objective for toxicity from ammonia. The USEPA recommends acute and chronic water quality criteria for the protection of aquatic life, which are expressed as mathematical formulas. The acute criterion varies depending on pH and on the presence or absence of salmonids. This criterion is expressed as the one-hour concentration of total ammonia nitrogen that shall not be exceeded more than once every three years. The chronic criterion varies depending on pH, water temperature, and the presence or absence of early life stages of fish. This criterion is expressed as the thirty-day average concentration of total ammonia nitrogen that shall not be exceeded more than once every three years. Examples of the acute criteria are presented in Table 3.

Table 3. Acute Toxicity Criteria for Total Ammonia Nitrogen (Criterion Maximum Concentration)

pH	Salmonids Present	Salmonids Absent
7.0	24.1 mg/L	36.1 mg/L
8.0	5.62 mg/L	8.4 mg/L
9.0	0.885 mg/L	1.32 mg/L

SUMMARY OF EXCEEDENCES OF WATER QUALITY OBJECTIVES FOR BIOSTIMULATORY SUBSTANCES

As previously stated, available data and other information suggest that harmful biostimulatory conditions are present in the mainstem Laguna and lower Mark West Creek, as demonstrated by elevated amounts of nutrients in the water column and in aquatic sediments, elevated levels of chlorophyll *a*, low dissolved oxygen levels, and the extensive presence of benthic macrophytes. The following sections provide evidence of elevated amounts of nutrients (i.e., total nitrogen and total phosphorus) in the water column.

Instream water samples for nutrients and other indicators of biostimulatory conditions have been collected in the mainstem Laguna and other watershed locations since the 1970s. Regional Water Board staff reviewed data and analyses presented by Otis (1990), NCRWQCB (1992), Church and Zabinsky (2005), Sloop et al. (2007), and NCRWQCB (2008), among others, to determine the overall status and trends of total nitrogen and total phosphorus concentrations over time in the greater Laguna watershed.

Nitrogen Levels Exceed Biostimulatory Substances Criteria

Using data from the studies referenced above, Figure 1 presents total nitrogen concentrations measured since 1989 at the four TMDL attainment locations established in the Waste Reduction Strategy for the Laguna de Santa Rosa (Morris 1995), which are located in the mainstem Laguna at Stony Point Road, at Occidental Road, and at Guerneville Road, and in lower Mark West Creek at Trenton-Healdsburg Road.

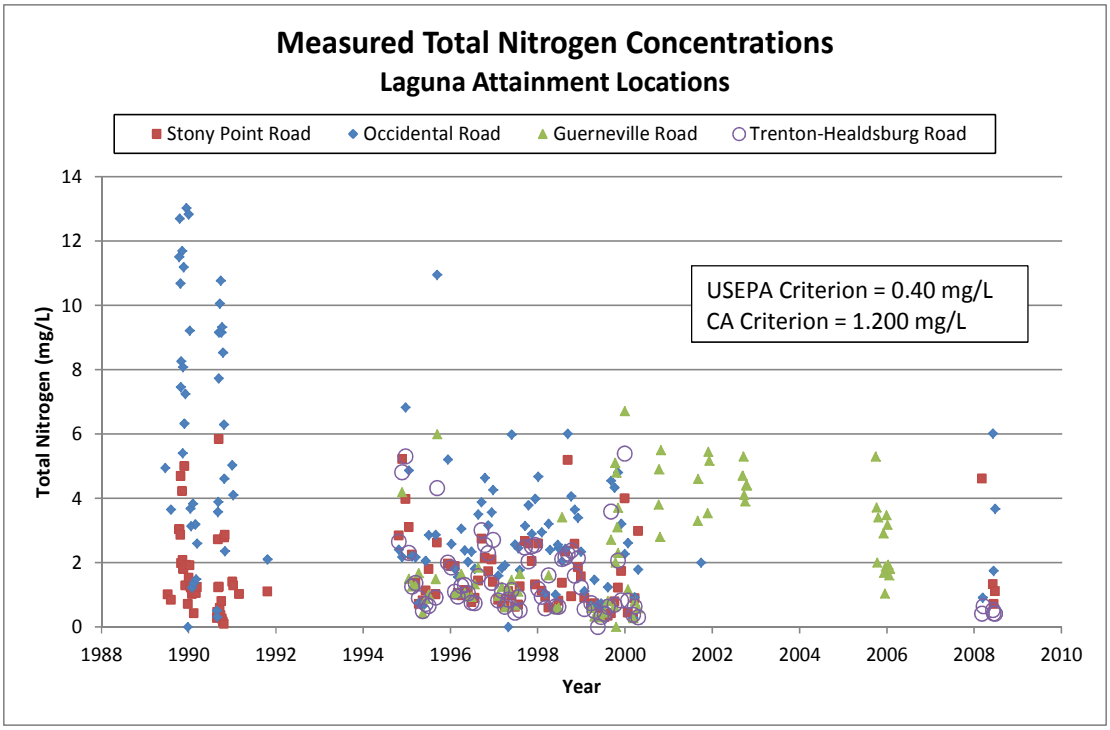

Figure 1. Total Nitrogen Concentrations Measured in the Laguna de Santa Rosa

Data presented in the Figure 1 reveal apparent reductions in total nitrogen concentrations since the late 1980s. However, concentrations measured most recently continue to exceed applicable water quality standards, as summarized in Table 4. In fact, total nitrogen concentrations in 100% of the 42 samples collected and analyzed at the four TMDL attainment locations during the period 2001-2010 exceed the USEPA criterion of 0.40 mg/L, and concentrations in 79% of the samples exceed the California criterion of 1.200 mg/L.

Table 4. Total Nitrogen Concentration Criteria Exceedence Rates in the Laguna de Santa Rosa

Location	Period	# of Samples	Median Total Nitrogen Concentration (mg/L)	Percent Greater than USEPA Criterion (0.40 mg/L)	Percent Greater than CA Criterion (1.200 mg/L)
Laguna TMDL Attainment Locations	1989-1994	84	2.750	93%	76%
	1995-2000	251	1.460	96%	57%
	2001-2010	42	3.235	100%	79%

Phosphorus Levels Exceed Biostimulatory Substances Criteria

Using data from the studies referenced above, Figure 2 presents total phosphorus concentrations measured since 1972 at the four TMDL attainment locations established in the Waste Reduction Strategy. These data reveal large reductions in total phosphorus concentrations since the 1970s, which are likely due to significant improvements to municipal wastewater treatment facilities and dairy management practices over the last several decades. Figure 3 presents total phosphorus concentrations measured since 1984, demonstrating that reductions appear to continue to decline over more recent time periods.

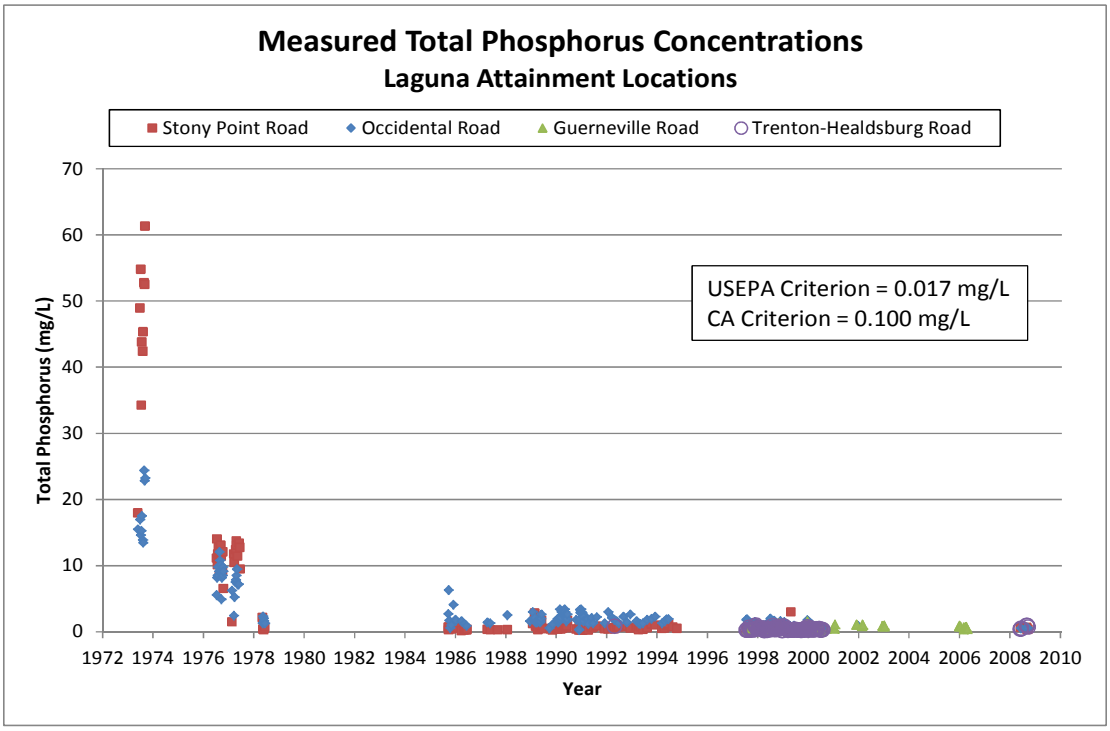

Figure 2. Total Phosphorus Concentrations Measured in the Laguna de Santa Rosa since 1972

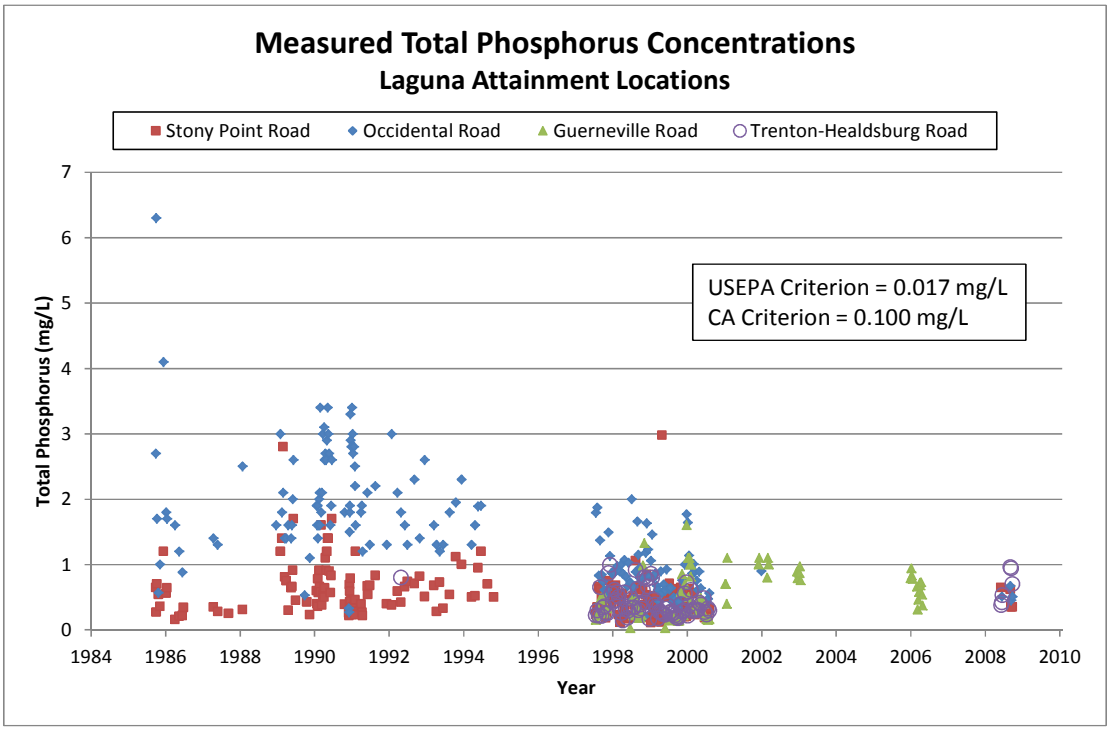

Figure 3. Total Phosphorus Concentrations Measured in the Laguna de Santa Rosa since 1985

While data presented in the above figures indicate substantial reductions in total phosphorus over time, concentrations nonetheless continue to far exceed applicable water quality standards, as summarized in Table 5. In fact, total phosphorus concentrations in 100% of the 43 samples collected and analyzed at the four TMDL attainment locations during the period 2001-2010 exceed both the USEPA criterion of 0.017 mg/L and the California criterion of 0.100 mg/L.

Table 5. Total Phosphorus Concentration Criteria Exceedence Rates in the Laguna de Santa Rosa

Location	Period	# of Samples	Median Total Phosphorus Concentration (mg/L)	Percent Greater than USEPA Criterion (0.017 mg/L)	Percent Greater than CA Criterion (0.100 mg/L)
Laguna TMDL Attainment Locations	1970-1984	81	10.440	100%	100%
	1985-1994	191	1.200	100%	100%
	1995-2000	291	0.430	100%	100%
	2001-2010	43	0.700	100%	100%

Phosphorus Levels Limit Biomass Production and Contribute to Biostimulatory Conditions

In addition to analyzing nutrient data measured in the Laguna de Santa Rosa over the last three decades, Regional Water Board staff reviewed scientific literature regarding nutrient limitations on biomass production (Butkus 2012a), including the *Report to Russian River Watershed Protection Committee and City of Santa Rosa on Phosphate Loading and Eutrophication in the Laguna de Santa Rosa* (Wickham and Rawson 2000) which states

> Limnologists widely regard phosphate as the predominant limiting nutrient for plant production in freshwater ecosystems. While other nutrients combine with phosphate to fulfill the metabolic needs of plants, such as nitrogen, sulfur, iron, and various other mineral and organic compounds, phosphate is typically the compound that is in lowest availability in free form. Where all available phosphate has been consumed in the course of the production cycle, plant growth stops. This can occur even though all other nutrients, including nitrogen, remain abundant. (p. 1)

Staff conclude that reductions of phosphorus loads are needed to control the amount of algal biomass production and reduce the adverse effects of eutrophication in the mainstem Laguna and lower Mark West Creek. This conclusion is based on the scientific literature and the widespread presence of *Azolla filiculoides* (a native water fern) in the mainstem Laguna de Santa Rosa and lower Mark West Creek, which severely limits the effectiveness of controlling nitrogen loads because of its role in converting atmospheric nitrogen through nitrogen fixation. Wickham and Rawson (2000, p 6) expand upon this concept by saying:

> Nitrogen, however, can never be completely controlled since it is available from numerous other sources, including natural ones. Nitrogen oxides are readily available from polluted air typical of an urbanized area such as the Santa Rosa Plain. Many species of photosynthetic bacteria and blue-green algae are nitrogen fixers capable of drawing nitrogen in molecular form from the atmosphere and incorporating it into plant tissue as they photosynthesize. The attempt to limit nitrogen in the Laguna, while a worthy goal for many reasons, is potentially fruitless if it is the sole nutrient being addressed.

Preliminary TMDL linkage analysis and modeling results support the conclusion that total phosphorus concentrations limit algal biomass production in the Laguna de Santa Rosa (Butkus 2012b). Results of water quality modeling indicate that aquatic sediments are highly enriched with organic material, which results in a relatively high sediment oxygen demand (SOD). SOD is caused by the oxidation of organic matter in benthic sediments. Sources of organic matter in sediments include leaf litter, soil entering the water body through erosion and deposition, particulate matter from wastewater discharges, and deposition of algal and macrophyte biomass. Regardless of the source, the oxidation of deposited benthic organic matter will exert a SOD on the water body.

Regional Water Board staff has established linkages between the total phosphorus concentration, algal biomass, carbonaceous biochemical oxygen demand (CBOD), and SOD.

According to the assessment, algal biomass contributes to CBOD in the water column, which upon senescence and settling, contributes to the SOD. In the mainstem Laguna and lower Mark West Creek, total phosphorus concentrations limit both phytoplankton and benthic algal biomass. Reductions in total phosphorus concentrations are therefore expected to reduce algal biomass, CBOD, and SOD, which is the primary driver of low dissolved oxygen in the water column.

Although the Laguna de Santa Rosa TMDLs are not yet fully developed, the evidence is clear that biostimulatory conditions exist and that instream phosphorus concentrations contribute to those conditions. Currently, the mainstem Laguna and lower Mark West Creek have no apparent capacity to assimilate additional phosphorus loads without continuing to exceed the Basin Plan's water quality objective for biostimulatory substances.

Nitrogen Levels Contribute to Biostimulatory Conditions

While phosphorus concentrations are the most important nutrient for algal biomass production and a have direct relationship to sediment oxygen demand, which is a primary driver of low dissolved oxygen levels, nitrogen concentrations can cause short-term algal growth. The exceedences of nitrogen biostimulatory criteria in the mainstem Laguna and lower Mark West Creek indicate that instream nitrogen concentrations likely contribute to the biostimulatory condition.

SUMMARY OF EXCEEDENCES OF WATER QUALITY OBJECTIVES FOR AMMONIA TOXICITY

Ammonia Levels Do Not Exceed Criteria

Regional Water Board staff reviewed data and analyses presented by Otis (1990), NCRWQCB (1992), Morris (1995), Church and Zabinsky (2005), Sloop et al. (2007), and NCRWQCB (2008), among others, to determine the overall status and trends of total ammonia concentrations and ammonia toxicity over time in the greater Laguna watershed.

Using data from the studies referenced above, Figure 4 presents total ammonia concentrations measured since 1989 at the four TMDL attainment locations established in the Waste Reduction Strategy for the Laguna de Santa Rosa (Morris 1995). These data reveal apparent reductions in total ammonia concentrations since the late 1980s.

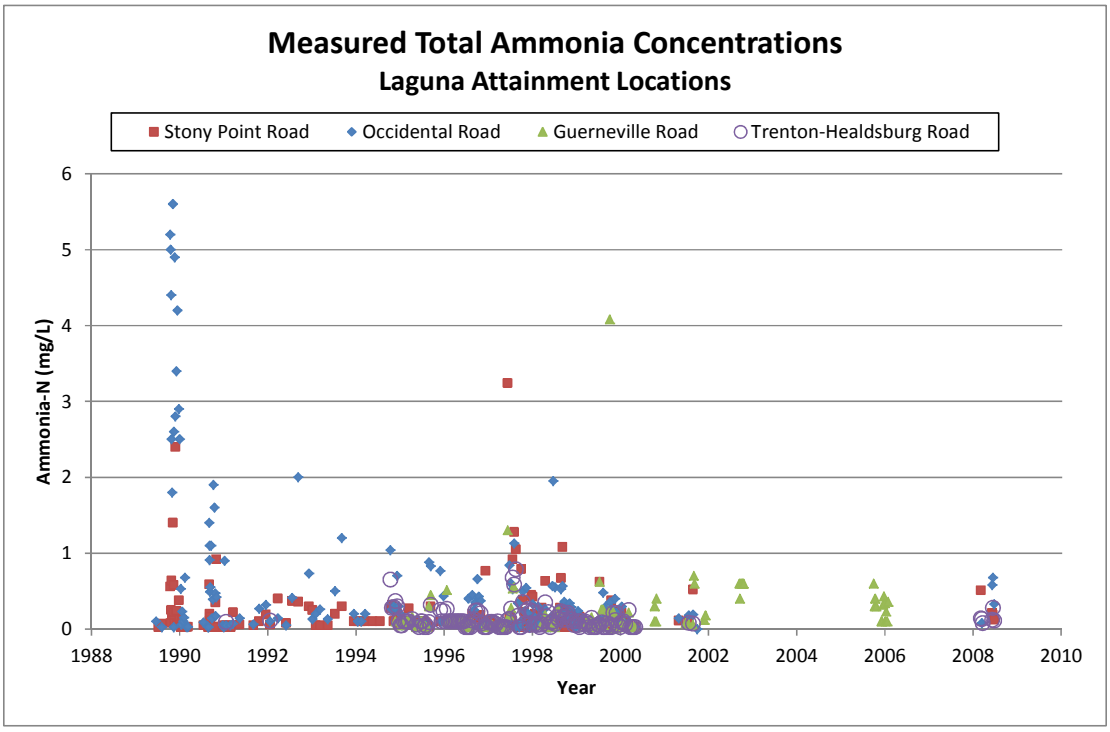

Figure 4. Total Ammonia Concentrations Measured in the Laguna de Santa Rosa since 1989

Regional Water Board staff coupled data presented in the above figure with corresponding (measured or inferred) water column pH values, and evaluated them against the 1999 USEPA criterion for acute ammonia toxicity, assuming the presence of salmonids. None of the measured ammonia concentrations exceed the current acute criterion, as summarized in Table 6. Staff are currently unable to conduct a similar evaluation against the 1999 USEPA criterion for chronic ammonia toxicity, due to lack of sufficiently frequent measurements during the sampled period.

Table 6. Acute Ammonia Toxicity Exceedence Rates in the Laguna de Santa Rosa

Location	Period	# of Ammonia Samples	Median Total Ammonia Conc. (mg/L)	Median pH	Percent Greater than 1999 USEPA Criterion
Laguna TMDL Attainment Locations	1989-1994	139	0.13	7.7	0%
	1995-2000	503	0.10	7.7	0%
	2001-2010	53	0.20	7.78	0%

CRITICAL CONDITIONS

The most critical conditions for dissolved oxygen concentrations and saturation levels - primary indicators of a biostimulatory condition – vary spatially along the length of the mainstem Laguna and lower Mark West Creek and also temporally throughout the year. Available data demonstrating these conditions are presented by Butkus (2011).

Available data show that dissolved oxygen concentrations and saturation levels increase and improve as water flows downstream from the upper portions of the mainstem Laguna toward the Russian River, although most measurements still do not meet the Basin Plan's water quality objective for dissolved oxygen of 7.0 mg/L.

In the greater Laguna de Santa Rosa watershed, the most critical conditions for biostimulatory impairment generally occur in the late summer. This is mainly due to the timing of the highest daily maximum air temperatures during the year, which cause higher water temperatures. High water temperatures lower the saturation potential for dissolved oxygen concentrations and increase the rates for many biochemical processes, which lower dissolved oxygen concentrations even further. This seasonal critical condition is readily observed in data from the mainstem Laguna at Occidental Road with lower dissolved oxygen concentration and saturation values in the summer and higher values in the spring and fall. Seasonal conditions at other locations vary and show dissolved oxygen concentrations at similar, low levels throughout the year.

HYDRAULIC/HYDROLOGIC PHENOMENA IN THE LAGUNA

There is evidence that during high flows in the Russian River, the mainstem Laguna and lower Mark West Creek back up, creating conditions causing the deposition of nutrient-laden solids. Sloop et al. (2007) describe the unique hydrology of the mainstem Laguna and lower Mark West Creek and conditions under which a flow restriction is created during flood events in the Russian River. Philip Williams & Associates (2004) describe the geologic outcrop in the area of the Trenton-Healdsburg Road crossing that limits the sediment transport capacity of the mainstem Laguna and lower Mark West Creek.

While there continue to be uncertainties regarding the dynamics of nutrient fate and transport in the mainstem Laguna and lower Mark West Creek, it is likely that winter discharges of phosphorus-laden particles into the water bodies of the greater Laguna watershed are captured and stored in the channels of the mainstem Laguna and lower Mark West Creek to become bioavailable later in the summer. Any such channel deposits therefore are likely to contribute to high levels of sediment oxygen demand, low levels of dissolved oxygen, and continued harmful biostimulatory conditions.

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